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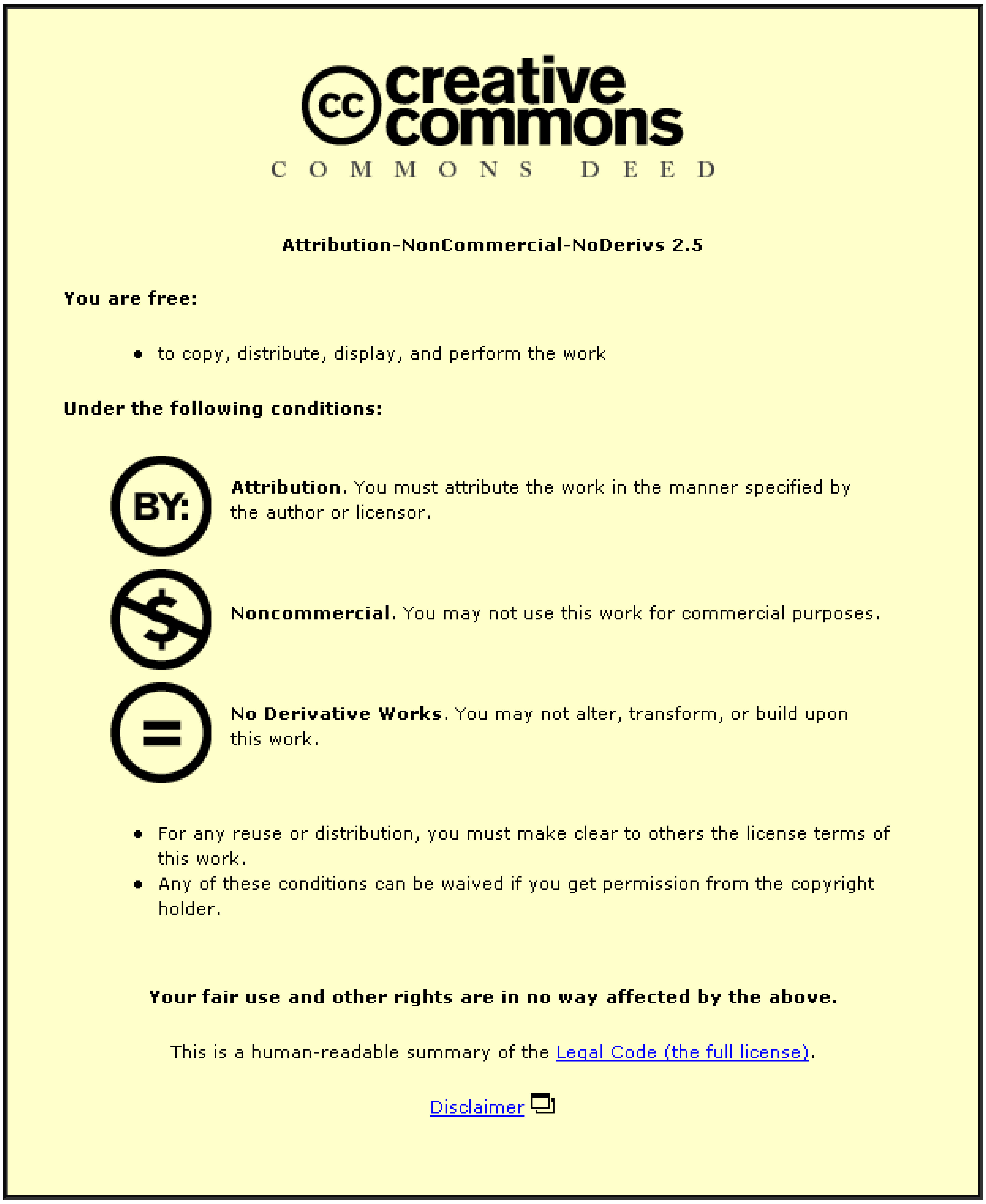

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KNOWLEDGE BASED DECISION SUPPORT SYSTEM FOR THE SELECTION AND APPOINTMENT OF SUB-CONTRACTORS FOR BUILDING REFURBISHMENT CONTRACTS

By

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of the requirements for the
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Dedication

To

My wife, Florence who has given me tremendous encouragement and support throughout the study and my daughter Nkeiruka and son Ebelechukwu Okoroh, who were both born during the period of this study, and my son Okwudili who waited all alone in Nigeria whilst I pursued this study.

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ABSTRACT

This thesis describes the results of research analysing the sub-contractor's risk elements in refurbishment projects. One of the main characteristics of refurbishment projects is that work is usually in small packages and scattered throughout the building making it unprofitable for one contractor to undertake. It is argued that the selection and appointment of the most suitable sub-contractors is very important in refurbishment projects as all other control measures have little effect once a totally unsuitable sub-contractor has been appointed.

The research methodology involved the extensive collaboration of a retired chief estimator with over thirty years experience in one of Britain's biggest construction firms with extensive knowledge in the management of sub-contractors and several other refurbishment contractors' senior management staff who were involved in choosing sub-contractors for their contracts.

Knowledge acquisition and representation and the evaluation of expert system shells are extensively reviewed.

One of the important features of knowledge based systems is its ability to handle uncertain knowledge. Fuzzy set theory is shown to have certain advantages over other methods of dealing with uncertainty and has been employed in developing this knowledge based system.

The research began with an evaluation of sub-contractors' selection and appointment as it is currently performed by refurbishment contractors. This exercise consisted of a wide range of criteria of which information is both qualitative and subjective in an unstructured intuitive manner with considerable reliance on the judgement of the evaluee. Thus, the research focused on a more formalised approach to the sub-contractor's appointment. An adaptation of the Repertory Grid knowledge elicitation technique and subsequent grid analysis provides a methodology for organising logically related propositions into a hierarchical structure.

A prototype knowledge based decision support system SSARC, for the selection and appointment of the most suitable sub-contractors for refurbishment projects, has been developed. This system represents a contribution in this area of research into refurbishment contracts which has been largely neglected to date.

CHAPTER ONE

INTRODUCTION

CHAPTER ONE

INTRODUCTION

1.1 Chapter introduction

This chapter describes the importance of the research. The research objectives together with the structure of the thesis are also provided.

1.2 Importance of the study

One of the most important changes in the UK construction industry in recent years is the tremendous growth of sub-contractors. This growth is so remarkable that in some projects, refurbishment contractors now sublet all their work. Refurbishment projects are highly labour intensive and usually involve small packages of work comprised of several trade sub-contractors. This drastically curtails mechanisation and promotes the use of sub-contractors as it is cheaper for the contractor to sublet work in small packages.

The increased use of sub-contractors in recent years is very important to the construction industry as their performance is now very critical to project success as all other control actions have little effect once a totally unsuitable sub-contractor has been appointed.

For instance a sub-contractor who over-runs his time allocation can cause the contractor to rearrange his schedule of work, which would involve alteration of labour and material schedules and reallocation of plant to offset delay. Programme changes however slight are costly to the contractor in time and effort. Also a delay caused by default of a sub-contractor can result in contractors incurring liability for large liquidated damages all of which the contractor may not be able to pass to the sub-contractor.
No matter how efficient a contractor is in his work organisation, a poor selection and appointment of sub-contractors would increase his uncertainty and risks for the successful execution of the job.

This problem is further exacerbated in projects where specialist sub-contractors are appointed by the client or the architect and the contractor tenders for work knowing neither the full extent of specialist work nor who is to carry it out. In some contracts, the main contractor is mandated to secure the performance of a sub-contractor he did not select and he is also responsible for the cost of re-nomination in the event of a nominated sub-contractor becoming insolvent. There is also the increased responsibility of control and co-ordination of the work of several different trade sub-contractors on site as these sub-contractors may not have the resources to organise and control their different activities. Thus, the performance of sub-contractors affects the outcome and quality of work, independently of the main contractor's competence.

This changing structure of the construction industry poses new problems for the contractors, for which innovation in sub-contractor risk management and control systems is required. At present contractors use rules of thumb and subjective evaluation to control and analyse sub-contractors' risks elements. This is basically due to the fact that the construction industry has an ill-defined and ill-structured environment. At every level of decision making, the contractor has to rely on his judgement and expertise. Also a large number of decision-making rules are based on the contractor's experience, assumptions and management style.

The selection of suitable sub-contractors therefore is very vital for successful execution of construction projects. The current practice of sub-contractor selection for refurbishment work is more of an art than a science. The process consists of a wide range of criteria for which information is both qualitative and subjective, and sometimes solely on financial gains.

The task is typically performed in an unstructured, intuitive manner with considerable reliance on the experience or on the judgment of the estimator, buyer and other senior staff.

There is therefore the need to develop a more formalised and structured approach to this process. The success of this exercise depends on being able to match sub-contractors with the right job. This simply means giving a sub-contractor the projects he can effectively and efficiently undertake without default. Many defaults by a sub-contractor in the past have been as a result of giving sub-contractors a job they cannot undertake. There are cases where good sub-contractors have been given inappropriate contracts and this has resulted in their default.

In refurbishment projects, work performance of a subcontractor is generally measured quantitatively and qualitatively. Quantitative measures sometimes are directly related to standards which were established based upon past empirical and analytical studies, experiments and observations.

Qualitative measures, on the other hand, are frequently expressed linguistically and subjectively (for example, good workmanship, or excellent performance). Such linguistic expressions are commonplace in refurbishment contract documents and specifications. During construction, sub-contractor performance is also assessed or approved qualitatively based on the subjective judgement of supervisors, contracts directors, site agents, client's representatives or other individuals responsible for the workmanship or safety provisions.

After construction, maintenance and periodic inspections are performed to ensure the functionality of the structure. Here again, performance is often measured qualitatively, yet no uniform method is in existence for assessing such qualitative measures.

Existing research work on control and risk management systems are developed based on mathematical laws, algorithm analysis and optimization's programmes. In these models, the creative components of the construction control mechanics, risk management systems and the significance of empirical knowledge have not been fully incorporated. As a result, contractors who use these models are faced with intractable questions and this deficiency has made it impossible for contractors to practically implement these algorithmic models successfully.

Given the strategic importance of sub-contractor performance there is therefore a need to develop a system that uses rule of thumb to solve problems and which also incorporates symbolic reasoning. One promising avenue which is worth looking into is to try to find out whether expert systems and fuzzy logic can be used to assist contractors in the management of these risks posed by sub-contractors and if so, to what extent.

In practice estimators, buyers, and other senior managers responsible for preparing tenders have gained considerable experience and expertise and can be relied upon for their good judgment and to make rational and reasonable decisions. This suggests that knowledge based systems incorporating decision support models based on simple heuristic decision rules may be more appropriate. Therefore, one possible approach to providing management decision-support in competitive tendering is through the use of knowledge based systems.

Knowledge based systems (KBS) have several characteristics that suggest their use could improve estimators' effectiveness in this area. Firstly, knowledge based systems emphasise qualitative rather than quantitative knowledge, although through the use of powerful hybrid representation schemes, knowledge based systems can support models incorporating both qualitative and quantitative features. Furthermore, knowledge based systems are capable of reasoning with incomplete, uncertain and inconsistent information. Together these characteristics suggest that the modelling capabilities of knowledge based systems closely match the reasoning carried out by estimators preparing tenders for refurbishment work.

Secondly, experience suggests that in this area, relevant knowledge is generally dispersed among several key personnel in the contractor's office, thus knowledge based systems provide a means of consolidating these multiple sources of expertise within a single knowledge base.

Finally, the computerised nature of knowledge based systems means that human fallibility and bias can be minimised thereby ensuring that tendering decisions are made in a more systematic, objective and equitable fashion.

1.3 Objectives of the research

The main objectives of the study were as follows:

i) To explore the potentials of applying knowledge based systems and fuzzy set theory in the evaluation of risks involved in the employment of sub-contractors in refurbishment work.

ii) The research also aimed to develop a prototype knowledge based systems which would support refurbishment contractors with regard to the selection and appointment of sub-contractors.

At the time of writing there was very little knowledge regarding the scope and applicability of knowledge based systems in refurbishment work. Empirical studies describing the success or otherwise of knowledge based systems in refurbishment work domains could therefore be regarded as an important contribution to knowledge in this area.

Another aspect of the research objectives was:

i) To identify the significant criteria which refurbishment contractors consider when they chose sub-contractors to work on their projects.

ii) To quantify these criteria.

iii) To provide a systematic and efficient sub-contractor's evaluation procedure, thereby making it consistent and defendable.

To achieve these objectives, an outline methodological framework described in chapter 5 was devised.

Knowledge based systems aim to capture the expertise of one or more human beings in a particular problem domain within a computer program. This expertise consists of knowledge and judgement, for example loosely associated facts and rules, often learnt from experience rather than theory. Therefore, the characteristics of KBSs suggest that they offer a possible route to further progress in providing decision support in the management of risks caused by the employment of sub-contractors. This study also explored the possible roles and benefits that KBS could provide in this area.

1.4 Layout of the thesis

The remainder of this thesis is organised into eight chapters

Chapter two provides a brief survey of the unique problems associated with refurbishment work. This chapter also provides a general overview of sub-contracting in the construction industry. It also reviews the risks and uncertainties associated with sub-contracting in refurbishment projects.

Chapter three provides a brief review of some of the literature relating to knowledge based systems. During the course of this study, there have been so many reports and papers published that it became practically impossible to review all of them. Therefore, only the ones that have some relevance to this study were considered. Special attention is given to knowledge acquisition and treatment of uncertainties in KBS.

Chapter four outlines the concept of fuzzy set theory. This chapter provides a general overview of fuzzy set theory.

Chapter five sets out the methodological framework for knowledge acquisition. This chapter also describes the format of the questionnaire survey and provides a brief outline of the personal constructs theory and the issues in the design of Repertory Grids.

The research methodology described in chapter five involved an extensive collaboration of a retired chief estimator from one of Britain's biggest construction companies and thirty-three contractors involved in refurbishment work.

In chapter six, the results of the questionnaire analysis from thirty-three refurbishment contractors is presented.

Chapter seven presents the result of the Repertory Grid analysis and the hierarchical framework developed for this model.

In chapter eight, the decision model SSARC developed using commercially available expert system shell **Leonardo** 3 is described. The developed prototype SSARC represents the potential of applying this technology to aid refurbishment contractors in the selection and appointment of sub-contractors.

Chapter nine summarises the main findings of this research and outlines proposals for further research in this area.

1.5 Findings of the research

As will be discussed in chapter 9, SSARC standardises the decision approach to sub-contractor appointment by consolidating multiple sources of unarticulated expertise within a single knowledge base. This improves both the consistency and the objectivity of sub-contractor's selection decisions by ensuring that decisions are reached systematically and that tenders are evaluated equitably.

Furthermore, the ability to use linguistic expressions enables contractors to assess the significance of the uncertainty. This is particularly beneficial in refurbishment work where such linguistic expressions are commonplace and also where the ultimate decision is the result of social interaction between several senior managers and where it is therefore necessary to reach a consensus decision. In such a situation, fuzzy set theory and knowledge based systems are beneficial in determining the significance of minor differences of opinions between the managers and thereby focussing the attention of the group onto the key issues where a consensus is required.

Finally, it facilitates certain decision about the use of sub-contractors and encourages the contractor to examine them critically. SSARC therefore clarifies thinking about decision-making and about uncertainty. In particular, it focuses attention on the key constructs and their inter-relationships influencing their sub-contractor selection decisions. Thus given the successful experiences with SSARC, it can be concluded that the KBS is appropriate for modelling sub-contractor selection decisions, at least in modelling decisions regarding the employment of the most suitable sub-contractor.

SSARC also provides several important and valued benefits to refurbishment contractors. These can be listed as follows:

1 It consolidates multiple sources of information and expertise in the contractor's office regarding the use of sub-contractors within a single knowledge base.

2 It provides an objective and consistent decision-making process that would improve the quality of the decisions in the management of risks caused from the use of sub-contractors.

3 It enhances the contractor's understanding of the key criteria, and their inter-relationships, affecting its selection and appointment decision process.

4 Using KBS as an experimental tool would enable contractors to evaluate the suitability of different trade sub-contractors.

5 It would enable contractors to combine qualitative and quantitative approaches and thus complement a contractor's descriptive knowledge base with a normative component.

6 It allows complete interrogation of the knowledge base and can explain the line of reasoning taken to arrive at a conclusion.

CHAPTER TWO

REFURBISHMENT PROJECTS AND SUB-CONTRACTING

CHAPTER TWO

REFURBISHMENT PROJECTS AND SUB-CONTRACTING

2.1 Introduction

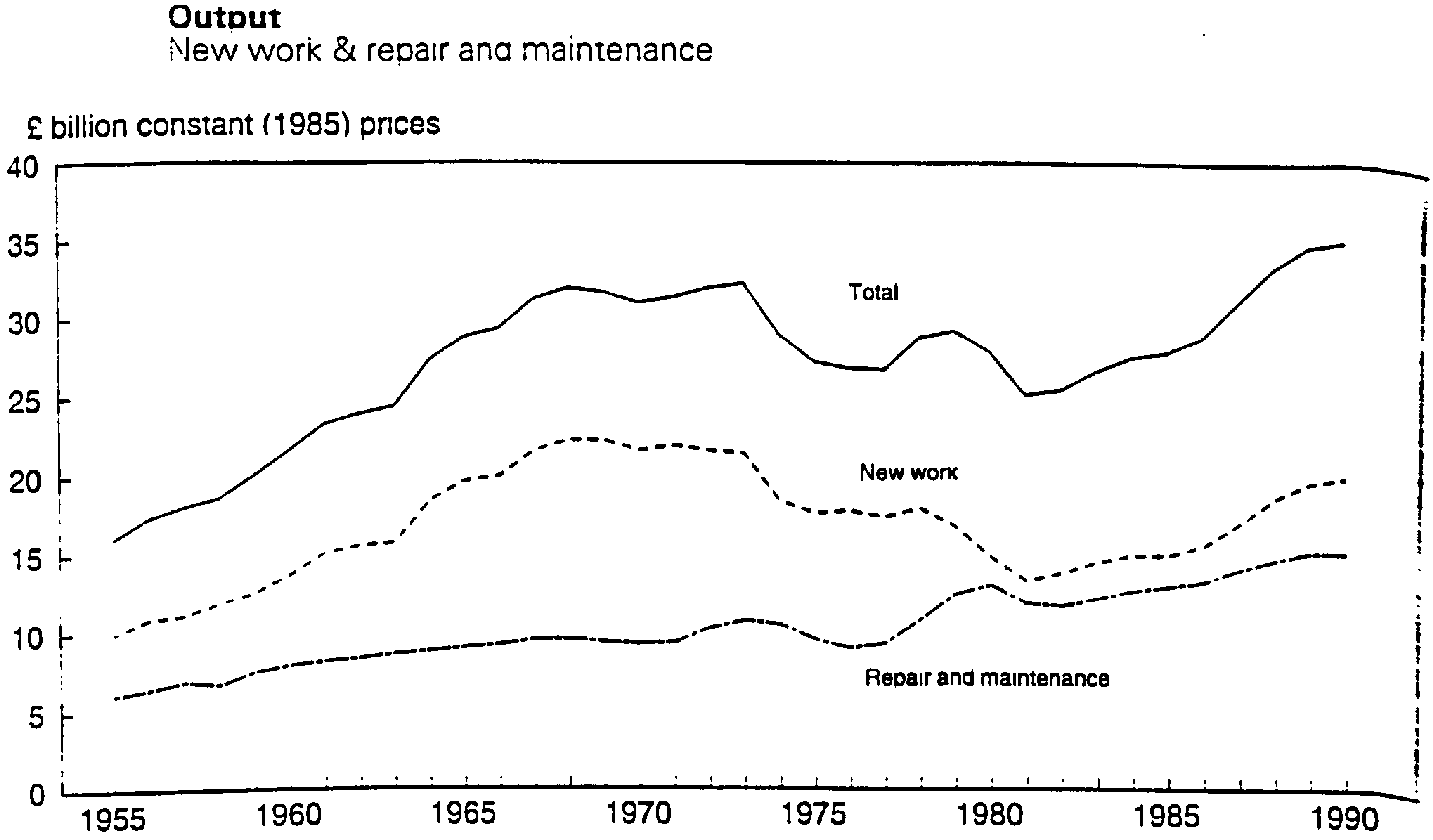
The construction industry has long been known for its use of sub-contracting to accomplish large complex tasks. Today, the size and complexity of a construction project can be immense as evidenced by the multinational consortium of companies now building the channel tunnel. Under such circumstances, companies must be able to form a network of reliable sub-contractors, many of them large firms which have not worked together before. Some companies therefore, have found it advantageous to focus on the design and management of the project leaving the actual construction to their affiliates. This chapter provides a general overview of refurbishment work and problems associated with refurbishment work. It also reviews the sub-contracting procedures in the construction industry and the current practice for choosing sub-contractors to work in refurbishment projects.

2.2 The refurbishment work sector of the construction industry

Refurbishment work encompasses a wider range of work which includes the repair, conversion, alteration, modernisation, improvement and extension of buildings.
According to the Department of the Environment (DOE), repairs and maintenance work includes all improvement work carried out on existing housing, but excludes improvement work to non-housing sectors which is classified as new build work. It also excludes the conversion of industrial and commercial buildings through refurbishment to housing units which is also considered as new build work. There is no accurate measurement to determine the actual value of refurbishment work in the UK construction industry. However, the DOE's (1) statistics on repairs and maintenance work are generally used by practitioners as a yardstick for monitoring trends in the refurbishment market.

Figure 2.1: Construction orders and output

(sources: Housing and construction statistics- 1985-1990)



2.3 Unique characteristics of Refurbishment work.

2.3.1 Introduction

Refurbishment work has characteristics that sharply distinguish it from new build construction projects.One of the unique problems with most refurbishment projects is the virtual impossibility of defining the exact scope of the work in advance. Refurbishment can be major work in which restoration of an historic house or quite minor in putting a new roof on a leaking post war school is carried out.

The original drawings and specification are usually long gone, there may have been many unrecorded alterations and modifications during the building's life, and deterioration behind the scenes may be far worse than assumed.

Many older buildings will contain materials, such as asbestos and high alumna cement concrete, which are now considered hazardous. The discovery of blue asbestos once

the refurbishment contract has started will destroy original cost and time estimates, even to the point of casting doubts on the viability of the whole project.
The noise, dust and disruption of major building works are often seen as a more tolerable alternative to the problems of temporarily relocating to other premises. Yet the nuisance factor is usually the least of the difficulties encountered. The continued presence of the tenant makes it virtually impossible for the contractor to maintain tight cost time control.

The type of contract chosen is much more important than in new build work. Traditional adversary attitudes have no place. A very flexible and oriented approach to management is necessary. Competitive lump sum tendering is unlikely to be satisfactory. The track record of the appointed sub-contractor is at least as important as their quoted rates. It is very much a case of 'penny wise, pound foolish' with the result of using inexperienced sub-contractors being higher costs in the long run.

only opinion?

2.3.2 Technical Skills

The accomplishment of refurbishment work requires the employment of the most modern knowledge and skills on the oldest buildings. Refurbishment might include retention of a tall total facade while the building behind it is demolished. This presents all sorts of problems even to experienced and skilled sub-contractors. The lateral support provided by the old building is temporarily lost and cannot be simply replaced by shoring, as access is required for new construction. Also the provision of new floor supports temporarily weakens the wall.

There are the structural considerations of excavating close to existing buildings to provide foundations at new levels. The subsequent underpining may produce conditions for differential settlement in the future. Differential movement between new and old materials and their matching in appearance create other major problems. Unmapped services in old buildings and obscured chimney breasts containing many flues are classic problems that are found in the majority of refurbishment projects.

The unpredictability of problems likely to be met not only cause headaches for the inexperienced sub-contractor; even specialist refurbishment contractors find refurbishment projects challenging, as one contractor describes:

"one of the cliche's of refurbishment projects is the beautiful old building discovered to be held together by generations of wall paper ... one never knows what structural horrors may be lurking behind a respectable surface."

2.3.3 Estimating skills

A number of contractors have gone out of business because of using under-priced sub-contractors quotations in their bids. They are tempted to win the job and failed to appreciate the high cost and difficulties involved. Underpricing is prevalent in this fierce competition, but it is obviously better to lose the job than lose the firm through insolvency. Pricing refurbishment work is different from new build. According to Quah (2) and Teo (3), this is because it often consists of small amounts of work scattered all over the building, the process of carrying out refurbishment work becomes more important than the quantity of work involved. The major difficulties encountered when pricing refurbishment projects include:

complying with strict noise regulations;

constant problems of accessibility;

restrictions on material supply to site;

estimating the amount of protection to existing and adjacent -buildings; and

estimating the risks and uncertainties.

2.3.4 Flexibility

Refurbishment work is further complicated by the fact that the building is often partially occupied by tenants throughout the construction period. Such contracts require a more flexible approach in their planning and co-ordination as the work is less predictable (higher element of uncertainty). Skill is needed to handle the job so that the least inconvenience is caused to occupants. This also calls for a substantial out-of-hours working arrangement and it may be necessary for such operations as scaffolding work to be carried out during odd hours when the building is vacated.

2.3.5 Detailed site work programme preparation

Organisation and progress control of refurbishment work are of paramount importance. With the many activities taking place on site, an estimate of the standard time of a particular site activity without careful site planning and control will not produce a better result than a "guesstimate".

2.3.6 Scheduling ability

Refurbishment projects require more complex planning and a clearer appreciation of the different trades that make up the workforce. In the majority of refurbishment contracts, clients usually impose stringent completion time constraints with liquidated damages clause on contractors throughout the construction period.

Refurbishment contractors are therefore very particular about meeting the completion targets. Because of foreseen and unforeseen problems in refurbishment, there must be direct liaison at a high level with the client's management.

2.3.7 Existing building

Working in an existing building involves greater risks than new build projects and is likely to provide some unpleasant surprises. These may include services in unexpected places, undated deterioration of the fabric, and fittings and finishings which have been damaged by adjacent building work. These are often compounded by the need of occupants to use the building during the refurbishment.

2.3.8 Standard method of measurement/ BOQ

The main problem in pricing any refurbishment work is that the standard method of measurement is basically designed for new work and it is difficult to measure the complexity and unpredictability that usually occur on refurbishment projects. Refurbishment work is poorly served by bills of quantities. In addition to their traditional cost control function, bills of quantities also act as an important check on the completeness or otherwise of the design. In refurbishment projects their use is the exception rather than the rule. For example, in most refurbishment contracts the bills of quantities hardly give the exact description or the quantity of work items that would be carried out on site. When they do, to all intents and purposes no truly standard method of measurement is adopted and under no circumstances could they be felt to fully describe and accurately represent the quantity and quality of the works to be carried out.

Bills of quantities for refurbishment work are prepared either by the quantity surveyors with little understanding of the work they are measuring or by consulting engineers with little appreciation of the function of bills of quantities. There are exceptions but it is rare to find adequate consideration given to the physical circumstances and arrangement of the types of fixing and supports to be priced, which is inevitable when the works are not yet fully designed.

2.3.9 Pricing difficulties

New buildings are generally built principally from the drawings and quantities are taken off from these drawings in accordance with the standard method of measurement. On most refurbishment projects, however, the drawings generally show any new work to be incorporated and provide locational reference for the other tender documents. It is these documents which lay out in detail the work required and which are used for the pricing. The contract documents are usually vague in specifying the quality and quantity of work required by the client. Clauses such as "cut out and replace all defective plaster" are found in the majority of refurbishment contract documents. Decisions have to be made as to whether to replace all plaster, defective or not, or whether to retain as much as possible.

2.4 Subcontracting in the construction Industry

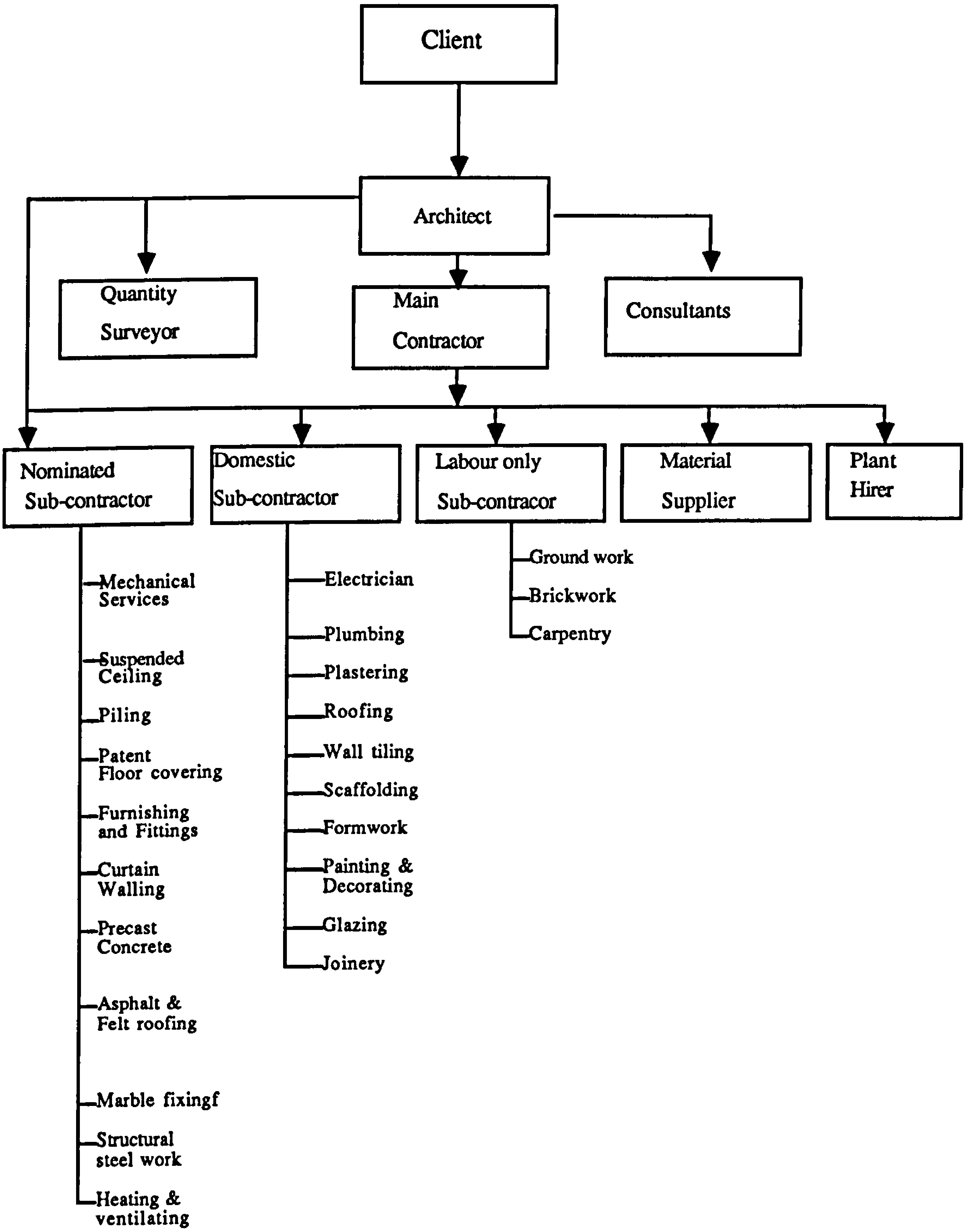
It is common practice in construction projects for parts of a project to be carried out by parties other than the main contractor, contracted by the clients to construct the project. A sub-contractor is defined in the oxford dictionary as:

" one who enters into a subcontract" and he (contractor) ... " hands over what he cannot do himself to others with whom he subcontracts"

Nominated sub-contractors are defined by the JCT 80:

"as persons whose final selection and approval for the execution of any work or for the supply and fixing of any materials or goods has been reserved to the architect ... such reservation to the architect can be effected either by the use of a prime cost sum or by naming a sole sub-contractor in the contract documents so that the main contractor is therefore bound to enter into a sub-contract with that person."

Figure 2.2: Typical site organisation in a refurbishment contract



Under clause 35.4 of the JCT standard form of building contract 1980 edition (4), the main contractor can object to a particular nominated sub-contractor. His objection will be held by the architect provided his objection is reasonable.

Sub-contracting involves a hierarchy, that is, a main contractor, a sub-contractor and a team employed by the sub-contractor. The contractor might be another organization or a single person, who has access to labour and equipment, if necessary, and who forms an ad hoc team to undertake part of the project.

The essential contribution of the sub-contractor is to carry out specific construction work, bringing his own expert labour, materials and special plant and machinery. For both nominated, domestic and labour only sub-contracting, the basis of employment is that the main contractor obtains vicarious performance of some of his duties under the contract, whilst remaining primarily responsible to the client for execution of the project.

2.5 Growth of sub-contracting in the refurbishment work section of the construction industry

Table 2.1: Changes in the structure of the construction industry

Firms by size, trade and region	1985	1990	% increase
Small (less than 13)	158,636	201,487	27
Medium (13-299)	8,943	8,041	[10]
Large (more than 300 men)	246	266	8
All firms	167,825	209,793	25
All firm excluding general builders and civil engineering contractors	94 065	122,297	30
Roofers	5,818	7,767	34
Glaziers	4,587	6,531	49
Plasterers	4,019	4,834	20
Demolition specialists	559	667	19
Scaffolding specialists	966	1,524	58
Plant hirers	3,664	4,626	26
Electrical	15,449	20,752	36
Scotland	11,172	12,735	14
Wales	7,733	9,612	24
South West	18,050	23,928	33
Midlands	27,790	32,653	18
South East	57,,302	77,780	36

Government statistics (1) summarised in table 2.1 show a considerable increase in the number of sub-contracting firms. Between 1985 and 1990, the number of scaffolding specialist firms grew by 58%, glaziers by 49% and demolition contractors specialists by 19%.

Taken individually or together the message is still the same; sub-contracting is rapidly expanding nationally. On many individual projects the level of sub-contracting can be over 90%.

There has been no single factor which has caused the increase in sub-contractors. According to Gray and Flanagan (5), it has partly resulted from a gradual squeeze of employment opportunities as the construction industry has responded to the variations in workload over the past 10 years. A variety of pressures from depression to boom, from high levels of employment to unemployment, from traditional technology to high technology, from predominance of public sector investment and the need to build faster, have all played their part in changing the construction industry. The emergence of the sub-contracted labour base of the construction industry has been a significant response to the volatility of this growth.

In construction terms, a contract is defined as an agreement between a client and a building or civil engineering contractor to do certain definite types of work at certain rates, generally within a stated time. A subcontract is defined as a part of a contract, often specialist work such as asphalting, which is done by a separate firm from the main contractor. The main contractor is responsible for the work, pays the sub-contractor and is paid by the client for it.

2.6 Factors influencing the growth of sub-contracting in refurbishment work

2.6.1 Demand uncertainty

One of the major problems that refurbishment contractors are faced with is demand uncertainty, in terms of being awarded successive contracts. In other words, the contractors do not operate with a stable demand pattern. The demand is unstable, difficult to predict and comes in batches.

Sub-contracting is one strategic action that can be employed to cope with long-term demand uncertainty. It allows the contractor, if he so chooses, to avoid the employment of a stable work force and investments in fixed resources under conditions of fluctuating demand. Under uncertain demand conditions, increases in investments in fixed resources are likely to aggravate the smoothing process and lead to low utilization problems due to difficulties in balancing of components. Although contracts for a single project or a number of simultaneous projects create certainty to some extent, they do not eliminate long-term uncertainty as it is uncertain that the same contractor will be able to secure contracts of the same type and size in the future.

Given the intensive nature of refurbishment projects and potential uncertainties on site, the use of sub-contractors may also offer advantages in managing uncertainties associated with input transactions and production operations.

2.6.2 Complexity of the transformation process

Another important characteristic of refurbishment projects is the complexity of the transformation process because of the variety of skills and specialised plant required. The contractor has to operate within these general contextual conditions. Attempts to solve these problems intraorganizationally require increases in investments in fixed resources, human or material, some of which may be specific in use. Complexity in this case is probably defined as the variety of component activities required to complete the project. Variety in components of a project might be due to the diversity of functions of the building or set of buildings or the special needs of the project. Multi-function buildings and/or unique needs are likely to increase the need for a wider range of labour specialties and specialized equipment which may not be at the disposal of the contractor.

2.6.3 Perceived environmental uncertainty

Sub-contractors perform some of the boundary spanning functions component for refurbishment contractors. Recruitment of personnel, procurement of supplies, stockpiling of inventories, obtaining credits are some of the buffering mechanisms taken over by sub-contractors. Sub-contracting eases this problem by providing a ready-made mobile labour force which can be moved from one project to another.

2.6.4 Local condition experience

Contractors have increasingly had to seek work further and further from their base and so have had to recruit the workforce locally, as the cost of using their own workforce has been too high.

Distant project locations would probably pose further potential contingencies in terms of climatic conditions and labour and materials procurement. Sub-contracting may serve as a convenient buffer for the technical core at the site to local environmental conditions. Moreover, spatial dispersion is likely to increase problems of co-ordination and control for the contractor.

2.6.5 Speedy construction

In the majority of refurbishment contracts, clients usually impose stringent time constraints on contractors both during tender preparation and construction or hand over.

Time limits imposed on the project by the client may be another important factor determining the amount of work subcontracted. Time limit is not conceived as the absolute duration of the project but the time available as compared to the time required for the completion of a normal piece of work. One of the potential benefits of sub-contracting is getting things done in a shorter time, owing to, primarily, specialization on the part of sub-contractors.

2.6.6 Ease in obtaining planning approval

Through the sub-contractor, the construction firm may also avoid getting involved in certain linkages with other external bodies. Design work may be subcontracted to a design and consulting firm, which not only presents a completed project to the main contractor but also solves the bureaucratic problems with authorities.

2.6.7 Client requirements

Certain constraints imposed on the project by the client may also affect the amount of work that is subcontracted. The intensity (size/duration) of the project and the penalties that are associated with time over-runs are such constraints. Time may also be a significant factor when there are no client imposed targets but it is difficult to pass on additional costs due to longer completion time to prospective customers. According to Lansley (6) and Hillebrandt (7) a high size/duration ratio implies tight schedules. Sub-contracting also enables the contractors to obtain additional resources to eliminate temporary bottle-necks and meet strict deadlines.

2.6.8 Flexibility

A major advantage of sub-contracting is the flexibility it allows the construction firm, given the nature of construction demand and technology. For stability/flexibility oriented firms sub-contracting is of value in-as-much as it provides for the flexibility that the firm seeks in responding to environmental and project demands.

For the small construction firm, sub-contracting is a coping device for survival. Availability of sub-contracting allows these firms to maintain a very limited administrative and resource capacity responding to project demands as they come. The role of this type of firm in the construction process is like the large contractor discussed by Clarke (8), but operating on a much smaller scale and with limited financial resources. There is high reliance on sub-contracting, the specific amount being determined, as discussed in the previous section, by the characteristics of the small number of projects that the firm performs at that point in time and the conditions in the localities in which the projects are carried out.

2.6.9 Increase in resources

Sub-contracting enables access to resources not available in-house. Higher diversity also implies higher levels of complexity to be managed, increasing the burden on the administrative capacities of the firm. By taking on a range of boundary spanning functions for the contractor, sub-contractors help to reduce environmental complexity and thus the pressure for structural elaboration. So, greater diversity is likely to lead, albeit at varying degrees, to higher levels of sub-contracting for all types of construction firms.

Specialisation on the part of the sub-contractor leads to cheaper prices for specialist work, because in theory, he is supposed to complete the task within the minimum time requirement. By specialising, the sub-contractor should be in a position to carry out the work far quicker than the main contractor.

2.7 Risks and uncertainty associated with sub-contracting in refurbishment work

Sub-contracting may have solved some of the problems outlined above, but has exposed the contractor to a number of risks. These risks arise basically from the fact that as soon as the contractor sub-contracts a portion of his work, he sacrifices a certain amount of authority over that part of the project.

For example, a sub-contractor who over-runs his time allocation can cause the contractor to rearrange his schedule of work, which would involve alteration of labour and material schedules and reallocation of plant to offset delay. Failure by a sub-contractor to complete his project or failure to pay bills may result in substantial delays to the project and consequent higher costs for both parties in the contract. Programme changes however slight are costly to the contractor in time and effort. Also a delay caused by default or time overrun by a sub-contractor can result in the contractor incurring liability for large liquidated damages which the contractor may not be able to pass to the sub-contractor.

Also, allowances at the estimating stage for attendances on sub-contractors are normally priced under preliminary items and commonly take the form of percentage addition to sub-contract bids. This cost varies from one attendance to another and does not reflect the realistic budgeted costs against which actual costs were priced. The risks associated with all attendances are borne by the contractor.

This problem is further compounded in projects where specialist sub-contractors are appointed by the client or the architect and the contractor tenders for work knowing neither the full extent of specialist work nor who is to carry it out. In some contracts, the main contractor is mandated to secure the performance of a sub-contractor he did not select and he is also responsible for the cost of re-nomination in the event of a nominated sub-contractor becoming insolvent. There is also the increased responsibility of control and co-ordination of work of several different trade sub-contractors on site as these sub-contractors may not have the resources to organise and control their different activities.

As a result of this increased use of sub-contractors, and coupled with the present state of the economy where competition for jobs is intense and keen among refurbishment contractors, sub-contractor's quotations have become increasingly important to the contractor's bidding success. Many refurbishment contractors accept and use bids from their sub-contractors for their construction projects only to find that during the actual construction process their performance incurs delays and costs due to a poorer than expected performance.

Many refurbishment contractors have gone out of business because they used under priced quotes from sub-contractors to win a job, only to realise that they could not deliver what they have contracted. No matter how efficient a contractor is in his work organisation, a poor selection and appointment of sub-contractors would increase his uncertainty and risks for the successful execution of the job. Furthermore, the performance of sub-contractors affects the outcome and quality of work independently of the main contractor's competence. Sub-contractor's financial default may result in serious financial problems and time delays for the contractor. The contractor should review carefully the selection procedures of the potential sub-contractors that will be involved in their projects.

2.8 Current sub-contractor's selection practice and decision process

As stated before, the current practice of sub-contractor's selection for refurbishment projects is more of an art than a science. The process consists of a wide range of criteria for which information is both qualitative and subjective.

The task is typically performed in an unstructured, intuitive manner with considerable reliance on the experience and judgement of the chief estimator, buyer or contracts director. Although experiences are sometimes exchanged through informal discussions and the use of formal meetings which are arranged at various stages of the project, in most cases, great dependence is placed upon the accumulated experience of certain key decision makers in the contractor's organisation. In some cases judgement may be influenced by biases of this key decision maker. This may be due to previous experience with the sub-contractor's site staff performance. This process can lead to incorrect decisions due to lack of application of a rational or systematic approach.

The result of studies on judgement Brehmer (9) and Baron (10) indicate that judgement processes are simple and inconsistent and that people have limited insight into them; such processes have been termed quasi-rational processes Hammond and Brehemer (11). The reason for this, according to Hammond (12) is "characteristic stems from midway between analytical and intuitive thinking". Basically, a quasi-rational process is seen as one that is partially rule-bound (analytical thinking) and partly relying on specific experience (intuitive thinking). Thus, people may have rules for making judgements but the judgements derived from these rules are checked against specific experience from cases similar to that at hand. If a rule derived judgement does not agree with whatever specific case that a person happens to remember, the judgement is modified. As a consequence, the process is not completely determined by the rules and is inconsistent, a conclusion that is particularly important in the analysis of human social interaction and conflict.

Traditionally, decision analysis has been concerned with situations in which the decision makers must choose between alternatives characterised by one objective. Profit maximisation has long been the prime objective of decision theorists in the business world. In recent years, however, there has been a growing awareness that most decisions cannot be adequately described in terms of a single objective. Businessmen are certainly interested in maximum profits, but they are also concerned about corporate good will, market share and future growth.

Likewise in refurbishment contracts, the selection of sub-contractors is also a decision characterised by multiple objectives. Contractors want to minimise the cost of projects, but also they require sub-contractors to maintain schedules, be quality-oriented, and safety minded, to mention a few objectives.

The primary objective of competitive bidding is that contracts are awarded to the "lowest responsible bidder" or "lowest and best bid." The term "lowest" is described by Richter (13) and Cusack (14); as "the bid which is momentarily the lowest in comparison to other bids and which responds to the requirements of the invitation for the bid". When meeting this criterion, a bid is said to be responsive. On the other hand, the term "responsible" or "best" addresses the bidder's ability to perform the work if awarded the contract. If the sub-contractor is judged capable of performing the contract he is said to be responsible. These two criteria responsiveness and responsibility are the backbone of any sub-contractor selection exercise.

CHAPTER THREE

KNOWLEDGE-BASED SYSTEMS

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KNOWLEDGE-BASED SYSTEMS

3.1 Introduction

In recent years, knowledge based systems have become the fastest growing application area of artificial intelligence. The main aim of the knowledge based systems is to document expertise thereby making its transferral to non-experts more effective. Knowledge based systems (KBS) have also the potential of offering a more automated approach to construction industry problem solving. According to Adeli (1), it is envisaged that knowledge based systems will have a significant effect on the construction industry. However, to accomplish this, it is necessary to address important issues of knowledge acquisition, knowledge representation, inference mechanisms and dealing with uncertainty, and user interfaces.

The purpose of this chapter is to address these issues as well as providing a useful discussion for the development of a knowledge based system which offers advice on the selection and appointment of a suitable sub-contractor for refurbishment contractors.

The basic features and development of knowledge based systems is presented. The potential application areas and the main merits for using knowledge based systems in the selection of a suitable sub-contractor in refurbishment is also outlined. Special attention is given to knowledge acquisition and implementation.

Knowledge implementation will focus on the methods of representing knowledge and on the different ways of dealing with uncertain knowledge.

This chapter will also provide a brief review of the literature relating to knowledge based systems.

3.2 Definitions of terms

The British Computer Society special group in knowledge based systems (2) defined a knowledge based system as:

"the embodiment within a computer of a knowledge component from an expert skill in such a form that the system can offer intelligent advice or take an intelligent decision about a processing function"

and

"one approach which by its very nature can replicate some of the decision making processes exercised by experts"

Thus, knowledge based systems comprise expert knowledge and the ability to manipulate that knowledge in order to infer conclusions about a particular problem domain. It allows the knowledge and experience of one or more experts to be acquired. This knowledge can then be used by anyone who considers it useful for examining their problem. However the purpose of the KBS is not to replace the experts, but to make their knowledge more widely available and permanently stored on computer. In addition to the ability to tackle problems which cannot be solved using conventional programs, KBS have other unique attributes. The internal structure of KBS makes the generation of explanation text a straightforward task (try asking a conventional computer program the questions of How? or Why? a particular answer has been given) and the same structure enables the knowledge base to be easily updated and modified.

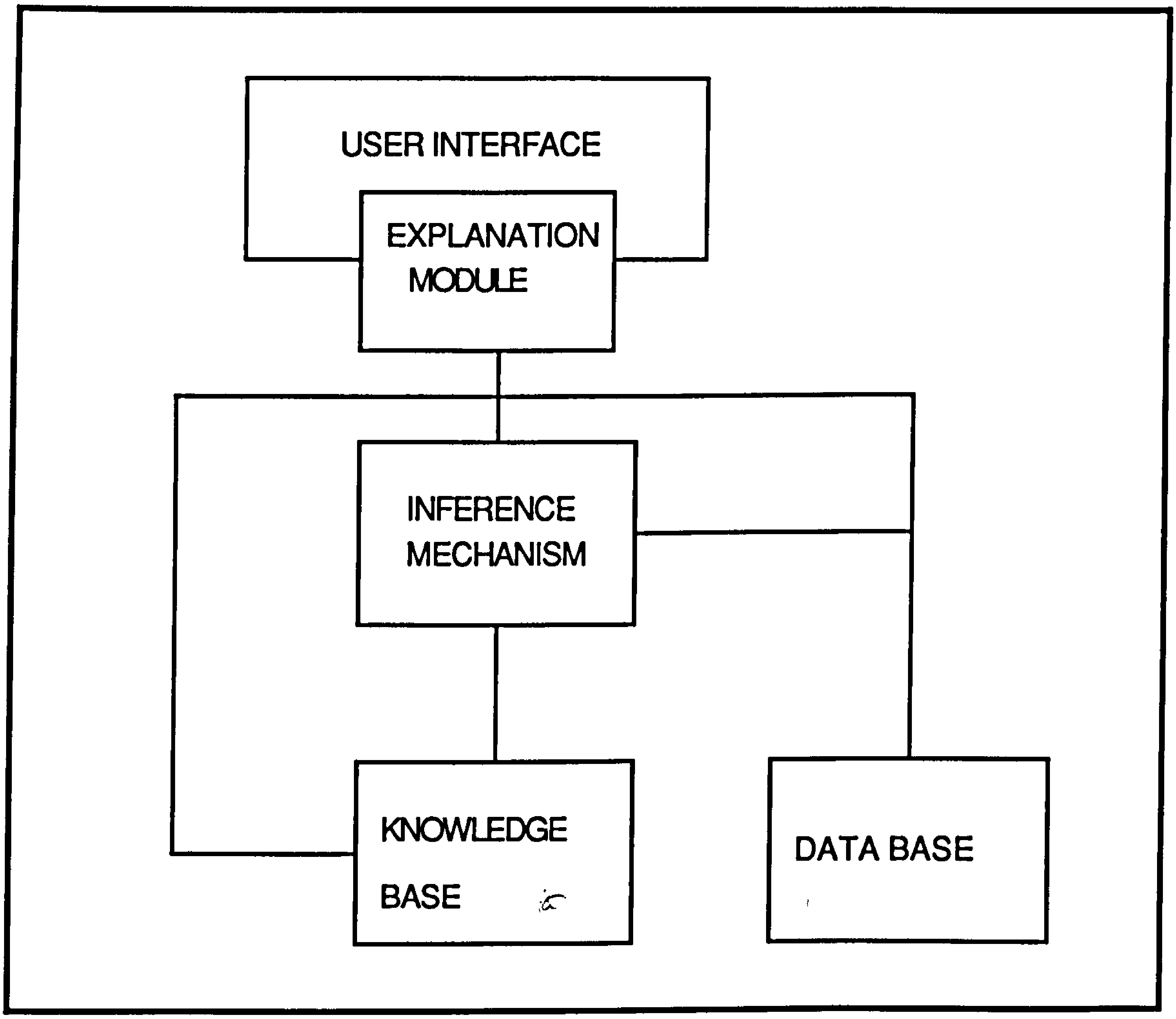
Kastner and Hong (3) and Assad and Golden (4) noted that:

"KBS can offer a recommendation based upon the information available and can justify its recommendations to the user. That is, knowledge based systems are capable of explaining their conclusions and reasoning and are capable of producing results consistent with experts in the area and like human experts are capable of offering recommendations in the light of a combination of incomplete, uncertain and conflicting information."

3.3 Features of a knowledge based system

3.3.1 Basic structure

FIGURE 3.1: KNOWLEDGE BASED SYSTEM COMPONENTS



A knowledge based system usually comprises of:

(a) A knowledge base;

(b) User interface;

(c) Data base ; and

(d) Inference Engine.

3.3.1.1 Knowledge base

The knowledge base contains the domain specific knowledge elicited from the domain expert. Human expertise is incorporated into a knowledge based system in the form of knowledge about a domain. The knowledge may comprise of rules, facts, reasons, rules of thumb, intuition or an inference net and is stored as a model on the computer to form the knowledge base to the system. The knowledge base contains an expert's knowledge about a particular domain. The expert's knowledge is normally entered into the knowledge base by a **knowledge engineer or system developer**. For the knowledge to be handled by the computer software, it must be represented in a 'formal' form. This is achieved using the editor (software or word processor).

3.3.1.2 User interface

This provides communication with the system developer and the eventual user of the system. It also controls the dialogue with the user in a form consistent with the user's understanding of the task being dealt with. This may be an **explanation module** which provides the user with information about questions asked, and decisions made, by the inference engine.

3.3.1.3 Data base

This contains facts about a domain. The facts include the components that are required for the design of a computer system. These facts can be initially known facts about a domain, facts that are used as input in order to begin the inference process and facts that are stored temporarily during the inference process.

3.3.1.4 Inference engine

The inference engine is responsible for manipulating the domain knowledge encoded in the system's knowledge base together with information provided by the system user during the consultation and information from external devices such as databases. It works out the logical consequences of rules and controls the operation of the knowledge base. It will often have to infer conclusions from incomplete and imprecise data. In most knowledge base systems, it will include a capability for explaining the reasoning in the knowledge base. It combines facts from the database with 'rules' in the knowledge base to produce expert level advice. This advice can be presented to a user or to another computer programme.

In a rule based expert system, it is the responsibility of the inference engine to select which rules to 'fire' and the appropriate time during the user's consultation in order to infer conclusions. Various search strategy approaches are available for controlling the manipulation of the knowledge. These approaches are known as **inference mechanisms** and are generally dependent upon the representation scheme being deployed.

The inference mechanism searches the knowledge base for a solution by looking for patterns that match a desired goal or data. There are two main strategies by which rules can be inferred by the inference mechanism. In general, rule based systems adopt a mixture of 'global' and 'local' inference mechanisms.

The global mechanisms are domain-independent procedures encoded within the inference engine, whilst the local mechanisms correspond to the expert's heuristic-knowledge and are used to focus the attention of global mechanism down more promising search paths. At the global level, production rules are normally manipulated using either a '**forward chaining**' or '**backward chaining**' inference strategy although in some rule based implementations, bi-directional strategies as described by Young (5) are deployed. Forward chaining strategies are also referred to as event or **data driven** strategies while backward chaining strategies are also known as **goal driven** strategies.

3.3.1.5 Forward chaining

In a forward chaining strategy, the inference engine cycles through the rules testing the truth of each rule's condition component against any existing information. This as described by Ramsey (6) and is known as the **recognised act cycle**. The existing information consists of data supplied by the user, data from an external devices and also information that has been inferred by the system during an earlier cycle of the inference engine. From those rules whose condition components are true the inference engine selects one rule to 'fire' a conflict resolution strategy.

3.3.1.6 Backward chaining

In the backward rule based systems, in addition to the rules in the knowledge base, there exists a primary goal. It is the responsibility of the inference engine to use the rules to establish a value for this primary goal. To do this, the inference engine looks for a rule whose action component would allow a value for the primary goal to be inferred provided that the rule's condition component was true. When such a rule has been identified the inference engine attempts to establish the truth of the rule's condition. If the truth of these conditions could be established, then the rule is fired and a value for the primary goal inferred. To establish the truth of these conditions the inference engine first tests the truth of each condition against the existing information. If the truth of all the conditions cannot be established in this manner, then those conditions whose truths are unknown are put in an agenda of temporary sub-goals. The inference engine then attempts to establish the truth of the sub-goals on the agenda in turn in the same way as described for the primary goal.

3.4 Tools for knowledge based systems development

One of the primary considerations in the development of knowledge based systems is the selection of the appropriate development tool. These tools are normally classified by language, environments, and shells.

Table 3.1: Knowledge Based Systems Tools

LANGUAGE	ENVIRONMENT	SHELLS
LISP PROLOG C PASCAL FORTRAM	KEE ART	CRYSTAL SUPEREXPERT LEONARDO 3 XI SAVOIR

3.4.1 Language

The language employed can be either a special purpose language for symbolic programming such as 'lisp' and 'Prolog' or a conventional one such as 'C' or 'Pascal'.

3.4.2 Environment

The environment contains various types of knowledge representation aids. These tools also give to the underlying language the environment it is written in. This enables the developers to incorporate specialist tasks.

3.4.3 Shells

Shells provide a more specific set of knowledge representation languages and inference mechanisms, geared to handle a particular class of problem. A shell is a software aid for developing the executing knowledge based systems. It is called a 'shell' because it lacks knowledge and data specific to any domain, but contains the facilities required to construct and run a system application. For example, the knowledge engineer does not have to design the inference engine or reasoning mechanism. A built-in user interface is provided to support explanation and user assistance. The inference engine of a 'shell' is independent of application and provides the inference mechanism (backward or forward chaining) as well as the method of reasoning. It also provides a method of searching the knowledge base. The form of knowledge representation is predetermined by the 'shell'. All the user has to do is to provide the knowledge and data and is therefore free to concentrate on knowledge acquisition. Whilst a great benefit in savings in the time is achieved with the use of shells, expert system shells restrict the flexibility of the development of the KBS. Both shells and environment differ from languages in the fact that they already contain control mechanisms that determine how they will reach a conclusion.

3.5 Building knowledge based systems with a shell

3.5.1 Evaluation of Expert System Shells

When evaluating conventional computer programme languages, the normal approach is to compare the features supplied by a language and its speed when performing certain tasks.

This approach according to Waterman (7) is not very useful when evaluating Expert System shells, mainly because most of the expert system shells on the market are very different both in terms of their internal structures and of the kind of applications for which they are intended. This makes them suitable for different application areas and the process of selecting the right shell for a particular application is often a very difficult task. Much of the confusion about expert system shells also arises from the fact that technical terms are not always used consistently. When it comes to evaluating Expert System shells, it is more a matter of evaluating a shell's suitability for certain classes of problems. Over the past few years the number of expert system shells has increased dramatically and as described by Waterman (8) the already crowded market is still growing rapidly.

TABLE 3.2 REVIEW OF EXPERT SYSTEM SHELLS

BACKGROUND PARADIGM	CRYSTAL VERSION 3.20	Xi PLUS VERSION 3.0	ART- IM VERSION 1.5	SUPEREXPERT	LEONARDO VERSION 3
KNOWLEDGE REPRESENTATION	Knowledge representation is in the form of rules. Procedural component to the knowledge base must be developed xtnly in 'c' programming language Uses forward and backward chaining	Knowledge rep is rule based. It is provided with a richer knowledge representation than crystal, allowing object attribute value to be defined.	It is a rule based programming tool It has procedural programming language, and object oriented programing language coded in Prolog,C, and lisp	Knowledge rep is in the form of rules and frames	Knowledge representation is in the form of rules and object-oriented programing language. Procedural language is included
INFERENCE AND CONTROL MECHANISMS	Uses forward and backward chaining to the knowledge base	Uses backwards and foward chaining although forward chaining is invoked through the use of 'demon' rules.	Primarily a forward chaining rule based system although backward chaining can be achieved.	Is a backward and forward chaining shell.	It is a forward chaining shell and opportunistic backward chaining
UNCERTAINTY HANDLING	Has facility to handle uncertainty, support Bayes function	Supports Bayes, fuzzy logic and certainty factors	It also supports Bayes, fuzzy logic and certainty factors	It contains no uncertainty facility	Support Bayes and Certainty factor
DELIVERY ENVIRONMENT	No knowledge of computer or formal training is required to be able to use it effectively within a short time	It requires a little more effort to get to know the shell and its features to use it competently. Need to be computer literate.	Not easy to use by an average programmer.	Aimed at naive users and domain experts	No knowledge of computer or formal training is required although in order to use the procedural language some knowledge of programming background is essential.
EXTERNAL PROGRAMME INTERFACE	Interfaces with lotus 1,2,3, dBase, and interactive video	Interfaces with applications written in other software	It has a flexible user. Interfaces with dBase. No interfaces with Lotus 1,2,3.	Interfaces with other computer programmes via "Mirle international"It also interface with spreadsheet and dBase.	Interfaces with Lotus 1,2,3. and dBase and other applications written in other languages.

TABLE 3.2 cont- REVIEW OF EXPERT SYSTEM SHELLS

BACKGROUND PARADIGM	CRYSTAL VERSION 3.20	Xi PLUS VERSION 3.0	ART- IM VERSION 1.5	SUPEREXPERT	LEONARDO VERSION 3
DOCUMENTATION AND SUPPORT	Entirely menu driven with relevant help on-line at any point	Existing manual provides a general overview of system and how to build expert system	Documentation consists of two large manuals, three slim booklets and installation instructions. They all provide extensive information required.	Well structured manual with good easy to follow tutorial section.	Documentation consists of well structured user and user guide reference manual and tutorial guide
SUPPLIER	Intelligent Environments,Ltd. Northumberland Hse, 15-19, Petersham Richmond, Surrey TW10, 6TP. UK.	Expertech Ltd. Expertech House, 163 Bestobell Road, Slough, Berkshire SL1 4TY	Inference Corporation 550 North Continental Boulvard EL Segundo, California 90025	Intellegent terminals 36, North Hanover street. Glasgow G12, 4AD	Creative Logic Ltd Brunel Science Park, Kingston Lane, Uxbridge Middlesex UB8 3PQ

3.5.2 Constraints on proposed methodology

At the start of the research at the Department of Building Engineering and Surveying Heriot-Watt University, Riccarton, Edinburgh, the department had not acquired any expert system shell. Thus, the researcher was advised to use the expert system shells in the Department of Computer Science of the University. During this period, there were five expert system shells in this department (table 3.2). These five expert systems shells were then thoroughly evaluated by the researcher in order to choose the most suitable shell.

The task of evaluating an expert system shell is very difficult. One of the difficulties is that it is impossible to say if a shell is a good or bad one. It should always be kept in mind what sort of problems the shell is meant to solve by trying to evaluate its quality, mainly because most shells are built to handle restricted problem areas and are not as flexible as high level languages. A summary of the major features of these shells is provided in table 3.2.

From this evaluation, it was concluded that there is a clear convergence among the features available in these shells. It is the researcher's opinion that Leonardo 3 is one of the most versatile of the popular expert systems shells available in the United Kingdom. The LEONARDO manual is well written and structured. The manual has an extensive menu map which gives a quick and simple overview of the shell's structure. The tutorial section is very extensive and is easy to follow as it guides the reader through the system. The function and command section is arranged in alphabetical order with a good explanation of each function and command, making the manual very quick to use as a reference. The LEONARDO RULES can be written using a standard ASCII editor supplied by the shell. The LEONARDO editor is just an ordinary screen editor in which line numbers are given with a code. Comments may easily be added whilst writing the rules. The OBJECT-FRAMES are created when these rules are compiled. If there are any syntax errors in the code, the system will give an error message, but no line number as a reference. Once the object-frames are created, the slots can be edited using the LEONARDO editor. It combines ease of use with flexibility and representational power, and was therefore chosen for use during the proposed research.

3.6 Classification of Expert System Shells

Expert system shells can be divided into four general types:

(i) induction tools;

(ii) simple rule-based tools;

(c) structured rule-based tools; and

(d) object-oriented tools.

3.6.1 Induction tools

These shells generate rules, based on a number of examples given by the knowledge engineer. The shell then applies an algorithm to the rules which determines the order the system will take when asking the user questions. These tools are very useful on simple or well structured tasks, but are inadequate for complex knowledge representation. **Superexpert**, from intelligent terminals, is a typical induction tool where the developer enters the examples on a spreadsheet-like form and the system generates the rules, based on the examples given. By entering these examples, the knowledge engineer specifies valid paths the system may take in order to reach a goal.

3.6.2 Simple rule-based tools

In this type of shell, IF...THEN rules are used to represent the knowledge in the knowledge base. The rules will be in the form such as:

If <subcontractor has a criminal record>

Then <do not select the firm>

The main weakness of these types of shells is the inability to sub-divide rules into various sets that can be arranged into a hierarchy. Typical applications are small rule bases containing from 100 to 300 rules.

3.6.3 Structured rule-based tools

These shells also use rules of the form IF...THEN to represent knowledge. But with structured Rule-Based tools one can arrange rules into a hierarchy. These systems are useful where a large number of rules are involved and the problem can be structured in a hierarchical form. The CRYSTAL shell from Intelligent Environment is a typical expert system shell in this class. CRYSTAL allows one to build a hierarchy of rules where one set of rules can inherit information acquired from an other set.

3.6.4 Object-oriented tools

These tools represent the knowledge as objects which can be given certain values. An object may contain facts, rules or pointers to other objects. These shells are perhaps the most powerful of the four classes, but the problem must be of a certain complexity to justify the use of a complex object-oriented shell. The Leonardo shell, from Creative Logic, is a typical example of an Object-Oriented tool. Leonardo represents knowledge as objects which are stored in a "frame" and "slot" structure. The frame representing the object and contains several slots where information related to the object can be stored. Leonardo also provides IF...THEN rules to use together with the object frames.

3.7 Construction industry potential applications

Some of the construction industry KBSs in the early stages of development are described in Kostem and Maher, (9), and in Brown and Jowitt, (10).
There are therefore many KBSs in civil engineering embracing a wide range of application areas. However, there are many practical difficulties in developing and using these systems. They are relatively expensive to develop. They are often computationally slow and require a large amount of storage capacity, potential users may see them as a threat to the value of their own expertise, and knowledge acquisition is difficult.

Some of the areas of possible construction applications include:

i) Defect diagnosis: e.g. dampness, water ingress, condensation, crack, decay and insect attack in timber, etc., paint failure.

BRE has identified defect diagnosis as an area where KBS can readily be applied with considerable benefit and a system called BREDAMP (11) has been developed to diagnose dampness and water ingress problems in buildings.

ii) Monitoring: The continuous interpretation of data and alarms relating to a process. A monitoring system is a partial diagnostic system with the requirement that diagnosis can be carried out in real-time.

Within a construction context; monitoring is likely to imply computer-based building services functions, e.g. building management systems (BMS) including fire and security, KBS in this field offer the prospect of building into existing systems some of the interpretive and advisory skills of a senior services engineer. Such a development would give BMS the ability to quickly recognise malfunctions, poor performance and the need for maintenance action.

iii) Control: The application of continuous reasoning to deduce an appropriate control action to satisfy a prescribe process objective. The classification is similar and complementary to monitoring.

iv) Planning: This is an activity which is fundamental to the construction industry, particularly with large complex programmes. Possible applications include:

- *programme estimating - an intelligent check-list;*
- *plant selection advice;*
- *critical path analysis to co-ordinate site activities; and*
- *cost management.*

v) Training: Instruction or guidance in an area of specialist expertise. The system may have training as an explicit objective or may exploit the explanation facilities of an expert system by another classification.

vi) Design: The production of specifications for the manufacture of objects to meet defined requirements. KBS can provide assistance with many of the problems encountered in building and services design, in particular they can:

- *help the designer assess the consequences of design decisions and allow possibilities to be explored tentatively;*

check a design against codes of practice, building regulations and other professional or statutory restrictions;

- *select building components or items of services plant to meet design objectives;*
- *prepare specifications for tender-based procurement exercise;*
- *disseminate design information for professionals working on other aspects of programming; and*

- *present design output to site engineers.*

vii) Prediction: Forecasting the future from a model of the past and present and predicting systems refer to things that change overtime and events that are ordered in time. There is considerable information at present in the application of expert systems to financial and economic prediction.

There is great potential for expert systems as intelligent check-lists when estimating or making cost predictions for large construction programmes.

The RICS have developed a large estimating expert system for advice on office development inconjunction with the department of trade or industry and 'Alvey' Club (12).

3.8 Refurbishment Work Applications

In practice, very few KBS have been developed in the construction management field, and those that have been developed tend to be well defined, rule-oriented, domains such as financial analysis, insurance, taxation and loan vetting. When considering KBS for refurbishment contracts applications, a distinction should be made on the predictive tasks involved in the financial analysis (e.g. cost forecasts, marketing forecasts, investment appraisal) and organisational decision making in which directors decide on an organisational strategy appropriate to a particular tasks (e.g. choice of a project, tender strategy, selection of a project team). Whilst many task in financial analysis are characterised by a core of more or less well structured data and knowledge, the same is not true of organisational decision-making in refurbishment work which may be much more weakly structured and therefore less amenable to current KBS techniques.

In general when decisions are made regularly under comparable conditions, about events which are largely determined by external factors one would expect a relatively structured approach to problem solving. By contrast, in refurbishment work there are many tasks where decisions are shaped, not only by external factors but also take into account the experience capabilities and future workload of the firm's personnel and its general policy, in such situations one is likely to find that experts rely on relatively unstructured methods in arriving at a decision.

3.9 Justification for the use of KBS in refurbishment work

There are many reasons which justify KBS development effort in the selection and appointment of sub-contractors in refurbishment. Firstly, the problems associated with default of sub-contractors are potentially serious and have significant financial and social impact on refurbishment contractors, therefore, there is a reasonable possibility of high payoff when a KBS is developed.

Secondly, for an inexperienced Estimator or Buyer, a KBS can act as an advisor when the professional experts are unavailable. KBSs are justified especially when significant expertise is being lost to a construction company through personnel changes (for example retirement, job transfers, etc). Also KBS development for the selection of sub-contractor is justified because of the dynamic, ill-structured, and high risk environment of refurbishment projects which requires quick decision-making.

To apply the conventional computer software techniques to a problem, there must be a sound mathematical model on which to base the algorithm, often in the refurbishment work, only a heuristic and intuitive knowledge of problems exists and in a majority of cases, data may be incomplete or "fuzzy".

KBS have the potential to permit the inexperienced Estimator, or Buyer in a contractor's organisation to give first level advice on routine matters, thereby freeing the chief Estimator to tackle more complex problems worthy of their often expensively acquired skills, instead of spending time dealing with problems of a routine nature.

In refurbishment work, highly skilled staff are frequently concentrated at head office. To apply this specialist knowledge to real practical problems it must be distributed in some way. It is often not possible to make an experienced estimator widely available in contractors' branch offices due to the cost of other considerations, but his specialist knowledge could be distributed in the form of KBS in these offices.

Estimators and Buyers are not permanent, they leave organisations for many reasons, taking their specialist knowledge with them. KBS can act as an archive for knowledge thereby providing a means of capturing and storing some limited, but possibly very valuable, expertise of a previous employee.

KBS can be a very effective way of bringing together and concentrating the experience of the Estimator, Buyer, and Contracts director during tender preparation and adjudication.

One of the most important characteristics of refurbishment work is that people with extremely high levels of expertise exist in these firms. They have had many years of professional construction experience, and can provide the knowledge necessary to building knowledge based systems. Many of these people (Estimators, Buyers and other key staff) are able to articulate and explain the methods of the decision processes they used in the evaluation of sub-contractors.

Also another reason why knowledge based system development for sub-contractor appointment is vital is that decision processes regarding sub-contractors is cognitive, and does not require physical skills. Also, the characteristic of decision process involved in choosing a sub-contractor is not too difficult or too complex for a knowledge engineer to approach. Many sources of information (for example, papers, books, etc) are available in this area which can establish the basic framework for knowledge acquisition.

Sub-contractor selection is not easy to model, it requires a person years of experience and practice to achieve the status of an expert. Finally, it is of manageable size to be handled adequately by knowledge based systems and it has a practical value.

Therefore, it can be concluded that the selection of sub-contractors is an appropriate area for knowledge based systems since it requires symbolic reasoning, and it is heuristic in nature, that is, it requires the use of rules of thumb to 'solve' problems. The model is capable of further development in order to integrate other aspects of decision-making in tendering and refurbishment contracts. It is planned that a further stage in this research and development work would begin shortly after the research programme reported here is concluded.

3.10 Knowledge based system development

The process of developing a KBS is called *knowledge engineering*, and often involves a collaborative process between the system's constructor, (knowledge engineer) and one or more experts in some problem domain.

3.10.1 Multiple Experts

In technical domains, KBS expert systems have often have been based on the knowledge of one recognised expert. In some large KBS several experts have been used Buchanan (13).
There is probably a strong case for eliciting knowledge from several experts in management applications, given the particular need for *strength of authority* and *breadth of expertise*, since different experts may approach the problem in a different manner.

Knowledge based system development can be considered as four consecutive but overlapping stages.

a) Selecting the problem

b) Knowledge Acquisition

c) System implementation

d) Testing and using the system

3.10.2 Selecting the problem

The problem that is selected should be suitable for solution by a KBS. The many application area in the construction industry where KBSs would be of potential benefit were outlined in section 3.7.

Estimators in refurbishment work often have to make decisions on the basis of incomplete and imprecise information during tender preparation.

The KBS provides a means of capturing the estimator's experience in handling uncertain and imprecise data. It therefore establishes a way of making the expertise more available.

Other factors like potential risks in the project, and the level of difficulty that the company would have on the construction site and the availability of an experienced project team for the project should also be considered in determining the suitability of the problem for solution by a KBS.

3.10.3 Knowledge acquisition

The knowledge acquisition stage refers to the process of acquiring the knowledge to enable system development. This process represents one of the main problems in system development. It is therefore discussed in detail in section 3.11.

3.10.4 System implementation

The implementation of the KBS requires appropriate structures to represent the acquired knowledge and the inference mechanism. Some of the structures for representing the knowledge includes: *production rules, frames,* and *semantic networks.* These representations will be discussed later in section 3.13 together with the main ways of carrying out inexact inferences.

3.10.5 Testing and using the system

Testing the prototype system involves evaluating its performance and revising it if necessary. Often the testing will be done in stages, each stage handling a different proportion of the problem that will eventually be addressed. Testing should be done by getting the domain experts to evaluate the system. Any problems uncovered at this stage might mean the knowledge engineer has to recycle through the previous development stages to restore them.

The system should be able to solve the problems for which it was constructed. However, it will be under continuous scrutiny and evaluation for some time before it will be ready for commercial use.

3.11 Knowledge acquisition

3.11.1 Knowledge acquisition process

Knowledge acquisition covers the whole process of obtaining knowledge from various sources (for example domain experts, text books, reports, codes of practice or manuals) to enable system development. It includes *knowledge elicitation,* the process by which knowledge is obtained from the domain expert, and the *interpretation technique* used to analyse this knowledge. These two processes are interrelated and overlap during knowledge base development. The elicitation process is often directed by the choice of interpretation model used to analyse the elicited knowledge.

3.11.2 Knowledge elicitation

3.11.3 Background

The construction of a KBS is an attempt to embody the knowledge of a particular expert within a computer program. The knowledge used in solving the problems must be elicited from the expert so that it can be acquired by KBS. According to Kitto (14) the elicitation of knowledge from the experts is one of the major bottle-necks in the construction of ESs. The main reasons for this in many cases is that experts find it hard to articulate and make explicit the knowledge they possess and use. An important part of a knowledge engineer's job is to help the expert to structure the domain knowledge and to identify and formalise the domain concepts.

Three types of knowledge elicitation techniques exist, route one is the psychological techniques which involve some kind of interaction between the Knowledge Engineer (KE) and the Domain Expert (DE).

The second route is machine induction, in which the computer induces rules from examples automatically.

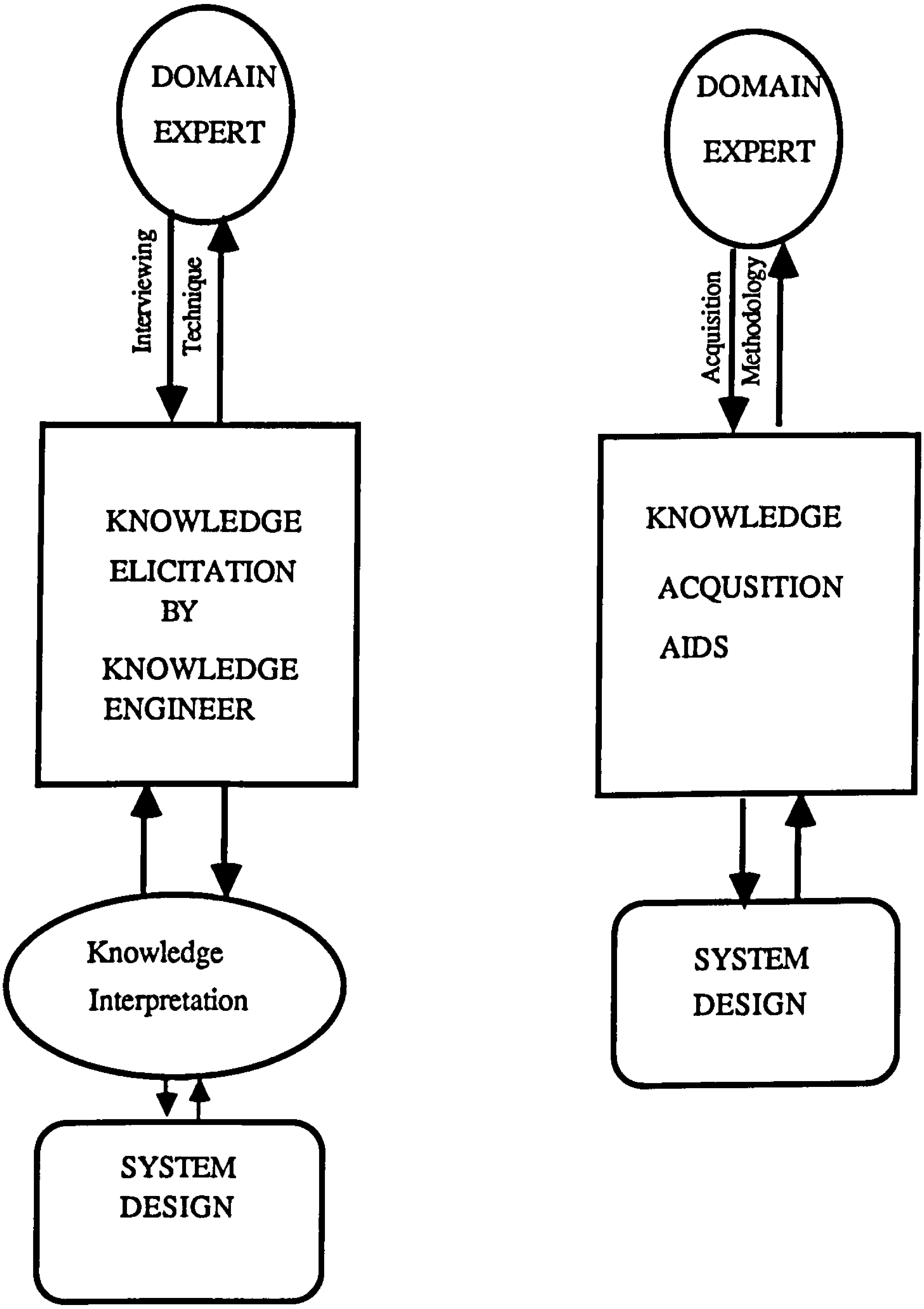
The third route is where the domain engineer plays the role of the DE.
Hart (15); has cited two main reasons why an expert should not play the role of the knowledge engineer. Firstly the expert will normally have insufficient knowledge about programming and KBS techniques. Secondly, the experts will find it difficult to describe their knowledge fully. For these reasons, this technique was not used.
For a domain like refurbishment contractors machine induction is inadequate. Bloomfield (16) developed a set of criteria for selecting domains suitable for the elicitation of knowledge by machine induction. One such criterion according to Bloomfield is that:

> *"Any chosen domain must contain sufficient examples that it is possible to construct a training set which constitutes a comprehensive encapsulation of expertise in that domain."*

Refurbishment projects cannot be completely encapsulated in examples as each project is unique. Hence only psychological techniques are considered in this study.

Direct interviewing is the technique most familiar to KE's and DE's. It is good to start the knowledge elicitation process using a technique that the DE feels comfortable with.

FIGURE 3.2: KNOWLEDGE ACQUISITION PROCESS



ROUTE ONE

ROUTE TWO

An interview may range from an informal chat to a highly structured discussion. To ensure that an interview is productive, the KE should have a set of good questions prepared beforehand to help him direct the discussion; instead of just open questions he needs to have clear and specific ones. The DE could also be asked to prepare and deliver an introductory lecture.

The knowledge engineer should also appreciate the problems faced by the domain expert, and it is advisable to have background knowledge of the domain.
For example, the knowledge engineer should be familiar with the domain terminology, and the most common problem solving models the expert might use. A good understanding of available programming systems that simplify the task of constructing a knowledge base and the methods commonly used for representing knowledge is desirable.

The problems of knowledge engineering might face during knowledge elicitation have been discussed by Shaw and Gaines (17), they suggested that:

"most of the problems are caused by the fact that the process of knowledge elicitation requires many hours of an expert's time who is already busy and has many demands on his time"

Some of the knowledge elicitation processes which have been identified by the researcher as useful are:

(i) concept sorting;

(ii) protocol analysis;

(iii) rapid prototype; and

(iv) repertory grid.

3.12 Concept sorting

Apart from the specialist knowledge which experts bring to bear on specialised areas, they are likely also to have a more global perspective of the domain and such heuristic knowledge will prove useful when there is a lot of information to be organised. As Chi (18) observed, concept sorting is a helpful technique for getting this organisational knowledge. The basic procedure is to obtain a set of concepts that broadly cover the domain. They can be delivered from a glossary or literature, or can be gleaned from an introductory tutorial talk given by the DE. The next step is to ask the DE to transfer each concept to a card and to sort the cards into a number of groups, describing what each group has in common. The groups can then alternatively be combined to form a hierarchy.

3.12.1 Weakness

Concept Sorting is only appropriate where there is a large set of concepts, ranging across the whole domain which require suitable structuring to become manageable.

3.13 Protocol analysis

Protocol analysis that leads directly to a production system model of problem solving was first described by Newell (19) and more recently by Ercsson (20). In this method the behaviour of the DE's is recorded (either video or audio) as the expert works through a problem or task and this protocol is transcribed and analysed by ultimately converting it to a set of productions that transform one solution state to the next. In this way, the KE is given not only the answer to the problem but also information about the problem solving process itself. It has been used on industrial settings, Bainbridge, (21) and as part of a systematic knowledge acquisition methodology, Breukner (22).

There are three different ways of generating protocol:

(a) Think - aloud protocol: here, the DE thinks aloud during the solving of the problem.
(b) Retrospective verbalisation protocol; in which the DE completely solves a problem by reporting how it was solved.
(c) Discussion protocols: a small number of DEs discuss with one another as they attempt to solve a problem.

Their merits are that they go beyond what experts can explicitly tell you in a problem solving situation to permit inference of what knowledge they must be using but either cannot verbalise or are unaware of. By reconstructing the solution using inferred production system rules, the expert's knowledge can be modelled. Such a method is particularly useful for eliciting procedures that experts use in problem solving, which they may not be able to articulate fully.

Protocols can also be taken concurrently with experimental as well as with real-world tasks. These incidental protocols may provide useful heuristic or facts which a knowledge engineer can use, either directly as domain knowledge, or indirectly as heuristic knowledge.

3.13.1 Weakness

An important problem with thinking aloud protocols is that the reporting may interfere with the DE's task performance. Related to this is any need to conform to real time constraints. For example, solving a maths problem allows the mathematician to stop and ponder. However, an operator dealing with an emergency may require immediate responses.

Also serious limitations occur (23, 24, 25, 26) when they are subsequently used to try to refine early versions of an expert system, in an attempt to elicit the essential expertise. One aspect of this problem is trying to capture, in the form of rules, knowledge that is not suitable for such a representation. This is not merely a problem of representation but also has implications for elicitation. Although the expert clearly has the knowledge, this may not be directly communicable in the prototype situation and must be inferred using other techniques.

For this technique to be effective, a representative set of problems has to be chosen, otherwise there could be serious errors of omission.

3.14 Rapid prototyping

Rapid prototyping is mainly used in testing and improving unfinished versions of knowledge based systems The DE is confronted with the prototype of an unfinished version of the system which is modified in the light of his comments. Each interaction brings the behaviour of the system closer to completion although, since it is often carried out without a clearly defined notion of completion it is perhaps better thought of as interaction towards adequate achievement. The method yields a set of dimensions defining the space containing the domain objects clustering on these dimensions and gives the structure that differentiates these domain objects from one another. That the method can uncover an independently agreed structure is shown by Shaw and Gaines (27) who used it to elicit constructs known to describe a real-world domain.

The weakness is that not all information can conveniently be represented as rules.

3.15 Repertory Grid

The use of Repertory Grid techniques was pioneered by the clinical psychologist Kelly (28) to support his model of human thinking called **personal construct theory.** Kelly proposed *personal construct theory* as an alternative to the psychological theories of his time which he regarded as insufficient in aiding the understanding and explanation of an individual's behaviour. In particular, he devised the Repertory Grid technique as an instrument to gather data about the ways an individual constructs or views the environment or world around them Smith (29).

As a clinical psychologist Kelly used Repertory Grids as a tool to help understand and explain his patients' behaviour so that he could then recommend an appropriate course of treatment or counselling. Since Kelly's original application, Repertory Grids have been used in the disciplines of social psychology, management, and most recently as a formal basis of knowledge acquisition for expert systems, Boose and Bradshaw (30); and Boose (31). This researcher used the Repertory Grid technique for knowledge elicitation. Details of this technique are given below.

3.15.1 Background to Repertory Grid

Repertory Grids are a way of producing a person's mental map on some topic. Access to such maps is a vital help in any research which involves people and decision making. Organisational psychologists are interested in all sorts of mental maps, such as the maps people have of their jobs, their workmates, the maps that selectors use when choosing between candidates, and mental maps of the organisation's structure.

According to Stewart and Stewart (32):

"Repertory grids offer an extremely flexible methodology for obtaining the mental maps of either individuals or of groups of people".

3.15.2 Personal Construct Theory

In 1955, George Kelly published his classic and enormously influential work *"The Psychology of Personal Constructs"* which provided a great impetus for cognitive psychologists and on the basis of his teaching and dealing with students and patients he came to the view that all people behave like scientists. As we go about our daily lives we explore and observe our environment. On the basis of these explorations we construct mental maps of our world.

When we need to make decisions, we refer to these mental maps. This basic notion of Kelly has received empirical support. Bender (33) obtained mental maps of how subjects viewed other people, on the basis of these maps he made predictions about how his subjects would behave towards the people and on the maps. Bender then checked the actual behaviour by asking the subjects' wives. He found a significant correspondence between the predictions and the actual behaviour. Similarly, Fransella and Bannister (34), were able to predict voting behaviour from mental maps of the political domain.

Kelly was also able to link our mental maps with our emotions. For example, aggression can be seen as an attempt to force the world to conform to our (inadequate) mental construction of the situation. Anxiety arises when we move into an area where our mental maps are sketchy and cannot provide a reasonable basis for action. Dread occurs when our construct system is about to collapse.

The underlying assumption on which personal construct theory is based is that knowledge of an individual's attitude towards an aspect of their world will enable predictions to be made of their world.

The theory suggests that as a scientist, man makes sense of the world through contrasts and similarity, Smith (35). In personal construct theory, this meaning and significance is believed to be obtained through the application of an individual unique set of constructs Bannister (36), that the individual has erected to make sense of their world.

Meaning and significance through the interpretative of contrast and similarity gives rise to Kelly's dichotomy of corollary; this states by Bannister and Mair (37) that:

"an individual's construct system is composed of a finite number of dichotomous bipolar constructs".

Thus constructs are believed to have two poles: a pole of affirmation and a negative pole. More recent authors use the terms emergent pole and implicit pole respectively, Shaw (38). For example, unless one has in mind the notion of black and white, it would not be appropriate to describe an object as white. Similarly, the notion of being good only makes sense as the semantic opposite of being bad, Gaines (39).

Since their original development, several researchers using Repertory Grids have relaxed the constraint governing the dichotomous nature of the constructs so that the constructs are only assumed to be bipolar, Bannister (36), Shaw and Gaines (17), thus allowing constructs to be measured on ordinal and interval scales of measurement as well as the original binary scale of measurement proposed by Kelly.
Possibly, the greatest of Kelly's contributions was to specify in more detail the nature of cognitive maps and to propose a method whereby they could be quantified and made objective.

According to Kelly (40), our cognitive maps are made up of two things: the elements and the constructs. The elements are the objects of our thoughts. They can be specific *objects* such as computer, satellite and laser. One of the most important types of element is other *people* such as mother, father, sub-contractor, contractors, specific manager or a specific colleague. Often role categories such as boss, subordinate or function manager can be used as an element. In organisational research, various components of the organization or the *functional departments* such as purchasing, production, or sales can be used as elements. Sometimes abstract objects form the elements. The exact choice of the elements will depend upon the purpose of the research study. In practice, the only limitation on the choice of the elements is the investigator's imagination. In essence, the elements are analogous to the towns on the map.

The constructs are the qualities the elements possess and which we use to differentiate among the elements of our thoughts. The constructs are the mental spectacles through which we see our world. They may be physical qualities such as durability, brilliance or size. Often, however, constructs are some kind of evaluation such as goodness, usefulness, appropriateness or they can be human attributes such as kindness, warmth or guile. According to strict Kellian theory, constructs are bipolar, they have an emergent pole and a contrast pole. In essence, the constructs are analogous to directions on a map.

3.15.3 Repertory Grid Methodology

Kelly also outlined the Repertory Grid technique as a way of quantifying and making these maps objective. The method has been considerably developed since Kelly's day. A modern repertory grid investigation on *one person* usually proceeds through five stages:

elicitation of elements

elicitation of constructs

preparing the grid

grading each element on each construct

analysing the results by computer

3.15.4 Eliciting the elements

The elicitation of elements is a vital stage since it forms the basis of everything that follows. The issue of whether to supply or elicit elements is often debated among grid users (41, 42, 43), inconclusively, since the answer depends upon the purpose of the research. It is, of course, open to the researcher to use both methods of identifying elements in the same grid, in which case elicitation should precede supply in order to avoid 'contamination' of the list of elicited elements. Given the need to identify elements according to the problem to be investigated, there can be no simple relationship between the source of the elements and the validity of the grid.

According to Pope and Keen (44), grids containing elicited elements suffer from the problem of vagueness. Contextual vagueness is also particularly noticeable in a study by Kevill, Shaw and Goodcare (45), whose evaluation of a diploma course in literacy development used grids in which the elements were aspects of the job of teaching which did not necessarily have any relevance to the purpose of the evaluation.

3.15.5 Elicitation of constructs

As described by Kelly (28), there are five principal approaches to the elicitation of constructs as follows:

a) Triadic construct elicitation

In this method the respondent is represented with three elements at a time from a list of representative elements and asked to distinguish in what ways two of the elements are alike and different from the third. The respondent is then requested to name the emergent pole and the implicit or contrast pole which discriminate the elements. The two contrasting poles of the elements are then recorded.

Whilst triadic elicitation is widely used (33, 37, 44), it does not always facilitate the production of constructs since, according to Keen and Bell (45), some respondents appear to find the cognitive demands of the procedure alien to the way they think, or will prefer to respond.

b) Dyadic construct elicitation

In this method, two elements only are presented to the respondent each time and is requested to discriminate the difference or likeness between them.

c) Free response construct elicitation

Through conversation, respondents provide their personal constructs instinctively.

d) Supply constructs

This is the fastest way to generate constructs whereby the researcher provides pre-determined constructs for the respondent to assign the necessary ratings. The uncertainty that is attached to a respondent's construing of a supplied construct place the supply of constructs upon distinctly uncertain foundations, Grover (46).

e) Laddering

This technique is normally used in conjunction with one of the above methods after some constructs have ben elicited. It involves asking the respondent a series of "why" or "how" questions so as to elicit more specific constructs.

Laddering is a technique commonly adopted to move between construct levels. Given a construct, one can either ladder "upwards" towards the central construct by asking which pole of the construct is more important to the individual and why. For example, in investigating the constructs of an individual about efficiency of work and the construct "*keeps good time / always late*" is elicited. It is possible to obtain further constructs (for instance, constructs such as "*shows commitment/no commitment*" may be elicited by laddering from the "*keeps good time / always late*" by asking the "why" question. This process may be repeated until the central construct of the respondent is revealed. Similarly constructs could be laddered "downwards" the "how" or "what" questions to obtain more specific constructs.

3.15.6 Preparing the grid

Generally, the grid is prepared with the elements and constructs arranged as shown in table 3.3 below:
When designing a grid, it is important to incorporate identification numbers and aids to facilitate data preparation.

Table 3.3: Estimators' Repertory Grid (Plant hirer constructs example)

CONSTRUCTS		ELEMENTS						CONSTRUCTS	
		S1	S2	S3	S4	S5	S6		
CR1	Competitive price	3	4	2	5	4	3	Uncompetitive price	CR1
CR2	Prompt treatment of invoice	4	1	4	4	3	3	Delay in the treatment of invoice	CR2
CR3	Good maintenance record	3	5	4	2	1	3	Poor maintenance record	CR3
CR4	Prompt repair of plant	3	4	5	1	2	3	Long delay to repair plant	CR4
CR5	Variety of plant	2	4	3	2	5	5	Small selection of plant	CR5
CR6	Nearness to site	3	4	5	4	2	4	Long distance from site	CR6

3.15.7 Grading the grid

Kelly's (28) original approach adopted a dichotomous form of grid, whereby respondents were asked to place ticks or crosses across elements for each of the constructs, but this method does not permit finer discrimination between elements or constructs. Furthermore, as noted by Bannister (36), the dichotomous grid may produce spurious relationships possibility caused by lopsidedness, too many ticks and few crosses or vice versa on a particular construct.

As such , in recent years two popular forms of the grid grading have emerged, namely: rating, Bannister (36) and ranking, Bannister and Mair (37) grids.
Generally, in practice it is less tedious for the respondents to rate elements than ranking them, especially when there is a large number of elements. Thus rating of elements is commonly used whereby the respondent is free to assign rating along a linear scale from the emergent pole to the implicit pole of each construct. A 5-point or 7-point scale is usually employed, which provides much finer discriminations between elements of constructs.

3.15.8 Analysing the grid

The elicited contractor's grids were analysed using the INGRIDA program from Slater's (47) Grid Analysis Package (GAP). INGRIDA, as its name implies, analyses individual grids. The Gap package contains several other programs which can be used in conjunction with INGRIDA or as alternative to INGRIDA and they allow a very wide range of situations to be investigated using the Repertory Grid methodology. Details of this program are provided in section 7.2.

Some rudimentary analysis can be performed without a computer but this is often restricted to some kind of content analysis of the elements and constructs. Bieri (48) suggested a relatively simple method of obtaining a measure of cognitive complexity but the process is tedious and crude. Some writers have used "scissors" and "tape" to focus grids: the grid is cut into strips which are then arranged so that the most similar elements are adjacent. The strips are taped and cut in the opposite direction so that the constructs can be rearranged in order of similarity. However, GAP is more comprehensive than most other grid analysis programs and it includes most of the features contained in other packages.

3.16 Knowledge Representation

3.16.1 General characteristics of knowledge representation

The following characteristics of knowledge representation have been identified by Watson, Shave and Moralee (49):

(a) A knowledge base should be flexible, so that its extension by way of revision will not necessitate major upheaval.

(b) The knowledge represented should be kept conceptually simple and as concise as possible as a result of which flexibility can be more easily achieved and inference engines more efficiently designed.

(c) The knowledge should be represented explicitly in order not only that the system exhibits transparency but also so that the experts who are assisting in the design of the system may examine the knowledge which it is being incrementally constructed. If this guide-line is not observed, then experts would be unable to determine the contents of the knowledge base and might, therefore, omit crucial knowledge or input material more than once.

(d) A representation should facilitate knowledge acquisition. That is, it should be designed so as to minimise those problems associated with extracting expert heuristic knowledge from human experts.

(c) A representation should be computable by some existing procedure, that is, it should be designed in such a way that it can be included as a collection of data structures within the computer system and so that a reasoning mechanism can operate upon it.

There are two fundamentally different approaches to knowledge representation, Assad and Golden (4). These are:

(i) Procedural representation; and

(ii) Declarative representation.

3.16.2 Procedural representation

Procedural representation is commonly used in traditional algorithmic programming. In this type of knowledge representation, knowledge is context dependent and embedded in the code. This results in an opaque knowledge, making it unintelligible and difficult to modify.

3.16.3 Declarative representation

In this type of knowledge representation, knowledge is encoded as data and is therefore more understandable, easier to modify and context independent. While semantics in procedural representation are distributed over the code, they are collected in one place in declarative representation. These characteristics are essential in knowledge based systems and due to the disadvantages mentioned above in procedural representation, this is not used in this research.
Some of the most commonly used declarative knowledge representation in KBS are:

i) production rules;

ii) semantic network; and

iii) frames.

3.16.4 Production rules

A production rule, Fost (50) is a statement in the form of:

If < condition> Then <action> type rule.

In other words "If these <conditions> hold, Then do something" or for example:

IF A THEN B

Where 'A' is the antecedent or evidence and 'B' is the consequent or action. The logic of a rule is that whenever the condition constituent of a rule is true or satisfied then the action constituent of the rule is said to have 'fired'. In general, constituent components of a rule are a logical proposition comprising of a set of facts or statements connected by logical operations which are required to be true for the rule to be fired.

Both antecedent and consequent can be compound statements, for instance;

IF A_1 or A_2 THEN B_1 and B_2

However, rules of this form are usually prohibited by practical inference engines. According to Attarwala and Basden (51), it is common to allow only rules of the form:

IF A_1 and A_2 or A_3 THEN B

In rule based expert systems, these If < condition> Then <action> type rules represent the bulk of the domain dependent knowledge in the knowledge base systems. The rule interpreter or inference engine determines how sets of rules are evaluated. It compares the antecedents with the facts and executes the rule whose antecedent matches the facts. This matching produces what are known as inference chains which indicate how the system infers the rules.

3.16.4.1 Strengths

Production rules have many strengths. First and foremost, rules are easy to understand. Secondly, they are highly modular and each rule expresses an almost self-contained chunk of knowledge and, as a result, rules are largely independent of one another. This transparency and modularity means that rules based expert systems are, at least in theory, easy to refine, modify and enhance, with new knowledge capable of being added largely independently of the system's existing knowledge. This property of a knowledge representation scheme to acquire new knowledge easily is referred to as acquisitional efficiency, Alvey (52). Moreover, production rules are a powerful representational scheme because they have been shown to be complete Feigenbaum (53) and as such display the property of representational adequacy, Hamilton (54), or logical adequacy, Ross (55).

3.16.4.2 Weaknesses

Production rules also have their weaknesses. The forward and backward chaining inference mechanism used to manipulate rules means that a system's reasoning can be difficult to follow and, as a result, production rule based systems can prove exceptionally difficult to debug. Furthermore, although each rule is transparent, in a rule based system, the domain's overall structure is often opaque. For example, a domain structure that is strictly hierarchical may be lost within a set of production rules.
Finally, the nature of the domain independent inference mechanisms used to manipulate the rules means the rule based systems become rapidly inferentially inefficient, Hamilton (54), that is slow to manipulate as the number of rules increases.

3.16.5 Semantic network

A semantic network consists of nodes which represent objects, concepts or events. The characteristics or attributes of an object can also be used as nodes. The nodes are connected by links or arcs which describe the relationships between the various nodes. Some of the most common arcs are "is_a" and "has_a". The arc "is_a" is used to show that an object belongs to a category of objects, while the arc "has_a" is used to identify attributes of the object nodes. Generally, a link designating almost any relationship can be used as an arc.

3.16.5.1 Strengths

One of the major strengths of semantic networks is their overall "flexibility," Assad and Golden, (4). In a semantic network it is easy to add new nodes and links to incorporate new knowledge and as such semantic networks are acquisitionally efficient. The semantics of a link are defined by the knowledge engineer and the semantic networks can be used to represent many different types of knowledge.

Unlike production rules, in a semantic network the overall domain structure is transparent and the system's reasoning is easy to follow and associations can be traced through the graph. Finally, in a semantic network concepts can inherit properties of others through the transactive associational links in the network and as such they are storage efficient representational schemes.

3.16.5.2 Weaknesses

One of the most notable weaknesses with semantic networks lies in modelling exceptions to the norm. Furthermore, semantic networks have been criticised, Assad and Golden (4), because their node semantics can be ambiguous. Also, although they are storage efficient, semantic networks are operationally inefficient and this problem is heightened by the fact that it is not generally possible to incorporate heuristic knowledge within a semantic network.

3.16.6 Frames

Ross (55) defined frames as

"a data structure that collects together knowledge about particular concepts and provides expectations or default knowledge about that concept".

A frame for a domain concept or object consists of a series of "slots" and associated values which represent the concept's characteristics or traits. A slot can also be used to reference another frame. Here they may provide greater detail on a particular attribute. KBS can be made up of a collection of frames that are linked together in this way. Together they form a hierarchy that can be used for reasoning purposes. In this respect a frame is similar to a record in a relational database with the frame's slots being equivalent to a record's fields. It is possible to link frames together into hierarchical networks creating instance and class frames to represent different levels of abstractions.

As with semantic networks, these hierarchical frame structures facilitate the use of reasoning or inference mechanisms that incorporate multiple level inheritance. Each instance frame is capable of inheriting properties from the higher level class frames with which it is associated. However unlike semantic networks, it is easy to handle exceptions to the norm in frame based representations because the exceptional value can be stored explicitly within that concept's frame. Furthermore, it is possible to have "procedural attachments" in Leonardo 3 (56) associated with a frame's slot which invoke either a set production rules or an algorithmic procedure to calculate the slot's value when it is needed. In this manner it is possible to create representationally powerful hybrid knowledge representations schemes incorporating both frames and production rules and also to incorporate algorithmic reasoning for a sub-component of the problem domain within an overall heuristic reasoning strategy.

Finally, frame slots may contain "default" values, Leonardo 3 (56), which allow for weak reasoning to be performed. These default values allow for probable values for a concept's trait to be used when the information available is incomplete.

3.16.6.1 Weaknesses

Although the concept of multiple-level inheritance is intuitively very appealing, it can give rise to several drawbacks within frame based representations. Firstly, there is unrestrained overriding of inherited properties, then it becomes impossible to represent either definitional conditions. Secondly, complex mechanisms are required to reason with frame based representations and these can rapidly become inferentially inefficient if there are several levels of inheritance within the hierarchical frame based network.

3.17 Dealing with uncertainty in KBS

3.17.1 Introduction

Uncertainty is inherent in any reasoning process, and it comes from a variety of sources. These include such examples as reliability of the information, ambiguity and vagueness within the representative language, incompleteness of the information, and imprecision in aggregation of the information from multiple sources.

Because most of the knowledge in KBS is obtained from humans and because much of human knowledge is imprecise, it is usually true that the expressions of facts and rules contain varying levels of uncertainty. Because of this it possible to hypothesize that the reasoning process used by experts in certain situations is approximate.

3.17.2 Choosing uncertainty treatment method in KBS

For KBS's to be fully utilised by refurbishment contractors, they must be capable of dealing with uncertainty. It is important to realise that a decision to choose, for example, the sub-contractor's quotes that a contractor will use in his bid is only one of a series of interrelated decisions that he has to address when deciding which sub-contractor to use on a particular contract. Equally important are the related decisions about the sub-contractor's overall performance, for example his workmanship, trade experience, technical competence, safety programme, to mention just a few. Uncertainties are usually present in each of these steps. For one thing, the information gathered during the evaluation of a sub-contractor may be incomplete or highly volatile. Important facts and details which have bearing on the problem at hand may be missing or may change rapidly. In addition, many of the facts available may be imprecise, vague or fuzzy.

Various methods are available for dealing with uncertainty in KBS but the main methods used to deal with uncertainties in KBS's are:

i) probabilistic approaches;

ii) certainty factors;

iii) influence diagrams; and

iv) fuzzy logic.

3.17.3 Probabilistic approaches

3.17.3.1 Bayesian probability theory

Bayesian probability theory has been fully described by various authors (57, 58, 59) and therefore only its main features will be given here. The oldest and best understood quantitative approach in the representation of uncertainty is the probability theory which is used in conjunction with Bayes' Rule for updating uncertainty. Application of probabilistic approaches to computer-based management systems offer a theoretical sound method for computing the probability of an event or sequence of events based on expert knowledge observations and other data specific to the problem at hand. This may be done through Bayes' Theorem which provides the mechanism to infer the probability of a failure of sequence in view of the specific evidence and from a priori probabilities of the failures and conditional probabilities relating to the observations to the possible failures.

3.17.3.2 Example

$$\{ F_i / D, H \} = \frac{\{ F_i \; D / H \}}{\sum_{j=1}^{n} \{ F_j / D, H \} \{ D / F_j \; H \}}$$

OR

$$\{ F_i / D, H \} = \frac{\{ F_i / H \} \{ D \; / F_i \; H \}}{\sum_{j=1}^{n} \{ F_j / D, H \} \{ D / F_j \; H \}}$$

As an example, suppose the sequence of sub-contractor failures F_i is one of **N** mutually exclusive work performance failures in a contract situation, **D** is the data vector of a specific contract and information gathered supporting that failed performance, and **H** (for history) is the common state of knowledge. Then if **[Fi/H]** is the priori probability of the i^{th} failure sequence given the present state of knowledge, the posterior probability of a failure given the observed data may be expanded as follows.

To use the probablistic approach one has to collect sufficient numerical data for a statistical characterisation of these factors.

3.17.3.3 Weaknesses

(i) Although probablistic models are useful for treating uncertainties in KBS's they are limited in their applicability in the decision making processes for refurbishment work, where many of the contractor's decision problems are imprecise, ill-defined and vague in nature. The imprecision, ill-definedness and vagueness that tend to characterise refurbishment work decisions are predominantly subjective and linguistic in their nature.

(ii) Historically, uncertainty was formalised in probability theory (60, 61), with Bayes' Rule providing a means of updating uncertainty overtime. Conversely, however historically, AI eschewed numerical computation in favour of symbolic methods, using this to demarcate itself from other branches of computer science. Kangari (62) notes for instance that "when the AI community was founded, computers were used mainly for number crunching. They were impressively good at this point but they were not intelligent. Intelligence seems to require more general kinds of symbolic manipulation".

Also the potential usefulness of Bayes' theorem in KBS's is limited because it is a closed form of knowledge representation. This is because the probabilities in the universe of discourse must sum to one and hence it is difficult to model their interdependence. In practical systems, either statistical independence is assumed or interdependence is modelled.

(iii) Bayesian approaches require a large amount of data or subjective estimates in order to determine the appropriate prior and conditional probabilities. Probability theory lacks expressiveness as a language of uncertainty for proposition such as "Good workmanship".

Although the probabilistic methods have a firm theoretical background they do not provide a reasonable framework for refurbishment contractor's types of KBS, at least for the time being. Studies show that experts do not use probabilistic information any more efficiently than novices. Indeed, the evidence suggests that experts are as prone to errors in probablistic judgement and biases as non-experts, Kahneman and Tversky (59). Indeed, Buchanan and Shortliffe (13) describe the difficulty in obtaining consistent conditional probability statements from experts. Another serious problem in adopting a probablistic approach is that the prior probabilities needed for the commonly used Bayesian approach are typically not available for refurbishment project analysis and the typical user of the system is not likely to be familiar with Bayesian theory. There is also the issue of the independence among the random variables. If one cannot demonstrate statistical independence, the number of necessary conditional probability statements can be very large Adams (63). Also besides randomness, the refurbishment contractor must deal with a variety of uncertainties including vagueness, imprecision and fuzziness. The use of a probablistic approach in these cases may be difficult. The contractor's decision-making process regarding the employment of subcontractors has many vague imprecise concepts which cannot be defined clearly or uniquely.

The probabilistic approach considers uncertainties to be random. In these methods the uncertainty associated with each parameter or the underlying model can be described by a probability distribution, i.e. the occurrence of an event is a matter of chance. However, not all uncertainties are random and some can be objectively quantified.

3.17.4 Certainty factors

MYCIN was designed to assist physicians in diagnosing and treating diseases caused by certain types of blood infection. It was developed at the Stamford Research Institute by Buchanam and Shortliffe (13) and others. MYCIN control structure is principally a backward-chaining or goal driven procedure of production rules. An important feature of MYCIN is its use of a 'certainty factor' to handle uncertain information.

The production rules embody knowledge about infectious diseases and are of the general form:

IF <premise> THEN <action> with <certainty factor>,

In this, the Clauses of the premise need to be satisfied in order to assert the action and the certainty factor must indicate the degree of belief that the rule used to do this is 'true'. A certainty factor is also associated with each clause of the premise. Certainty factors can range from -1 (certainly "false") to +1 (certainly "true") with intermediate values and 0 representing an unknown degree of belief.

The certainty factor approach allows evidence for and against the hypothesis of a clause, and is defined by the following relation:

$$CF[h/e] = MB[h/e] - MD[h/e],$$

Where CF[h/e] is the certainty of the hypothesis given evidence e, and MB and MD are the measures of belief and disbelief in h given e. The MB and MD values range from 0 to 1. The certainty factor should not be construed as a measure of probability because it is not derived from a population sample. Hence, CF[h/e] cannot be used to infer anything about CF[7h/e].

The certainty factor for the conjunction and disjunction of different Clauses of a premise are interpreted as the maximum or minimum operators of fuzzy sets sections. This certainty factor is then multiplied by the certainty factor of the rule to give an overall certainty factor for the appropriate action. However, if other rules come to the same conclusion or action then a combined certainty factor can be computed from the following formulae:

$$\text{CF (combined)} = \begin{cases} CF1 + CF2\,(1-CF1); & CF1, CF2 > 0 \\ -(\,|CF1| + |CF2|\,(1 - |CF1|\,)); & CF1, CF2 < 0 \\ \dfrac{CF1 + CF2}{1 - \min(|CF1|, |CF2|)}\;; & CF1 \times CF2 < 0 \end{cases}$$

Where CF1 and CF2 are the certainty factors computed from rules 1 and 2. The combination of +1 and -1 is defined as 1. Consider for example the rules:

C:- A, B [0.75] and C:- G; H [0.6], and the certainty factors

CF [A] = 0.8, CF[B] = 0.75, CF[G] = 0.4, CF [H] = 0.6, then

CF (combined) = 0.56 + 0.36 (1 - 0.56) = 0.72.

The combined certainty is stronger than either separately.

Buchanan and Shortliffe (13) conceived the certainty factor model purely on intuitive grounds and asserted that it is an alternative to probability theory. However, Adams (63) shows that a part of the model can be derived from probability theory with the same assumption of statistical independence. That part of the model is the two parameters MB and MD which are defined for each rule as:

$$MB(H/e) = \frac{\max(P(H/e), P(H)) - P(H);}{1 - P(H)}$$

$$MD\,(H/e) = \frac{P(H) - \min(P(H), P(H/e))}{P(H)}$$

Where P(H) and P(H/e) are the a priori and a posterior probabilities. The certainty factor associated with the rule is:

$$CF(H/e) = \left| \begin{array}{lll} -1 & \text{if} & P(H) = 0 \\ [\ MB(H/e) - MD(H/e) & \text{if} & P(H) \neq 0, 1 \\ 1 & \text{if} & P(H) = 1 \end{array} \right.$$

The certainty factor approach used in MYCIN has been found intuitively satisfactory for practical problems. However, Blockley and Baldwin (64) have criticised the approach as it,

"seems rather ad hoc and lacks an adequate theoretical underpining".

3.17.5 Influence diagrams

Influence diagrams were conceived by researchers while developing automated aids for decision analysis. The concept of graphically representing probabilistic influence was motivated by the need of human beings to communicate among themselves and with computers about the structure of complex decision problems involving many uncertain variables. A good piece of work on influence diagrams is given by Miller (65) and Howard (66).

Influence diagrams are powerful tools for representing knowledge because they allow three levels of specification Howard (66).

(i) relational;
(ii functional;and
(iii) numerical.

The nature of the influence represented can be either deterministic or probabilistic. This parallels the hierarchical nature of human knowledge in developing expert systems based on influence diagram technology. First the major system influences are encoded, then the structure of functional relationships of the influences is determined, and finally the specific parameters are added by the appropriate experts at their levels of expertise.

3.17.5.1 Example

According to Howard (66), an influence between two random variables 'a' and 'b' is said to exist when the variables are not probabilistically independent. Thus an influence exists between two random variables 'a' and 'b' if and only if [b/a, H] [b/h] where [b/H] is the probability distribution for **b** conditioned on the history or state of information"H".

FIGURE 3.3: INFLUENCE DIAGRAM BETWEEN TWO VARIABLES

b influences a

An influence is designated in influence diagrams by placing the names of the uncertain state variables within circular nodes (figure 3.3). The nodes are connected by directed arcs as shown in figure 3.3. Mathematically this represents [a/b] at the **relational level.** The hierarchical features of influence diagrams allow the modelling and knowledge encoding processes to be broken into 3 phases. The structure of the diagram paints a view of the broad picture capturing the critical variables and their relationships. This is the representation at the relational level. At the **functional level**, the probability distribution of each uncertain variable is assigned conditioned on the values of the variables on which it depends. The knowledge at the functional level may include some combination of expert knowledge and results derived from an analytical model of the system.

At the **numerical level**, the rules of inference for probability are used to determine the unconditional distributions on all uncertain variables.

3.17.6 Fuzzy set theory

The theory of fuzzy sets attempts to provide a systematic approach for dealing with vagueness as distinct from randomness. Fuzzy sets theory was first introduced by Zadeh (67) as a method for reasoning with vague information. It is a generalisation of classical set theory by extending the classes of objects to those whose boundaries are not sharply defined. In such cases, fuzzy set theory is not only suitable for formally modelling uncertainty but is also suitable for handling human orientation.

Full illustrations of fuzzy set theory are given in the next chapter.

3.18 Summary

A detailed description of the basic feature of a knowledge based system has been presented. It is concluded that KBS has features which can be useful in the refurbishment work domain. 7

The inference mechanism manipulates the facts in the data base with the rules in the knowledge base in order to infer conclusion. Rules can be inferred by following a forward or backward chaining strategy.
Some of the potential merits of using KBSs' in refurbishment work are that: 7

i) they can aid experienced estimator in clarifying his thinking about decision-making and uncertainty;

ii) they can be integrated with CAD and mathematical programming packages to provide a simple and efficient decision support system; and

iii) they are a reasonably effective way of documenting expertise which is important when it is expensive and scarce.

CHAPTER FOUR

OVERVIEW OF FUZZY SET THEORY

CHAPTER FOUR

OVERVIEW OF FUZZY SET THEORY

4.1 Introduction

This chapter discusses the theoretical background of fuzzy set theory as developed by Zadeh(1). The objective is to present those aspects of fuzzy set theory which would be useful in the understanding of the linguistic variables used in the knowledge based decision support systems for the management of risks caused by the employment of sub-contractors.

4.2 Basic principle of fuzzy sets

In classical set theory, a set is defined as a collection of objects having a general property.

Thus, a set of building contractors may be defined and it is possible to choose easily which contractors are members of this set and which are not. It is also possible to define a subset of building contractors such as those building contractors who are highly skilled in refurbishment contracts. Within the general building contractors, it is possible to identify building contractors who are also highly skilled in refurbishment contracts. The intersection of the set of building contractors with the set of those highly skilled in refurbishment contracts tells us which building contractor is highly skilled in refurbishment contracts and who is not. The union of both of these sets gives the set of building contractors who are not highly skilled and those who are highly skilled in refurbishment contracts.

If this classical set concept is extended to embrace another kind of set, say a subset of "very experienced" refurbishment contractors, it is possible for one to ask here, "How experienced is very experienced?" A satisfactory answer to this question may be a difficult one as the class of "very experienced" refurbishment contractors is not a set in the classical sense, but belongs to a fuzzy, not crisply defined type. The definition of "very experienced" may involve a spectrum of human perceptions and the class of "very experienced" refurbishment contractors is therefore said to represent a fuzzy set.

Fuzzy set theory attempts to ease this dilemma by allowing items to be members of sets with something less than the firmness of the 'yes-no' decision. Ordinary set theory allows items to be members with a grade of membership of either 1 or 0. That is , they are either members of the set or they are not. Fuzzy set theory provides suitable mathematical models where the subjective character of input information remains transparent in the results. Fuzzy set theory was developed by Zadeh (2) to cope with imprecise knowledge. This growing field introduced by Zadeh has extensively been reviewed by other researchers (3,4,5,6,7,8).

4.3 Concept of fuzzy set theory

Since Zadeh (1) introduced this concept in 1965, fuzzy set analysis has been employed in numerous areas. The concept is founded on the notion that qualitative expressions usually involve the realm of human perceptions, subject to a range of interpretations. While the values of these expressions are inexact in quality, they are meaningful qualitative expressions and usually consist of linguistic variables and linguistic values. A linguistic variable is a variable whose values are not numbers but words or sentences in a natural language. Fuzzy set theory provides a framework for dealing with such variables. Linguistic variables and fuzzy sets have the relationship of goal and tool. Manipulating natural language expressions is the goal, and fuzzy set theory is a tool to achieve that goal. For instance the term, "Excellent workmanship", as used in most refurbishment contract documents, is a linguistic variable. It is information expressed in words or phrases that has value which is not clearly defined. The linguistic value may be Excellent, Good, Satisfactory, Fair, Awful, depending on the subjective judgement of the evaluator. Zadeh considered these values as fuzzy sets.

4.4 Fuzzy sets

Zadeh further stated that, since we tend to reason approximately, we are able to summarise much information and then extract pertinent and important items. Approximate reasoning, which encompasses the fuzzy set concept, is capable of coping with the fuzzy nature of qualitative performance measures. To fully appreciate the prospective application of Zadeh's thinking to refurbishment work, we need to understand some basic definitions and mathematical operations. These are explained below in this chapter.

4.5 Membership grades

Fuzzy set theory allows items to be elements of the set with a grade of membership which can lie anywhere in the range 0 to 1.

According to Zadeh (9,10):

"a fuzzy set is a class with unsharp boundaries, that is, a class in which the transition from membership to non membership is gradual rather than abrupt."

These grades of membership are defined subjectively, reflecting the individual's own opinion of the truth of the statement that item 'A' is a member of the set 'AA'. As with ordinary sets, fuzzy sets can be subject to the laws of union, intersection, complementation and so on, in such a way that ordinary sets appear as a special case of fuzzy sets.

4.6 Natural language computation

The theory of fuzzy sets represents an attempt at constructing a conceptual framework for a systematic treatment of fuzziness in both qualitative and quantitative ways. A fuzzy set 'A' in a universe of discourse X is characterised by a membership value of $\mu_A(x)$ which associates with each point in X a real number in the interval [0,1] as follows:

$$A = \left\{\mu_A(x) \,|\, x\right\}, \text{---------------} 1$$

where A is a fuzzy set

$\mu_A(x)$ is a grade of membership of x in A, and is a real number between zero and one.

$|$ is a delimiter and

x is a generic element of universe X (which is an integer number between one and ten).

= should be interpreted as "is defined to be"

Here, we may consider the universe of discourse X as a linguistic variable. The element x indicates the level of workmanship. As an example, if A is Excellent, then x may range from "implementation according to the specification" (x=1) to "totally unacceptable construction practices" (x = 0). The membership function $\mu_A(x)$ is the corresponding degree of belief which is highest for a higher performance level and which decreases for a lower performance level.

These definitions of linguistic variables can be provided by the user or the system designer. If defined by the system designer, the assumption is that these definitions correspond in some way to the user's intuitive meaning for the terms. The objective of the natural language computation is to convert natural language expressions into fuzzy sets. Thus, it is possible to define sets that are based on vague linguistic terms, for example, “excellent work reference”, “good safety records”, “poor workmanship”, "attractive bid" and so on.

The grades of membership are subjective, in the sense that their specification is a matter of definition rather than objective experimentation or analysis.

Example

Using linguistic terms such as Excellent, Good, Satisfactory, Fair and Awful, it is possible to rate a sub-contractor's performance on quality of workmanship. Evaluation using these terms, although qualitative, is meaningful to the estimators as well as others in the construction industry. If a numerical grade is desired, say for a sub-contractor considered to have a Good workmanship record, an estimator may assign a number of say, 7 on a scale of 1 to 10. Obviously, there is uncertainty associated with such "mapping" of one's perception to a numerical grade.

Using the above example for evaluating the sub-contractor's workmanship quality, if the quality of workmanship is deemed as 'Good' a fuzzy number 7 may be used to reflect this assessment. Fuzzy numbers are a subset of the more general term, fuzzy sets. The fuzzy number 7 read as 'about 7' might be expressed as follow (in a discrete form here for simplicity).

$$B\,[\text{Good}] = [0|5,\ 0.5|6,\ 1.0|7,\ 0.5|8,\ 0|9]$$

In fuzzy set notation, the number after the delimiter (|) is a member of the set and the value before the delimiter is the credibility (or degree of support) of that number. This example of fuzzy number '7' may be interpreted as follows: for the term "Good" assigning a grade of 6 or 8 for the perception,"Good" is considered to be somewhat appropriate (with a degree of support of 0.5), while assigning a grade of 5 or 9 or any others is absolutely inappropriate as the degree of support is zero. Thus, the fuzzy number '7' can reflect the term "Good" more precisely than a real number 7. The non-random uncertainty is modelled here by a fuzzy number.

The following fuzzy estimates of the ratings and degree of importance used to develop SSARC were provided by the chief estimator as described in chapter 5.

LEVEL OF WORKMANSHIP

A [Excellent] = [0|7, 0.5|8, 1.0|9]

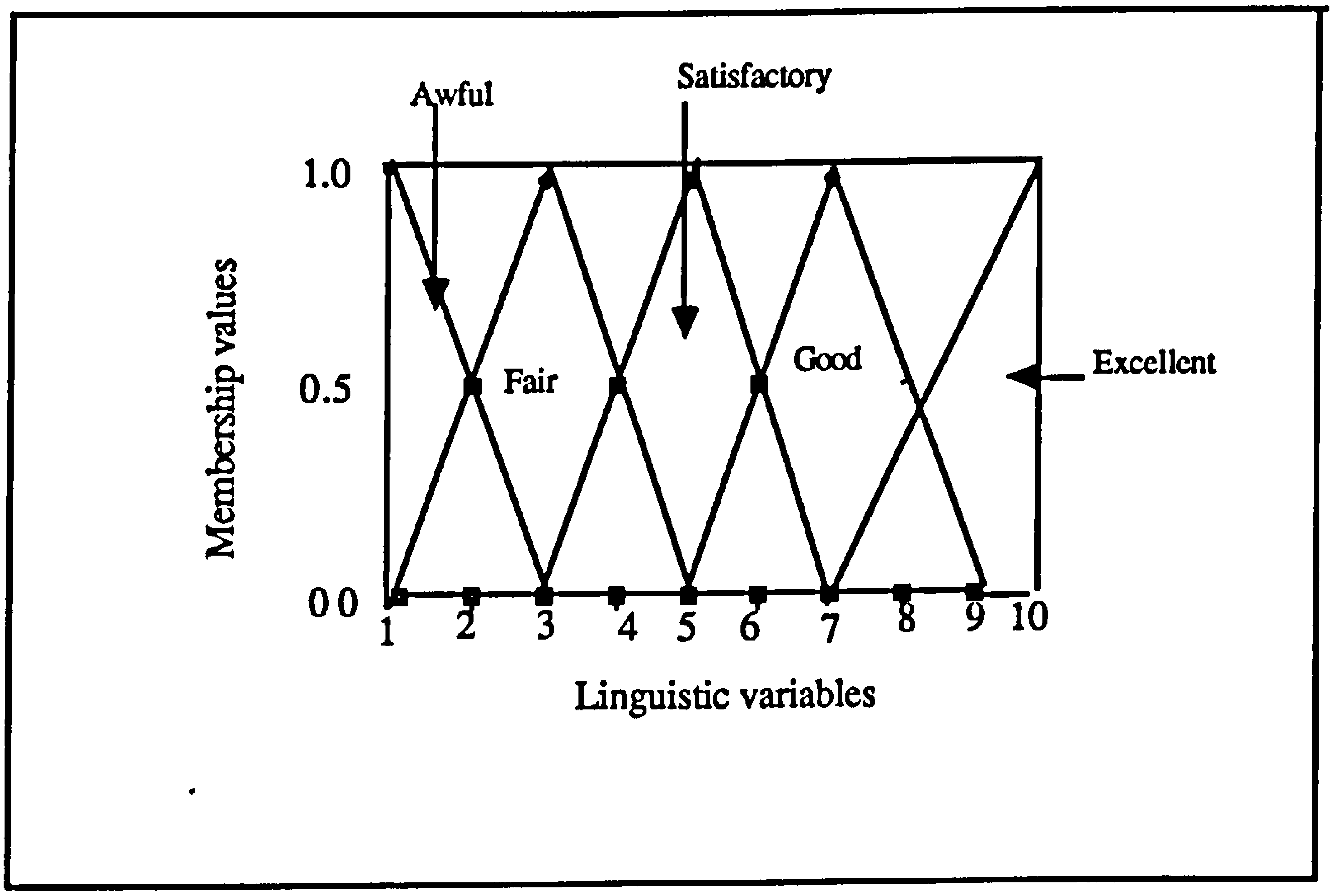
B [Good] = [0|5, 0.5|6, 1.0|7, 0.5|8, 0|9]

C [Satisfactory] = [0|3, 0.5|4, 1.0|5, 0.5|6, 0|7]

D [Fair] = [0|1, 0.5|2, 1.0|3, 0.5|4, 0|5]

E [Awful] = [1.0|1, 0.5|2, 0|3]

FIGURE 4.1: GRAPHIC REPRESATATION OF LINGUISTIC VARIABLES



DEGREE OF IMPORTANCE

A [Extremely important] = [0|6, 0.5|7, 1.0|8]

B [Very important] = [0|5, 0.5|6, 1.0|7,0.5|8,0|9]

C [Important] = [0|3, 0.5|4, 1.0|5, 0.5|6, 0|7]

D [Not very important] = [0|1, 0.5|2, 1.0|3, 0.5|4, 0|5]

E [Unimportant] = [0|1, 1.0|2, 0.5|3]

4.7 Mathematical operation of fuzzy set theory

In general, any fuzzy subset 'A' can be expressed mathematically by 'n' discrete values of x together with membership values, $\mu_A(x)$, as follows:

$$A = \left\{ \mu_A(x_1) \mid x_1, \mu_A(x_2) \mid x_2, \text{----------}; \mu_A(x) \mid x_n \right\} \text{--------}2$$

The calculation of the fuzzy weighted average, a generalisation of the normal weighted mean is defined as:

$$R_{ave} = \frac{\sum_{i=1}^{n} R_i \times W_i}{\sum_{i=1}^{n} W_i}$$

where R_{ave}, is the fuzzy set representing the overall weighted average ratings of an alternative.

R_i, is the fuzzy set that represents rating of the alternative based on a particular criterion, and;

W_i, is the fuzzy set representing the weight (or relative importance) assigned to that particular criterion.

The addition, multiplication and division in the equation above are fuzzy arithmetic operations.

4.8 Extension principle

In order to use fuzzy sets in practical problems, some operational rules similar to those in classical set theory need to be defined. These operational rules are referred to as Zadeh's extension principle (11).

One of the most powerful concepts of fuzzy set theory is the extension principle. This is a generic method for extending functions over a fuzzy subsets base over the integer. It permits the extension of non-fuzzy mathematical operators (addition, multiplication, and divisions) to deal with fuzzy quantities.

Values of the fuzzy variables along with their degree of membership are used to calculate the membership function resulting from an operation.
Thus, they are defined as follows:

Let $A = \{ \mu_A(x) | x; \ 1 \leq x \leq n\}$-----------4

$B = \{ \mu_B(y) | y; \ 1 \leq y \leq n\}$------------5

Where$\mu_A(x)$ and $\mu_B(y)$ are grades of membership function that characterise the fuzzy sets 'A' and 'B' respectively, and

x, y, and n are integers

4.8.1 Fuzzy addition

The fuzzy addition is defined as:

$A + B = \{ \min[\mu_A(x), \mu_B(y)] \, | \, (x+y) \quad 1 \leq x; y \leq n \}$------6

4.8.2 Fuzzy multiplication

The fuzzy multiplication is defined as:

$A \times B = \{ \min[\mu_A(x), \mu_B(y)] \, | \, (x \times y) \quad 1 \leq x; y \leq n \}$--------7

4.8.3 Fuzzy division

The fuzzy division is defined as :

$A+B = \{\min[\mu_A(x), \mu_B(y)] \, | \, [x+y] \quad 1 \leq x; y \leq n \}$------8

In the fuzzy division operation, the Clement's algorithm (6) is used. The Clement's algorithm involves two assumptions:

i) Any division (x + y) not resulting in an integer is deleted.

ii) Any division resulting in a quotient greater than 'n' is discarded.
A detailed illustration of the fuzzy arithmetic computation is displayed in section 4.11.

4.9 Properties of fuzzy sets

4.9.1 Fuzzy normalisation

Past studies (6,12) have indicated that more reasonable results can be obtained where a fuzzy normalisation operation is conducted after each fuzzy addition, multiplication, and division. The fuzzy normalisation NOR, is defined as:

$$\text{If } C = \text{NOR } [R]$$
$$\text{then } C = \{\mu_C (x) \mid x; \quad 1 \leq x \leq n\} \text{--------} 9$$

$$\text{Where} \quad \mu_c(x) = \{\mu_{R(x)} \mid \max \{\mu_R(i); \; 1 \leq x \leq n\} \text{--------} 10$$

Normalisation enables the reduction of all fuzzy sets to the same base. Normalisation ensures that at least one element of the set has a degree of membership of one. This is done by dividing the degree of membership of each element in the set by the maximum degree of membership of any element in the set. If this maximum degree of membership is one, then the set is not modified by this division. If, on the other hand, the maximum degree of membership in the set is a number less than one, then dividing by this maximum will increase the degree of membership of each element and at least one element will have a degree of membership of one after the division.

4.9.2 Linguistic approximation (Best Fit Method)

A linguistic approximation is the translation of the evaluated fuzzy set (R) back to a linguistic expression, for example (Excellent, Good, Satisfactory, Fair, Awful). This is done by calculating the ***Euclidean distance***, from the given fuzzy set R, to each of the fuzzy sets, 'Excellent' 'Good' 'Satisfactory' 'Fair' or 'Awful', representing the natural language expressions.

Thus, the fuzzy weighted average R_{ave} can be evaluated back to a linguistic expression such as Excellent, Good, Satisfactory, Fair, or Awful. For instance, the Euclidean distance between fuzzy set R and a Fuzzy set A is estimated as follows:

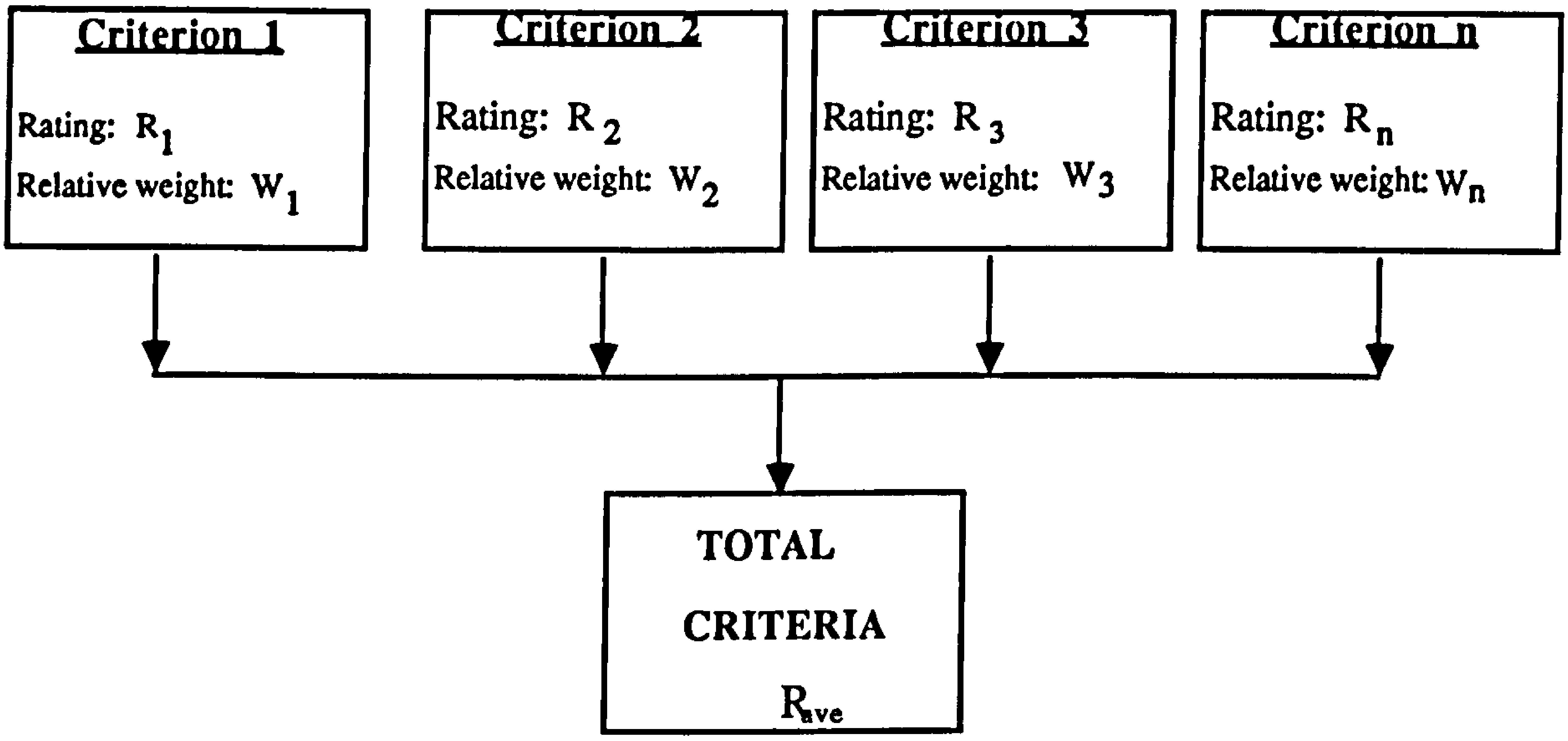
$$d(R, A) = \left(\sum_{n=1}^{n} [\mu_R(i) - \mu_A(i)]^2\right)^{\frac{1}{2}}$$

where d(R, A) is the Euclidean distance between fuzzy sets R and A

$[\mu_R(i)$ and $\mu_A(i)]$ are membership values of element of the two fuzzy sets. The linguistic expression that produces the shortest Euclidean distance is assigned to R.

4.10 Model total criteria rating

FIGURE 4.2: HIERARCHICAL BREAKDOWN OF TOTAL CRITERA



The procedure for finding the total criteria rating serves two objectives:

1 To integrate models obtained from several experts into a standard performance model.

2 To combine the values of various criterion in order to obtain the trade overall rating.

4.11 Fuzzy set theory calculation illustration

If the sub-contractor's expected workmanship and safety programme was rated as 'excellent' (R_1) and 'Fair' (R_2) respectively, and their corresponding degree of importance to the proposed project were 'important' (W_1) and 'Extremely important' (W_2) respectively. The fuzzy computation of the above representation is as follows:

$$R_{ave} = \frac{(R_1 \text{ x } W_1) + (R_2 \text{ x } W_2)}{W_1 + W_2} \qquad \text{------------}12$$

Since it is not feasible to perform the above calculations by hand for even a small example as described above if the universe over which the fuzzy set are defined is the set {1, 2, 3, 4, 5, 6, 7, 8, 10}, the universe to the set is restricted to {1, 2, 3, 4 } as shown below.

A = Excellent = [0.0/1, 0.1/2, 0.6/3, 1.0/4]
B = Good = [0.0/1, 0.2/2, 0.9/3, 0.7/4]
C = Satisfactory = [0.2/1, 1.0/2, 1.0/3, 0.2/4]
D = Fair = [1.0/1, 0.6/2, 0.1/3, 0.0/4]
E = Awful = [1.0/1, 0.2/2, 0.0/3, 0.0/4]

Extremely important = [0.0/1, 0.1/2, 0.6/3, 1.0/4]
Very Important = [0.0/0, 0.2/2, 0.9/3, 0.7/4]
Important = [0.2/1, 1.0/2, 1.0/3, 0.2/4]
Not Very Important = [0.0/1, 0.6/2, 0.1/3, 0.0/4]
Unimportant = [1.0/1, 0.2/2, 0.0/3, 0.0/4]

Thus,

R_1= [0.0/1, 0.1/2, 0.6/3, 1.0/4]
R_2= [1.0/1, 0.6/2, 0.1/3, 0.0/4]
W_1= [0.2/1, 1.0/2, 1.0/3, 0.2/4]
W_2= [0.0/0, 0.2/2, 0.9/3, 0.7/4]

The fuzzy weighted average Computation R_{ave} is as follows:

R_1 x W_1 = [0.0/1, 0.1/2, 0.6/3, 1.0/4] x [0.2/1, 1.0/2, 1.0/3, 0.2/4]

max[min(0,0.2), (the (1x1) component), min (0,1.0), (the (1x2) component)
min(0,1.0), (the (1x3) component), min (0,0.2), (the (1x4) component)
min(0.1,0.2), (the (2x1) component), min (0.1,1.0), (the (2x2) component)
min(0.1,1.0), (the (2x3) component), min (0.1,0.2), (the (2x4) component)
min(0.6,0.2), (the (3x1) component), min (0.6,1.0), (the (3x2) component)
min(0.6,1.0), (the (3x3) component), min (0.6,0.2), (the (3x4) component)
min(1.0,0.2), (the (4x1) component), min (1.0,1.0), (the (4x2) component)

min(1.0,1.0), (the (4x3) component), min (1.0,0.2), (the (4x4) component)]

= max[min(0.0/1 ,0.0/2, 0.0/3, 0.0/4, 0.1/2, 0.1/4, 0.1/6, 0.1/8
0.2/3, 0.6/6, 0.2/4, 0.6/9, 0.2/12, 1.0/8, 1.0/12, 0.2/16)]

$R_1 x W_1$= [0.0/1, 0.1/2, 0.2/3, 0.2/4, 0.6/6, 1.0/8, 0.6/9, 1.0/12, 0.2/16]

Normalising the above (that is, dividing all numerators with the highest numerator) we have:

$R_1 \times W_1$= [0.0/1, 0.1/2, 0.2/3, 0.2/4, 0.0/5, 0.6/6, 0.0/7, 1.0/8 ,0.6/9, 0.0/10, 0.0/11, 1.0/12, 0.0/13, 0.0/14, 0.0/15, 0.2/16]

Similarly:

$R_2 \times W_2$= [1.0/1, 0.6/2, 0.1/3, 0.0/4] x [0.0/0, 0.2/2, 0.9/3, 0.7/4]

= [0.0/1, 0.2/2, 0.9/3, 0.7/4, 0.6/6, 0.6/8, 0.1/11, 0.1/12, 0.0/16]

Normalising the above we have:

$R_2 \times W_2$ = [0.0/1, 0.2/2, 0.9/3, 0.7/4, 0.0/5, 0.6/6, 0.0/7, 0.6/8, 0.0/9, 0.0/10, 0.1/11, 0.1/12, 0.0/13, 0.0/14, 0.0/15, 0.0/16]

$W_1 + W_2$ = [0.2/1, 1.0/2, 1.0/3, 0.2/4]+[0.0/0, 0.2/2, 0.9/3, 0.7/4]

max[min(0.2,0.0) (the (1+1) component), min (0.2,0.2) (the (1+2) component)
min(0.2,0.9) (the (1+3) component), min (0.2,0.7) (the (1+4) component)
min(1.0,0.0) (the (2+1) component), min (1.0,0.2) (the (2+2) component)
min(1.0,0.9) (the (2+3) component), min (1.0,0.7) (the (2+4) component)
min(1.0,0.0) (the (3+1) component), min (1.0,0.2) (the (3+2) component)
min(1.0,0.9) (the (3+3) component), min (1.0,0.7) (the (3+4) component)
min(0.2,0.1) (the (4+1) component), min (0.2,0.2) (the (4+2) component)
min(0.2,0.9) (the (4+3) component), min (0.2,0.7) (the (4+4) component)]

$W_1 + W_2$ = max[min{0.0/2, 0.2/3, 0.2/4, 0.2/5, 0.0/3, 0.2/4, 0.9/5, 0.7/6, 0.0/4, 0.2/5, 0.9/6, 0.7/7, 0.1/5, 0.2/6, 0.2/7, 0.2/8}]

= [0.0/2, 0.2/3, 0.2/4, 0.9/5, 0.9/6, 0.7/7, 0.2/8]

Normalising the above, we have:

$W_1 + W_2$ = [0.0/1, 0.0/2, 0.22/3, 0.22/4, 1.0/5, 1.0/6, 0.78/7, 0.22/8]

Similarly,

$R_1 \times W_1 + R_2 \times W_2 =$ [0.0/1, 0.1/2, 0.0/3 0.2/4, 0.0/5, 0.0/6, 0.0/7, 1.0/8
0.6/9, 0.0/10, 0.0/11, 1.0/12, 0.0/13, 0.0/14
0.0/15, 0.2/16] + [0.0/1, 0.22/2, 1.0/3, 0.78/4
0.0/5, 0.67/6, 0.0/7, 0.67/8, 0.11/9, 0.0/10,
0.0/11, 0.11/12, 0.0/13, 0.0/14, 0.0/15, 0.0/16]

= [0.0/2, 0.0/3, 0.22/4, 0.22/5, 1.0/6, 0.78/7
0.78/8, 0.67/9, 0.67/10, 0.67/11, 0.67/12,
0.11/13, 0.67/14, 0.11/15, 0.67/16, 0.11/17,
0.11/18, 0.0/19, 0.11/20, 0.11/21, 0.0/22,
0.0/23, 0.11/24, 0.0/25, 0.0/26, 0.0/27, 0.0/28,
0.0/29, 0.0/30, 0.0/31, 0.0/32]

Normalising:

= [0.0/1, 0.0/2, 0.0/3, 0.22/4, 0.22/5, 1.0/6, 0.78/7
0.78/8, 0.67/9, 0.67/10, 0.67/11, 0.67/12,
0.11/13, 0.67/14, 0.11/15, 0.67/16, 0.11/17,
0.11/18, 0.0/19, 0.11/20, 0.11/21, 0.0/22,
0.0/23, 0.11/24, 0.0/25, 0.0/26, 0.0/27, 0.0/28,
0.0/29, 0.0/30, 0.0/31, 0.0/32]

$$R_{ave} = \frac{(R_1 \times W_1) + (R_2 \times W_2)}{W_1 + W_2} =$$

$$\frac{\begin{array}{l}[0.0/1, 0.0/2, 0.0/3, 0.22/4, 0.22/5, 1.0/6, 0.78/7, 0.78/8, \\ 0.67/9, 0.67/10, 0.67/11, 0.67/12, 0.11/13, 0.67/14, \\ 0.11/15, 0.67/16, 0.11/17, 0.11/18, 0.0/19, 0.11/20, \\ 0.11/21, 0.0/22, 0.0/23, 0.11/24, 0.0/25, 0.0/26, 0.0/27, \\ 0.0/28, 0.0/29, 0.0/30, 0.0/31, 0.0/32]\end{array}}{[0.0/1, 0.0/2, 0.22/3, 0.22/4, 1.0/5, 1.0/6, 0.78/7, 0.22/8]}$$

Applying Clement's algorithm as discussed in section (4.9.3), that is:

(a) Ignoring any division not resulting in an integer; and

(b) Discarding divisions resulting in a quotient greater than 4.

First division to get a quotient = 1 is:

a = max [min (0, 0) (the (1+1) component), min(0, 0) (the (2+2) component),
min (0.22, 0)(the (3+3) component), min(0.22, 0.22) (the (4+4) component),
min (1.0, 0.22)(the (5+5) component), min(1.0, 1.0) (the (6+6) component),
min(0.78, 0.78)(the (7+7)component),min(0.22,0.78)(the(8+8) component)]

max[0, 0, 0, 0.22, 0.22, 1.0, 0.78, 0.22]

max = 1.0

i.e 1.0|1

Division to get a quotient = 2

b = max[min(0, 0) (the (2+1) component), min(0.0, 0.22) (the (4+2) component),
min(0.22, 1.0)(the (6+3) component),min(0.22,0.78)(the (8+4) component),
min(1.0, 0.67)(the(10+5)component),min(1.0,0.67)(the (12+6) component),
min(0.78,0.67)(the(14+7)component),min(0.22,0.67)(the(16+8)component)]

max[0, 0, 0.22, 0.22, 0.67, 0.67, 0.67, 0.22]

max = 0.67

i.e 0.67|2

Division to get a quotient = 3

b = max[min(0, 0) (the (3+1) component), min(0, 1.0) (the (6+2) component),
min(0.22,0.67)(the(9+3)component),min(0.22,0.67)(the(12+4) component),
min(1.0, 0.11)(the(15+5)component),min(1.0,0.11)(the (18+6) component),
min(0.78,0.11)(the(21+7)component),min(0.22,0.11)(the(24+8)component)]

max[0, 0, 0.22, 0.22, 0.11, 0.11, 0.11, 0.11]

max = 0.22

i.e 0.22|3

Division to get a quotient = 4

b = max[min(0, 0.22) (the (4+1) component), min(0, 0.78) (the (8+2) component),
min(0.22, 0.67) (the(12+3)component), min(0.22,0.67) (the(16+4)component),
min(1.0, 0.11) (the (20+5) component), min(1.0, 0.11) (the (24+6) component),
min(0.78, 0.0) (the (28+7)component), min(0.22, 0.0) (the(32+8)component)]

max[0, 0, 0.22, 0.22, 0.11, 0.11, 0, 0]

max = 0.22

i.e 0.22|4

Therefore :

$$\frac{(R_1 \text{ x } W_1) + (R_2 \text{ x } W_2)}{W_1 + W_2} = [1.0|1, 0.67|2, 0.22|3, 0.22|4]$$

Mapping back the above result to a linguistic expression, i.e

Excellent = [0.0/1, 0.1/2, 0.6/3, 1.0/4]
Good = [0.0/1, 0.2/2, 0.9/3, 0.7/4]
Satisfactory = [0.2/1, 1.0/2, 1.0/3, 0.2/4]
Fair = [1.0/1, 0.6/2, 0.1/3, 0.0/4]
Awful = [1.0/1, 0.2/2, 0.0/3, 0.0/4]

using the Euclidean distance formulae, i.e

$$d(R, A) = \left(\sum_{n=1}^{n} [\mu_R(i) - \mu_A(i)]^2\right)^{\frac{1}{2}}$$

Let $R = [1.0 | 1, 0.67 | 2, 0.22 | 3, 0.22 | 4]$

then the distance from R to Excellent i.e

$$d(R, \text{Excellent}) = [(0.0 - 1.0)^2 + (0.1 - 0.67)^2 + (0.6 - 0.22)^2 + (1.0 - 0.22)^2]^{\frac{1}{2}}$$

$$= 1.44$$

$$d(R, \text{Good}) = [(0.0 - 1.0)^2 + (0.2 - 0.67)^2 + (0.9 - 0.22)^2 + (0.7 - 0.22)^2]^{\frac{1}{2}}$$

$$= 1.383$$

Similarly,

d(R, Satisfactory) = 1.165.
d(R, Fair) = 0.262.
d(R, Awful) = 0.563.

Therefore, the rating with the shortest distance (0.262) is Fair. Thus, the probability of this sub-contractor meeting the performance requirements for quality of workmanship and safety programme is considered Fair.

This is a reasonable deduction, considering the importance of safety provision in refurbishment projects. In this particular case, the safety provisions on site is considered extremely important. Although the quality of workmanship of this sub-contractor is rated excellent, the contractor sees the provision of safety measures as very vital in the contract. This could be a city centre site where the sub-contractor is required to comply with strict safety provision to avoid injury or even death to members of the public and the workmen on the site. The overall total criteria ratings for each trade sub-contractor can be evaluated. These are described fully in chapters seven and eight.

CHAPTER FIVE

CONCEPTUAL FRAMEWORK AND RESEARCH METHODOLOGY

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CONCEPTUAL FRAMEWORK AND RESEARCH METHODOLOGY

5.1 Introduction

Knowledge acquisition is a key phase in any methodology for constructing knowledge based systems, deciding what knowledge should be brought to bear on a problem, how the knowledge can be used in a programme, how to elicit, interpret, organize and encode it in a knowledge based system are all aspects of knowledge acquisition. The power of the knowledge based system depends crucially on the quality of the knowledge it obtains. The process of knowledge acquisition is complex and fraught with difficulties and is a lengthy and difficult process. It is therefore important that the knowledge engineer is aware of the available knowledge acquisition methodologies or aids in order that the most suitable one is chosen for the particular problem.

This chapter describes the research methodology adopted as well as the nature of the research data and its organization. It discusses how the research data were collated and coded to facilitate the development of the knowledge based systems in the refurbishment work domain. It explains how the experiences of the various experts involved in the selection and appointment of sub-contractors were captured. It also details the framework for knowledge acquisition and knowledge elicitation.

5.2 Sample Selection

As this study is the third phase of the on-going research programme in refurbishment work which started with Quah (1), and followed by the work of Teo (2), thus initial contact had already been made through the Builders Conference in London. The \ contractors used for this research were selected from the 100 contractors used by Teo (2).

The Builders' Conference in London helped to produce a list of 59 suitable contractors selected from a total of 100 contractors. The main reason for adopting this approach was to maintain consistency and to enable the researcher to make use of the data base which had been built-up over a number of years.

The Builders' Conference in London is a trade association which was established in 1935 by 60 London contractors with the aim of reducing the intensity of competition. It achieves this objective by providing a tender reporting service to over 200 of its members through the exchange of tender bid information among contractors. The Builders' Conference is an independent body and as such the data collected is free from biases.

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5.3 Meeting with domain expert

This researcher was fortunate during the early stages of the study to have the services of a retired chief estimator from one of the refurbishment contractors who participated in the first two phases of the research programme mentioned above. The chief estimator had worked in the construction industry for over 30 years and had been an estimator in one of Britain's biggest construction companies for more than 25 years.

5.3.1 First meeting

At this first meeting which was attended by the researcher's supervisor, and the chief estimator, a detailed description of the workings of knowledge based systems and the past research work on refurbishment work was discussed. The work by Quah (1) was made available to the chief estimator to acquaint him with the background of the on-going research work in refurbishment work.

5.3.2 Second meeting

At this meeting, the chief estimator brought with him two contract documents of the projects he worked on just before his retirement. The two documents contained details of the sub-contractor's work and all the lists of sub-contractors who tendered for the project. The contract document also indicated the sub-contractors who were used in the contract. The chief estimator then explained the reason why some sub-contractors were chosen and also why other sub-contractors were rejected for the contract. He also explained the company's policy on sub-contracting. He then gave the researcher a chart on the procedure used in the company for the selection and appointment of sub-contractors (figure 5.1). From the discussions and the informal protocol collected, the researcher was able to produce 10 rules. Furthermore, from the documents which the chief estimator brought and from the literature that the researcher had read, it was possible to build a small prototype for sub-contractor selection and this was built, for domestic sub-contractors' evaluation.

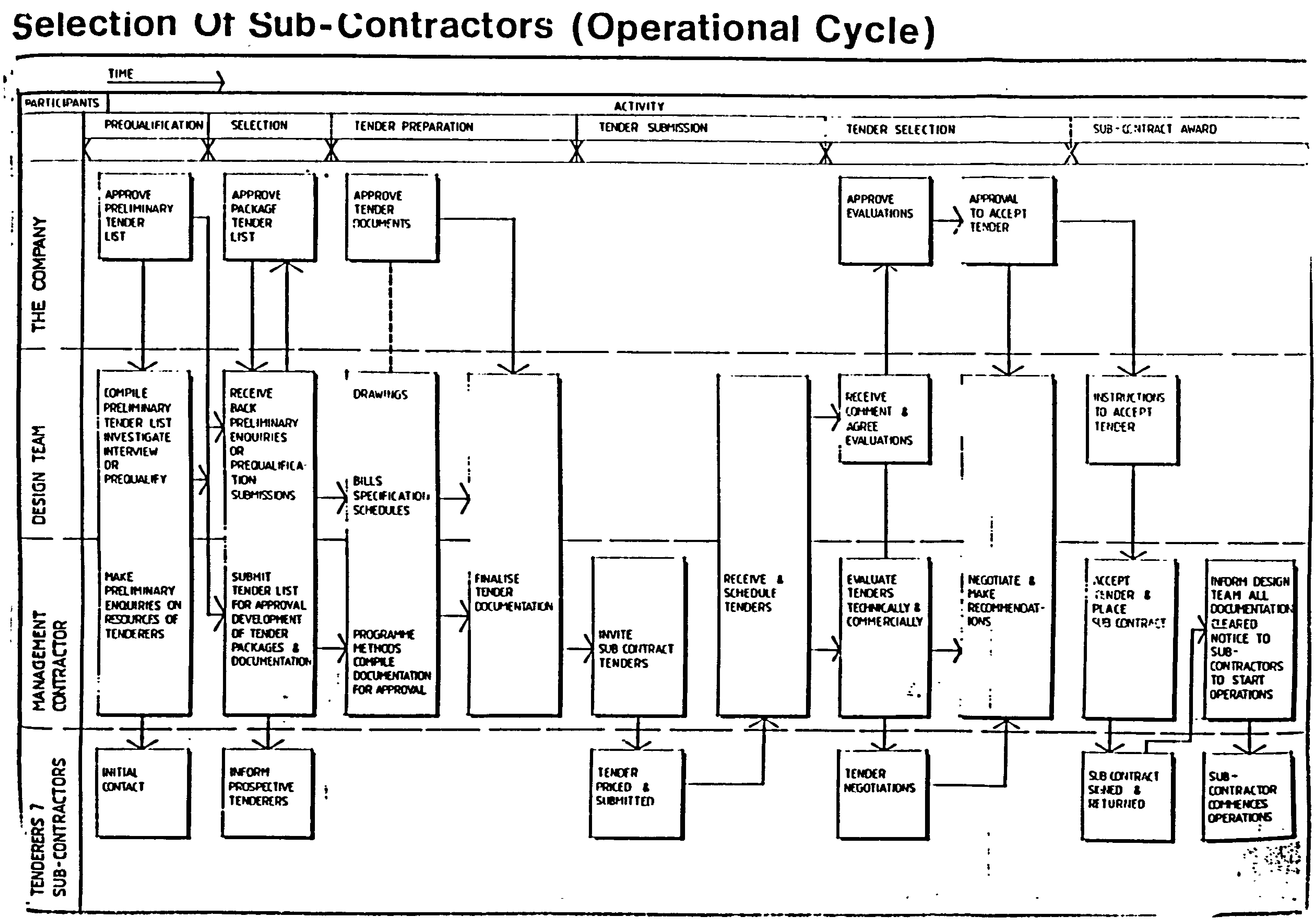


Figure 5.1: Domain Experts' Company's Sub-contractor's Selection and Appointment Procedure

5.3.3 Third meeting

This meeting took place one month after the previous one. When the chief estimator saw the runs and rules of the system, he was very surprised by the progress that had been made. He spent most of the time in this session commenting on the rules. After this session, the researcher was able to refine the rules and try the system on other trade sub-contractors.

5.3.4 Fourth meeting

This meeting took place two months after the preceding one. At this meeting, with the domain expert attended by the researcher's supervisor, it was agreed that since different refurbishment contractors use different criteria in the selection and appointment of their sub-contractors, the use of one domain expert would make the proposed KBS of limited use. Therefore, the data collection should cover a large sample of refurbishment contractors. A knowledge based system for the selection and appointment of sub-contractors that could not be used within the domain of refurbishment contractors would clearly be unsatisfactory. Moreover, a knowledge based system that offered superficial coverage in an area like selection and appointment of sub-contractors will fail both to perform at the level of an expert and offer adequate counsel.

The personal construct theory also recognises that different individuals may construe events or experiences in different ways. This is reflected in the Bannister and Mair (3) individuality corollary which states that:

"each individual's construct system is thought to be unique"

This is not suggesting that each individual's construct system is necessarily distinct or that individual's construct systems are mutually exclusive, indeed it is a converse to the individuality corollary to reflect that individuals may construe events or experiences in similar ways. The Fransella & Bannister (4) commonality corollary states that :

"To the extent that one person employs constructs of experience which are similar to that of another, his processes are psychologically similar to that of the other person".

According to Shaw and Gaines (5); and Gaines (6) the principle ideas underlying Repertory Grids have been developed so that comparisons between construct systems represented by two or more grids (i.e, multiple grids) can be made. Such comparisons appeal to both the individuality and commonality corollaries to determine the differences and similarities respectively between the constructs systems of multiple grids.

There are also various reasons why it may be expedient to make comparisons between multiple grids. By comparing two or more grids elicited from different contractors, it is possible to identify each contractor's core structure. Core structure is defined by Shaw and Gaines (5) as:

"the set of elements and constructs that are central to the individual's psychological maintenance process".

Also Smith (7) noted that:

"if two or more grids originated from two individuals, it is possible to identify the level of shared understanding between the individuals with respect to the same domain of discourse"

Finally, multiple grids elicited from a small group of contractors can be compared to determine the consensus of opinion and to identify those contractors of the group whose views are the most dissenting. It is in this respect of revealing differences and similarities between individuals' construct systems that Repertory Grid techniques are regarded as a useful tool for modelling multiple expertise in knowledge acquisition for expert system development.

5.4 Seminar presentation

After this fourth meeting, the researcher proceeded to present a short seminar to a group of contractors, mainly directors, estimators, and quantity surveyors, who had participated in the second phase of the study during a conference in London. This conference was organized by the Builder's Conference in London. Not only did this seminar work as a vehicle for establishing further contact with a certain top official in the construction company who participated in key decision making within the company, but it also give the authority of this senior executive to take this research further. At this meeting, the researcher presented the research outline and explained the direction the proposed research work would take. Questions were taken from the contractors and some of them offered some suggestions on the areas they would want the research to cover.

5.5 Knowledge elicitation technique used

The knowledge acquisition was carried out in two stages:

i) Questionnaire survey; and

ii) Repertory Grid interview.

5.5.1 Survey questionnaire

This stage of knowledge elicitation consisted of soliciting detailed information on how refurbishment contractors choose their sub-contractors, through a survey questionnaire.

5.5.1.1 Questionnaire objectives

The questionnaire was designed to achieve the following objectives:

i) to determine whether most refurbishment contractors use any clearly definable criteria in the selection and appointment of their sub-contractors.

ii) to identify the criteria which are used by these contractors.

iii) to investigate how frequently these criteria have been employed during the selection and appointment of sub-contractors.

iv) to investigate the decision-making processes involved regarding the selection and appointment of sub-contractors.

v) to serve as a preliminary investigation prior to the Repertory Grid knowledge acquisition exercise from the selected contractors.

5.5.1.2 Questionnaire Design

The questionnaire design was developed on the following guide-lines mentioned in Hoinville (8).
Hoinville (8) prescribes that a good questionnaire should have the following properties:

1. It must be clear, unambiguous, uniformly workable, and easy to answer.

2. It should be designed to minimize potential biases and errors from the respondents.

3. It should help in engaging the interest of the respondents since people's participation in the survey is voluntary.

5.5.1.3 Questionnaire layout

The following strategies was adopted to reduce biases associated with the mail questionnaire and to achieve maximum response:

1. A clear instruction was given at the start of each question on how to complete the questions.

2. The questions were typed on the left hand side of the page with the possible answers to the right.

3. Being a somewhat long questionnaire, some reluctance to respond was thought to be inevitable on the part of potential respondents. Thus to aid completion an attempt was made to place questions that were easier to answer towards the front and end of the questionnaire.

4. In an attempt to achieve a higher return and completion ratio, the average time it would take to complete the questionnaire was determined during the pre-testing and was assessed as 15 minutes. The questionnaire was also pre-tested to eliminate any misleading and unwanted aspects.

5. Each question was worded in a manner that made it simple, clear and as brief as possible. The pre-testing helped in determining the effective wording of the questions.

6. Categories were used to obtain information about the companies financial turnover and other private details instead of specific figures. Respondents according to Moser (9) are likely to let you know that their salaries are between £10,000 and £25,000, but reluctant to specify them as say £12,000. Also the use of categories is beneficial when analysing the data, in that it is more useful to analyse by groups than by specifics.

7. The problem of 'central tendency concept' i.e. the tendency of people to avoid an extreme stand and to choose the 'middle' answer on a question as described in Kaln and Cannell (10) was overcome by providing an even number of categories to force the respondents to take one side or the other.
8. Internal consistency checks were built into the questionnaire in that some questions had to be answered in a similar manner.

9. Consideration was given to the intended means and type of analysis that would be used which is described in chapter 6. Each question, sub-section and category was designated in an SPSS-X data entry format.

5.5.1.4 Improving the success rate

To improve the success rate for completion of this long and somewhat sensitive questionnaire, the following techniques were used:

1. A number of respondents as mentioned in section 5.4, were personally contacted in a seminar organized by the Builders' Conference in London where the researcher presented an outline and objectives of the research. Research requirements were put to the directors, estimators, quantity surveyors, and contracts managers of all the companies concerned.

2. Assurance was given on the cover of the questionnaire that all information would be treated in the strictest confidence.

3. All potential respondents received a personal letter stating the purpose of the research, the researcher and his supervisor's name.

5.5.1.5 Questionnaire format

Individual criticisms were invited at the initial draft of the questionnaire from fellow research associates and members of academic staff in the department. Also the most appropriate statistical tests to be used in the analysis discussed with a statistician in a university statistics department with regard to the design and format of the questionnaire and the results expected.

The questionnaire was then sent to the chief estimator for his comment on the layout, and the wording of the questions and the likely time it would take to complete and a further meeting was held with the chief estimator to discuss the issues raised on the questionnaire.

The final agreed draft was then passed to the researcher's supervisor for his comment. Some further changes and modifications were recommended on the layout of the questionnaire and the wording of the questions and some additional questions were added.

After all the corrections were made and the final approval of the questionnaire given by the researcher's supervisor, questionnaires was sent to each of the 59 selected contractors with a covering letter signed personally by the researcher's supervisor. A self stamped addressed envelope was also enclosed for the return of the questionnaire direct to the researchers supervisor.

In case the self addressed envelope might be mislaid, the return address was included at the bottom of the last page to the questionnaire (appendix A). The survey questionnaire was set in four parts:

i) Information about the company.

ii) Sub-contractor's policy and methods.

iii) Sub-contractor's information.

iv) Decision-making, consisting of nine pages as shown in appendix (A).

5.5.1.6 Information about the company

The first part of the questionnaire primarily sought information about the company size and level of sub-contracting. It aimed to identify the company's annual turnover, its total directly employed labour force and the level of sub-contracting compared to its annual turnover and the company's years of experience in refurbishment work.

5.5.1.7 Sub-contractor's policy and methods

Part two elicited information on the company's policy on sub-contracting and different types of sub-contractors the company had worked with in the past. This section focuses on which sub-contracting types offered larger financial reward, ease of monitoring administration and quality of workmanship.

5.5.1.8 Sub-contractor's information

Part three sought information on the data gathering processes that were employed during decision making stages. Internal consistency checks on some aspects of the questionnaire were built into this part of the questionnaire.

5.5.1.9 Decision-making

Part four elicited information on the decision-making methods then currently used by the refurbishment contractors regarding the selection and appointment of sub-contractors.

5.5.1.10 Questionnaire survey response

A total of 35 questionnaires were returned, out of which 33 were usable from the 59 questionnaires sent out representing, an overall return rate of 59% which, according to Runnel Ballane(11), is a reasonable response.
After detailed analysis of the questionnaires and further discussions with my supervisor on the results. it was decided to interview the 32 contractors who indicated in the survey questionnaire they would like to participate in the personal interview stage.

5.5.2 Repertory Grid Interview

5.5.2.1 Knowledge elicitation exercise

Most of the knowledge elicitation was carried out in January 1991. Because it was the beginning of the year, construction activities were just beginning to take off in earnest and most estimators had some spare time to sit down and be interviewed, which probably elicited more careful responses than it would have been possible at another month of the year. Also, during the same period, recession was hitting the construction industry badly, and there were very few or no new refurbishment contracts in the London area, so that most chief estimators, buyers and contracts directors interviewed were giving more thought to their competitiveness with the result that the respondents were probably more responsive than they might have been at other more prosperous times. Also their immediate concern with competitiveness at that time perhaps stimulated them to more fully participate in the knowledge elicitation exercises because it might enhance their own perceptions and competitiveness in the current difficult market place.

The interviews produced a recorded description of the contractors' knowledge, and the way in which the knowledge is manipulated to select the most suitable sub-contractor for a particular trade.

5.5.2.2 Knowledge elicitation preparation

The researcher telephoned all the 32 contractors who indicated their willingness to participate in the knowledge elicitation exercise. During the telephone contact to arrange the date for the interview, the researcher discovered that two of the contractors who had participated in the survey questionnaire had become insolvent. It was decided to interview the remaining 30 contractors. These 30 respondents were either the directors, chief estimators, buyers, contracts directors, or other senior member of staff in their company. During the telephone contact, the company official was informed of the main purpose of the knowledge elicitation exercise and the nature of the research project and given explanation of what a Knowledge Based System is and is not. During this telephone conversation, the name of the right person or persons whose job it is to choose subcontractors was established and the researcher requested a personal interview to be arranged.

5.5.2.3 Repertory Grid knowledge elicitation

As discussed in chapter 3, the knowledge elicitation technique adopted was the Repertory Grid technique, Kelly (12), and the type of questions asked were tailored to suit rule-based knowledge representation.

5.5.2.4 Grid design

In designing the repertory grid, the researcher followed closely the work of Keen and Bell (13).
According to Keen and Bell (13), there are five methodological decisions that must be made before using the Repertory Grid. These are described as follows:

1. The purpose of the Repertory Grid.
2. Choice of elements and constructs.

3. Elicitation procedure.

4. Grading of the grid.

5.5.2.5 Objectives of the Repertory Grid

The main purposes of the Repertory Grid knowledge elicitation exercise were:

i) To elicit the main criteria and sub-criteria which the contractor considers when choosing the most suitable sub-contractors.

ii) To determine the extent to which these criteria are used, albeit subjectively or intuitively.

iii) To obtain a sense of the degree of importance and the structure of the criteria and sub-criteria perceived by each contractor.

iv) To determine the sources of data collection used by contractors to form an evaluation where the contractor had no previous knowledge of the sub-contractor.

v) To determine the effects the criteria had on the costs and duration of the contractor's own work.

5.5.2.6 Choice of elements and constructs

There are basically two approaches to the elicitation of elements and constructs, namely the **provided** and **free-response** techniques (14, 15, 16). In the case of provided elements or constructs, both the elements and the constructs would be provided by the researcher but in the case of free-response, the domain experts through conversation provide their personal elements or constructs. The researcher supplied all the elements to the contractors. The reasons behind the provision of elements were:

i) It allowed the researcher to choose representative elements which were representative of all sub-contractors which all contractors had used in the past. This provided a common basis for the comparisons of criteria and sub-criteria used among these contractors. Elements determined the focus of the grid. According to Esterby-Smith(17) and Kevill et al. (18), elements in a grid must be representative of the problem area to be studied.

ii) It reduced the burden of the contractor trying to recall too many sub-contractors which his company had used in the past.

iii) It enabled the contractor to focus his attention on those aspects of his thoughts and feelings which were relevant to the selection and appointment of sub-contractors.

These elements were printed on standard formatted response forms as shown in the examples in tables 5.1 to 5.10. Full details of the Repertory Grid data is shown in appendix B.

Table 5.1: Estimators' Repertory Grid (Domestic sub-contractor constructs)

CONSTRUCTS	ELEMENTS						CONSTRUCTS	
	S1	S2	S3	S4	S5	S6		
CR1 Competitive bid	2	4	2	5	3	3	Uncompetitive bid	CR1
CR2 Consistency of quoted rates	3	5	4	5	4	4	Inconsistency priced rates	CR2
CR3 Adequate turnover	3	3	4	2	3	3	Unacceptable turnover	CR3
CR4 Reasonable claims	3	4	5	5	2	3	Inflated claims	CR4
CR5 Technical competence	2	5	2	2	2	5	Incompetent contractor	CR5
CR6 Good work reference	3	2	4	3	2	4	Poor work reference	CR6

Table 5.2: Buyers' Repertory Grid (Domestic Sub-contractor constructs)

CONSTRUCTS	ELEMENTS						CONSTRUCTS	
	S1	S2	S3	S4	S5	S6		
CR1 Good financial reference	3	5	4	1	4	4	Poor financial reference	CR1
CR2 Technical competence	2	5	2	2	2	5	Incompetent contractor	CR2
CR3 Good safety programme	5	2	2	5	3	3	Poor safety programme	CR3
CR4 Good relationship with our firm	3	1	4	2	3	3	Poor relationship with our firm	CR4
CR5 Prompt start on site	3	4	5	1	2	3	Late start on site	CR5
CR6 Good work reference	3	5	4	4	2	4	Poor work reference	CR6

Table 5.3: Contracts Directors' Repertory Grid (Domestic sub-contractor constructs)

CONSTRUCTS	ELEMENTS						CONSTRUCTS	
	S1	S2	S3	S4	S5	S6		
CR1 Good work programme	3	4	1	4	5	4	Poor work programme	CR1
CR2 Good safety programme	5	2	2	5	3	3	Poor safety programme	CR2
CR3 Prompt start on site	2	4	5	1	2	3	Late start on site	CR3
CR4 Contact address	5	5	4	5	4	4	No fixed address	CR4
CR5 Technical competence	5	5	2	2	2	5	Incompetent contractor	CR5
CR6 Competitive bid	5	2	4	5	3	3	Uncompetitive bid	CR6

Table 5.4: **Estimators'** Repertory Grid (**Labour only constructs**)

CONSTRUCTS	ELEMENTS						CONSTRUCTS
	S1	S2	S3	S4	S5	S6	
CR1 Competitive bid	5	2	2	5	3	3	Uncompetitive bid CR1
CR2 Contact address	3	5	4	1	4	4	No fixed address CR2
CR3 Adequate turnover	3	1	4	2	3	3	Unacceptable turnover CR3
CR4 Prompt start on site	3	4	5	1	2	3	Late start on site CR4
CR5 Technical competence	2	5	2	2	2	5	Incompetent contractor CR5
CR6 Good work reference	3	5	4	4	2	4	Poor work reference CR6

Table 5.5: **Buyers'** Repertory Grid (**Labour only constructs**)

CONSTRUCTS	ELEMENTS						CONSTRUCTS
	S1	S2	S3	S4	S5	S6	
CR1 Contact address	3	5	4	1	4	4	No fixed address CR1
CR2 Technical competence	2	5	2	2	2	5	Incompetent contractor CR2
CR3 Good safety programme	5	2	2	5	3	3	Poor safety programme CR3
CR4 Adequate turnover	3	1	4	2	3	3	Unacceptable turnover CR4
CR5 Prompt start on site	3	4	5	1	2	3	Late start on site CR5
CR6 Good work reference	3	5	4	4	2	4	Poor work reference CR6

Table 5.6: **Contracts Directors'** Repertory Grid (**Labour only constructs**)

CONSTRUCTS	ELEMENTS						CONSTRUCTS
	S1	S2	S3	S4	S5	S6	
CR1 Good work reference	3	5	4	4	2	4	Poor work reference CR1
CR2 Prompt start on site	3	4	5	1	2	3	Late start on site CR2
CR3 Contact address	3	5	4	1	4	4	No fixed address CR3
CR4 Technical competence	2	5	2	2	2	5	Incompetent contractor CR4
CR5 Good safety programme	5	2	2	5	3	3	Poor safety programme CR5
CR6 Competitive bid	5	2	2	5	3	3	Uncompetitive bid CR6

Table 5.7: **Estimators'** Repertory Grid (**Material supplier constructs**)

CONSTRUCTS	ELEMENTS						CONSTRUCTS
	S1	S2	S3	S4	S5	S6	
CR1 Provision of storage facilities	1	2	1	5	3	1	Unassailability of storage facil. CR1
CR2 Prompt replacement of matls	3	4	4	1	4	5	Delay in replacing matls CR2
CR3 Bulk purchase discount	3	3	4	2	3	3	Small supplier CR3
CR4 Nearness to site	3	4	5	1	2	3	Long haulage of materials CR4
CR5 Prompt delivery to site	2	4	2	2	2	5	Late delivery on site CR5
CR6 Provision of fixing services	3	1	4	4	2	4	No fixing services provided CR6

Table 5.8: Buyers' Repertory grid (Material supplier constructs)

CONSTRUCTS		ELEMENTS						CONSTRUCTS	
		S1	S2	S3	S4	S5	S6		
CR1	Competitive price	1	3	2	4	3	5	Nit picking	CR1
CR2	Prompt replacement of matls	3	5	4	1	1	5	Delay in replacing matls	CR2
CR3	Bulk purchase discount	3	5	4	3	1	1	Small supplier	CR3
CR4	Nearness to site	3	4	5	1	2	2	Long haulage of materials	CR4
CR5	Prompt delivery to site	2	4	2	2	2	2	Late delivery on site	CR5
CR6	Provision of fixing services	3	4	4	4	2	2	No fixing services provided	CR6

Table 5.9: Estimators' Repertory Grid (Plant hirer constructs)

CONSTRUCTS		ELEMENTS						CONSTRUCTS	
		S1	S2	S3	S4	S5	S6		
CR1	Competitive price	3	4	2	5	4	3	Uncompetitive price	CR1
CR2	Prompt treatment of invoice	4	1	4	4	3	3	Delay in the treatmt of invo	CR2
CR3	Good maintenance record	3	5	4	2	1	3	Poor maintenance record	CR3
CR4	Prompt repair of plant	3	4	5	1	2	3	Long delay to repair plant	CR4
CR5	Variety of plant	2	4	3	2	5	5	Small selection of plant	CR5
CR6	Nearness to site	3	4	5	4	2	4	Long distance from site	CR6

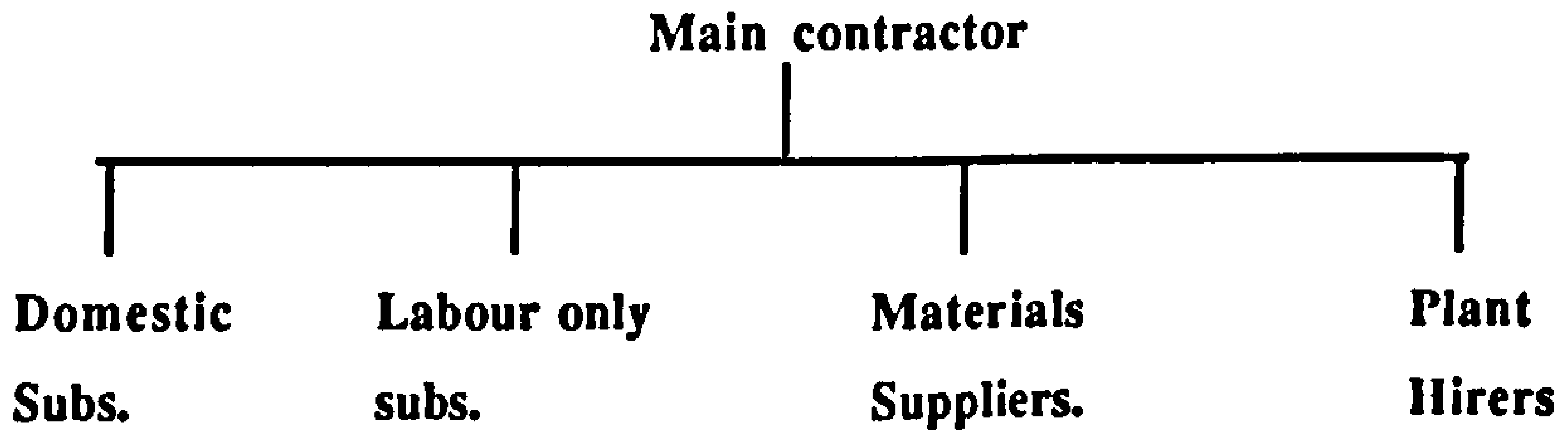
Table 5.10: Buyers' Repertory Grid (Plant hirer constructs)

CONSTRUCTS		ELEMENTS						CONSTRUCTS	
		S1	S2	S3	S4	S5	S6		
CR1	Competitive price	3	5	2	5	3	5	Uncompetitive price	CR1
CR2	Prompt treatment of invoice	1	2	4	4	3	2	Delay in the treatmt of invo	CR2
CR3	Good maintenance record	3	5	3	2	1	5	Poor maintenance record	CR3
CR4	Prompt repair of plant	2	4	5	1	2	5	Long delay to repair plant	CR4
CR5	Variety of plant	2	4	3	2	5	5	Small selection of plant	CR5
CR6	Nearness to site	4	4	1	1	4	5	Long distance from site	CR6

5.5.2.7 Grid design

During knowledge elicitation four categories of sub-contractors which the contractors had used in the past as shown in figure 5.1 were used as pre-determined elements.

Figure 5.2: Trade sub-contractors



5.5.2.8 Constructs

Constructs on the other hand are dimensions which may evolve when considering a particular set of elements but can usually be applied to a further range of elements. The dimentionality of a construct allows one to extract matrices of inter-relationships between constructs and between elements.

For Kelly (19), constructs do not exist in isolation but are linked with each other in a more or less coherent and hierarchical manner. During the elicitation of constructs, the free-response technique was used whereby each domain expert through conversation supplied his own constructs. The reason for adopting this approach was to ensure that all constructs elicited cover the range of constructs which the contractor considered and felts are important or not important when choosing his sub-contractors. Thus, the aim is not to encapsulate the whole of a contractor's construct systems but that part of it which was relevant to judging the success or failure of the services provided by sub-contractors.

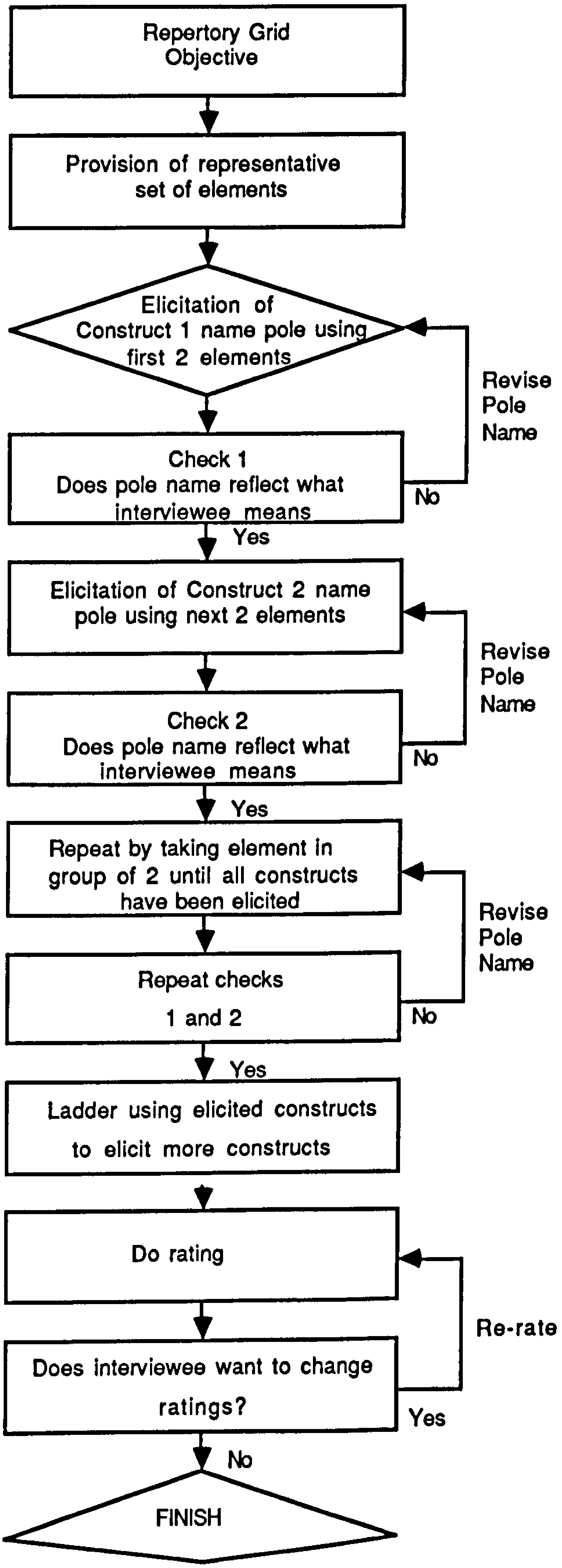
5.5.2.9 Experimental knowledge elicitation

Prior to carrying out the knowledge elicitation exercise the researcher carried out several "dummy" grid interview (dry runs) with friends, fellow research associates and academic members of staff in the department together with the chief estimator in order to come to grips with some of the 'mechanics' of completing the grids as suggested by Boose (20) and Pope and Keen (21). This exercise enabled the researcher to develop his sensitivity to what was actually happening during an elicitation session. As a result of these experimental knowledge elicitation exercises some adjustments were made in the elements descriptions and the wording of some of the questions. Also, during this pre-testing of the Repertory Grid it was discovered that some elements tended to dominate the type of constructs being produced, thus distorting the overall grid. Also, some people had considerable difficulty in thinking of new constructs. Because of these problems, it was decided to use the 'dyads' elicitation technique (as discussed in section 3.12.5.5) whereby two elements are selected at a time and the subject is asked to say whether they are alike or different, and what it is that makes them alike or different.This approach appeared to have helped to relax the respondent and eased elicitation of the constructs.

5.5.2.10 Interview framework

The framework adopted during the interview is shown in figure 5.3 below

FIGURE 5.3: REPERTORY GRID ELICITATION FRAMEWORK



All knowledge elicitation started with the researcher explaining the overall objectives of the research and the purpose of the Repertory Grid knowledge elicitation exercise. An assurance was given to all contractors of complete confidentiality and therefore no direct mention will be made of names or sources of information.

Thereafter, the domain experts were asked to provide the criteria they usually consider when they choose their sub-contractors. During the elicitation of constructs, random sets of two elements were displayed and the domain expert was asked the reasons why the sub-contractors were used in their projects. In each category of sub-contractor, the domain experts were asked the criteria for deciding whether the service provided was, 'excellent', 'good', 'satisfactory', 'fair' or 'awful'.

Thus both the differences and similarities of say an excellent and awful services provided by sub-contractors the company had used were also used to generate constructs.

The rationale behind this process was to enable the researcher to identify the key constructs which discriminate between say an 'excellent' and 'awful' service that the contractor had experienced from a particular sub-contractor.

A construct is not necessarily composed of a phrase and its semantic opposite but it is a contrast. According to Kelly (13)

"You can only understand what I mean by 'good' if you also understand something of what I mean by 'bad'".

Also by asking both differences and similarities of the two sub-contractors, the domain expert gets out both implicit and explicit poles of the construct and, as a result, the data are much tighter, crisper, and easier to understand. The good aspects of the performance of a 'awful' sub-contractor were also elicited and vice-versa.

5.5.2.11 Recorded knowledge elicitation

All knowledge elicitations took place in the domain expert's office and were all tape recorded. A typical knowledge elicitation lasted between two to two and half hours and no domain expert objected to being tape recorded and, in addition, all responses were written down during the interview. Once the transcripts of the tape recordings were produced they had to be analysed and refined until the knowledge was in a form which reflected the contractor's decision-making process. The interview attempted to be active with respect to motivating fullness of responses and with respect to directing the communication to the objectives of the interview. Discretion being applied, however, to allow the subject latitude to expand any area which he considered important. The confidentiality of the interview and contents was stressed to reassure respondents.

Thus, a flexible and conversational approach was adopted during all of the knowledge elicitation exercises and a relaxed atmosphere was maintained throughout the knowledge elicitations to enable the respondent to express his view and opinions freely. It is vital to employ this approach as the area of investigation is highly sensitive and normally contractors are cautious about sharing knowledge with their respective competitors.

Also, it is highly likely that with the calibre of respondents who were involved in the management of construction, a rigid interview might not have raised their interest to the level achieved by asking them to volunteer their experiences to a researcher from a university.

5.5.2.12 Laddering

To improve the quality and relevance of the elicited constructs the technique of laddering was used (as described in section 3.12.5.1) in conjunction with the elicitation of constructs from dyads to generate super ordinate constructs from, elicited constructs that appeared to have little general value. For example, if a contractor commented that "sub-contractor "S1" has a good relationship with our firm" the contractor was then asked to describe why having a good relationship with their firm was important in the selection of the sub-contractor. The contractor's response was that:-

"the sub-contractor's ability to work harmoniously with site staff".

In this way a series of new constructs were generated using some of the previous constructs elicited from the domain experts.

This process is repeated several times until the domain expert cannot identify any new constructs. The use of laddering also helped the researcher to develop a hierarchy of sub-criteria which represented features of the main criterion. To improve the coverage of the problem domain for each respondent two hypothetical sub-contractors (ideal and least preferred sub-contractors) were included in each individual grid.The respondents were also asked to comment on some of their answers on the questionnaire and their experiences on the services provided to their company by nominated sub-contractors.

5.5.2.13 Grading of the grid

Rating

Each contractor was asked to rate each element on each construct (i.e working across the rows using a 5-point scale. Rating according to Bannister (22) allowed finer discriminations to be represented, thus reducing the problem of lopsidedness.

The conversational approach adopted during the elicitation process was very useful to the researcher during the knowledge elicitation exercise. Not only did it enable the researcher to check whether the domain expert was happy with the pole names which they placed on a construct, i.e. "do they reflect what the domain expert means?," but also after rating each construct the respondents may wish to change one or more ratings. In addition, if having rated each construct, he may feel that this process has caused some changes in the original meaning which he had ascribed with his pole names and thus he may wish to change these pole names in order to fully represent the meaning which he was implementing when rating the constructs.

It also allows the researcher to ascertain whether a particular construct is applicable to most of the elements within the grid. Where the respondent was having difficulty applying a particular construct to a majority of the elements, this construct could then be omitted from the grid rather than forcing the respondent to enter a mid point value on the scale for the other constructs. The conversational approach provided the researcher with a much richer data base and a firmer ground for interpretation.

5.5.2.14 Advantages of the survey questionnaire

The use of the survey questionnaire offered the following benefits:

i) It allowed the contractors adequate time to respond to the questions thereby increasing the reliability and accuracy of the responses.

ii) The information obtained from contractors was standardized and consistent due to the structuring of the survey questions.

iii) It was one of the simplest and most direct ways to obtain qualitative information from a wide population of contractors and it also gave some indication of contractor's thinking.

iv) It was relatively less expensive than other research approaches to survey such a large pool of contractors. Furthermore, specific information was obtained through the use of the questionnaire.

5.5.2.15 Advantages of the Repertory Grid Interview

The Repertory Grid interview provided the following advantages:

(a) The elicitation of a grid makes the expert think twice about a problem and helps clarify issues in his mind.

(b) It provided a flexible approach and accurate measurement of subtle perceptions and was easily adaptable.

(c) It allowed the contractors to increase their awareness of the use of criteria for the selection and appointment of sub-contractors. This served as useful feedback information with which to improve their management and control of sub-contractors on their projects. It also allowed the contractors to make explicit what is implicit in their thinking process thereby potentially enhancing the quality of their decisions and judgements.

(d) It enabled both the researcher and the respondents not only to identify the major criteria commonly used to choose sub-contractors but it also identified the ways these constructs were obtained from sub-contractors.

(e) This technique also affords and facilitates comparisons of selection and appointment processes among different contractors. It explores the degree of agreement and disagreement among contractors in their respective approaches to sub-contractor's selection and appointment procedures.

(f) Grids could be analysed to find patterns or associations for further investigations.

CHAPTER SIX

ANALYSIS OF QUESTIONNAIRE RESULTS

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ANALYSIS OF QUESTIONNAIRE RESULTS

6.1 Introduction

This chapter presents the results of the research survey questionnaire of refurbishment contractors. The questionnaire was analysed with the statistical package for social science (SPSS-X) using the Hewlett Parkard main frame computer of Loughborough University of Technology as shown in appendix C.

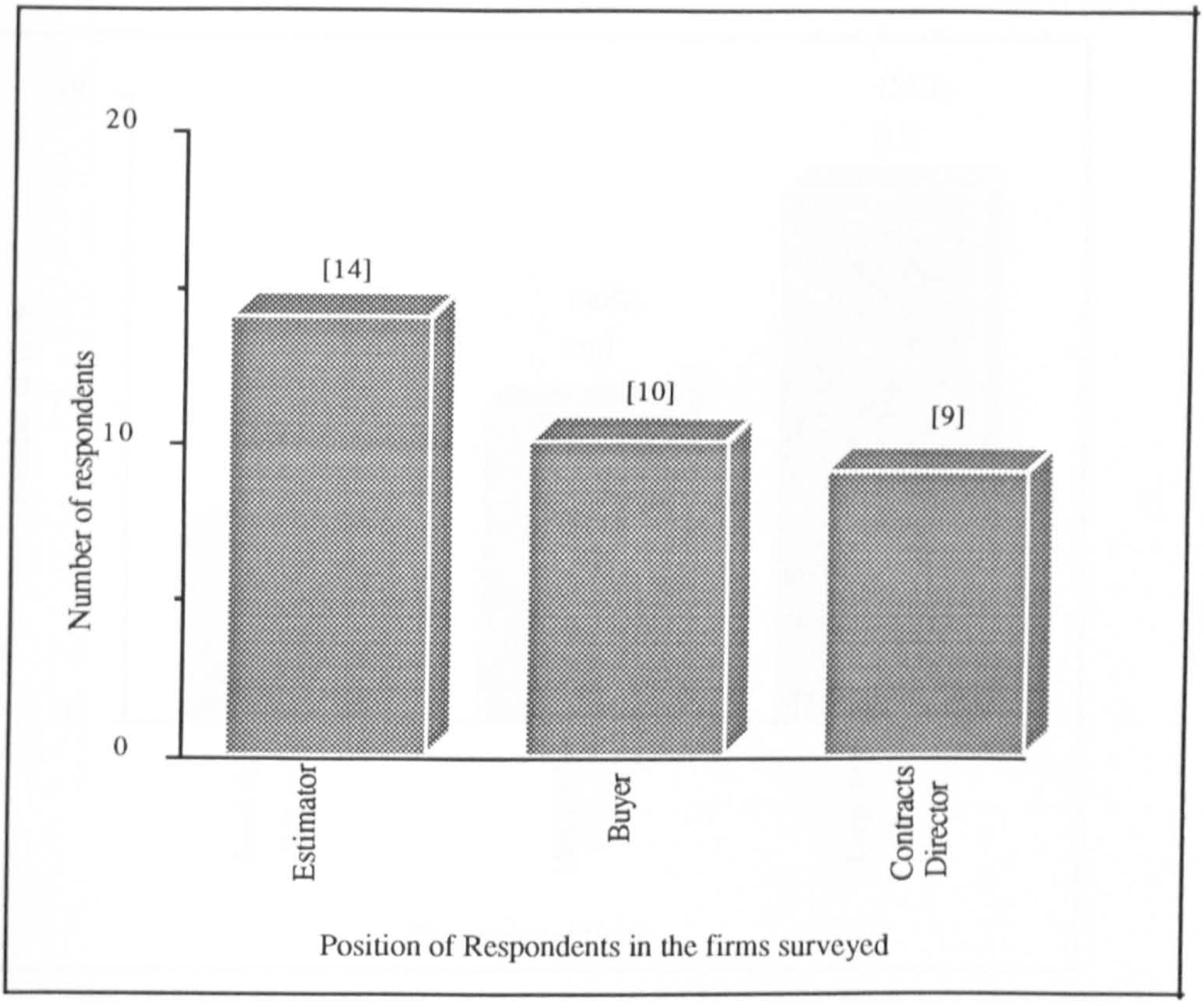
Due to the exploratory nature of this survey, the analyses of the survey are presented in a manner which allows some general comment and conclusions to be made on the results of the survey.

The primary objective of the questionnaire was to determine if refurbishment contractors use any criteria in the selection and appointment of sub-contractors. Also the questionnaire sought information on the sub-contracting policies of refurbishment contractors and on the criteria they use (if any), in the selection and appointment of their sub-contractors. It also investigated how the information on these sub-contractors is gathered and used when a decision is made to choose a sub-contractor.

6.2 Respondent's position

Figure 6.1 indicates the respondent's position in all the firms that participated in the survey. Thirty-three refurbishment contractors participated in the survey and the respondents in these firms were made up estimators, directors, and buyers.

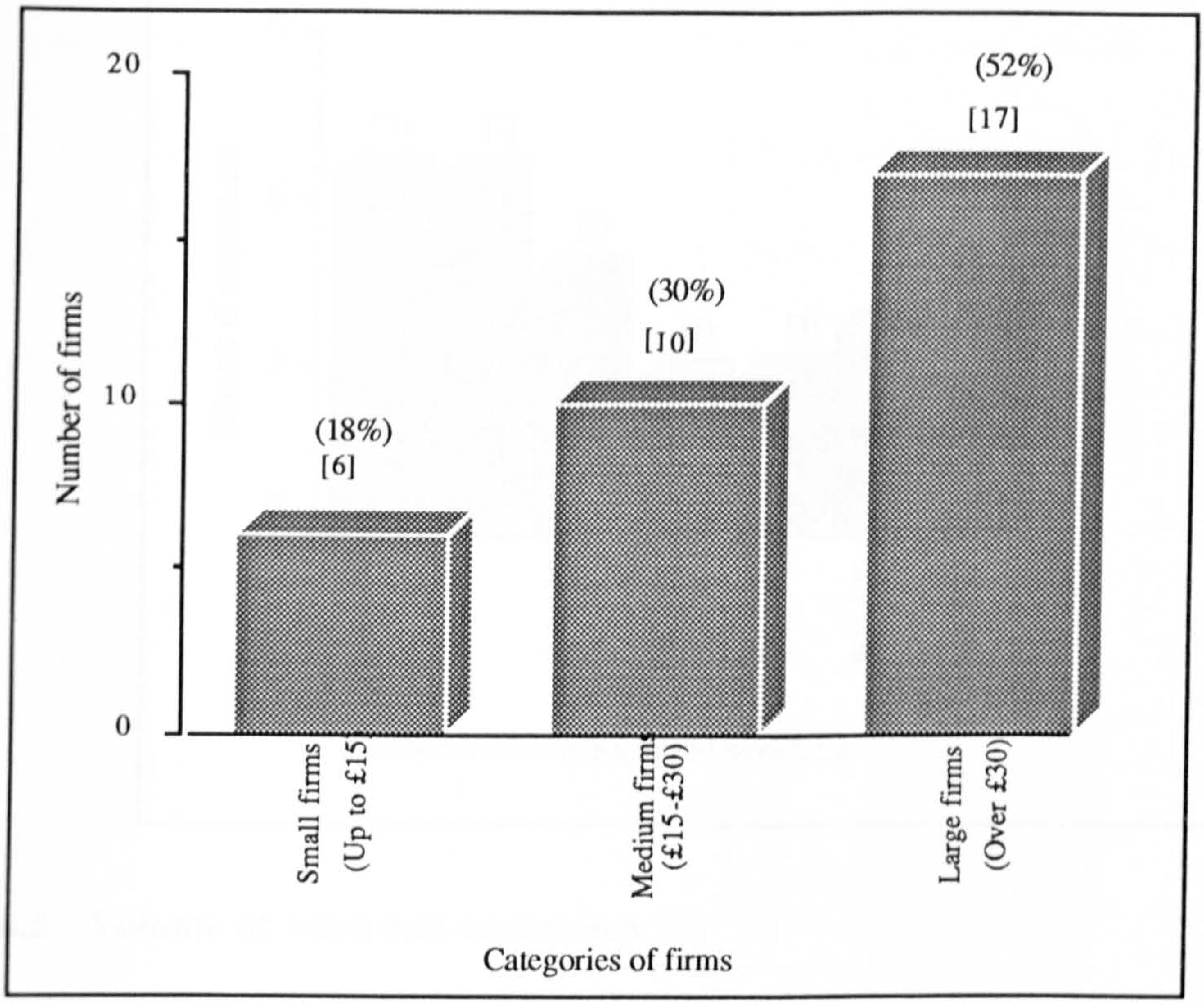
FIGURE 6.1: RESPONDENTS POSITION IN THE FIRMS SURVEYED



6.3 Company size/annual turnover

This section analyses the annual turnover of firms that took part in the survey. All contractors are classified by size using the value of their annual turnover. This measure displays an organization's financial and physical ability to operate at a particular level of output. The range of values used to classify refurbishment contractors by their annual turnover are grouped into large, medium, and small sized firms are shown in figure 6.2. The responses received from large contractors represented 52% (17 firms) and that received from medium sized firms was 30% (10 firms), whilst small firms represented 18% (6 firms) of the total number of contractors that participated in the survey questionnaire.

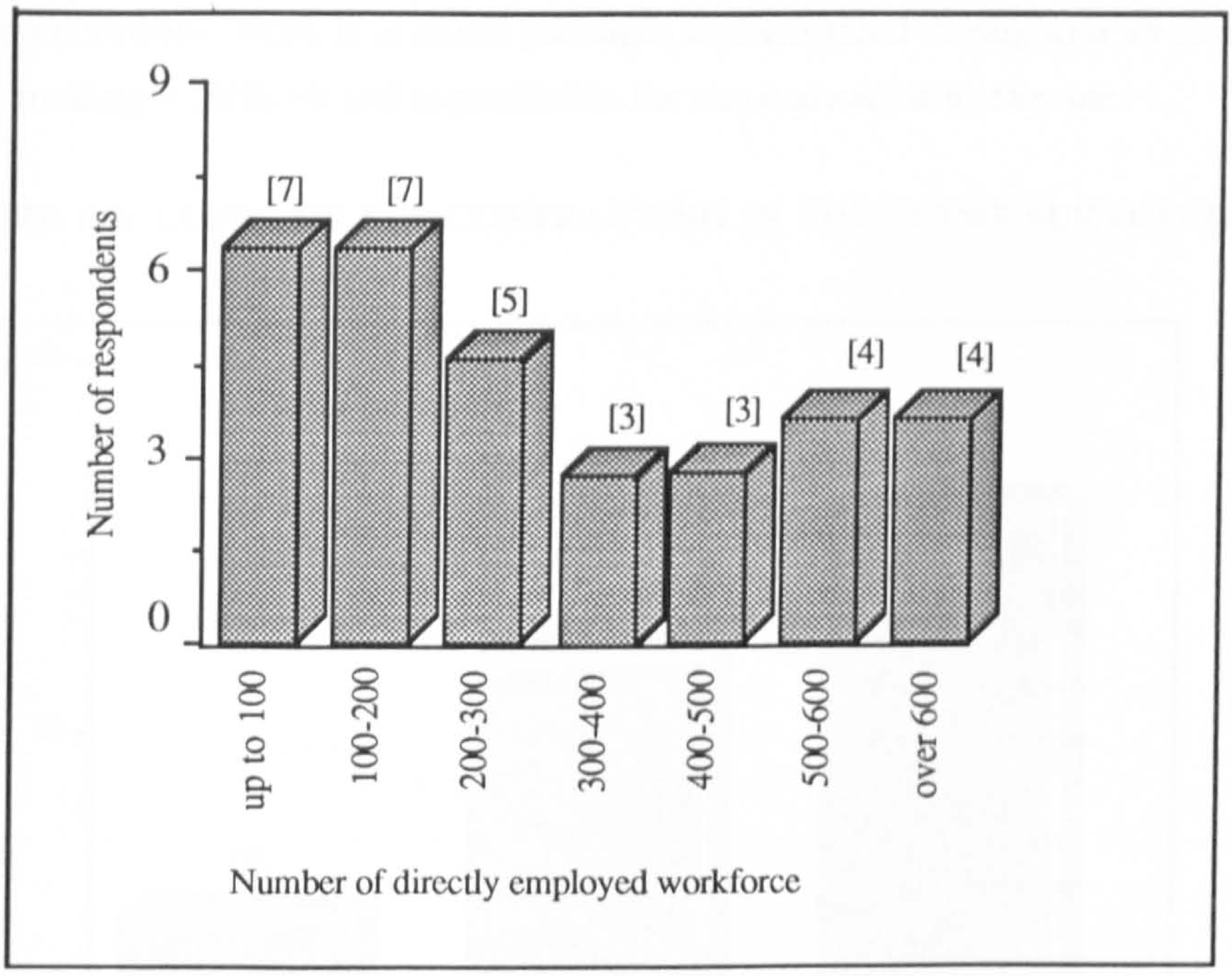
FIGURE 6.2: SIZE OF FIRMS MEASURED BY ANNUAL TURNOVER (MILLIONS)



6.4 Directly employed labour force

Figure 6.3 shows the directly employed labour in all the firms that participated in the survey. There is no discernible pattern regarding the distribution of the directly employed labour force among the firms surveyed.

FIGURE 6.3: DIRECTLY EMPLOYED LABOUR

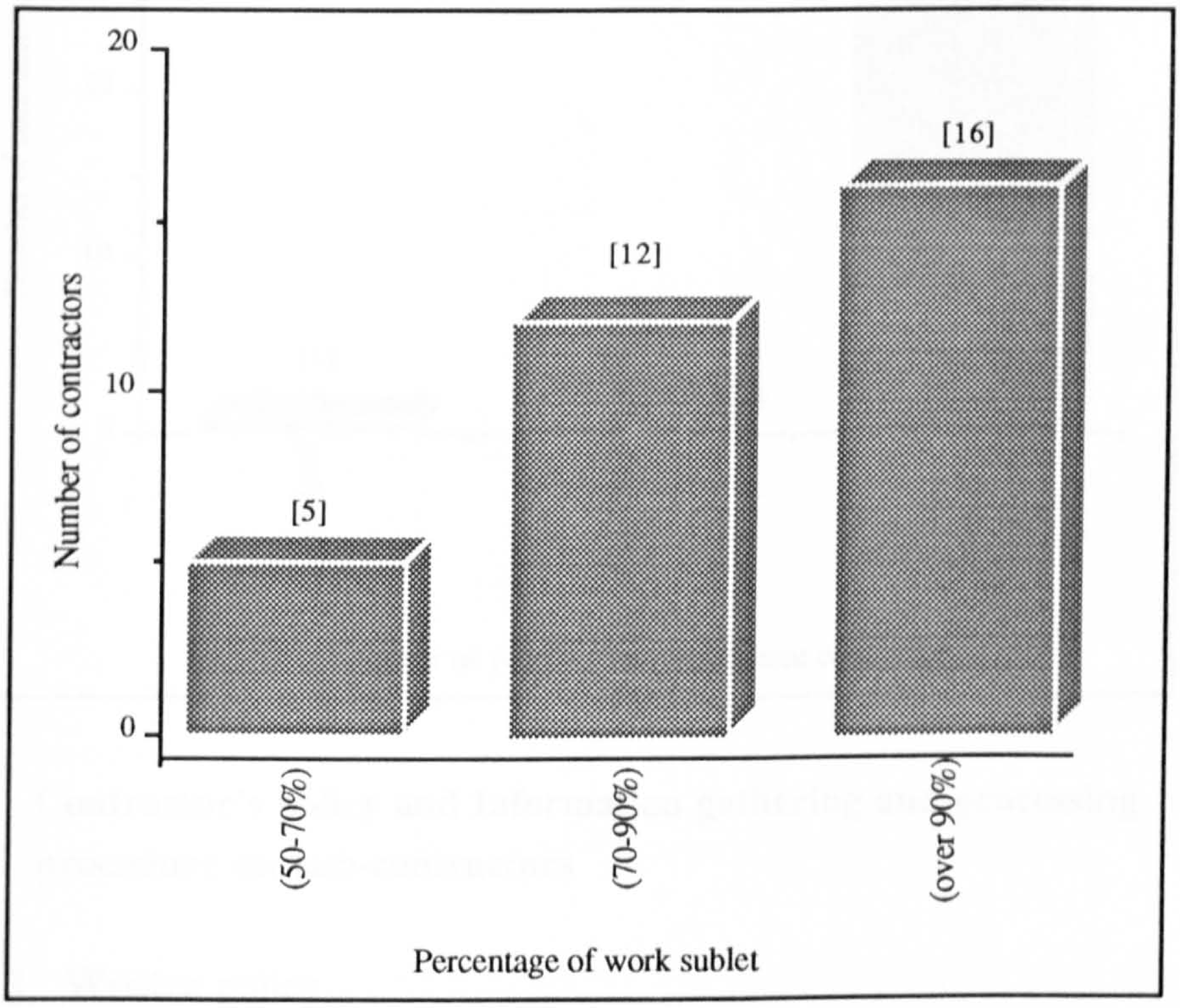


6.5 Volume of work sub-contracted

Figure 6.4 below indicates that the majority of contractors sublet over ninety percent of their work. Five companies during the interview did mentioned that they now sublet all of their work. The only staff they have in-house on their sites are contracts managers and contracts supervisors who undertake the supervision and monitoring of the projects and performance of their sub-contractors. When asked why they were sub-contracting all their work, reasons for savings in overheads and construction cost and flexibility were cited. Sub-contracting relieves these firms of the need to maintain an in-house capability across a diverse range of activities, many of which have a high degree of technical specialism. Furthermore, these contractors indicated how in-house administrative overheads were saved by sub-contracting, with the management team able to maintain flexibility in responding to external and internal fluctuations.

The survey revealed that all the companies who took part in the survey sublet over fifty percent of their contracts. A number of reasons have already been stated in chapter 2 why refurbishment contractors sublet their works but perhaps the most important reason for the dramatic increase in subletting is the unpredictable nature of refurbishment work where complexity is greater in extent and specialist in nature than new build. Also due to the present economic climate full subletting would appear to offer greater financial returns, therefore one would naturally expect a high degree of sub-contracting to take place. Also, refurbishment work consists of small labour intensive operations, work is in small packages and scattered throughout an existing building making it difficult and unprofitable for one contractor to execute.

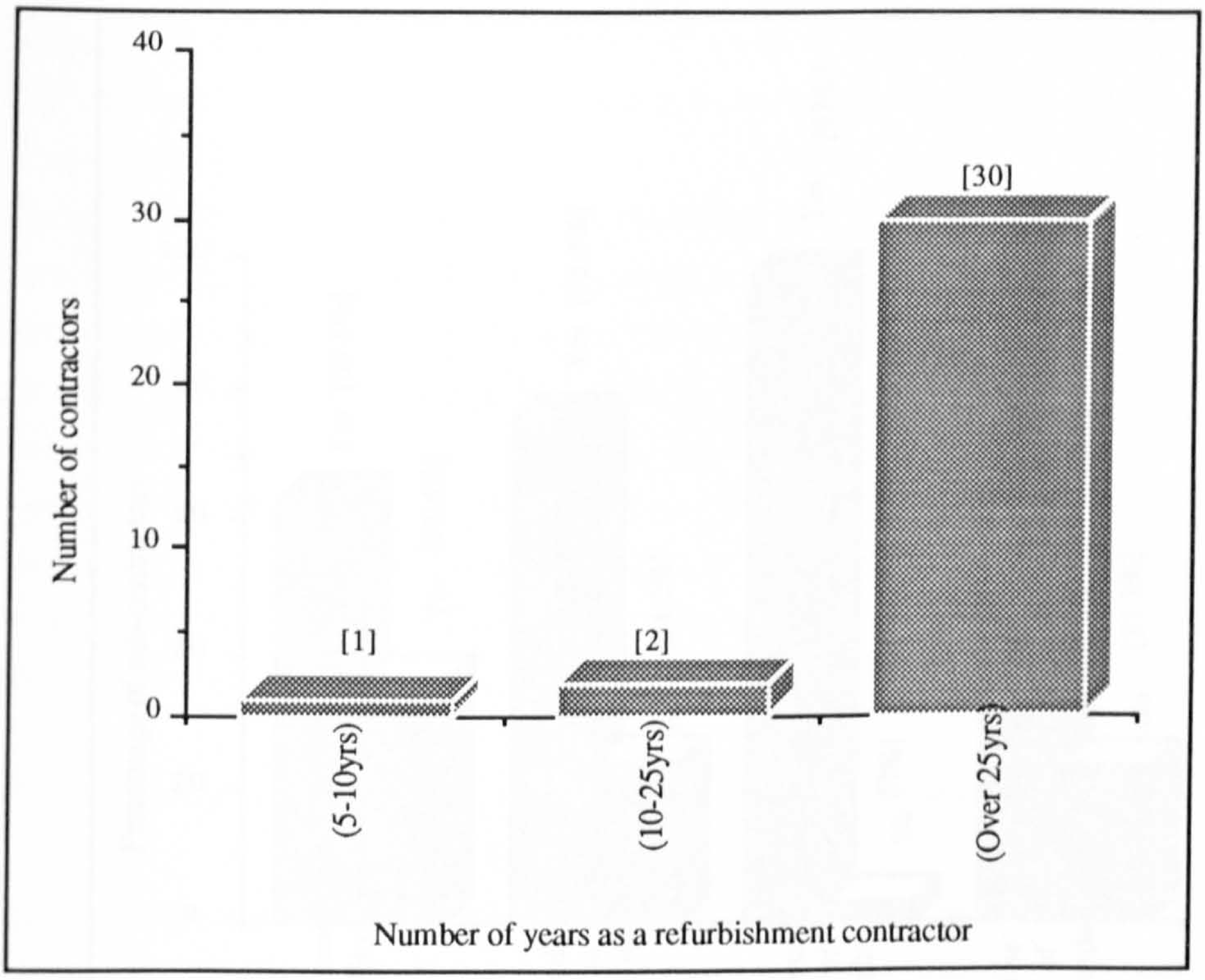
FIGURE 6.4: LEVEL OF SUB-CONTRACTING IN THE FIRMS SURVEYED



6.6 Years of experience in refurbishment work

All but one of the firms who took part in the survey have had more than 20 years contracting experience in refurbishment projects. The objective of this question was to determine whether these firms were well established and therefore successful. The researcher was keen to obtain information only from well established refurbishment contractors who have proven good performance records through time. As figure 6.5 shows, over 30 contractors or 91% of the respondents have been in refurbishment work for over 25 years.

FIGURE 6.5 : NUMBER OF YEARS EXPERIENCE IN REFURBISHMENT WORK



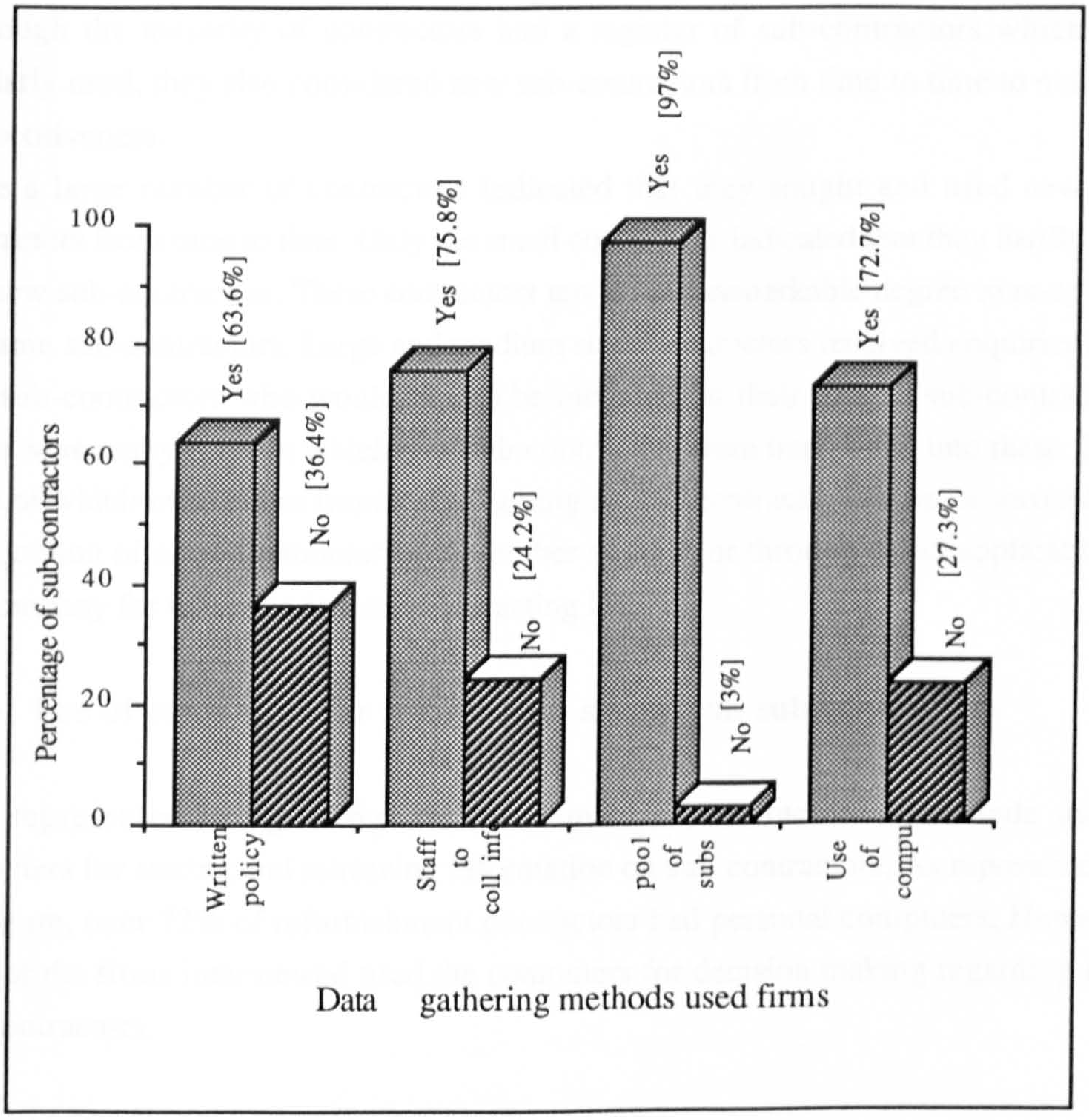
6.7 Contractor's policy and Information gathering and processing procedure on sub-contractors

6.7.1 Written policy

Figure 6.6 below depicts the respondents' policy on sub-contracting and information gathering and processing procedures practiced in these firms regarding sub-contracting. As shown in figure 6.6 over 63% of the respondents have a written policy regarding the employment of sub-contractors.

The objective of this question was to find out whether refurbishment contractors have a policy regarding the employment of sub-contractors and whether they keep any type of record on sub-contractors' performance on site and how this information is collected and used. During the interview, it was evident that apart from the amount of money the contractor would make on sub-contractors' bids, most large and medium sized refurbishment contractors did use some form of non-monetary criteria during sub-contractors' evaluation. However, the assessment of these criteria are usually done intuitively and subjectively with considerable reliance on judgement and upon the accumulated experience of the evaluee.

FIGURE 6.6: RESPONDENTS POLICY ON SUB-CONTRACTING



For instance, the sub-contractor's past work experience, past work performance reference, to mention just two criteria, are assessed before a sub-contractor is chosen for a particular contract. Also these firms did keep records of sub-contractor's past performance on their projects. However, they were hardly ever consulted during sub-contractor's decision-making. The reason for this may be due to the short time allowed to submit a bid by the client. Usually, the estimator went to a sub-contractor who would give him a quotation within the time allowed for the tender. For most small contractors, however, the main deciding factor was the amount of money the contractor stood to make on the sub-contractor's bid.

6.7.2 Policy on finding and employing new sub-contractors

Although the majority of contractors had a register of sub-contractors which they regularly used, they also considered new sub-contractors from time to time to maintain competitiveness.

Quite a large number of contractors indicated that they sought and used new sub-contractors from time to time. Only the small contractors indicated that they hardly used any new sub-contractors. These contractors tended to a remarkable degree to re-appoint the same sub-contractors. Large and medium sized contractors received enquiries from new sub-contractors who would like to be included on their lists of sub-contractors. There were many ways in which new sub-contractors were introduced into these firms, some of which were either former staff setting up sub-contracting firms, or through the introduction of a sub-contractor by a member of staff, or through direct application to the company for inclusion in a sub-contracting list.

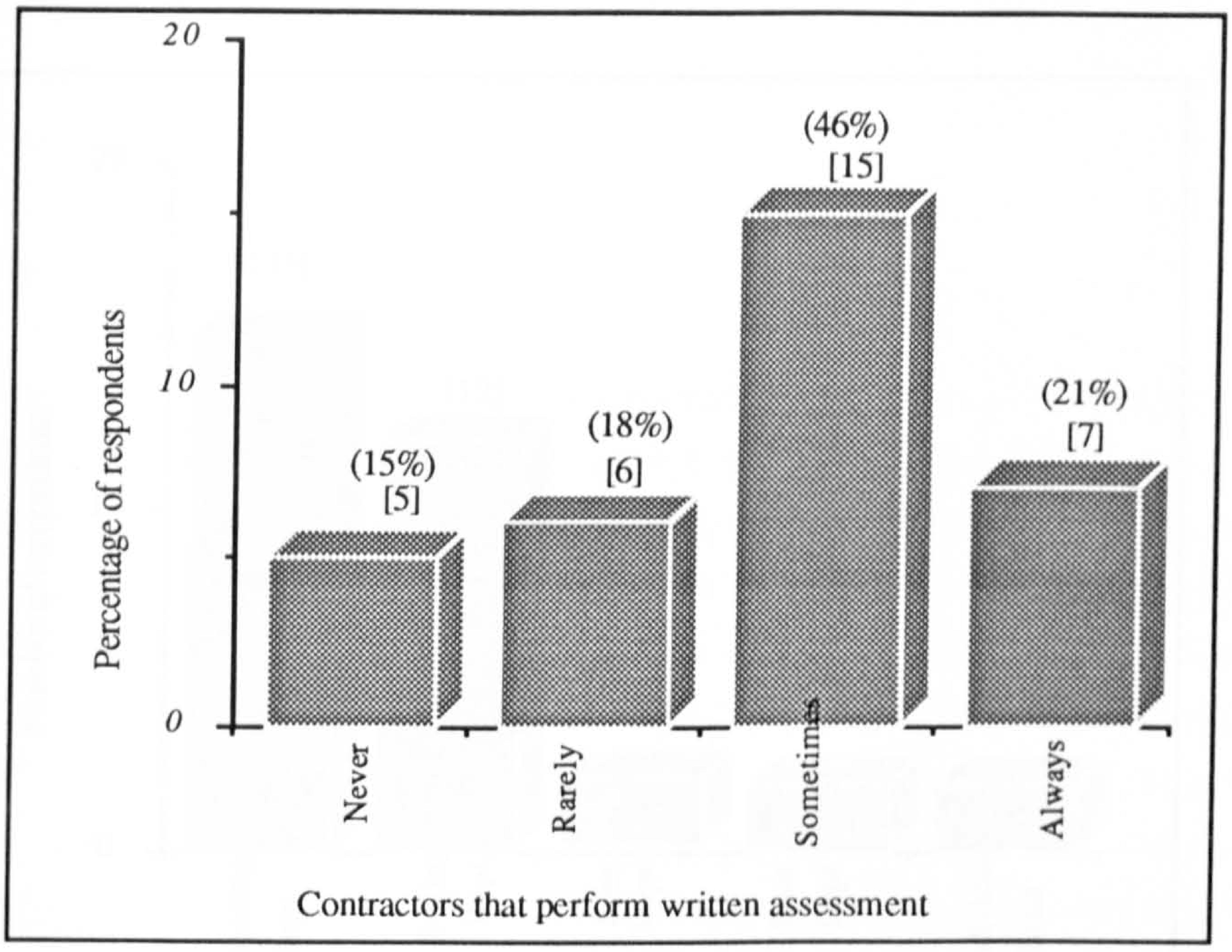
6.7.3 Use of computers for information storage on sub-contractors

Also represented in figure 6.6 are the number of contractors who made use of computers for storing and retrieving information on sub-contractors. As represented in the figure, over 72% of refurbishment contractors had personal computers. However, none of the firms interviewed used the computers for decision making regarding their sub-contractors.

6.7.4 Written assessment

Written assessment on a sub-contractors performance on site was also carried out mainly by large and medium sized contractors. This was usually done by the site agent or project director. The sub-contractor's general performance was assessed on the job and at the end of his contract. The firms which carried out written assessments of the sub-contractor's performance are represented in figure 6.7. The figure indicates that 46% or 15 contractors sometimes carried out written assessments'; whereas 21% of the respondents always carried out written assessments. Feedback from site staff is essential if the decision-making process on sub-contractors is to be effective, as crucial information on sub-contractors' activities should be obtained at all times.

Figure 6.7: Site Agent Written Assessment

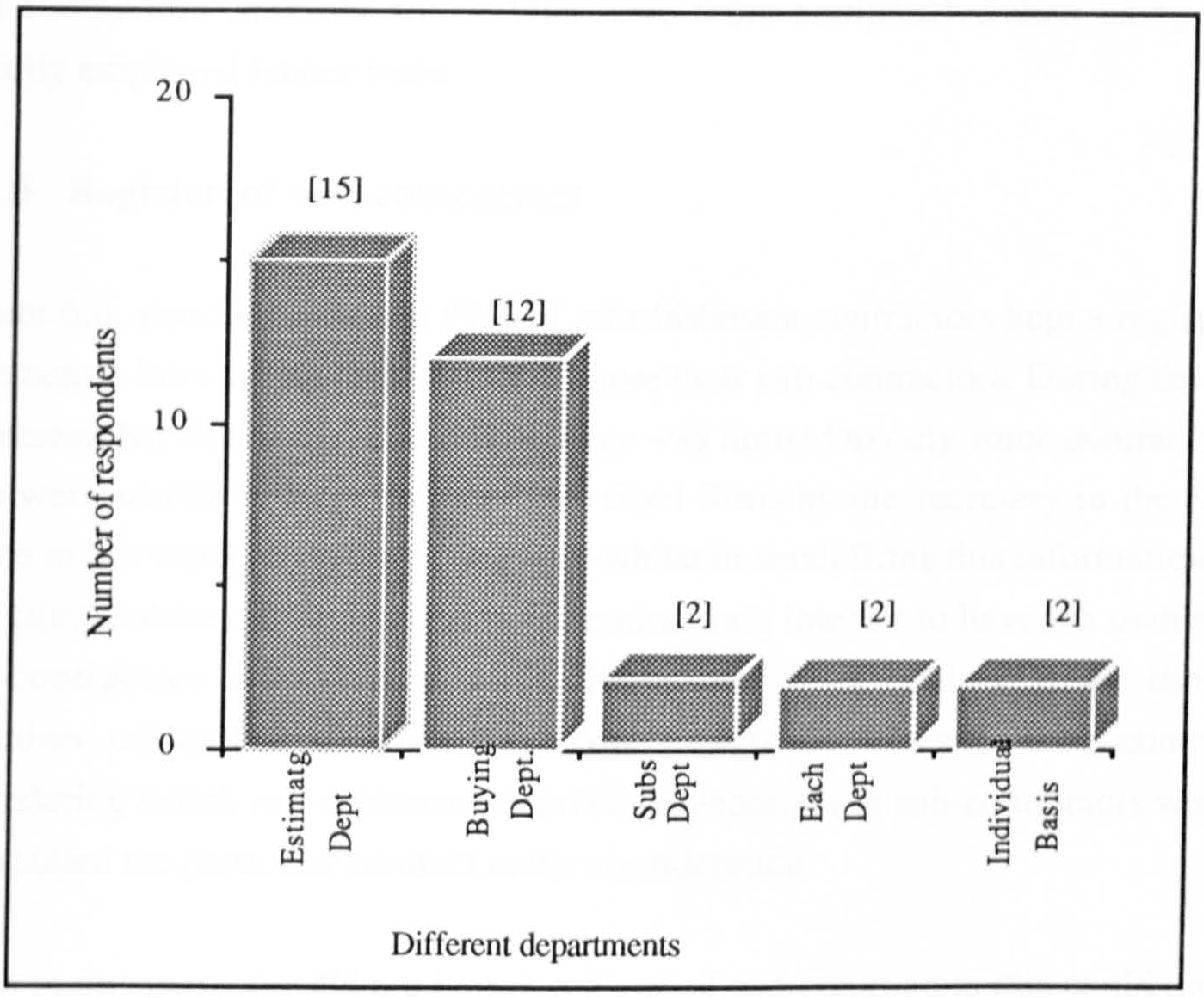


6.7.5 Member of staff specifically designated to collate information

As shown in figure 6.6 above over 75% of the respondents had staff specifically designated to collate information from site on sub-contractors' performance. In some firms data for decision making on sub-contractors were held by each department whereas some firms had a sub-contractors' department. However, as shown in figure 6.8, the result of this survey indicated that the majority of the information was kept by the estimating and the buying departments. Only some of the big contractors had a sub-contractors' department.

However, among the firms which had a sub-contractors' department, the staff in this department worked very closely with the estimator and the buyer during the selection and appointment of sub-contractors. This staff also kept records of new sub-contractors when they applied to be included on the firm's sub-contractor list. This result is rather surprising as one would have expected that those contractors that sublet over fifty percent of their contracts would have some form of central information storage for all the sub-contractors they used which would afford them quick information retrieval on any particular sub-contractor they were evaluating.

FIGURE 6.8: DEPARTMENT RESPONSIBLE FOR SUB-CONTRACTOR INFORMATION COLLATION



The only obvious explanation for this is that, perhaps, most of these sub-contractors were well known by the key staff of these firms and there was a constant consultation between all parties within the firms and any information regarding the past performance of any particular sub-contractor could easily be obtained from members of staff in the firm.

During the interview, it was evident that the majority of contractors practised a two tier selection process. The first tier involved the estimating department who used sub-contractors' quotations to price their bills of quantities.

After the contract had been awarded to the contractor, the buyer would then re-negotiate a further reduction from the sub-contractor following the award of the contract. In part, this may have been as a result of an inaccurate quotation obtained initially from the sub-contractor. However, it is believed that it was an attempt by the buyer to improve on the already submitted prices. This result helps to shed more light upon Quah's (1) finding on why refurbishment sub-contractors bids vary more widely than new builds. Thus, since sub-contractors, well aware that their bid would be re-negotiated by the buyer, inflated their bids to make allowance for later negotiation, since failure to reduce their price presumably means that the sub-contractor was unlikely to be awarded the contract. This result perhaps also partly explains the reason why most contractors were shedding their directly employed labour force and were depending more and more on sub-contractors' services whose bids were more competitive than using their own directly employed labour force.

6.7.6 Register of sub-contractors

Figure 6.6, also indicates that 97% of refurbishment contractors kept a register of sub-contractors from where they regularly chose their sub-contractors. During the interview the researcher discovered that this practice was limited to only some contractors. These lists were stored by large and medium sized firms by the secretary in the estimator's office in her word processing computer, whilst in small firms this information was kept in a filing cabinet. It was in the main contractor's interest to have his own register of sub-contractors who wished to be invited for work. This register should have contained relevant details of each sub-contractor so that when the main contractor was considering which sub-contractor to invite to tender, those sub-contractors were chosen who suited the particular contract under consideration.

If the main contractor did not have a register of sub-contractors this could quite easily be compiled by employing the questionnaire method, used by local authorities in obtaining a list of contractors.

This questionnaire should include:

area of operations

size and type of work

labour and supervisory resources available

record of size and type of work previously carried out

insurance cover employed

references from:

i) trade

ii) professional

iii) bank/other financial institutions

These registers must be updated regularly and notes and remarks added to show:

performance

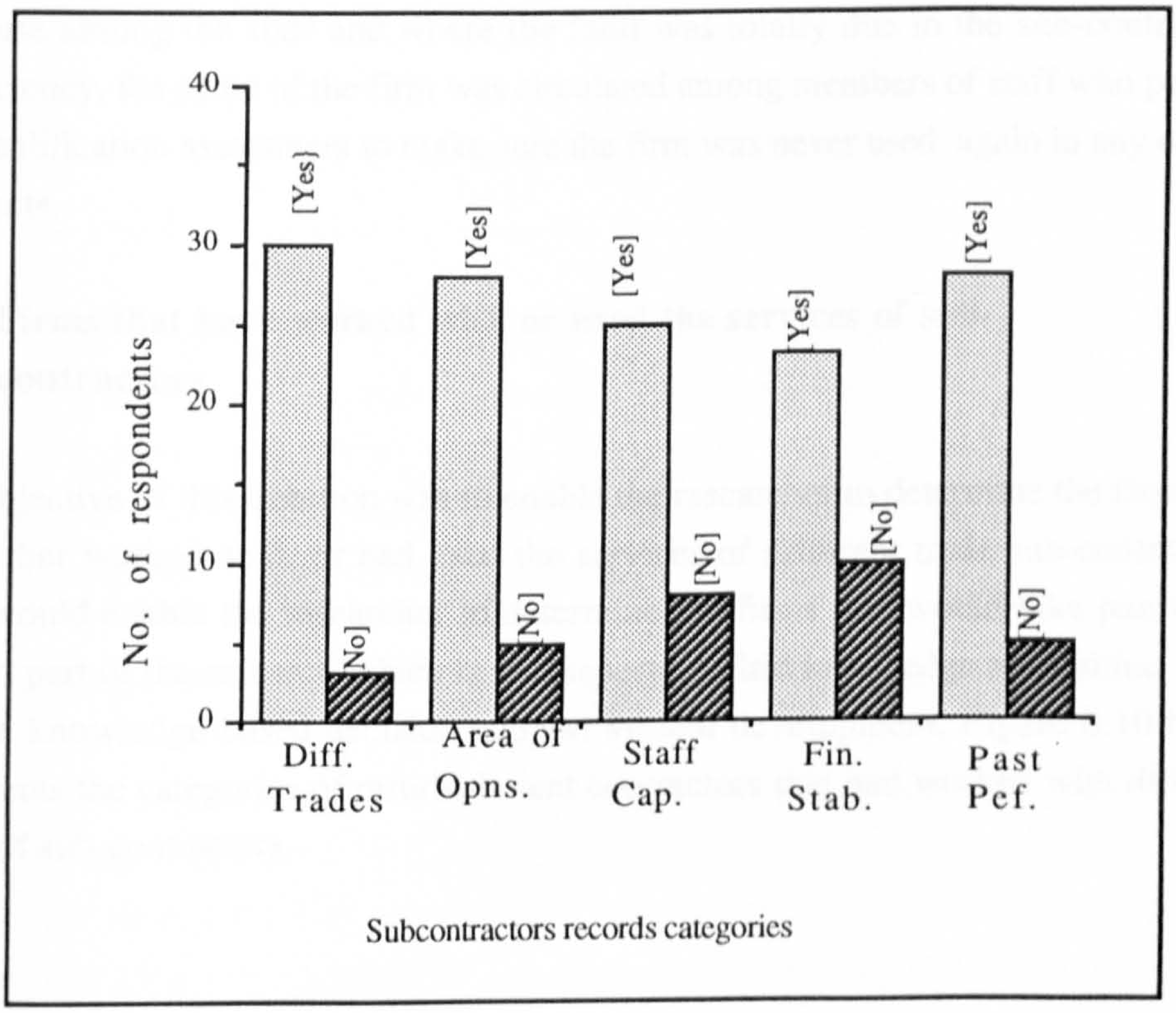
site feedback information

records and details of contracts successfully carried out

adverse comments where applicable

names of senior and supervisory staff employed during the contract.

FIGURE 6.9: RECORDS KEPT ON SUB-CONTRACTORS



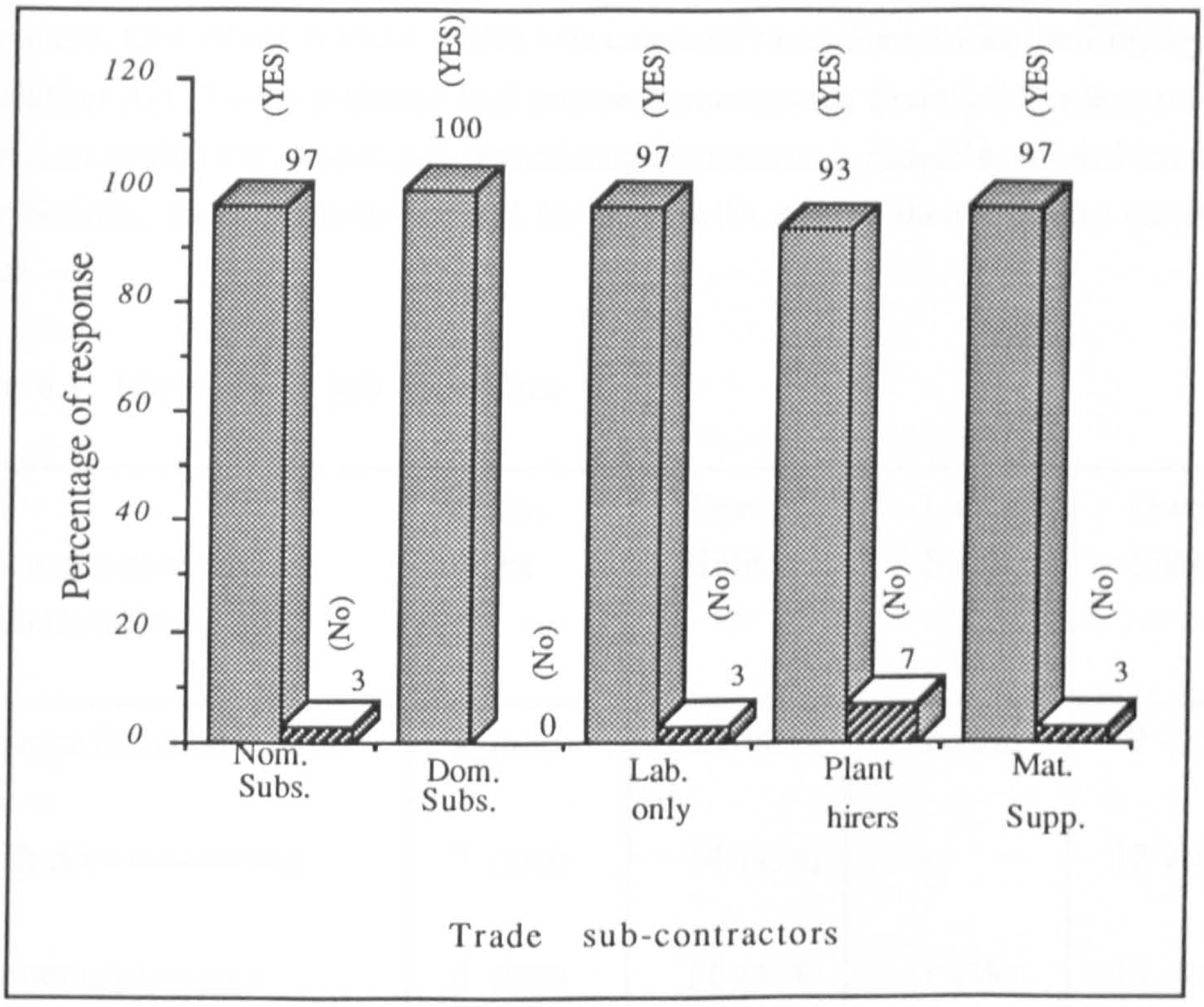
This part of the survey also sought information on the type of records kept by refurbishment contractors on their sub-contractors. As shown in figure 6.9 above the majority of contractors kept records of sub-contractors that have worked for their firms in the past.

The information kept consisted of the name of the sub-contracting firm, his contact address, his trade, contact person's telephone and facsimile numbers, region of operation, labour size, in terms of labour strength, and the value of work it could undertake, their financial capability and past performance, to mention just a few.
Data on sub-contractors' performance is derived from their activities during past and current projects and from other sources in the industry like material suppliers, grapevine, and competitors the sub-contractor had worked for in the past, interviews, consultants, Builders' Conference, questionnaire, progress report, and client reference.
Whenever a job is to be sublet, the sub-contractor was first contacted by telephone and given details of the proposed contract and date for the receipt of tenders and once the firm had indicated willingness to submit a bid, it was then sent the tender documents. This method improved the number of quotations that were received by the contractor.
A substantial number of contractors also kept records of unsuitable sub-contractors. This was very common with large and medium sized contractors. Whenever a sub-contractor performed below expectation, the reason for this performance is discussed in-house among the staff and where the fault was totally due to the sub-contractor's inefficiency, the name of the firm was circulated among members of staff who perform pre-qualification assessment to make sure the firm was never used again in any of their contracts.

6.8 Firms that have worked with or used the services of sub-contractors

The objective of this question was to enable the researcher to determine the firms that had either worked with, or had used the services of different trade sub-contractors. This would enable the researcher to determine the firms that would take part in the second part of the research which is the Repertory Grid knowledge acquisition phase for the knowledge based decision support system development. Figure 6.10 below represents the categories of refurbishment contractors that had worked with different types of sub-contractors.

FIGURE 6.10: PERCENTAGES OF CONTRACTORS WITH DIFF. SUBS. WORK EXPERIENCE



From the survey, only 3% of the respondents indicated that they had never engaged the services of labour-only sub-contractors. Also 7% of the respondents indicated that they had never engaged the services of a plant hiring firms. These contractors are large firms that had their own in-house plant hiring department. All contractors indicated that they had used domestic sub-contractors.

6.9 Methods of job execution that offer the greatest financial returns

Table 6.1 represents the type of sub-contracting that offered greatest advantages in terms of financial returns to the contractor. The table shows that domestic sub-contractors offered the best advantage in terms of financial returns. This fact was confirmed during the interview by the majority of contractors. The reason for this according to one contractor during the interview was

"We stand to make more profit with a sub-contractor selected and controlled by ourselves"

This view was also echoed by the majority of contractors. They pointed out that during those uncertain times, it was more profitable and prudent to use domestic sub-contractors wherever possible. Many firms advocated that they were intending to reduce their own directly employed labour force and relied more on the services of sub-contractors. One of the reasons which was constantly mentioned was the Employment Legislation Act. This legislation had imposed tremendous financial burdens on most contractors in that they had to pay redundancy payments, employer's national insurance contributions, sickness benefits and holidays with pay to their directly employed labour.

Table 6.1: Methods of job execution

Benefits derived from sub-contracting	Nom. Subs	Dom. Subs	Lab Subs	Own Subs
Larger financial returns	2 (6%)	20 (61%)	2 (6%)	9 (27%)
Effective monitoring	7 (21%)	14 (43%)	-	12 (36%)
Better organisation	6 (18%)	11 (33%)	1 (3%)	15 (46%)
Quality of workmanship	10 (33%)	8 (24%)	3 (3%)	11 (40%)
Less administrative worries	13 (49%)	7 (21%)	5 (6%)	8 (24%)

However as indicated in table 6.1, 27% of the contractors did indicate that larger financial returns could be gained by the use of their own labour force, whilst 6% of the contractors indicated that larger financial returns could be gained by the services of nominated sub-contractors, and 6% of the contractors said they gained larger financial returns by using labour-only sub-contractors. Reasons for increasing costs for clearing untidy sites by their staff, failure to comply with safety precautions which were very important in refurbishment project sites, poor workmanship and the difficulties encountered in the supervision of their work were mentioned as the reasons for the reduced financial gains in the use of labour-only sub-contractors.

Most of the big contractors did comment during the interview that the use of nominated sub-contractors reduced their competitiveness during tendering and thus affected their overall profit. The majority of the contractors indicated that the use of nominated sub-contractors was becoming less and less on their contracts. They pointed out that their clients were opting for what they called *"preferred sub-contractors"*. These sub-contractors were either recommended by the client or his representative or employed by the contractor with the client's approval. Whatever his method of employment, it is solely the responsibility of the contractor to guarantee his performance. The contractor is no longer entitled to make claims for extension of time or to submit other claims if his work was delayed by default of the sub-contractor as obtained under the nominated sub-contractor's contract agreement.

6.10 Methods of job execution that offer effective monitoring

In the survey, 43% of the contractors indicated that effective monitoring was achieved with domestic sub-contractors. The major reason advanced for this by one contractor was that :

> "Nominated sub-contractors are more responsive to the demands of the Architects who appointed them to the project and therefore, their monitoring and coordination create problems for the contractors with subsequent financial cost".

None of the contractors indicated that effective monitoring was achieved by the use of labour-only sub-contractors. The majority of the contractors indicated that labour-only sub-contractors were very difficult "to get hold of" and that "making contact with some of them" was problematic as some of them did not have contact addresses or telephones. High labour turnover rates were also mentioned as a problem they had with labour-only sub-contractors.

6.11 Methods of job execution that offer better organisation

Table 6.1 represents the contractors' responses to the question on method of project execution that offered better organisation. In table 6.1, 46% contractors indicated that their own labour force provided better organisation whilst 33% indicated that their domestic sub-contractors provided better organisation. Only 18% and 3% of the contractors indicated that nominated sub-contractors and labour-only sub-contractors respectively provided better organisation.

Most contractors preferred to use their own labour force wherever possible as better organisations were naturally more readily found when it is directly within their charge.

Nevertheless, many contractors were forced to sublet their work for reasons mentioned in chapter 2.

6.12 Methods of job execution that offer the best quality of workmanship

Table 6.1 above shows that the contractor's own labour force provided better quality of workmanship. About 24% of the respondents indicated that domestic sub-contractors provided better quality of workmanship, whilst 33% of the contractors indicated that better quality of workmanship was provided by nominated sub-contractors.

The respondents during the interview said that where the work in question was within their area of their specialisation, they provided the best quality of workmanship, although some contractors did say that specialist sub-contractors, especially electrical, heating and ventilating sub-contractors, provided good quality of workmanship in their domain of specialisation.

6.13 Methods of sub-contracting that offer less administrative worries

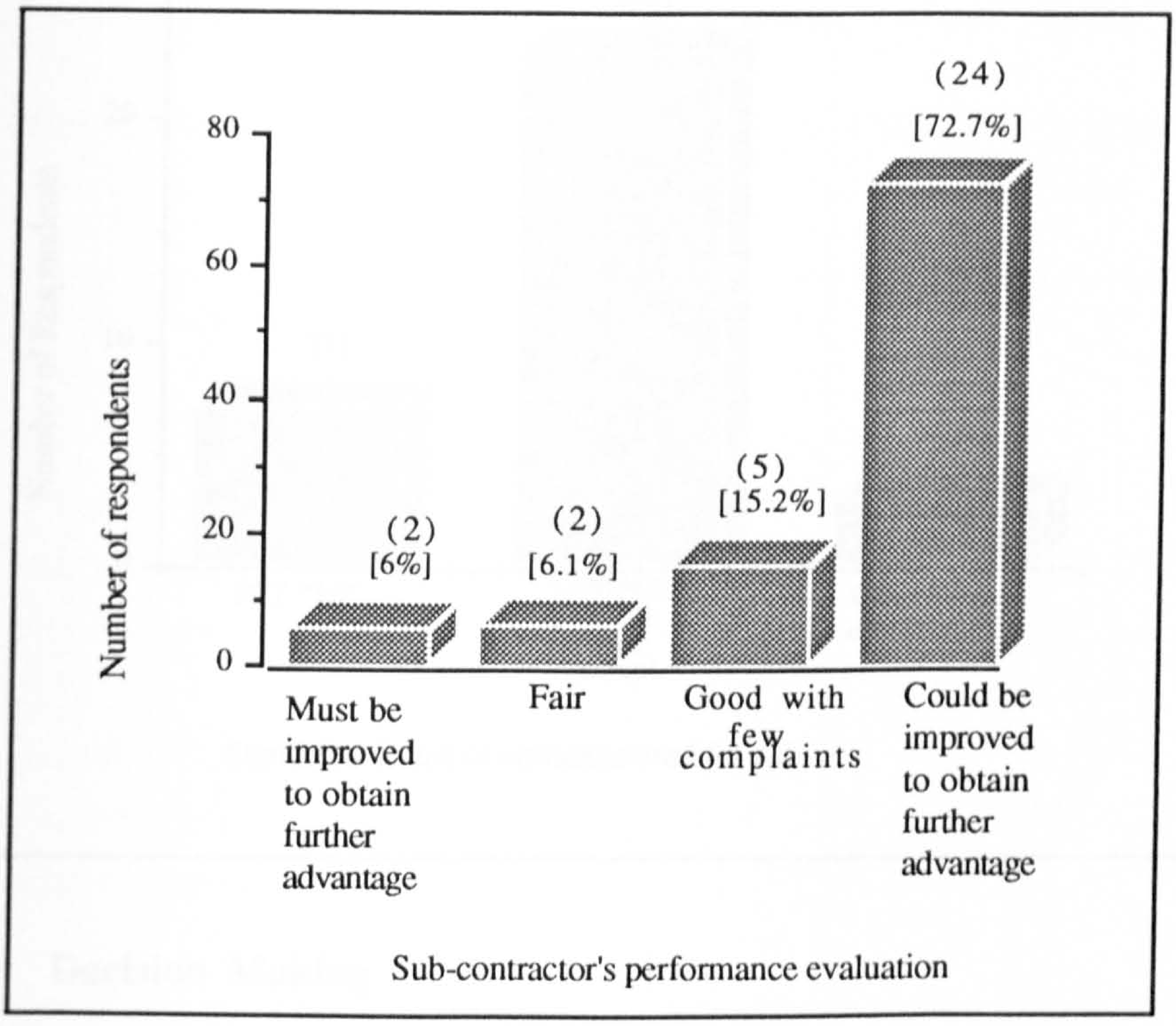
As shown in table 6.1 above, 49% of the contractors indicated that nominated sub-contractor offered less administrative worries. This was followed by contractor's own labour force which was indicated by 24% of the contractors and 21% for domestic sub-contractors. This result is probably expected since nominated sub-contractors were not engaged by the contractors and were directly responsible to the client. However, the contractors would have to integrate nominated sub-contractors to fit within his own site team.

6.14 Services provided by sub-contractors

The majority of the contractors (72.7%) as shown in figure 6.11 indicated that the services provided by their sub-contractors could be improved to obtain further advantage. Only 15.2% indicated that their services were very good with few complaints, and 6.1% indicated that their services were fair, whilst 6% indicated that their services must be improved to maintain profitability and commercial competitiveness.
Thus, it would seem from the above result that the majority of the contractors would want to see the services provided by the sub-contractors improved to obtain further advantage.

This result is not particularly surprising considering the huge increase in litigation against sub-contractors by the contractors.

FIGURE 6.11: PERFORMANCE EVALUTION FOR SUB-CONTRACTOR'S SERVICES



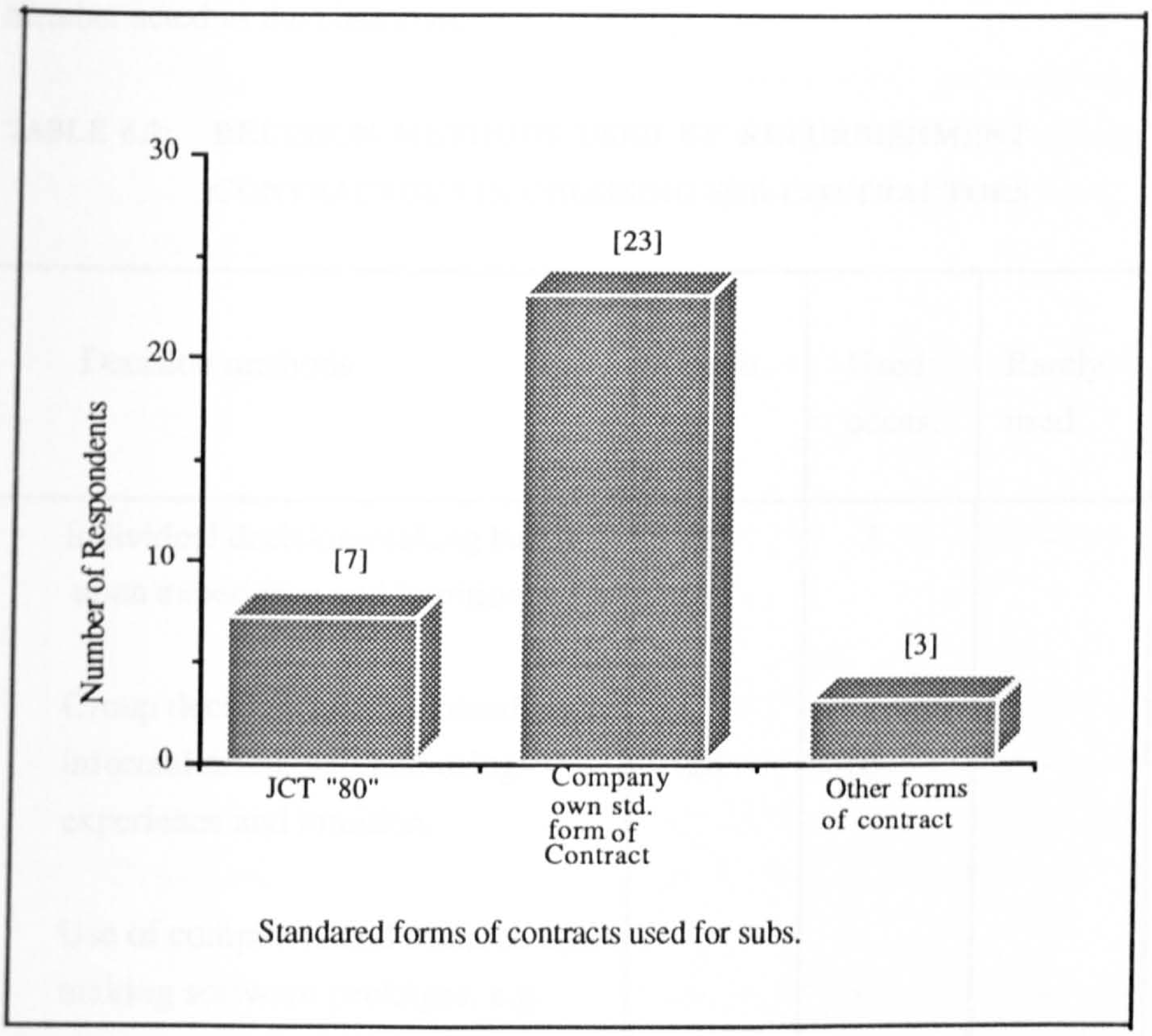
6.15 Standard form of contracts used for project execution

As shown in figure 6.12, the use of contractor's own standard form of contract for sub-contracting emerges as the most popular standard form of contract used by refurbishment contractors for project execution. The use of the JCT 80 standard form of contract was the second most popular standard form of contract.

Most contractors during the interview said that it was usually the project type that determined the standard form of contract that would be used. However, the majority of large and medium firms contractors had their own standard form of contract.

This result is probably due to the fact that most standard form of conditions of contract did not adequately cover the unpredictability and complexities that surrounded refurbishment projects. Thus, most contractors in an effort to cover some of the risks and uncertainties they are exposed to on refurbishment projects, incorporated their own clauses in the contract agreement with sub-contractors.

FIGURE 6.12: CONDITION OF CONTRACTS USED FOR PROJECT EXECUTION



6.16 Decision Making

This part of the questionnaire sought information on the decision-making process used by refurbishment contractors in sub-contracting.
The objective of this section was to establish the mode of decision-making methods that were in general use by refurbishment contractors during sub-contracting.

In table 6.2, individual decision making based upon experience and intuition appears to be the most popular method used by refurbishment contractors. The second most popular method used by the firms surveyed is group decision making.

These two methods were used subjectively and intuitively. In the medium and large firms, group discussions were held between the estimator, the buyer, contracts directors and the quantity surveyor before a particular sub-contractor was short listed.

This group discussion gave a balanced decision-making process and this was the method generally adopted in situations where the subcontract work was complex and critical to the overall work programme. During these discussions the senior staff member acted as the chairman.

TABLE 6.2: DECISION METHODS USED BY REFURBISHMENT CONTRACTORS IN CHOOSING SUB-CONTRACTORS

Decision methods	In gen. use	Used occas.	Rarely used	Never used
Individual decision-making based upon experience and intuition.	30	3	-	-
Group decision-making based upon informal discussion and using experience and intuition.	20	10	-	3
Use of computers and decision upon making software packages, e.g. expert systems.	-	-	-	33
Use of management consultants	-	-	-	33
Use of operational research techniques decision trees, utility, theory linear programming and fuzzy set theory	-	-	-	33
Use of Bayesian method	-	2	-	31

6.16.1 Use of management consultants for decision making

None of the contractors indicated that they had used the services of management consultants during decision making exercises. It is obvious that this type of decision-making was too personal to the individual contractor and too crucial to the contractor for it to be left in the hands of a third party, such as a management consultant.

6.16.2 Operational research and computer software packages

Also, all the respondents indicated that they had never used operational research, utility theory, linear programming, decision trees or computer software packages. Only two firms indicated that, they had used Bayesian methods, although not directly during sub-contracting decision making.

All these methods were too complicated and time consuming which indicated the reason why none of the firms surveyed used them.

6.17 Criteria that imposes the greatest constraints on decision-making when choosing sub-contractors

The objectives of this part of the questionnaire were two-fold; firstly, it sought to find out if refurbishment contractors used any criteria when choosing their sub-contractors and where they do use criteria, to find out which of the criteria the contractors found most difficult to obtain information during the decision-making process.

Secondly, it introduced the respondents to the idea of rating criteria which the researcher intended to use in the second phase of the research.

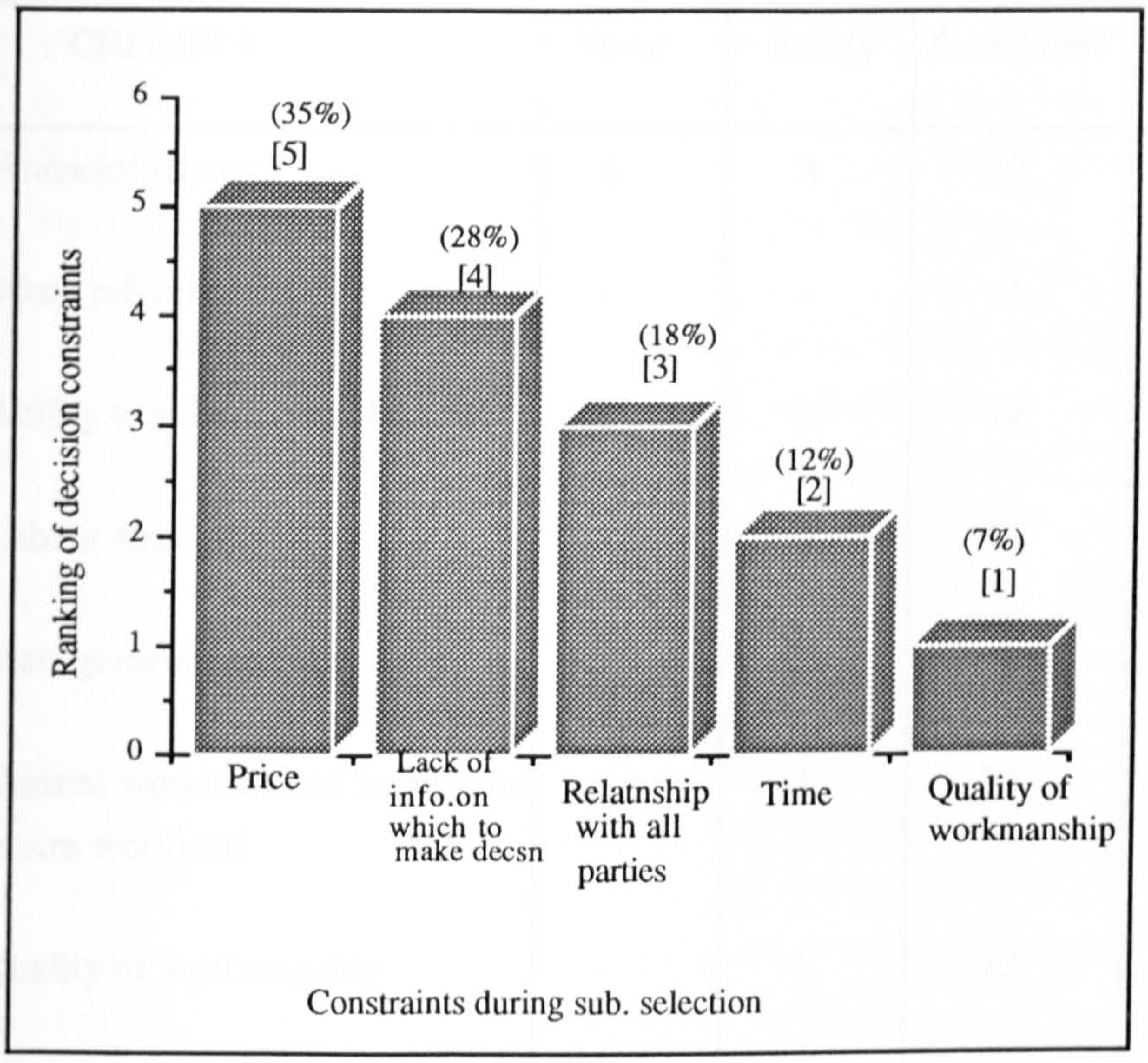
As shown in figure 6.13; the price that the sub-contractor submitted for the job was the criterion that the majority of contractors indicated that imposed greatest constraint in decision making regarding sub-contractors' selection. The difficulty as one contractor explained at interview was:

> "Determining the price which the firm can win the contract with and make his margin and also the price which the sub-contractor can do the job, make his mark up and without going bankrupt".

However, 28% of the contractors also indicated that **lack of information** available to them at the pretender stage imposed the greatest constraint. A contractor would find it almost impossible to make any meaningful decision on a sub-contractor if adequate information which would assist him to make the decision was not gathered on a particular sub-contractor.

Also, 18% of the respondents indicated it was the **relationship** between the sub-contractor and the contractor's staff that would be involved in the contract that imposed the greatest constraint. In the process of choosing a sub-contractor, it is very important to choose a firm that can "get on" with both the contractor's office and the site staff satisfying different interest groups. Another important consideration at this stage would be to chose a firm that was likely to be approved by the client and the consultants.

FIGURE 6.13: SUB-CONTRACTOR DECISION CONSTRAINTS AT SELECTION



The time allowed by the client was indicated by 12% of the contractors as a problem. Estimators had a short time to submit their bid. Within this short time, they would have to decide the sub-contractor whose quotation they were going to use for the project and those likely to give them a genuine bid.

Only 7% of the respondents indicated that the quality of workmanship imposed greatest constraint.

The most important consideration here would be to choose a sub-contractor who would ensure that each step in the sequence of activity was done correctly, at the right time and that there was no inefficiency in his work sequence. The environment in which refurbishment contractors and their sub-contractors work was most complex.

Therefore, it is vital to assess the sub-contractor's contribution to each part of the process to determine whether his own workforce could meet the specified quality of workmanship.

6.18 Criteria used by refurbishment contractors

Table 6.3: CRITERIA USED IN THE SELECTION AND APPOINTMENT OF SUB-CONTRACTORS

CRITERIA	Never	Rarely	Sometimes	Always
Financial strength	6	8	12	7
Work reference	-	-	8	25
Ability to submit bona-fide bid	1	4	16	12
Labour strength	-	2	14	17
Management capability	-	30	2	1
Current workload and anticipated future workload	1	1	23	8
Quality of workmanship	-	2	12	19
Transportation/project.location	27	4	-	2
Safety records and/wkg practice	-	11	7	15
Reliability and trustworthiness	-	-	8	25

From table 6.3 below it would appear that most contractors did use some form of criteria when choosing their sub-contractors. This was very important especially where the sub-contractor had not worked in the past for the contractor. These criteria constitute major aspects of construction management for refurbishment projects which should be considered by all refurbishment contractors. These criteria can make the difference between the actual cost of a project and its hypothetical minimum construction cost.

Contractors to a large extent put themselves in the hands of the sub-contractors they used for their works. A choice had to be made between the bids of a sub-contractor and the contractor had to consider these competitive bids on the basis of tender value, stated construction durations, and expected quality of workmanship.

To make a choice on the basis of the bids alone could leave both the contractor and the client waiting for project completion long after the date stated in the contract. Even the quality of the finished project may vary from what was pre-defined. Those contractors who regularly used a certain sub-contractor in their contracts could use the criteria to measure the performance of the sub-contractor's team for future projects and thus reduce the risks of cost over-runs and delays in the project completions.

In the survey, most large contractors required their sub-contractors to submit together with their bid the names, qualifications and years of experience of all their site and office staff that would be involved in the proposed contract before their final selection. Before a new sub-contractor was included on the sub-contractor's list of the majority of large and medium sized contractors, they were required to complete a questionnaire regarding their previous work experience.

Most large and medium sized firms rarely assess the **management capability** of their sub-contractors. The main reason for this as pointed out by one contractor was :

"the sub-contractor's organisation is too small to provide this function as we have in-house contracts managers and contracts directors who can provide this management function efficiently and cheaply on site for our sub-contractors".

Also, most contractors consider that their own site management staff were capable of directing the sub-contractor's site performance to an extent that both parties gained mutual benefit irrespective of the sub-contractor's administrative capabilities in the project. Only small sized firms assessed the management capabilities of sub-contractors.

Quite a large number of refurbishment contractors sometimes assessed the **workload and future commitments** of their sub-contractors before their engagement. However, a great number of them admitted during the interview that future work commitment of a sub-contractor was very difficult to be precisely determined, since most of the time they rely on what their sub-contractor tells them about their current and future work commitments. Also the mere fact that a sub-contractor was less busy today does not mean he would not be busy tomorrow.

On **project location experience**, the majority of the contractors said that they always used local sub-contractors for their projects and that all their sub-contractors had quite good work experience in the area. The evaluation here would cover the ability of the sub-contractor to provide the required labour, plant and materials for the trade.

Most contractors indicated that they rarely assessed their sub-contractor's ability to provide transportation for their workers because all their contracts were in the London area and in the city centre, where workforce transportation to site is not a major problem.
From table 6.3, quite a number of respondents always assess their sub-contractor's past **safety records** before they were selected. This exercise was usually done by the safety officer in the contractor's office. Most medium and large sized contractors required their sub-contractor to submit a safety programme for the project before they were selected. The standard form of contract may also stipulate that the sub-contractor should provide an indemnity insurance policy cover for their workforce before they are selected for the project. Also the sub-contractor was expected by the contractor to maintain a tidy site during his tenure on site. Due to the nature of refurbishment work which takes place on confined sites and may involve demolition of moving structures, it was vital for the contractor to regularly monitor the safety system adopted by the sub-contractor on site, since he was responsible for the overall safety on the site. It was highly unlikely that poorly trained workers working for sub-contractor may only be interested in achieving the bonus payments.

On **financial strength**, it was discovered that the financial capabilities of sub-contractors were not checked with any degree of in-depth consistency by medium and large sized contractors. The reason for this, according to one contractor was that:

"Obtaining information to assess sub-contractor's financial standing is time consuming, difficult and expensive.---Also most of the information they obtained from financial institutions tended to be out of date and unreliable."

Despite this negative approach towards financial capability assessment, over 50% of the contractors interviewed had experienced bankruptcy among their sub-contractors whilst in their employment.

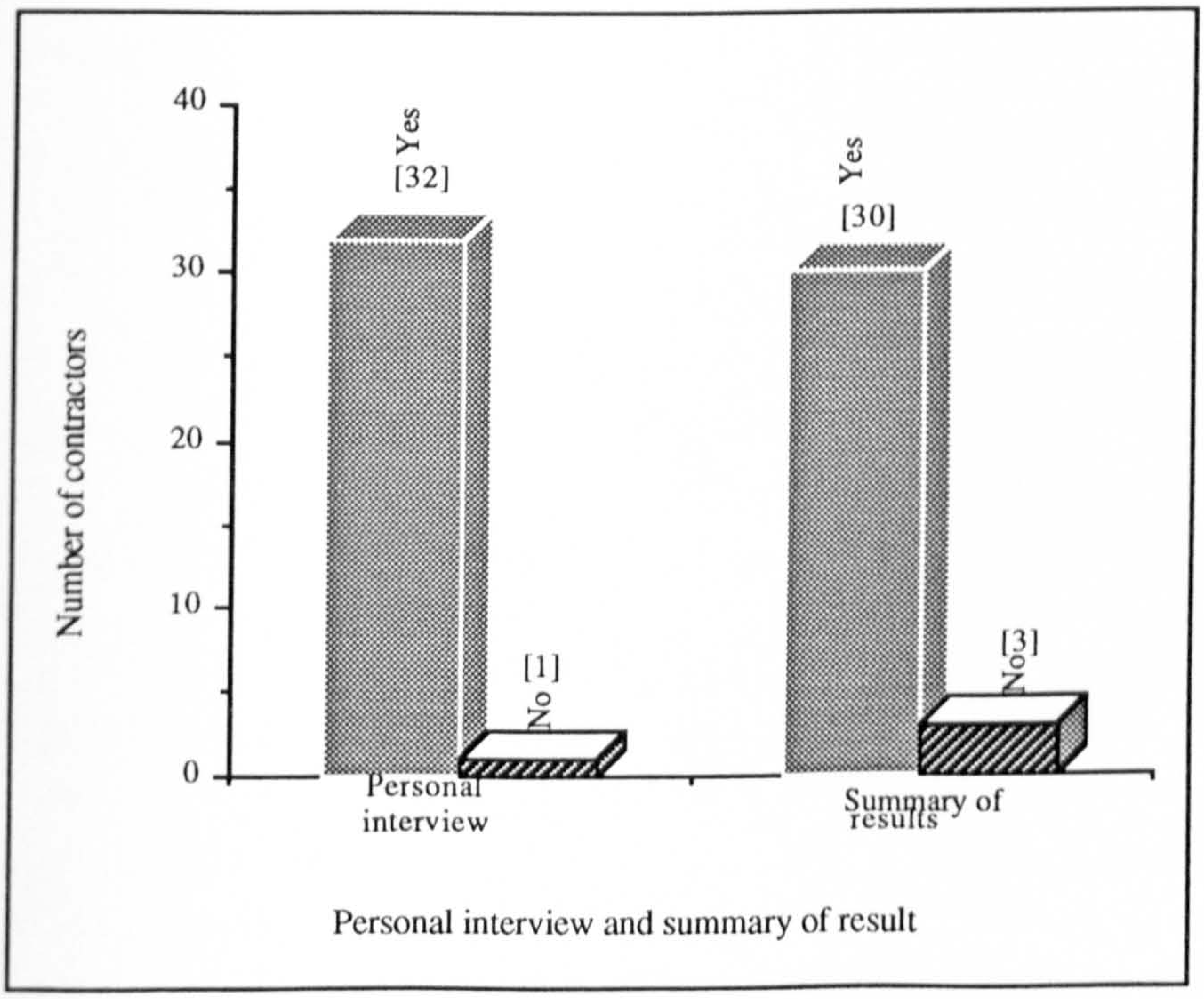
Some large contractors during the interview admitted that they had given financial assistance to some of their sub-contractors who were experiencing financial difficulties to enable them complete their projects. The objective here would be to find out if the sub-contractor could support the project financially without going into liquidation. The volatility and risks associated with refurbishment projects make assessment of sub-contractor's financial strength vital in the evaluation process. Obviously, if a sub-contractor is not financial stable, this will severely affect his ability to perform the work required for the trade. Sub-contractor's likely financial failure was a risk that refurbishment contractors should always consider especially in large projects with many sub-contractor's involved.

For those contractors who sometimes or rarely assess their sub-contractors with reference to some of the criteria mentioned in table 6.3, the reason they advanced for this during the interview was that they already knew the capability of their sub-contractors and that they hardly ever used new sub-contractors. The majority of these firms were either small or medium sized contractors.

6.19 Personal interview and research summary

Figure 6.14 shows the number of respondents who agreed to be interviewed and the number of contractors who would like a summary of the research respectively.

FIGURE 6.14: AGREEMENT ON PERSONAL INTERVIEW/SUMMARY OF RESULTS



6.20 Conclusion

The questionnaire results demonstrate that refurbishment contractors did use criteria during the selection and appointment of their sub-contractors. However, these criteria were used intuitively and subjectively during decision making on sub-contractors.

The results also showed that the rating and the degree of importance among all these criteria can be established. In conclusion, the survey indicated that sub-contracting formed a substantial part of restructuring that was going on in most refurbishment firms. The criteria for choosing sub-contractors varied from one contractor to another. However, prior to the late 1980's, the crucial discriminatory criteria was the money the contractor would make on the contract. In the refurbishment sector of the construction industry of the 1990's, it was recognised by most refurbishment contractors that having the lowest bid was less important than the total service which sub-contractors gave with emphasis on technical competence and safety programme.

CHAPTER SEVEN

ANALYSIS OF REPERTORY GRID

CHAPTER SEVEN

ANALYSIS OF REPERTORY GRID

7.1 Chapter objective

The main objectives of the Repertory Grid analysis were first to identify the natural structure and pattern between elements and the constructs and also to establish the most important and least important criteria used by refurbishment contractors during the selection and appointment of sub-contractors.

Other objectives were to establish the similarities and differences among refurbishment contractors' criteria and to provide the underlying hierarchical inference network that refurbishment contractors applied during their decision making process of engaging sub-contractors.

Grid analysis helps the researcher to understand and explain the refurbishment contractor's psychological reasoning processes by highlighting the existence of conceptual relationships between grid constructs and revealing how the refurbishment contractor uses the constructs to distinguish between the elements in the grid.

7.2 Chapter introduction

The Repertory Grid data base consists of a fully rated grid obtained through knowledge elicitation of thirty refurbishment contractors described in chapter five. The respondents were made up of experienced chief Estimators, Buyers, and Contracts directors. All the respondents had at least twenty years experience in refurbishment contracts. The Repertory Grid contains information on the criteria considered by these contractors when they chose sub-contractors.

These data were stored in a Hewlett Packard main frame computer system at Loughborough University of Technology. Appendix B shows the elicited Grids. The grids were analysed using the Grid Analysis Package (GAP) developed by Slater (1). There were sixty eight different types of analysis on the GAP programme. The seven principal programmes include: INGRIDA, DELTA, SERIES, ADELA, PREFAN AND COIN.

Each of these analyses plays a key role in the interpretation of all the contractors' grids. Firstly, the group individual grids was performed to determine how different decision-makers participating in this study viewed decision variables used in the selection of suitable sub-contractors in refurbishment work packages. Secondly, the groups combined grids were analysed to determine the conceptual relationship between the group construct and therefore validate the hypothesis of construct's commonality. Thirdly, principal component analysis was applied to the combined grids and individual contractor's grid to identify the top level fundamental constructs or the principal components of the underlying decision processes for sub-contractor selection.

7.3 Visual Examination

Visual inspection of the rows and columns of the grid matrix in the Estimators combined grid table 7.1, below for instance, revealed quite a lot of useful information in the decision-making processes of the chief estimators. For instance, looking along the first row of the estimators' grid it is observed that the mean score of all chief estimators who participated in the survey on element (S1) on construct CR1 "competitive bid" is 5 out of the possible rating of 5 which indicated that all Estimators gave sub-contractor (S1) a top rating on this construct. This is also the case of element (S2) and (S5). Also a close visual examination down the first column (S1) revealed that the mean score for construct CR2, CR6 and CR7 to mention just three constructs was 5. It is possible to go on to examine other rows and to compare the entries in different rows noticing, for instance, that constructs CR7 and CR9 "project type experience" and "Work area experience" provide nearly very similar ratings while constructs CR7 and CR15 were rated quite differently.

Also, it is possible to examine other columns and noticing, for instance, that elements (S1) and (S2) are very nearly rated consistently high on all constructs and are evidently treated as paragons of all the virtues, or notice the striking change that occurs in the rating of element (S7) when construct CR7 comes up.

Thus, the grid on visual examination displays an experimentally selected part of the system formed by the interaction of all contractor's elements with all the constructs. This interaction evidently reveals quite a complicated structure hence the need for computer analysis. However, from a quick visual overview of all the domestic sub-contractors' grids, labour only sub-contractors' grids, material suppliers' grids, and plant hirers' grids (appendix B), it is possible to hypothesis that these experts used similar constructs when choosing a sub-contractor.

Table 7.1: Estimators Repertory Grid(Domestic Sub-contractors constructs)

CONSTRUCTS		ELEMENTS										CONSTRUCTS
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
CR1	Competitive bid	5	5	4	1	5	4	2	3	3	2	Uncompetitive priced rates
CR2	Consistency of priced rates	5	5	4	4	5	2	1	1	1	3	Overloading of priced rates
CR3	Early quotation	4	4	3	4	4	2	1	1	3	5	Late quotation
CR4	Pricing all items in BOQ	3	5	1	1	4	5	2	3	5	5	Lump sum quotation
CR5	Keen to work for us	4	2	4	2	1	4	3	5	5	3	Persuaded to send in quotation
CR6	Capable of financing his contract	5	3	5	2	2	1	1	1	4	3	Likely to go into liquidation
CR7	Project type experience	5	4	3	4	2	2	1	1	5	5	Inexperience on project type
CR8	Project size experience	3	2	2	1	3	4	5	5	3	4	Inexperience on project complexity
CR9	Geographical area work experience	2	5	2	3	5	5	1	2	1	4	No work experience in the area
CR10	Technical competence	3	4	3	3	3	2	1	2	5	5	Technical incompetence
CR11	Prompt commencement site work	3	4	3	5	4	3	5	1	2	5	Late start on site
CR12	Good record of schedule maintenance	3	4	3	2	3	5	4	2	3	4	Late completion of work schedule
CR13	Good quality of workmanship	4	3	4	3	2	3	4	5	1	1	Poor quality of workmanship
CR14	Quality rated firm	3	3	3	3	4	2	2	1	5	5	Quality unrated firm
CR15	Experienced site foreman	2	2	1	1	1	2	2	2	3	4	Inexperienced site foreman
CR16	Properly registered company	3	3	4	5	4	5	5	4	4	5	Unregistered company
CR17	Agreement on work programme	4	5	2	4	3	1	4	3	4	5	Unacceptable work programme
CR18	Capable site management	4	4	4	4	3	5	4	3	4	5	Incapable of managing his work
CR19	Adequate cashflow	3	5	1	3	2	1	1	2	1	3	Unstable firm
CR20	Good financial reference	3	4	3	1	2	1	4	2	4	3	Poor financial reference
CR21	Reasonable claims	3	4	3	1	2	1	4	2	4	3	Inflated claims
CR22	Reasonable work valuations	4	2	4	1	2	2	4	5	5	3	Inflated work valuations
CR23	Reliable and honest firm	3	4	5	3	3	1	2	4	5	3	Unreliable and untrustworthy firm
CR24	Good trade reference	4	4	2	1	2	5	2	4	2	3	Poor trade reference
CR25	Good relationship with our firm	3	4	4	4	2	3	1	2	3	3	Poor relationship with our firm
CR26	Adequate plant and equipment	5	5	4	5	3	4	5	4	5	3	Inadequate plant and equipment
CR27	Good safety records	4	3	5	4	3	3	2	4	1	1	Poor safety records
CR28	Good safety programme	3	4	4	5	5	4	4	2	1	1	Poor safety programme
CR29	Client approval	4	5	3	3	1	1	2	4	5	4	Client disapproval

7.4 Analysis of variation, mean rating and construct variability

An INGRIDA (1) analysis of the variation was performed on the group's constructs to determine whether there are differences in construct perceptions among each group (Estimators, Buyers and Contracts directors). The result of the analysis is shown in table 7.2. For the sake of clarity in the analysis, only ten constructs with the largest and smallest variations are presented in table 7.2 and table 7.3. Details of the result of all the analysis are presented in appendix D.

According to Slater (1), and Smith (2), "constructs which account for the most variation within a grid are constructs which possess most meaning for that person, while low variation indicates less valued constructs".
The interpretation of these results is difficult because no comparative data are available. However, by comparing the variations and the mean ratings, it is possible to provide some meaningful interpretation.

7.4.1 Domestic Sub-contractors' Grids

7.4.1.1 Analysis of Estimators, Buyers and Contracts Directors' Grids

Table 7.2 provide a list of constructs commonly considered by the Estimators, Buyers and Contracts directors during the selection and appointment of sub-contractors for refurbishment work. The constructs are arranged in ascending order ranked according to their variation.

7.4.1.2 Estimators' grid

The Estimators' constructs variations range from a minimum of 18.50 to a maximum of 24.40, which clearly indicates that some constructs are more highly regarded by the Estimators than others. Examination of the computer output in table 7.2 revealed that the most meaningful constructs to the Estimators were: "consistency of priced rates in the BOQ" (24.40); "competitive bid" (24.00); "pricing all items in the BOQ" (23.60); "technical competence" (22.90); "reliability and trustworthiness" (22.10); "quality of workmanship" (20.10); "work area experience" (19.60); "client approval" (19.60); "safety records" (19.50) and "experience with the proposed contract documentation" (18.50).

Table 7.2 Domestic Sub-contractors' Constructs With Largest Variation

S/N	Most Valued Constructs	Variation	Mean Rating
	Estimator		
1	Consistency of priced rates	24.40	3.40
2	Competitive bid	24.00	3.00
3	Pricing all BOQ items	23.60	3.20
4	Technical competence	22.90	2.90
5	Reliability and trustworthiness	22.10	2.70
6	Quality of workmanship	20.10	2.70
7	Work area experience	19.60	3.30
8	Client approval	19.60	3.20
9	Safety records	19.50	3.20
10	Contract document experience	18.50	2.80
	Variability = 0.6794		
	Buyer		
1	Contract document experience	26.40	3.60
2	Reliability and trustworthiness	24.00	3.00
3	Competitive bid	23.60	3.20
4	Work design capability	23.60	3.20
5	Quality of workmanship	23.60	3.20
6	Technical competence	23.60	3.20
7	Consistency of priced rates	22.10	3.30
8	Work area experience	22.10	3.30
9	Safety records	20.10	3.30
10	Client approval	20.10	3.30
	Variability = 0.6975		
	Contracts Director		
1	Technical competence	24.10	3.30
2	Work design capability	22.10	3.30
3	Safety records	18.50	3.50
4	Quality of workmanship	18.00	3.00
5	Competitive bid	17.60	3.80
6	Client approval	16.50	3.50
7	Consistency of priced rates	16.10	3.30
8	Contract document experience	15.60	2.20
9	Work area experience	14.40	3.60
10	Reliability and trustworthiness	14.00	3.30
	Variability = 0.5457		

Thus, from the results in table 7.2, the three most meaningful constructs to the Estimators were "consistency of priced rates in the BOQ", "competitive bid", and "pricing all BOQ items".

7.4.1.3 Buyers' Grid

Similarly, in table 7.2, the variation of the Buyers' constructs range from a minimum of 20.10 to a maximum of 26.40. The most meaningful constructs to the Buyers were "experience with the proposed contract documentation" (26.40); "reliability and trustworthiness" (24.00); "competitive bid" (23.60); "design experience" (23.60); "quality of workmanship" (23.60); "technical competence" (23.60); "consistency of priced rates in the BOQ" (23.60); "work area experience" (22.10); "safety records" (22.10); and "client approval" (20.10).
Also from the above results in table 7.2, the three most meaningful constructs to the Buyers were "experience with the proposed contract documentation", "reliability and trustworthiness" and "competitive bid".

7.4.1.4 Contracts Directors' Grid

Table 7.2 displays the variation of the Contracts directors' constructs. The Contracts directors' constructs variation range from a minimum of 14.10 to a maximum of 24.10. The most meaningful constructs to the Contracts directors were "technical competence" (24.10); "design experience" (22.10); "good safety records" (18.50) "quality of workmanship" (18.00); "competitive bid" (17.60); "client approval" (16.50); "consistency of priced rates in the BOQ" (16.10); "experience with the proposed contract documentation" (15.60); "work area experience" (14.40); "reliability and trustworthiness" (14.10).

Thus the most meaningful constructs or criteria indicated by all the three groups were "experience with the proposed contract documentation" (26.40); "consistency of priced rates in the BOQ" (24.40); "technical competence" (24.10); "reliability and trustworthiness" (24.00); "competitive bid" (23.60); "work area experience" (22.10); "good safety records" (22.10); "quality of workmanship" (18.00). This result gave credence to the hypothesis that there may be common constructs which these contractors regularly used when choosing the most suitable domestic sub-contractors for refurbishment work packages.

In comparing the results from the three groups, it is interesting to note their similarities and small differences. For example, Estimators indicated "consistency of priced rates in the BOQ", as the most meaningful construct, the Buyers indicated "experience with the proposed contract documentation", whilst the Contracts directors most meaningful construct was "technical competence".

Other constructs which appeared high in the three groups construct system were "competitive bid", "reliability and trustworthiness", "work area experience", "good safety records", "quality of workmanship", and "client approval". Thus, it can be inferred that these constructs were regularly used by refurbishment contractors when choosing domestic sub-contractors.

The explanation provided by refurbishment contractors for using these constructs were as follows :

i) Consistency of priced rates

Estimators are under tremendous pressure as refurbishment clients usually impose a very short time limit in which they are required to submit their tenders. Also, in the majority of refurbishment contracts, it is always a problem and very difficult for the estimators to calculate exactly the appropriate mark-up to be allowed in the tender and the allowance that is to be made for preliminary work items. This is because in most refurbishment projects, measured items in bills of quantities (BOQ), like temporary supports for weak structures, formation of openings, stripping of finishings, may be more than what was previously allowed for in the BOQ. This problem is compounded if the sub-contractor fails to price his bill items properly or overloads certain bill items, as it is much difficult to calculate and adjust such bills during the variation and valuation of work. The majority of Estimators usually did not use any sub-contractor that did not price his BOQ properly.

ii) Contract document experience

The standard form of building contracts like the JCT 80, GCE/WKS1 may be appropriate for new build but are often inappropriate for use in refurbishment work due to the unpredictability that surrounds refurbishment projects. There were also too many uncertainties in refurbishment contracts which these documents failed to cover adequately. Also, the BOQ in most cases did not adequately cover the unique complexities in its description of the work. It fell short of communicating clearly and adequately the extent of work that needed to be done. Therefore, the majority of refurbishment contractors used their own standard form of contract to cover the shortfalls in these standard forms of contracts. The majority of the Buyers said they would only use a sub-contractor who had had previous work experience with their own contract documents, whilst both the Estimators and the Contracts directors pointed out that settlement of claims which were inevitable in most refurbishment projects could be a difficult problem if the sub-contractor misinterpreted their standard form of contract.

iii) Geographical area experience

Most estimators preferred to use sub-contractors who had had previous work experience in the area of the proposed project. Estimators believed that such a sub-contractor would be in a good position to ascertain most accurately the BOQ rates and would also be in a good position to assess any local factors that were likely to affect work performance on site. For instance, a local sub-contractor would be in a good position to know if there was an old mining operation near the site, or the nearest refuse tip, or any previous subsidence, and the effect of weather during the construction period. All these factors would affect the unit cost.

iv) Competitive bid

The small packages of work operations which were scattered at different locations within the building made it difficult to assess labour productivity rates, materials and plant rates in refurbishment projects. This was because site access was restricted due to existing structures, which was a serious problem in urban sites. This made site work operations very difficult and slow. Coupled with these problems was the unpredictability of the exact work content and level of difficulties that contractors would actually find when construction work commenced on site. This made it extremely difficult for Estimators to asses accurately the cost of these items in advance. Estimators, Buyers and Contracts Directors said that in the majority of cases, their contracts were awarded to a sub-contractor whose bid was not only competitive but had taken great care in the preparation of his tender.

v) Technical competence and innovation

Refurbishment work may involve the matching up of new work to existing work, repairs of defective work and realignment of floors to provide space for services and computer line distribution. Also, there may be underpinning of old work operations which were particularly difficult because of the close proximity of surrounding buildings. These weak structures might have to be shored up while the floors were replaced and bearing provided at new levels. This type of work called for the use of a sub-contracting firm that had technical expertise in these areas and whose firm was capable of providing the technically competent staff necessary for these types of jobs.

vi) Quality of workmanship

Refurbishment work may involve the conservation, preservation, and alteration of very important historic and strategic buildings. For example, it maybe the refurbishment of pre- and post-war buildings, like churches, mosques, refurbishment of industrial and commercial buildings like the London Dockland, Canary wharf, installation of air conditioning systems and central heating, information technology equipment. It may include the refurbishment of expensive or priceless ornamental fittings or the provision of stained glass windows to buildings of great historical value where a very high standard of workmanship is of paramount importance. This type of work requires a sub-contractor which can provide the high standard of workmanship that is required.

vii) Correct design of work

Refurbishment work involves a mixture of old or traditional skills with a variety of relatively new techniques. Sometimes, it may require the provision of modern communication equipment, provision of air conditioning, upgrading of finishings or trunking for services in an existing building or the replacement of the entire structure with an entirely new structure.

In older buildings, it is common for original drawings either to have been destroyed or lost. Also, the client's brief is usually vague and very little information is available on the structural condition of the existing foundation, columns, beams, walls and floors. Also, a thorough site visit to determine conditions which might affect design work, which is usually possible in new build programme, may be very difficult due to the fact that the building may have tenants in occupation. This makes the redesign of refurbishment work very challenging and taxing. Contracts Directors, in particular expressed their preference for a sub-contractor who can produce a design that is practical and with reasonable inevitable changes during construction.

viii) Reliability and trustworthiness/Work reference

Frequently, in refurbishment work, tenants are in occupation whilst work is carried out. In some cases, where there were no tenants, there could be very costly equipment in the building being refurbished. It is very important that the track record of the sub-contractor who will be used on the project is very well sourced, so that sub-contractors with dubious characters or criminal records are barred from the site. This is very important, especially when the building being refurbished has expensive equipment lying openly unsecured, for example, computers, facsimile machines, and other communication equipment.

ix) Client approval

This is particularly important as sub-contractors may be used to working in highly sensitive premises, such as the premises of High Commissions, embassies and government offices. The client may require that all sub-contractors that would be used on the site be properly vetted and that any workmen with criminal records are not used for the project. Also some companies may wish to protect their vital products from competitors. Therefore, they make sure that any sub-contractors that have any links with their competitors are not used in the project.

x) Good safety records

Generally, refurbishment work requires more protective safety measures and safety provisions to be taken compared to new build work. This is because this construction is carried out within existing buildings or in proximity with other buildings and sometimes may have to be undertaken with tenants in occupation. Safety provisions must be made to protect the existing building and adjoining buildings from collapsing. The building occupants would have to be protected together with the general public. Also, the sub-contractor must comply with the Health and Safety at Works Act 1974. Sometimes, both the building occupants, members of the general public and the workers must be protected from hazardous toxic substances which may be present on the site. Temporary work may be required so as to ensure the building is safe and secure throughout the construction period.

In some building sites, protective screens may have to be erected to reduce the noise and dust that would come from the construction site activities and also to ensure the safety and comfort of the general public, the building occupants as well as the workmen. In addition, the sub-contractor would have to protect the newly refurbished building to avoid damage or pilferage.

7.4.1.5 Domestic sub-contractors' least variations

Table 7.3 Domestic Sub-contractors' Constructs With Smallest Variation

S/N	Least Valued Constructs	Variation	Mean Rating
	Estimator		
1	Quick response to calls	14.90	3.10
2	Provision of bond and warranty	14.90	2.90
3	Trade registration	14.10	3.30
4	Keen to work for us	14.10	3.30
5	Adequate cashflow	12.10	2.70
6	Capable site organisation	8.90	2.90
7	Contact address	8.10	3.30
8	Quality rated firm	8.00	2.00
9	Possession of current tax papers	6.10	4.30
10	Site management capability	5.60	4.20
	Buyer		
1	Implementation of site decisions	13.60	3.80
2	Quality rated company	12.90	3.90
3	Adequate cashflow	12.90	3.90
4	Keen to work for us	12.90	2.90
5	Legally registered company	12.50	3.50
6	Consistently bid for us	12.50	3.50
7	Provision of bond and warranty	12.50	3.40
8	Site management capability	12.40	2.50
9	Quick response to calls	8.10	3.70
10	Early quotation	5.60	3.80
	Contracts Director		
1	Trade registration	6.50	3.50
2	Possession of recent tax papers	6.00	4.00
3	Consistently bid for us	5.60	4.20
4	Quality rated company	5.60	3.80
5	Keen to work for us	4.90	3.50
6	Receipt of quotation on time	4.40	3.40
7	Adequate cashflow	4.10	3.70
8	Provision of bond and warranty	4.00	4.00
9	Early quotation	4.00	4.00
10	Site management capability	2.90	2.90

Table 7.3 contains the list of constructs with the lowest variations. The constructs which are least meaningful to the three groups included "site management capability" (2.90); "early quotation" (4.00); "provision of bond and warranty" (4.00); "adequate cashflow" (4.10); "receipt of quotation on time" (4.40); "keen to work for us" (4.90).

It is interesting to observe that "site management capability" has one of the lowest variation among the three groups construct system. This unexpected low variation for " site management capability" can be attributed to the type of management skills required in the majority of refurbishment projects. In refurbishment projects, the sequence of work is less uniform and sequential than in new-build projects, and often involves the simultaneous working of multiple trades in different parts of a building. It may involve as many as 25 different trade sub-contractors working in 25 different work packages in one building at the same time. Thus, it is more difficult to plan the flow of work to attain the high productivity normally expected in new build projects due to problems of site constraints, restrictions on working hours and additional necessary precautions for emergency works.

More management resource inputs are required to ensure the smooth running of the project as the working schedule sequence and timing for all sub-contractors must be co-ordinated from a central source so as to minimise disruption of the work of other sub-contractors and the activities of the occupying tenants.
This demands higher management and supervisory skills which most sub-contractors are too small to provide. Whilst new build can be planned and quantified in advance with reasonable accuracy, refurbishment projects are prone to changes in the original work programme. Unexpected work changes usually occurs when structures are taken out or replaced. Work plans need to be revised constantly and promptly to meet completion dates. In the majority of refurbishment projects the management function is provided by the main contractor.

7.4.1.6 Variability of constructs

The variability of the three groups' constructs varied between 0.5457 to a maximum of 0.6975 whilst the mean ratings of the three groups varied between a minimum of 2.70 to a maximum of 3.80 as shown in table 7.2. These two values provided an indication of the general agreement in the rating of the various constructs among the contractors. Variability gives an overall impression of how well the contractors are using the rating scales. The higher the variability the better, and according to Slater (1) the normally acceptable value is between 0.50 to 0.70. As shown in table 7.2, the variability of the

Estimator Grid was (0.6975) whilst that of the Buyer was (0.6794). Estimators' and Buyers' variabilities are much higher than that of the Contracts Director (0.5457), which clearly indicated that both the Estimator and the Buyer viewed these constructs as having a big influence in the decision to choose a suitable sub-contractor more than the Contracts director.

7.4.1.7 Analysis of Labour-only Sub-contractors' Grid

Table 7.4 depicts the labour-only sub-contractors' constructs with highest variation for Estimators, Buyers and Contracts Directors. The most meaningful constructs common to the three groups were "contact address" (24.00); "site meeting and decision implementation"(21.88); "quality of workmanship" (21.50); "competitive bid" (18.88); "maintenance of tidy site" (18.88); "inflationary claims" (18.88); "good work reference" (17.88); "prompt start on site" (17.88). Thus, it can be inferred that these constructs are regularly used by refurbishment contractors when choosing labour-only sub-contractors.

Estimators considered "contact address" (18.88); "competitive bid" (18.88); and "prompt start on site" (18.88); as the most meaningful constructs, whilst Buyers regarded "competitive bid" (18.88); "quality of workmanship" (18.00); "contact address" (17.88) as the most meaningful constructs. On the other hand, the Contracts Directors' most important constructs were "contact address" (24.00); "site meetings attendance" (21.88); and "quality of workmanship" (21.50).

The explanation provided by refurbishment contractors for using "competitive bid" and "quality of workmanship" were also mentioned for labour-only sub-contractors selection.
The explanation provided for using the following constructs: "contact address", "maintenance of tidy site" "site meetings attendance" "inflationary claims" "Good work reference" and "prompt start on site" were as follows:

i) Contact address

In refurbishment work the unexpected usually occurs, when structures are taken out or replaced. Work programmes may need to be revised constantly and promptly to meet completion dates, therefore it is vital that the sub-contractor can be contacted within a short period. Work programmes may be revised and the sub-contractor may be required to start on site at short notice. This is particularly important as labour-only sub-contractors are difficult to get hold of in emergencies. The majority of labour-only subcontractors have no offices and therefore operate from their homes, with some having their wives acting as secretary. Some have answering machines which take recorded telephone messages.

Table 7.4: Labour-Only Sub-contractors' Constructs With Largest Variation

S/N	Most Valued Constructs	Variation	Mean Rating
	Estimator		
1	Contact address	18.88	3.13
2	Competitive bid	18.88	3.13
3	Inflationary claims	18.88	2.88
4	Good work reference	17.88	3.38
5	Prompt start on site	15.88	3.38
6	Maintenance of tidy site	15.50	3.25
7	Attendance of site meeting	14.00	2.50
8	Site decisions implementation	13.88	3.38
9	Quality of workmanship	11.88	2.38
10	Relationship with our company	11.88	3.63
	Variability = 0.6427		
	Buyer		
1	Competitive bid	18.88	3.13
2	Quality of workmanship	18.00	3.00
3	Prompt start on site	17.88	3.38
4	Good work reference	16.00	3.00
5	Contact address	15.88	2.38
6	Inflationary claims	15.88	3.63
7	Maintenance of tidy site	15.50	2.75
8	Work area experience	15.50	2.75
9	Site decisions implementation	14.88	3.13
10	Site meeting attendance	14.88	3.13
	Variability = 0.6987		
	Contracts Director		
1	Contact address	24.00	3.50
2	Site meeting attendance	21.88	2.63
3	Quality of workmanship	21.50	3.26
4	Competitive bid	18.88	3.13
5	Maintenance of tidy site	18.88	2.88
6	Prompt start on site	17.50	2.75
7	Experienced site foreman	16.00	3.00
8	Good work reference	16.00	3.50
9	Site decisions implementation	15.50	2.75
10	Priced rates consistency	15.50	3.25
	Variability = 0.6180		

ii) Site meeting attendance/Decision implementation

In the majority of the refurbishment contracts, the extent and problems of the work are not normally discovered until after construction work has commenced on site. There is also lots of emergency work, which may range from repairs of burst water pipes to the erection of emergency temporary supports, scaffolds to protect existing structures on site which were about to collapse as a result of a "gale force wind", of which no previous provision was made for in the BOQ. There are usually lots of variations and contracts revisions in refurbishment contracts. There is, therefore, the need to liaise with the project co-ordinator and consultants to resolve problems from time to time. Effective communication is of paramount importance. It is, therefore, very vital that sub-contractors consult on a regular basis with the Contracts director or contractor's representative on site to iron out problems that are bound to arise on site.

iii) Tidy site

Often, tenants are in occupation whilst construction work is going on. It is, therefore, necessary for the sub-contractor to remove debris each day after the day's work is completed to prevent accidents both to the occupying tenants and members of the public.

iv) Prompt commencement on site

Because refurbishment work may require sub-contractors to work in a very restricted area or confined site, labour output is very much reduced. It is vital, therefore, that a sub-contractor is on site when he is required in order to meet the completion period. Also, the client usually imposes stringent completion deadlines on the contractors. Therefore contractors favour a sub-contractor who would be on site on the day he is expected to start his work, which would ensure early completion and reduce the possibility of paying liquidated damages to the client. This would also ensure that the work of other sub-contractors is not delayed.

v) Inflationary claims

There is also a higher proportion of remeasurement work in refurbishment projects, as many work items are usually not possible to ascertain until work is completed. Therefore in many refurbishment projects, there are always many provisional items which are determined when the actual work is completed on site. As such, there is always a tendency for a claims conscious sub-contractor to inflate his claims. Estimators in particular are very wary of such sub-contractors at selection period and avoid giving them contracts.

vi) Trade reference

Common sense dictates that a sub-contractor seeking to be selected for electrical work should have electrical work experience. References may provide valuable insight into the professional competence and work experience of each sub-contractor. Reference letters would enable contractors to verify that an individual mentioned in the letter is used in the contract.

7.4.1.8 Labour-only sub-contractor's least meaningful constructs

Table 7.5 shows the labour only sub-contractor's construct system with the lowest variation for the three groups. The three groups' construct system displayed marked similarities among the least important constructs. Both groups agreed that the following constructs "receipt of quotation on time", "consistently bid for us", "similar project type experience" and "financial strength" were not very important. The results clearly demonstrate that there was more agreement than disagreement on the least important constructs between the three groups. The reasons the contractors gave for the surprisingly relatively low variation on "similar project type experience" and "financial strength" were as follows:

i) The majority of refurbishment projects are unique in nature and non-repetitive, so finding a sub-contractor with exactly the same project type experience is very rare and usually not insisted upon during sub-contractor's evaluation. Therefore, most refurbishment contractors did not regard this construct as very important when choosing sub-contractors.

ii) Also, whilst small refurbishment contractors assess the financial strength of most of their sub-contractors, most large contractors do not assess sub-contractors financial capabilities with any seriousness. In fact, some large contractors provide financial assistance to some of their sub-contractors.

Table 7.5 Labour-Only Sub-contractors' Constructs With Smallest Variation

S/N	Least Valued Constructs	Variation	Mean Rating
	Estimator		
1	Consistently bid for us	8.88	2.88
2	Keen to work for our company	8.00	3.00
3	Financial strength	7.88	2.63
4	Similar project type experience	7.50	2.75
5	Receipt of quotation on time	5.00	2.25
6	Good union relationship	4.38	1.88
	Buyer		
1	Receipt of quotation on time	11.88	3.63
2	Consistently bid for us	10.88	3.88
3	Keen to work for us	10.88	3.12
4	Plant and equip. availability	10.88	2.88
5	Similar project type experience	7.50	2.25
6	Financial strength	5.88	3.13
	Contracts Director		
1	Good union relationship	10.88	3.13
2	Possession of current tax papers	10.00	2.50
3	Financial strength	8.88	1.88
4	Consistently bid for us	8.00	3.00
5	Similar project type experience	6.88	3.88
6	Receipt of quotation on time	6.00	2.50

7.4.1.9 Variability of constructs

The variability of the three groups' constructs ranges between 0.6180 to 0.6987, whilst the mean ratings of the three groups varies between a minimum of 2.38 to a maximum of 3.63 as shown in table 7.4. These two values show that there is general agreement in the rating of the various constructs among the contractors. However, the variability of the Estimator's and Buyers' constructs are much higher than that of the Contracts Directors. This indicates that Estimators and Buyers view these constructs as being more essential in choosing sub-contractors.

7.4.1.10 Analysis of material supplier's grids

The material suppliers constructs variation are presented in table 7.6 The Estimators' material suppliers constructs variation ranged from a minimum of 3.00 to a maximum of 11.50. Also the Buyers' materials supplier construct variation ranged from a minimum of 3.33 to a maximum of 13.50.

Table 7.6: Material Suppliers' Constructs Variation

S/N	Most Valued Constructs	Variation	Mean Rating
	Estimator		
1	Competitive price	11.50	2.50
2	Prompt delivery of materials to site	10.83	3.17
3	Provision of fixing services	10.83	3.17
4	Provision of storage facilities	10.83	3.17
5	Nearness to site	9.50	3.50
6	Prompt treatment of invoice	9.33	3.33
7	Supply of high quality materials	6.83	3.17
8	Prompt replacement of defective materials	5.50	3.50
9	Relationship with our company	4.83	3.83
10	Membership of trade association	3.17	2.83
11	Provision of credit facility	3.83	2.83
12	Bulk purchase discount	3.00	2.00
	Variability = 0.5836		
	Buyer		
1	Competitive price	13.50	3.50
2	Prompt delivery of materials to site	13.50	2.50
3	Provision of fixing services	13.33	2.67
4	Provision of storage facilities	13.33	2.33
5	Nearness to site	10.83	2.83
6	Supply of high quality materials	10.00	3.00
7	Prompt treatment of invoice	8.83	1.83
8	Availability of credit facility	8.00	2.00
9	Consistency in quoting for us	7.33	3.33
10	Relationship with our company	5.50	3.50
11	Bulk purchase discount	4.83	4.17
12	Receipt of quotation on time	3.33	1.67
13	Prompt replacement of defective materials	3.33	2.67
	Variability = 0.6629		

The constructs which are common to the two groups were: "competitive price" (13.50); "prompt delivery of materials on site" (13.50); "ability to provide fixing services" (13.33); "provision of storage facilities on site" (11.50); and "nearness to site" (13.33).

The two groups' results in table 7.6 clearly demonstrate that both Estimators and Buyers considered common constructs when choosing material suppliers.

The explanation provided by refurbishment contractors for using these constructs were as follows:

i) Prompt delivery of materials to site

Refurbishment work imposes restricted access for material delivery. Usually, deliveries of materials are meticulously planned and programmed.The slightest delay or failure to deliver the material at the arranged time may mean a further one week delay due to stringent restrictions that maybe imposed by the client or the local authority. The client usually imposes restricted delivery hours. For instance, there might be restrictions on the movement of delivery vehicles or access may be restricted within a certain time of the day or at night time or weekends. Also, failure to deliver the material at the required date may result in serious financial losses to the contractor.

ii) Quality of materials

As mentioned in section 7.4.1.4, most refurbishment work may involve the refurbishment of buildings with high historical value. It may include the refurbishment of an art theatre, churches or banks. Some of the materials that would be used on such projects may include "one off" ornamental stained glass windows, which only few material suppliers are capable of meeting the prescribed specification. The quality and nature of materials required for such work are unique. In some cases materials may have to be manufactured specifically for the project or imported from abroad.

iii) Nearness to site

Refurbishment contractors also preferred to use suppliers who are nearer to the project site or those suppliers with material depots near to the project site. This will also help the contractor to cut down the material transportation costs and relieve the pressure on the management who would have to plan and co-ordinate the flow of materials to the site to ensure that the delivery of materials does not disrupt the work programme. This problem is further compounded when the project is in a city centre site, where there is usually traffic restrictions (for example, access highway load limitation) which may permit loading and unloading of materials at specified times and may also restrict the movement of certain vehicles in an area.

iv) Ability to provide fixing services

Refurbishment projects require a sub-contractor with technical knowledge for matching existing materials to new ones to blend perfectly. Also, ability to fix material in a restricted surrounding. These operations are particularly difficult because of the close proximity of surrounding buildings and services. Fixing techniques vary from one building to another. Work is often slow and difficult due to the confined space available for workmen and difficult positions and postures that workmen would have to assume to avoid disturbing the occupying tenants or knocking down existing structures. Also, the fixing of materials may be restricted to certain times of the day. It may mean the fixing of materials at odd hours or at night time in poorly lit surroundings or in basements.

v) Competitive price

The small units of work and non-continuous operations at different locations within the building make it difficult to assess the exact cost of the material requirement for the project. Also materials handling costs are hard to determine because of the difficulties involved in hoisting up small quantities of materials and access through small openings. Usually the Buyer opts for a supplier that would give the firm a generous discount.

vi) Provision of storage facilities

Site constraints are usually the unique features of most refurbishment work and this causes enormous problems in the storage and handling of materials on site. These problems are compounded if the building site is in occupation/or in a city centre. Contractors prefer to use suppliers who can provide them with temporary materials storage containers which they would use to store materials close to the site for easier accessibility. This measure would cut down the problem of the contractor having to move materials a long distance, which can be very expensive and also reduces the problem of material damage/pilferage which usually results from this type of transportation. This is particularly important in city centre sites where space for the storage of materials may not be available.

7.4.1.11 Material supplier least meaningful constructs

The results in the table also indicated materials with lowest variation. From table 7.6, the construct with the lowest variation is " discount for bulk purchase".

The reason the contractors gave for this was that most refurbishment work are in small packages comprising different trades/materials. Materials are usually purchased in small quantities and thus there is no benefit of bulk purchase to the contractor. There are usually problems of inadequate site storage facilities which restrict the amount of materials that could be stored on site at any one time.

7.4.1.12 Variability of constructs

The variability of the two groups constructs ranges between 0.5836 to 0.6629, whilst the mean ratings of the three groups varies between a minimum of 1.67 to a maximum of 4.17 as shown in table 7.6. These two values show that there is a general agreement in the rating of the various constructs among the contractors. However, the variability of the Buyers' constructs are much hire than that of the Estimators. This indicates that Buyers view these constructs as being more essential in choosing material suppliers than the Estimators.

7.4.1.13 Analysis of Plant hirers' grids

The Estimators' plant hirer's construct variation range from a minimum of 1.50 to a maximum of 15.33 while that of the Buyer's constructs range from a minimum of 5.33 to maximum of 13.33.

The two groups' construct systems displayed marked similarities. Both groups indicated "technically qualified and experienced plant operator"(15.33); "prompt repair of broken down plant"(13.33); "competitive price" (13.33); "plant variety" (10.83); and "nearness to site" (10.00) as the most meaningful constructs. The explanation provided by refurbishment contractors for using these constructs were as follows:

i) Technically experienced plant operator

Due to the nature of restricted access in which refurbishment work is carried out, special skill may be needed to use certain plant, for example non-standard cranes. Usually, special types of plant are required on the site, for example special scaffolding, tie backs, lifting plant and boring tools which required an operator with technical expertise to operate the plant in difficult surroundings.

Table 7.7 Plant Hirers' Constructs Variation

S/N	Most Valued Constructs	Variation	Mean Rating
	Estimator		
1	Technical qualified and experienced operator	15.33	2.33
2	Prompt repair of broken down plant	13.33	3.33
3	Competitive price	10.83	3.17
4	Large selection of plant	10.00	3.00
5	Nearness to site	9.50	3.50
6	Prompt treatment of invoice	7.30	3.33
7	Good plant maintenance records	6.83	4.17
8	Long term hiring facility	5.50	3.50
9	Relationship with our company	4.00	4.00
10	Plant delivery to site on time	1.50	4.50
	Variability = 0.6219		
	Buyer		
1	Prompt repair of breakdown	13.33	3.33
2	Competitive price	13.33	2.67
3	Technical qualified and experienced operator	10.83	3.17
4	Large selection of plant	10.83	3.17
5	Good plant maintenance record	10.83	2.83
6	Nearness to site	10.00	3.00
7	Provision of credit facility	10.00	3.00
8	Prompt treatment of invoice	9.33	2.67
9	Meeting security requirements	7.33	3.33
10	Relationship with our company	5.33	3.33
	Variability = 0.6817		

Buyers usually preferred to use sub-contracting firms who could also provide them with skilled operators and an operator who could handle the plant expertly.

ii) Good plant maintenance record

In refurbishment sites, plant movement is severely restricted and there are many obstructions that the plant have to manoeuvre around, which severely impedes plant efficiency. Thus, a number of breakdowns can occur on site. Many contractors said they only used plant hirers with a good maintenance record.

iii) Variety of plant

The logic is that the more equipment the supplier owns, the more work it can be used to perform. In the majority of refurbishment projects, the mechanical plant used on site are commonly non-conventional due to the constraints imposed by the existing structures and services. This plant range from hand tools to non-standard heavy lifting equipment, for example non-standard cranes with reach and lifting capacity (long lead items e.g. special heating and air conditioning (HVAC) equipment) with attachments for dust and noise reduction. There are only few plant hiring companies who can provide these types of plant.

iv) Competitive price

The small units of work and non-continuous operations at different locations within the building make it difficult to assess plant output rates. It is difficult to determine these rates due to the fact that plant used is commonly non-conventional and also due to the constraints imposed by the existing structures and services plant operations are often slow and difficult due to the confined space available for plant operators. Also, due to the limited space the plant operators would have to work in, there is a high occurrence of breakdown of mechanical plant when compared to new build projects. It is usually very difficult for Estimators to adequately estimate and allow for these costs. Most Estimators usually prefer to use plant companies who can provide them with special discounts.

v) Prompt replacement of breakdown plant

Due to the limited space the plant operators would have to work in on site there are frequent breakdowns of mechanical plant that are used in refurbishment work compared to new build projects. Thus, it is important that broken down plant is promptly replaced or repaired to minimise work disruption.

vi) Nearness to project site

The local authority may impose restrictions on the movement of heavy plant. Also, there may be traffic regulations on the use of public roads by certain plant. Therefore, refurbishment contractors usually prefer to use local plant hiring firms who have offices and plant depots nearer to the project sites. This is particularly important in city centre sites, where space for the storage of plant may not be available.

7.4.1.14 Variability of constructs

The variability of the two groups' constructs varies between 0.6219 to 0.6817, whilst the mean ratings of the three groups varies between a minimum of 2.33 to a maximum of 4.50 as shown in table 7.7. These values show that there is an agreement in the rating of the various constructs among the contractors. However, the variability of the Buyer' constructs are much higher than those of the Estimators. This indicates that the Buyers view these constructs as been of greater importance in choosing plant hirers than the Estimators.

7.5 Correlation Analysis for the Groups Grid

7.5.1 Introduction

In order to investigate further the construct commonality which the above results indicated and also to investigate if there is any conceptual relationship between the groups constructs system, the COIN programme of Slater (1) was used. This programme compares two or more grids with the same constructs. The COIN programme calculates and lists the correlation of each Grid in the set and the average correlation of each construct.

All constructs were normalised to facilitate comparison across all constructs as well as providing a rationale for determining their correlation from origin. It is assumed that the lower the correlation the greater the amount of disagreement.

The domestic sub-contractors' Grid was formed by aligning the Estimators, Buyers and Contracts directors' Grids by the twenty two common constructs and ten elements. The Grids comprised of sixty six rows of constructs and ten columns of elements.

The labour only sub-contractors' Grid was formed by aligning the Estimators', Buyers' and Contracts Directors Grids' by the twelve common constructs and eight elements. The Grid comprised of thirty six rows of constructs and eight columns of elements.

The materials suppliers' Grid was formed by aligning the Estimators' and Buyers' Grids by ten common constructs and six elements. The Grid comprised twenty rows of constructs and six columns of elements.
The plant hirers' Grid was formed by aligning the Estimators' and Buyers' Grids by the eight common constructs and six elements. The Grid comprised sixteen rows of

constructs and six columns of elements. The detailed result of the computer output produced from the analysis of the combined Grid with COIN is displayed in tables 7.8 to 7.11.

7.5.2 Domestic sub-contractors, consensus grid

Table 7.8 Domestic Sub-contractors' Correlation Results for Estimators, Buyers and Contracts Directors

S/N	Constructs	Correlations
1	Relationship with site staff	0.952
2	Maintenance of schedule	0.928
3	Trade reference	0.852
4	Safety programme	0.850
5	Site decision implementation	0.835
6	Quality of workmanship	0.830
7	Adequate cashflow	0.818
8	Reliability and trustworthiness	0.800
9	Maintenance of tidy site	0.788
10	Pricing of all BOQ rates	0.792
11	Technical competence	0.779
12	Keen to work for us	0.756
13	Contract document experience	0.745
14	Financial strength	0.739
15	Work area experience	0.739
16	Client approval	0.727
17	Management capability	0.721
18	Job size experience	0.721
19	BOQ priced rates consistency	0.711
20	Work programme agreement and implementation	0.709
21	Reasonable claims	0.708
22	Competitive bid	0.648

The results of the correlation analysis for domestic sub-contractors in table 7.8 indicated that the correlation among the 22 common constructs ranged from a minimum of 0.648 to a maximum of 0.952. This suggested that there was a strong agreement among the groups on these constructs. There were two constructs where the correlations were particularly strong. These were "maintenance of work programme" (0.928); and "relationship with site staff" (0.952) and a surprisingly low correlation by "competitive bid" 0.648.

A plausible explanation for this very strong correlation may be attributable to the unique features of refurbishment work. Refurbishment clients usually demand very short completion periods in most of their contracts. This is mainly due to the nature of refurbishment projects where the majority of clients maybe in occupation while work is going on and would not want to put up with the noise and dust and other disturbances caused by the work activities any longer than necessary. A few clients who may not be in occupation would want to take possession of the completed building within a very short period. It is usual for refurbishment clients to insert liquidated damages clauses in the contract agreements. Ability to work on weekends, during holidays and odd hours are important ingredients which both Estimators, Buyers, and Contracts Directors look for when evaluating sub-contractors, since work flexibility is vital in refurbishment projects.

Also refurbishment contracts involve "crises management" and this places considerable strain and pressure on contractor's site supervisory staff. There is therefore, a need to have a sub-contractor that would 'get on' with the Contracts Director and his supervisory site staff.

It is surprising to notice that the construct "competitive bid" has one of the lowest correlations. The only possible explanation for this is that it is not uncommon for refurbishment contractors to use a sub-contractor who may not necessarily have submitted the lowest bid but may possess the technical capability and competence to complete the project faster and to offer a better quality of workmanship than others. By taking this action, the contractor would probably increase his overall bid thereby taking the risk of not winning the job but assuring more profit if he did win the job. Alternatively, the contractor may absorb the cost difference himself or try to have the sub-contractor absorb it or try to negotiate the sharing of the differences with the sub-contractor he wants to use on the project. Also, evaluation of a competitive bid should be balanced with the abilities of the sub-contractor to finish the work within the budget and contract amount, how well scheduling is used and the sub-contractor's skills in pre-construction planning and organisation, as well as the amount of claims filed during the construction of the project and the reasonableness of the sub-contractor's work valuations.

7.5.3 Labour only subcontractors' consensus grid

A similar analysis using the labour only sub-contractor's combined grid was performed. The results obtained are shown in table 7.9. All the constructs display a very strong correlation (0.606 to 0.970). These results suggested that there was a strong agreement among the groups on the constructs. In particular, constructs "safety programme" (0.970); "size of workforce" (0.909) and "experienced foreman" (0.818) have very strong correlations.

The reasons for the high correlation on "safety programme" could be attributable to the fact that refurbishment work is more dangerous than new build, due to its inherently uncertain nature. For example, there is a large proportion of demolition work, stripping of toxic asbestos and dangerous moving structures.

Table 7.9: Labour-Only Sub-contractors' Correlation Results for Estimators, Buyers and Contracts Directors

S/N	Constructs	Correlations
1	Safety programme	0.970
2	Size of sub-contractor labour force	0.909
3	Experienced foreman	0.818
4	Attendance of site meeting	0.782
5	Quality of workmanship	0.770
6	Work reference	0.776
7	Decision implementation	0.758
8	Competitive bid	0.727
9	Inflationary claims	0.721
10	Prompt start on site	0.706
11	Contact address	0.702
12	Technical competence	0.606

Also, protective screens may have to be erected to reduce the noise and dust that would come from the construction and to ensure the safety and comfort of the general public and building occupants as well as the workmen. Also, the majority of the buildings in which the majority of sub-contractors would have to work may be in a very poor structural condition and require a well thought out safety programme to minimise the likelihood of accidents on site. Most refurbishment contractors interviewed, and in particular the Contracts directors, said they usually used a sub-contractor with a good safety programme to reduce the likelihood of accidents on site.

Also, when refurbishing buildings which are in occupation, existing services must be maintained either through relocation or the provision of temporary services. Thus, there is a need to chose a firm who has an experienced site foreman in this type of work. Refurbishment work is also labour intensive when compared to new build. Work is often slow and difficult due to the confined space available for workmen and difficult positions and postures that workmen would have to assume to avoid knocking down existing services and structures. Also, in most cases tenants would be in occupation.

This makes work operations very difficult and painfully slow thus contributing immensely to the reduction in labour output. The majority of the contractors interviewed preferred to use a sub-contractor who was prepared to put sufficient workmen on site to complete the job on time and within the programme.

In table 7.9, the construct "technical competence" has a correlations of (0.606). A plausible explanation for this may be attributed to the differences in the skill required or involved in the execution of refurbishment projects. For instance, ground work and electrical sub-contractors must possess a high technical skill whereas a bricklayer or carpenter need not have quite the same technical skills. Brickwork and carpentry trades are usually simpler and involve fewer risks.

Also, in trades like groundworks, electrical, lift installation, and piling projects, huge costs and profits are usually involved for both contractors and sub-contractors, compared to that involved in brickwork contracts. As such, it requires the heavy commitment of resources. Only a limited number of sub-contractors are competent to undertake such trades. Such trades involve a high proportion of specialist work and protective measures such as noise and dust protection.

7.5.4 Material suppliers' consensus grid

Similarly correlation analysis using material suppliers was performed. The results obtained are shown in table 7.10. There were *nine* constructs where the correlations were very strong and *one* construct whose correlation was not very strong "site fixing of materials" (0.582).

Table 7.10 Material Suppliers' Correlation Results for Estimators and Buyers

S/N	Constructs	Correlations
1	Quality of materials	0.859
2	Discount for bulk purchase	0.861
3	Prompt replacement of defective materials	0.855
4	Competitive price	0.842
5	Prompt delivery on site	0.758
6	Nearness to site	0.750
7	Provision of storage facility	0.727
8	Relationship with our company	0.721
9	Prompt treatment of invoice	0.618
10	Provision of fixing services on site	0.582

The result suggested that there was a stronger agreement among the groups on the constructs than disagreement. The reason for the low correlation for materials fixing on site could be attributed to the differences in the size of the company. Some of the large contractors have within their organisation a materials department. This department is responsible for the purchase and the delivery to site all the materials used in all the contracts. Also, most of these firms have trained staff in-house whose job it is to handle all site materials fixing and, therefore, they do not see these constructs as major problems when evaluating sub-contractors. Most small and medium sized contractors do not have a department specifically designated to purchase and fix materials.

7.5.5: Plant hirers' consensus grid

The correlation of plant hirers represented in table 7.11 suggested that there is quite a strong correlation among all the constructs. Nevertheless, there is one construct "plant variety" (0.602) whose correlation was not very strong but was still significant. A plausible explanation could be attributable to the type of plant used in refurbishment projects. In refurbishment contracts, the majority of plant that is used is non-conventional. However, there were quite a significant number of refurbishment projects where the conventional types of plant were regularly employed.

Table 7.11 Plant Hirers' Correlation Results for Estimators, Buyers and Contracts Directors

S/N	Constructs	Correlations
1	Competitive bid	0.830
2	Nearness to site	0.824
3	Prompt repair of breakdown plant	0.788
4	Prompt treatment of invoice	0.757
5	Plant maintenance record	0.709
6	Relationship with our company	0.703
7	Provision of drivers and banksman	0.700
8	Plant variety	0.602

7.6 Principal component analysis

7.6.1 Introduction

The principal component form of analysis was developed as a method for simplifying the records of a large number of correlated variables by reducing them to a possible smaller number of independent measurements, ordered from largest to the least according to the amount of variation they recorded. Principal component analysis involves transforming an original set of variables into a set of hypothetical variables which are uncorrelated. The first hypothetical variable or component is derived in such a way that it accounts for the maximum variance. The second component accounts for the maximum variance subject to being uncorrelated to the first and so on. A detailed description of the analysis is given by Slater (1).

Principal component analysis was performed on the combined Grid of the four trades sub-contractors. The rationale for applying this technique to the combined Grid was the understanding of a large and complex problem with a minimum number of criteria that contribute to the decision. There are two possible interpretations which can be applied to the principal component analysis results.

i) Representation of a problem by a reduced number of significant constructs which explain most of the variations in the grid.
ii) Representation of a problem by including a larger number of constructs, some of which do not significantly explain the variation in the Grid. However, these constructs are helpful in making the decision.

The latter interpretation has been applied to the combined grid analysis. For according to Slater (1), components which show relatively small amounts of variation are not necessarily devoid of psychological interest.

In identifying the principal constructs that constitute a component, it must be remembered that each of the constructs elicited from the contractors was bi-polar. Thus, in briefly describing the constructs with a high loading on a component, one must not forget that when the construct "quality of workmanship " was elicited, the contractor had considered the range available (that is both poles of the constructs) and then made a judgement.

In the selection of constructs the researcher adopted a convention of considering only those constructs with a loading greater than that corresponding to a vector value of ±0.300 (that is vector loading greater than 0.300 or less than -0.300).

7.6.2 Domestic sub-contractor's principal component analysis

The constructs which were shown to carry heavy loadings in Component One were "competitive bid" (0.8857); "technical competence" (0.8535); "quality of workmanship" (0.8047); "work area experience"(-0.7824). The second Component revealed the following constructs with loading vector value over ±0.300 "safety records" (0.6618); and "financial strength" (-0.5871).

Table 7.12 Principal Component Analysis Results for Domestic Sub-contractors

Constructs	Component One		Component Two	
	Vector	Loading	Vector	Loading
Competitive bid	0.3522	0.8857		
Technical competence	0.3394	0.8535		
Quality of workmanship	0.3112	0.8047		
Work area experience	-0.3112	-0.7824		
Financial strength			0.3503	0.6618
Safety records			-0.3108	-0.5871

7.6.3 Labour-only sub-contractor's principal component analysis

The principal component analysis for the labour only sub-contractors' combined grids is outlined in table 7.13 and also revealed that there were two components with vector value greater than ±0.300.

Table 7.13 Principal Component Analysis Results for Labour-Only Sub-contractors

Constructs	Component One		Component Two	
	Vector	Loading	Vector	Loading
Competitive bid	0.3896	0.8581		
Quality of workmanship	0.3685	0.8118		
Maintenance of work schedule	0.3621	0.7974		
Work area experience	-0.3805	-0.8380		
Safety programme			0.3949	0.8027
Contact address			-0.3173	-0.6450

The constructs which were shown to carry heavy loadings were "competitive bid" (0.8581); "quality of workmanship" (0.8118); "maintenance of work schedule" (0.7974); and "work area experience" (-0.8380). The second Component revealed the following constructs with loading vectors valued over ±0.300 "safety programme" (0.8024); and "contact address" (0.6450).

7.6.4 Principal component analysis for material suppliers and plant hirers

Similarly, principal component analysis was performed on the material suppliers' and plant hirers combined grids and their results are represented in tables 7.14 and 7.15. The constructs with loading values over ±0.300 for the material suppliers in the first Component were "competitive price" (0.9644); "prompt delivery of materials" (0.8401); and "provision of storage facilities" (-0.8146). The second Component revealed one construct with a loading vector value over ±0.300 "quality of materials" (0.5647). For plant hirers the following constructs have loading over ±0.300 in the first component "variety of plant" (0.8126); and "competitive price" (0.7673). The second Component revealed the following constructs with loading vector value over ±0.300 "prompt replacement of breakdown plant" (0.6268) and technically experienced operator" (0.6099)

Table 7.14 Principal Component Analysis Results for Material Suppliers

Constructs	Component One		Component Two	
	Vector	Loading	Vector	Loading
Competitive price	0.3736	0.9644		
Prompt delivery of materials	0.3255	0.8401		
Provision of storage materials on site	-0.3156	-0.8146		
Quality of materials supplied			0.3250	0.5647

Table 7.15 Principal Component Analysis Results for Plant Hirers

Constructs	Component One		Component Two	
	Vector	Loading	Vector	Loading
Variety of plant	0.3459	0.8126		
Competitive price	0.3266	0.7673		
Replacement of plant			0.3662	0.6268
Experienced plant operator			0.3564	0.6099

7.7 Construct classifications

From the principal component analysis it was found that these constructs elicited from refurbishment contractors may be broadly grouped into four main categories shown in tables 7.16 to 7.19 as follows:

1) Technically related criteria
2) Cost related criteria.
3) Relationship related criteria
4) Scheduling related criteria

(1) Technically related criteria

These are constructs relating to the technical capabilities that the sub-contractor is likely to bring to the proposed contract. They cover areas like; the ability of the sub-contractor to meet the site constructability requirements of refurbishment projects, his level of work experience and the ability to interpret and use the contract documents effectively.

(2) Cost related criteria

These categories of constructs are concerned with the ability of the sub-contractor to complete the work within budget. They also cover things like: ability of the sub-contractor to provide a realistic tender price for his trade, his cost control system, his overall financial strength and the sub-contractors claims record.

(3) Relationship related criteria

These are constructs relating to the sub-contractor's relationship with the contractor's organisation, the client, and all the consultants that would be involved in the contract.

(4) Scheduling related criteria

These are constructs which describe the sub-contractor's ability to meet the work schedule. That is, how well scheduling is used, the sub-contractors skills in pre-contract planning and organisation, and ability to complete his work on time.

Table 7.16 Classification of Domestic Sub-Contractors Constructs

S/N	Classification	Contractors Constructs
1	Technically related criteria	i) Project type experience. ii) Project size experience. iii) Work area experience. iv) Technical competence. v) Quality of workmanship. vi) Maintenance of tidy site. vii) Experienced site foreman. viii) Site organisation capability. ix) Safety programme. x) Quality rated company. xi) Materials specification compliance. xii) Contracts document experience. xiii) Work reference.
2	Cost related criteria	i) Competitive bid. ii) Adequate turnover. iii) Early quotation. iv) Pricing of BOQ items. v) Provision of bonds and warranty. vi) Default experience. vii) Adequate cashflow. viii) Financial strength. ix) Inflated claims.
3	Relationship related criteria	i) Contact address. ii) Keen to work for us. iii) Reliability and trustworthiness. iv) Trade registration. v) Good relationship with our company. vi) Prompt response to calls. vii) Client approval.
4	Scheduling related criteria	i) Work programme agreement. ii) Prompt start on site. iii) Schedule maintenance. iv) Plant and equipment provision. v) Site meeting attendance. vi) Implementation of site decisions.

Table 7.17 Classification of Labour-Only Sub-Contractors Constructs

S/N	Classification	Contractors Constructs
1	Technically related criteria	i) Experienced site foreman. ii) Safety records. iii) Safety programme. iv) Maintenance of tidy site. v) Project type experience. vi) Project size experience. vii) Work area experience. viii) Quality of workmanship. ix) Contracts document experience. x) Work reference.
2	Cost related criteria	i) Early receipt of quotation. ii) Possession of recent tax papers. iii) Competitive bid. iv) Pricing of BOQ items. v) Default experience. vi) Inflated claims. vii) Financial reference.
3	Relationship related criteria	i) Contact address. ii) Keen to work for us. iii) Reliability and trustworthiness. iv) Trade registration. v) Good relationship with our company. vi) Prompt response to calls. vii) Relationship with site staff. viii) Trade union relationship.
4	Scheduling related criteria	i) Work programme agreement. ii) Prompt start on site. iii) Schedule maintenance. iv) Site meeting attendance. v) Plant and equipment provision. vi) Implementation of site decisions. vii) Work completion records.

Table 7.18 Classification of Material Suppliers Constructs

S/N	Classification	Contractors Constructs
1	Technically related criteria	i) Good packaging. ii) Provision of storage facility. iii) Provision of fixing services. iv) Type and quality of materials. v) Quality bond provision. vi) Membership of trade association.
2	Cost related criteria	i) Provision of credit facility. ii) Bulk purchase discount.
3	Relationship related criteria	i) Contact address. ii) Prompt replacement of defective materials. iii) Good working relationship. iv) Prompt response to calls. v) Nearness to site. vi) Consistency in quoting for us. vii) Prompt treatment of invoice.
4	Scheduling related criteria	i) Bulk supplier. ii) Prompt delivery to site.

Table 7.19 Classification of Plant Hirers Constructs

S/N	Classification	Contractors Constructs
1	Technically related criteria	i) Prompt repair of breakdown plant. ii) Large selection of plant. iii) Provision of drivers and banksman. iv) Meeting security requirement.
2	Cost related criteria	i) Competitive price. ii) Provision of credit facility. iii) Receipt of quotation on time.
3	Relationship related criteria	i) Working relationship with our company. ii) Prompt treatment of invoice. iii) Consistency in quoting for us.
4	Scheduling related criteria	i) Plant maintenance record. ii) Nearness to site.

7.8 Principal component analysis of individual contractors constructs

The principal component analysis was performed on each of the thirty contractors who participated in the interviews to identify the most important constructs used by each contractor during the selection and appointment of sub-contractors in refurbishment contracts. From this results, it is possible to identify the most principal constructs for each contractor.

A summary of the three most important constructs for each contractor was extracted from the computer printouts of the principal component analysis as shown in table 7.20. This listing shows the three most important constructs each refurbishment contractor considered whenever they chose their sub-contractors.

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades

Contractor Code	Grouping of Major Constructs
*3 Domestic Subs	Technical competence. Competitive bid. Quality of workmanship.
Labour-Only Subs	Contact address. Trade experience. Competitive bid.
Material Suppliers	Competitive price. Relationship with our company. Prompt replacement of defective. materials at no extra cost.
Plant Hirer	Competitive price. Variety of plant. Prompt repair of breakdown.
*11 Domestic Subs	Competitive bid.. Quality of workmanship Technical competence.
Labour-Only Subs	Contact address. Competitive bid. Trade experience.
Material Suppliers	Prompt replacement of defective. materials at no extra cost. Competitive price. Fixing of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Provision of plant operator.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*12 Domestic Subs	Technical competence. Competitive bid. Quality of workmanship.
Labour-Only Subs	Trade experience. Contact address. Competitive bid.
Material Suppliers	Competitive price. Prompt replacement of defective materials. Prompt treatment of invoice.
Plant Hirer	Competitive price. Prompt repair of breakdown. Prompt treatment of invoice.
*15 Domestic Subs	Trade reference. Competitive bid. Technical competence.
Labour-Only Subs	Work area experience. Contact address. Competitive bid.
Material Suppliers	Competitive price. Prompt replacement of defective materials. Fixing of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*32 Domestic Subs	Work design. Competitive bid. Quality of workmanship.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Prompt replacement of defective materials. Nearness to work area.
Plant Hirer	Competitive price. Prompt repair of breakdown. Good relationship with our firm.
*37 Domestic Subs	Competitive bid. Work area experience. Contact address.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Provision of fixing services. Quality of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*20 Domestic Subs	Good relationship with our firm. Work area experience. Consistency of priced rates.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Provision of fixing services. Quality of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.
*16 Domestic Subs	Good relationship with our firm. Work area experience. Consistency of priced rates.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Provision of fixing services. Quality of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*5 Domestic Subs	Good relationship with our firm. Work area experience. Consistency of priced rates.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Provision of fixing services. Quality of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.
*9 Domestic Subs	Work design. Competitive bid. Quality of workmanship.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Prompt replacement of defective materials. Nearness to work area.
Plant Hirer	Competitive price. Prompt repair of breakdown. Good relationship with our firm.

Contractors' reference number that participated in the knowledge acquisition exercises.

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*29 Domestic Subs	Trade reference. Competitive bid. Technical competence.
Labour-Only Subs	Work area experience. Contact address. Competitive bid.
Material Suppliers	Competitive price. Prompt replacement of defective materials. Fixing of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.
*27 Domestic Subs	Good relationship with our firm. Work area experience. Consistency of priced rates.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Provision of fixing services. Quality of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*30	
Domestic Subs	Competitive bid. Technical competence. Consistency of priced rates.
Labour-Only Subs	Competitive bid. Contact address. Quality of workmanship.
Material Suppliers	Competitive price. Provision of storage facilities. Nearness to site.
Plant Hirer	Competitive price. Provision of storage facilities. Nearness to site.
*14	
Domestic Subs	Technical competence. Quality of workmanship. Competitive bid.
Labour-Only Subs	Contact address. Quality of workmanship. Work area experience.
Material Suppliers	Prompt replacement of defective materials. Provision of fixing for materials. Competitive price.
Plant Hirer	Competitive price. Prompt repair of plant. Nearness to site.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*7 Domestic Subs	Work area experience. Competitive bid. Consistency of priced rate.
Labour-Only Subs	Work area experience. Contact address. Competitive bid.
Material Suppliers	Competitive price. Prompt replacement of defective materials. Prompt treatment of invoice.
Plant Hirer	Competitive price. Good relationship with our firm. Variety of plant.
*18 Domestic Subs	Competitive bid. Work area experience. Technical competence.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Provision of fixing services. Quality of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*33	
Domestic Subs	Work reference. Technical competence. Consistency of priced rates.
Labour-Only Subs	Competitive bid. Contact address. Quality of workmanship.
Material Suppliers	Competitive price. Provision of storage facilities. Nearness to site.
Plant Hirer	Competitive price. Prompt treatment of invoice Plant maintenance
*4	
Domestic Subs	Good relationship with our firm. Work area experience. Consistency of priced rates.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Provision of fixing services. Quality of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.

Contractors' reference number that participated in the knowledge acquisition exercises.

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*6 Domestic Subs	Work design. Competitive bid. Quality of workmanship.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Prompt replacement of defective materials. Nearness to work area.
Plant Hirer	Competitive price. Prompt repair of breakdown. Good relationship with our firm.
*10 Domestic Subs	Trade reference. Competitive bid. Technical competence.
Labour-Only Subs	Work area experience. Contact address. Competitive bid.
Material Suppliers	Competitive price Prompt replacement of defective materials Fixing of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*25 Domestic Subs	Good relationship with our firm. Work area experience. Consistency of priced rates.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Provision of fixing services. Quality of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.
*35 Domestic Subs	Competitive bid. Technical competence. Consistency of priced rates.
Labour-Only Subs	Competitive bid. Contact address. Quality of workmanship.
Material Suppliers	Competitive price. Provision of storage facilities. Nearness to site.
Plant Hirer	Competitive price. Prompt treatment of invoice. Plant maintenance.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*38 Domestic Subs	Technical competence. Quality of workmanship. Competitive bid.
Labour-Only Subs	Contact address. Quality of workmanship. Work area experience.
Material Suppliers	Prompt replacement of defective materials. Provision of fixing for materials. Competitive price.
Plant Hirer	Competitive price. Prompt repair of plant. Nearness to site.
*40 Domestic Subs	Work area experience. Competitive bid. Consistency of priced rate.
Labour-Only Subs	Work area experience. Contact address. Competitive bid.
Material Suppliers	Competitive price. Prompt replacement of defective materials. Prompt treatment of invoice.
Plant Hirer	Competitive price. Good relationship with our firm. Variety of plant.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*45 Domestic Subs	Competitive bid. Work area experience. Technical competence.
Labour-Only Subs	Competitive bid. Work area experience. Contact address.
Material Suppliers	Competitive price. Provision of fixing services. Quality of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.
*42 Domestic Subs	Work reference. Technical competence. Consistency of priced rates.
Labour-Only Subs	Competitive bid. Contact address. Quality of workmanship.
Material Suppliers	Competitive price. Provision of storage facilities. Nearness to site.
Plant Hirer	Competitive price. Prompt treatment of invoice. Plant maintenance.

Contractors' reference number that participated in the knowledge acquisition exercises.

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*50 Domestic Subs	Technical competence. Competitive bid. Quality of workmanship.
Labour-Only Subs	Contact address. Trade experience. Competitive bid.
Material Suppliers	Competitive price. Relationship with our company. Prompt replacement of defective materials. at no extra cost.
Plant Hirer	Competitive price. Variety of plant. Prompt repair of breakdown.
*54 Domestic Subs	Competitive bid. Quality of workmanship. Technical competence.
Labour-Only Subs	Contact address. Competitive bid. Trade experience.
Material Suppliers	Prompt replacement of defective materials. at no extra cost. Competitive price. Fixing of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Provision of plant operator.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

Table 7.20 Principal Component Analysis Results of Contractors Grid and Grouping of Individual Contractors Most Important Constructs for Different Trades cont-

*59 Domestic Subs	Technical competence. Competitive bid. Quality of workmanship.
Labour-Only Subs	Trade experience. Contact address. Competitive bid.
Materials Suppliers	Competitive price. Prompt replacement of defective materials. Prompt treatment of invoice.
Plant Hirer	Competitive price. Prompt repair of breakdown. Prompt treatment of invoice.
*22 Domestic Subs	Trade reference. Competitive bid. Technical competence.
Labour-Only Subs	Work area experience. Contact address. Competitive bid.
Material Suppliers	Competitive price. Prompt replacement of defective materials. Fixing of materials.
Plant Hirer	Competitive price. Prompt repair of breakdown. Variety of plant.

**Contractors' reference number that participated in the knowledge acquisition exercises.*

As represented in table 7.20, it was observed that most contractors employed similar constructs when they chose their sub-contractors. Thus it can be concluded that constructs like "competitive bid", "technical competence" and "quality of workmanship" were frequently used by most refurbishment contractors.

7.9 Principal component analysis for ideal and least preferred sub-contractor

During the grid elicitation interview each refurbishment contractor was also requested to enumerate the criteria for an ideal and least preferred sub-contractor (section 5.5.2.12). The objective for this was to explore whether all contractors shared the same opinion with regard to their ideal and least preferred sub-contractors. There were two principal components which had vectors value of ±0.300.

The key criteria obtained from all refurbishment contractors for the ideal and least preferred sub-contractor are listed in tables 7.21 and 7.22 respectively.

Table 7.21: Major Constructs Pole Related to an Ideal Sub-Contractor

Types of sub-contractors	Ideal Sub-contractor major constructs
Domestic Sub-Contractor	(a) Ability to do all types of work for which eligibility is requested. (b) Competitive bid. (c) Ability to prepare a bona fide bid. (d) Technical competence. (e) Ability to meet performance schedule. (f) Quality of workmanship. (g) Honesty and reliability. (h) Good design experience. (i) Safety programme. (j) Work area experience.
Labour-Only Sub-Contractor	(a) Quality of workmanship. (b) Contact address. (c) Competitive bid. (d) Integrity and skill of workforce. (e) Good relationship with our firm. (f) Safety programme.

Table 7.21: Major Constructs Pole Related to the ideal Sub-Contractor cont:-

Material Supplier	(a) Competitive price. (b) Prompt replacement of defective materials. (c) Ability to provide fixing for materials. (d) Prompt delivery of materials. (e) Ability to provide storage facilities on site.
Plant Hirer	(a) Competitive price. (b) Adequacy of plant and equipment. (c) Prompt repair of breakdown plant. (d) Good relationship with our firm.

Table 7.22: Major Constructs Pole Related to the Least Preferred Sub-Contractor

Categorisation of least preferred sub-contractors' constructs	
Types of sub-contractors	CONSTRUCTS
Domestic Sub-Contractor	(a) Uncompetitive bid. (b) Failure to complete the work or project in accordance with specs and contract conditions. (c) Failure to refund over payment. (d) Lack of competence. (e) Poor quality of workmanship. (f) Incomplete pricing of BOQ. (g) Previous default experience and work abandonment. (h) Submission of unbalanced bid. (i) False certification. (j) Poor work design. (k) Past conviction of criminal offence.

Table 7.22: Major Constructs Pole Related to the Least Preferred Sub-Contractor cont:-

Labour-Only Sub-Contractor	(a) Being in arrears on existing or previous contracts. (b) Uncompetitive bid. (c) Failure to submit documents requested by the contractor. (d) Delay in work completion and failure to pay liquidated damages. (e) Abandonment of work and delinquent progress. (f) Continual failure to do acceptable work. (g) Abandonment of work. (h) Lack of competence.
Material Supplier	(a) Long delay in replacing defective materials (b) Serious delay in delivering materials to site. (c) Overcharging for materials supplied. (d) Long delay in the treatment of invoice. (e) Uncompetitive price.
Plant Hirer	(a) Long delay in replacing. breakdown plant. (b) Uncompetitive price. (c) Poor working relationship with our firm. (d) Long delay in the treatment of. invoice.

7.10 Hierarchical Rule-based decision model

The principal component analysis of ideal and least preferred sub-contractor formed the basis for a hierarchical decision framework for the sub-contractor selection and appointment model. The model provides a means for decomposing the refurbishment contractors' selection and appointment decision-making process into a number of sub processes, thus formalising the sub-contractor's evaluation process.

The constructs from the two components are shown in table 7.21 and 7.22. Using these constructs, it was possible to develop a simple hierarchical inference network for the refurbishment contractors, sub-contractor's selection decision-making strategy which is represented in figure 7.1.

FIGURE 7.1 SSARC INFERENCE NETWORK

The model also provides a logical method of sub dividing the key criteria into a number of sub-criteria. Thus, there exists a hierarchy of sub-criteria upon which each criterion is dependent. Associated with each criterion and sub-criteria are simple decision rules. The decision rules are represented as an object oriented knowledge representation format. The rational for this model is two-fold. Firstly, to provide refurbishment contractors with a structured aid to the decision making involved in the selection of a suitable sub-contractor. Secondly as an attempt to compile a simple heuristic sub-contractor selection decision making process for use in the knowledge based decision support system.

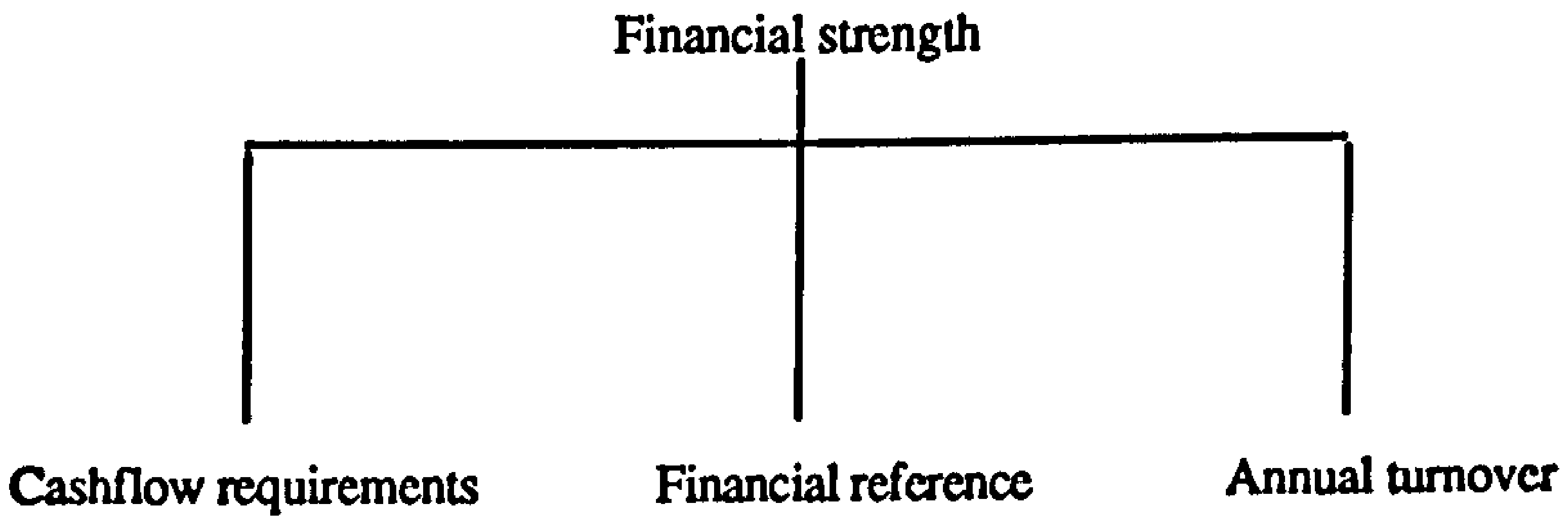
7.11 Degree of Detail

The level of detail required for any trade will primarily be a function of the project size and complexity. The rationale for including the above detail is to provide the user of the model with a structured system to aid sub-contractor selection and appointment decisions. It is a management decision and, therefore, the prerogative of the model user to include or exclude items he feels are appropriate or inappropriate for the evaluation.

7.12 Knowledge representation and uncertain inference

Each criterion within the knowledge base has a series of attributes or sub-criteria. The sub-criteria help to describe the main characteristic of the proposition. For example, the criterion financial strength is composed of three sub-criteria as shown in figure 7.2.

Figure 7.2: Financial Strength Representation



If financial_strength is (excellent,Good,Satisfactory,Fair,Awful) done
and cash_flow_requirement is done
and financial_reference is done
and annual_turnover is done
Then financial strength is done

For example, if we restrict the system to deal with the evaluation of one trade sub-contractor, say an electrician; also, if we assume there are three sub-contractors to be evaluated (SubA, SubB, SubC). The criterion to be borne in mind when making this evaluation could be the financial strength of the sub-contractor. The ratings for the sub criteria could be "excellent", "good", "satisfactory", "fair" and "awful". The degree of importance for these criteria on the proposed project could also be "extremely important" "very important", "important", "not very important", and "unimportant."

Setting this up as a rule based system, would look something like this:

```
If financial_strength_required is extremely important
    and cash_flow_requirement is excellent
    and  financial_reference is satisfactory
    and annual_turnover is good
then Suitable_subcontractor include subA

If financial_strength_required is important
    and cash_flow_requirement is good
    and  financial_reference is satisfactory
    and annual_turnover is satisfactory
then Suitable_subcontractor include subB

If financial_strength_required is unimportant
    and cash_flow_requirement is satisfactory
    and  financial_reference is satisfactory
    and annual_turnover is good
then Suitable_subcontractor include subC

seek suitable subcontractor
```

However, if the above illustration is expanded to cover all the alternative values of the concerned variables, that is the false status of the above conditions, extensive rules would have to be written in order to satisfy all possible outcomes. It is easy to see that the size of the rule base quickly becomes very large.

Moreover, if all the criteria required to operate the system were to be written in If...Then rules, then it would be accompanied by enormous expansion in the number of rules required for the whole system.

This would make the system very difficult to be expanded, updated and maintained. The implication of this is that adding an extra rule to a large rule base system will almost always cause unpredictable results.

Clearly, these problems are compounded if the knowledge based system is to be used to gather feedback from the contractors from whom the grid was elicited, as is generally the situation in grid based studies. A better plan is to recognise that all sub-contractors' ratings and degrees of importance are instances of the general class of object called a sub-contractor. It is possible then to store the particular criteria with the associated ratings and degree of importance of any trade sub-contractor in a frame for that instance. Then a single rule can be used to search the whole class of sub-contractors.

For example, using the above illustration

```
for all subcontractors
          If fin_stre_required is deg of imp: of sub
          and cash_flow is cashflow: of sub
          and fin_ref is fin_ref: of sub
          and annual_turnover is annual_turnover: of sub
          Then suitable_sub includes ratings:of sub
seek suitable_sub
```

As more knowledge about various trades and their sub-contractors is added to the knowledge base, it is only necessary to create a new frame for the new sub-trade, without increasing the size of the rule base.

7.13 Conclusion

The elicited grids from chief Estimators, Buyers and Contracts Directors were analysed with INGRIDA. The objectives and methods of analysing a Repertory Grid by this method have been discussed.

The most significant results obtained can be summarised as:

i) Estimators, Buyers, and Contracts Directors all applied similar criteria when choosing sub-contractors. Also, from the grid analysis, it was possible to identify the most important and least important constructs that these groups considered when they chose their sub-contractors.

ii) The combined grids formed by aligning the groups' grids suggested the existence of conceptual relationships between constructs used for decision-making. The relevance of construct relationships derived from the combined grids is not only that they highlighted the existence of conceptual relationships between the groups' constructs, it also validated the earlier interpretations of constructs commonality derived from the groups' individual grids and also draws attention to the similarities and differences between Chief Estimators', Buyers' and Contracts Directors' decision-processes regarding sub-contractor selection.

iii) The constructs were found to complement each other rather than contradict each other and thereby provide a broader insight into the groups' decision making processes.

iv) There was also a high level of agreement between these experts regarding the relative degree of importance attached to these criteria.

v) The results of the principal component analysis identified the key criteria that influence the decision-making process when choosing sub-contractor. Furthermore, the number of pertinent decision parameters has been reduced to a more manageable number for effective decision-making.

Each of these identified criteria was characterised by relevant sub-criteria. As a result, the hierarchical decision model for refurbishment contractors based on the contractors' ideal and least preferred sub-contractor was formulated by combining their respective views, thereby encompassing a broad based selection perspective. This facilitated a structured systematic, and rationale approach to the sub-contractor selection decision-making processes used by refurbishment contractors.

The hierarchical rule base illustrates how rules can be used to manipulate information from one frame to another using values of various slots. This combination, that is frames and rules, offers a very powerful tool for representing knowledge. Updating, maintaining and expansion of the system can be achieved with relative ease. Information concerning a particular object can be traced easily by calling its frame. Information can be changed, rules can be updated if necessary and new information can be added. This feature makes such representation more favourable than using production rules only. The result confirms that refurbishment contractors use similar constructs when choosing sub-contractors.

CHAPTER EIGHT

MODEL DESCRIPTION

CHAPTER EIGHT

MODEL DESCRIPTION

8.1 Introduction

This chapter describes the sub-contractor selection and appointment model for refurbishment contractors (SSARC), a prototype knowledge based decision support system which has been developed to aid refurbishment contractors with the selection and appointment of their sub-contractors.

The systems knowledge is coded in a Leonardo 3 expert system shell. SSARC has been developed to run on any IBM compatible PC's supporting MS-DOS.

8.2 General Features

The general features of SSARC are shown in figures 8.1 and 8.2. It consists of the **user interface, inference engine, knowledge bases and external programme.** The implementation of SSARC in the Leonardo expert system shell allows the user to interact with the system in a very friendly manner using natural language expressions implemented in fuzzy logic. The user's communication with the system is via the *user interface* (menu selection). Help is available to the user at most points of the consultation. The system can explain 'why' it asked a question, what the terms in the question mean and how it reached a particular conclusion. The system has a 'WHY' option that allows the user to follow the "chain" of reasoning SSARC used to arrive at a particular conclusion.

8.3 Knowledge Base

The knowledge base is represented in a unique frame structure. Frames are types of data bases for representing characteristics and features of objects. A frame consists of a number of attributes called slots in which different characteristics and features of an object or chunk of information are described. For instance, all sub-contractor's evaluative constructs for example "quality of workmanship", "safety programmes", "financial strength" to mention just three constructs evaluated by SSARC are described together with other data kept on a particular sub-contractor necessary to carry out the evaluation are described.

FIGURE 8.1: GENERAL FEATURES OF SSARC MODEL

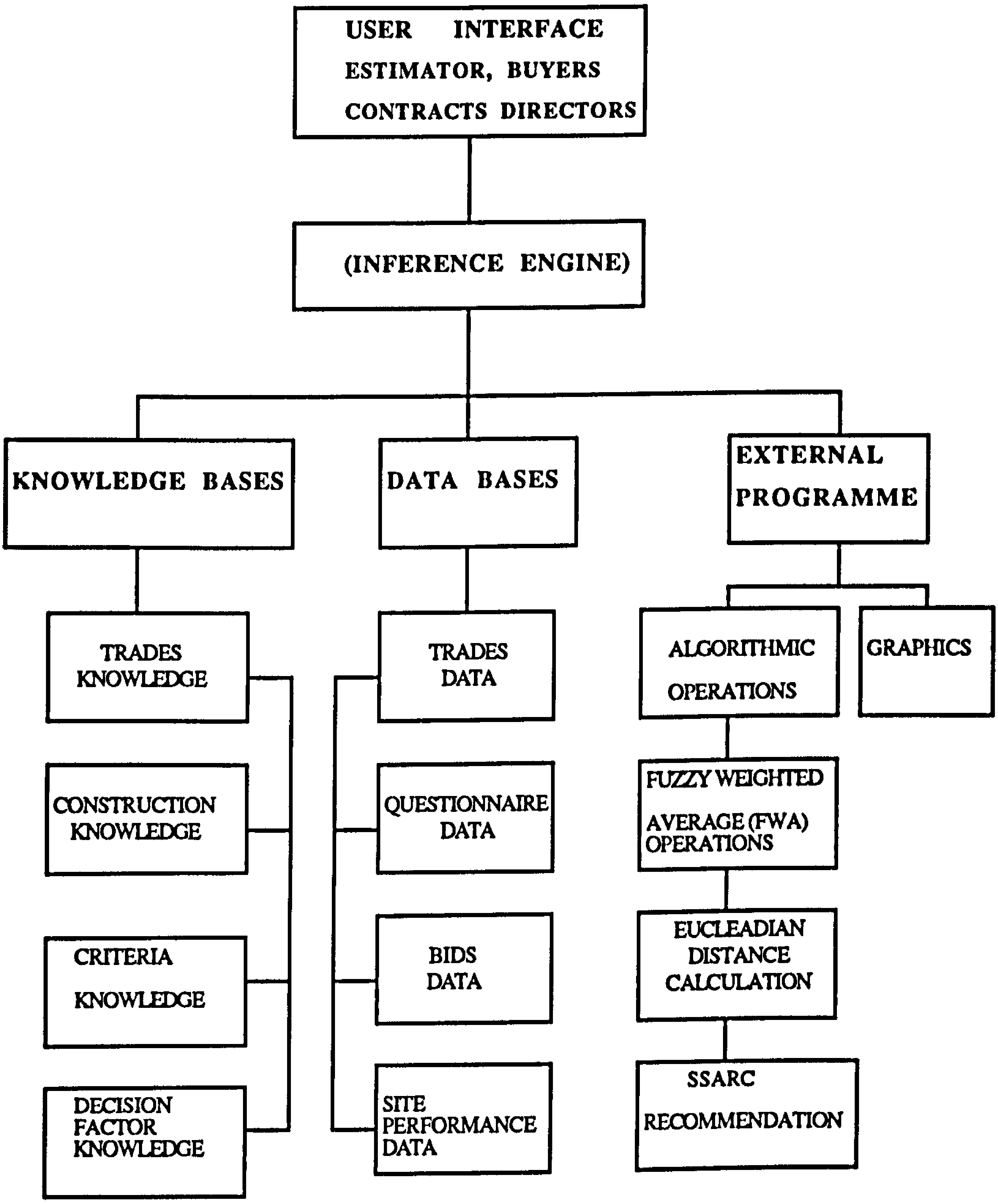
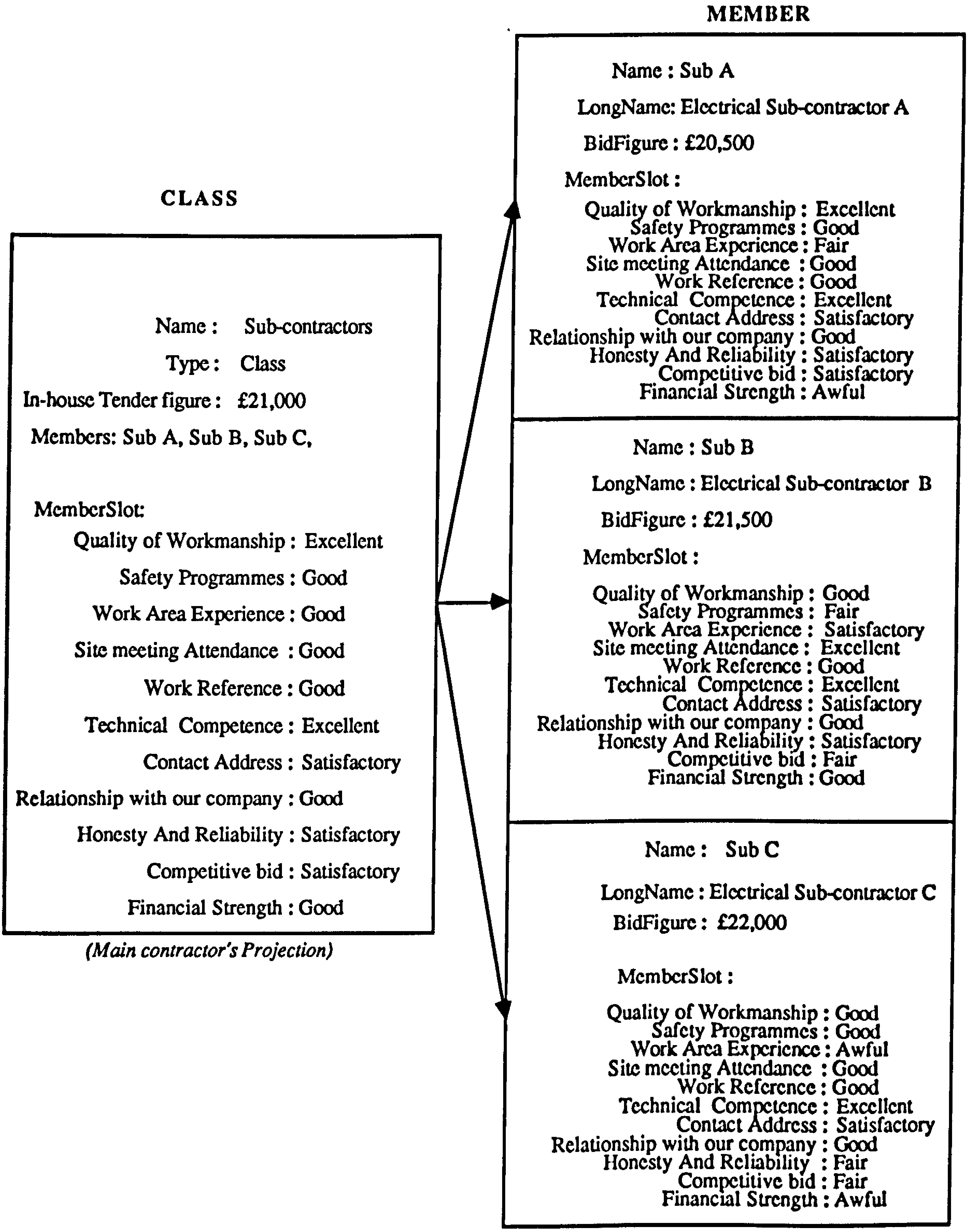


FIGURE 8.2 SSARC FRAME, CLASS AND MEMBER REPRESENTATION



Name : Sub-contractors
Type : Class
In-house Tender figure : £21,000
Members: Sub A, Sub B, Sub C,

MemberSlot:
Quality of Workmanship : Excellent
Safety Programmes : Good
Work Area Experience : Good
Site meeting Attendance : Good
Work Reference : Good
Technical Competence : Excellent
Contact Address : Satisfactory
Relationship with our company : Good
Honesty And Reliability : Satisfactory
Competitive bid : Satisfactory
Financial Strength : Good

(Main contractor's Projection)

Name : Sub A
LongName: Electrical Sub-contractor A
BidFigure : £20,500
MemberSlot :
Quality of Workmanship : Excellent
Safety Programmes : Good
Work Area Experience : Fair
Site meeting Attendance : Good
Work Reference : Good
Technical Competence : Excellent
Contact Address : Satisfactory
Relationship with our company : Good
Honesty And Reliability : Satisfactory
Competitive bid : Satisfactory
Financial Strength : Awful

Name : Sub B
LongName : Electrical Sub-contractor B
BidFigure : £21,500
MemberSlot :
Quality of Workmanship : Good
Safety Programmes : Fair
Work Area Experience : Satisfactory
Site meeting Attendance : Excellent
Work Reference : Good
Technical Competence : Excellent
Contact Address : Satisfactory
Relationship with our company : Good
Honesty And Reliability : Satisfactory
Competitive bid : Fair
Financial Strength : Good

Name : Sub C
LongName : Electrical Sub-contractor C
BidFigure : £22,000
MemberSlot :
Quality of Workmanship : Good
Safety Programmes : Good
Work Area Experience : Awful
Site meeting Attendance : Good
Work Reference : Good
Technical Competence : Excellent
Contact Address : Satisfactory
Relationship with our company : Good
Honesty And Reliability : Fair
Competitive bid : Fair
Financial Strength : Awful

As shown in figure 8.3, the first attribute in the frame name: sub-trade is called a slot. The first expression in this slot '**Name**' is known as the slot's name while the second expression "trade-sub" is the slot's value. The second attribute in this frame **LongName:** is used to hold a long descriptive name of the slots name for the display (figure 8.3, and 8.4 and 8.5). The third attribute **AllowedValue:** contains the allowed ratings or degree of importance for each criterion as shown in figure 8.4 and 8.5. This slot lists the values which are accepted by the object frame.

Figure 8.3: Typical Object Frame Representation in SSARC

Name: Trade_sub
LongName: Trade sub-contractor
Type: List
AllowedValue: Joinery, Bricklayer, Plumber, Carpentry, Plasterer, Electrical, Roofer, Air Conditioner
QueryPrompt: Indicate your list of preference
QueryPreface: Please choose the trade sub-contractor you would want to evaluate. Use the cursor keys to point at the selected option, and then, the <Ins Key> to add any other option you may wish to include to the list. The <Del Key> can be used to remove an option.

The **Query Prompt** and **Query Preface:** contain messages or instructions that appear on the screen for the user when input is awaited by the system. During execution the frame is scanned in order to determine the method for obtaining the value of the corresponding object' the object frame restricts the possible value selected by the user to one of five ratings or level of importance offered in the 'Allowed value' slot (figures 8.4 and 8.5).

Each slot may have one name only but may have several values; that is, list of values. These values can be "FixedValue" or "procedures". In order to relate and manipulate information from one object to another, they must be able to "send messages" to each other. In the model, frames use such a technique which allows information in an object to be changed when the object's frame is modified. This is done in SSARC by two communication methods. Firstly, by using what is known as "RuleSet" (figure 8.7).

Figure 8.4: Linguistic representation of construct ratings

Name: Safety_prog_rating
LongName: Safety programme for the proposed project.
Type: Text
AllowedValue: Excellent,Good,Satisfactory,Fair,Awful
QuerryPrompt: Please indicate your rating for Sub's Safety programme.
QuerryPreface: Which of these ratings reflect your assessment of the sub-contractor's ability to meet our requirements in terms of his safety programme? Use the cursor up or cursor down arrow to select your answer, use the <RETURN> key to enter your answer.

Figure 8.5: Linguistic representation of construct weights

Name: Safety_prog_weight
LongName: Safety programme for proposed project
Type: Text
AllowedValue: Extremely important, Very important, Important, Not very important, Unimportant
QuerryPrompt: Please indicate your weight for Subs' Safety programme
QuerryPreface: Degree of importance of Safety programme to the proposed sub-contractor's project. Use the cursor up or cursor down arrow to select your answer, use the<RETURN> key to enter your answer.

Figure 8.6: SSARC Main Rule Headings

```
/* KNOWLEDGE BASED SYSTEM FOR THE SELECTION AND
/* APPOINTMENT OF SUB-CONTRACTORS FOR BUILDING
/* REFURBISHMENT CONTRACTS
        control common
        /*Declarations
            if trade_sub includes x
            then declarations are complete
```

```
/* Get the system initialised

                if start is yes
                and open_file_for write is done
                then file_init is done;

                if file_init is done
                and get_selection_criteria is done
                then data_entry is done;

                if data_entry is done
                and close_data_file is done
                and dummy is yes
                then run procrig3(dummy);
                data file is created
            seek data_file
```

8.3.1 RuleSet

A RuleSet is a subset of rules that is used to determine the value of an object, the value of which is required by a rule elsewhere in the KB. The concepts of these rules are similar to those of the production rules described in section 3.13.4, which are based on the IF...Then principle. In this case, however, the condition of the rule is a slot's value of a specific object.

Figure 8.7: RuleSet Representation

```
     Name:  get_selection_criteria
 LongName:
     Type:  Text
  RuleSet:
              if start is yes
            then run openfile();
            openfile_for_write is done
```

The RuleSet is placed within the object frame and is executed when the value of the object is sought. The rules in the RuleSet behave exactly as those in the main RuleSet, the only difference being that the goal of the RuleSet is the object whose frame the

RuleSet is within.
The advantages or benefits of using RuleSet in this way in SSARC include clarity of structuring at design stage, faster compilation and efficient execution of the structured system.

8.3.2 Procedure

The second communication method in SSARC is by using what are known as **procedures** (figure 8.8) written in a particular slot within the frame itself.

Figure 8.8: Procedure Representation

```
      Name:      procrig3
  LongName:
      Type: Procedure
AcceptText: Dummy
   Rollout:
  External:      d : mio\ rig3.exe
     Body:
               call d:\ mio\rig3
    hold
    return
```

The procedures call the values from other slots in the same frame or other frames, manipulate them and return new values. Upon calling the procedure from within the knowledge base, the commands are executed in the same format as the standard high level programming language ('Pascal', 'C', or 'Fortran').

In SSARC, the **procedure** was also used for the interaction of the KB with the external programme written by the researcher (appendix E) which performs the algorithmic operations.

8.3.3 Databases

The databases contain information held on sub-contractors. This information includes sub-contractor firms details, for example *directors' names, annual turnover, project type, contract value range* and so on (see figure 8.2 and appendix F). It also contains questionnaire details that are completed by sub-contractors when they first applied for inclusion in the refurbishment contractor's sub-contractor lists. It also contains performance data and previous bid data. This information is entered into the database and is stored in standard ASCII (American Standard Code for Information Interchange) text files on the hard disk.

8.4 External Programme

The external programmes consist of a algorithmic model which is implemented in fuzzy logic for natural language interfaces. The fuzzy set provided the user linguistic variables. Fuzzy logic is used in the calculation of various values and are incorporated in decision rules employed in the inferencing process. This is described in detail below.

8.5 Rollout

Rollout in SSARC as shown in figure 8.8 above is the procedure where the values of the criteria are stored in memory whilst execution of the external programme occurs. Upon completion of the programme, execution is returned to Leonardo and the values of the criteria are returned and displayed to the decision maker on the screen.

Parameter-passing from Leonardo to the external programme was performed by opening and writing to an ASCII text file from within (SSARC). Leonardo then read these parameters into the programme once Leonardo had rolled out.

SSARC fuzzy set theory application is programmed in Pascal programming language developed by this researcher. The details of the computer programme are shown in appendix E.

The fuzzy set operation in SSARC consists of three parts:

i) Natural language rating of criteria.

ii) Fuzzy logic evaluation of degree of importance of criteria; and

iii) Linguistic approximation.

8.6 Natural language rating of criteria

In SSARC, this part involves information acquisition from the user. The knowledge base request from the user to rate the sub-contractor on all the criteria using five linguistic variables (Excellent, Good, Satisfactory, Fair and Awful). These linguistic variables are displayed on the screen (see figure 8. 4), together with full instructions on how to make any selection.
Also, details of the meaning of these linguistic variables for each criterion are displayed to the user. The choice of five rating levels of performance is appropriate because more or fewer categories appear to be either too many or too few for user friendliness and accuracy of evaluation. Also, these five ratings levels of performance can easily mesh with the levels of importance attached to each construct.

8.7 Fuzzy evaluation of degree of importance

The second part of fuzzy operation involves the evaluation of the relative degree of importance of each criterion for the project to be awarded.

The system allows the user to estimate linguistically the degree of importance of each criterion to the proposed project to be sublet. Once all the required data are collected from the user, this information is translated into fuzzy calculations. The criterion ratings are then combined with the criterion weights for all criteria to produce total criteria for the sub-contractor for that particular trade to be let. The fuzzy weighted average is calculated using the formulae as described in section 4.6.

$$R_{ave} = \frac{\sum_{i=1}^{n} R_i \text{ x } W_i}{\sum_{i=1}^{n} W_i}$$

where R_{ave} is the fuzzy set representing the overall weighted average ratings of an alternative.

R_i, is the fuzzy set that represents rating of the alternative based on a particular criterion; and

W_i is the fuzzy set representing the weight (or relative importance) assigned to that particular criterion.

The summation, multiplication and division in the above equation are fuzzy arithmetic operations which were previously discussed in chapter 4.

8.8 Normalisation

Another concern in the implementation of the above equation is whether the fuzzy normalisation operation should be conducted after each fuzzy operation, addition, multiplication, and division. Past studies (1, 2) have indicated that more reasonable results can be obtained with normalisation than without normalisation. Therefore, in SSARC model fuzzy normalisation is computed after each of these operation.

8.9 Linguistic approximation

The objective of this part of the model was to find an appropriate natural language expression for the sub-contractor estimated fuzzy set [R]. The mapping back (as it is called) to natural language expression in SSARC uses the "Best fit method." This method has been described in section (4.10.2) and [R] is obtained by the calculation of the Euclidean distance from the given fuzzy set [R], to each of the fuzzy sets (Excellent, Good, Satisfactory, Fair or Awful) representing the natural language expressions.

The Euclidean distance between fuzzy set [R] and fuzzy set expression (Excellent) or A is estimated as:

$$d(R, A) = \left(\sum_{n=1}^{n} [\mu_R(i) - \mu_A(i)]^2\right)^{\frac{1}{2}}$$

where d(R, A) is the Euclidean distance between fuzzy sets R and A,

$[\mu_R(i)]$ and $[\mu_A(i)]$ are membership values of element of the two fuzzy sets. The linguistic expression that produces the shortest Euclidean distance is assigned to R.

The Euclidean distance between fuzzy set [R] and pre-defined [A] natural language (e.g. Excellent, Good, Satisfactory, Fair and Awful) is calculated. After the Euclidean distance is calculated, the model assigns the appropriate natural language to the lowest Euclidean distance associated with fuzzy set [R]. For example, if the fuzzy set [R] that represents the sub-contractor's score in the evaluation has the lowest Euclidean distance within a pre-defined natural language expression is Excellent, the model assumes that the fuzzy set [R] is transmitted "Excellent" which indicate that the sub-contractor has an excellent chance of meeting all the performance requirements for the trade.

8.10 Checking and execution of the Knowledge Base

SSARC provides a comprehensive check function that can be used to check and compile the completed KB. During checking, all rules, frames and objects procedures are scanned for any syntax errors and other compilation errors. The checked rules and procedures object frames are then compiled in the KB and a list of all objects procedures and frames created by the rules are displayed. This ensures that no wrong rules, objects or frames are created and thus requires additional editing. The checking ensures that the KB is compiled into an executable format. If the checking is satisfactory, then execution of the KB can commence.

The "Default" method is used in SSARC for execution required by a user and invokes a principle known as "backward chaining", (section 3.3.1.5) to be applied to the execution of the KB.

The structure of the model is open-ended so it facilitates an addition of more knowledge in the form of decision rules to the initial version of the system.

As the model is applied to practical cases, it will facilitate the creation of more heuristic decisions, rules, as well as identifying additional criteria to be incorporated into the system.

After applying the model to a particular sub-contractor pre-qualification process, judgement is still required from the decision-maker. In practical selection of the most suitable sub-contractor decision making exercise, no substitute has been found for judgements made by experienced contractors who has a thorough knowledge of the prevailing circumstances. If all the items presented in this model are addressed, a reasonably sound decision should result.

8.11 Practical Application Of SSARC

8.11.1 Introduction

The objective of this section is to demonstrate the result obtainable from SSARC.

8.11.2 Project Characteristics

Project data used in this sample was supplied by the two refurbishment contractors for the systems. Extracts for one of the example is presented in tables 8.1 and 8.2. The project used for the application is a large office refurbishment contract in Reading City Centre in England. In all, there were 50 in-place sub-contractor's work packages. The contract was awarded to the main contractor in 1989 and the project was handed over to the client in December 1990. In this example, two electrical sub-contractors who will simply be called Sub-contractor A and B were evaluated using SSARC.
An example application with SSARC is presented in appendix G.

The total evaluation for each sub-contractor is measured by the Euclidean distance.

The lowest Euclidean distance for Sub-contractor A was Excellent.

Which indicated that sub-contractor A had an excellent chance of meeting all the performance requirements for the project.

The lowest Euclidean distance for Sub-contractor B was Awful, which indicated that sub-contractor B had a low probability of meeting all the performance requirements for the project.

The best sub-contractor for this trade as recommended by SSARC is sub-contractor A.

This assessment would also help the estimator to decide on the percentage to be applied to the risk-caused by the employment of a particular sub-contractor. In this case, SSARC would recommend the use of sub-contractor A because he has the lowest Euclidean distance.

TABLE 8.1 PERFORMANCE ASSESSMENT OF SUB-CONTRACTORS (SUB-CONTRACTOR'S REF NO 7/90)

CODE	SUB-CONTRACTOR PERFORMANCE CRITERIA EVALUATION	PERFORMANCE ASSESSMENT LEVELS					DEGREE OF IMPORTANCE ATTACHED TO THE CONSTRUCTS				
		EXCELLENT	VERY GOOD	GOOD	SATISFACTORY	AWFUL	EXTREMELY IMPORTANT	VERY IMPORTANT	IMPORTANT	NOT VERY IMPORTANT	UNIMPORTANT
1	FINANCIAL STRENGTH	*					*				
1a	Meeting cash flow requirements										
1b	Financial reference										
1c	Annual turover										
2	WORK AREA EXPERIENCE				*				*		
2a	Labour requirement/availability										
2b	Material availability										
2c	Weather experience										
2d	Plant availability										
3	SAFETY POLICY				*						
3a	Safety programme							*			
3b	Foreman safety experience										
3c	Insurance provision										
3d	Safety equipment										
4	QUALITY OF WORKMANSHIP			*				*			
4a	Quality rated company					*		*			
4b	Workmanship record										
5	WORK REFERENCE										
5a	No of years experience										
6	TECHINICAL COMPETENCE		*								*
6a	Work complexity										
6b	Proposed contract docs knowledge										
6c	Staff experience and knowledge										

TABLE 8.1: cont:- PERFORMANCE ASSESSMENT OF SUB-CONTRACTORS (SUB-CONTRACTOR'S REF. NO 7/90

CODE	SUB-CONTRACTOR PERFORMANCE CRITERIA EVALUATION	PERFORMANCE ASSESMENT LEVELS					DEGREE OF IMPORTANCE ATTACHED TO THE CONSTRUCTS				
		EXCELENT	VERY GOOD	GOOD	SATISFACTORY	AWFUL	EXTREMELY IMPORTANT	VERY IMPORTANT	IMPORTANT	NOT VERY IMPORTANT	UNIMPORTANT
7	RELATIONSHIP WITH OUR COMPANY	*									*
7a	Site staff relationship										
7b	Head office relationship										
8	COMPETITIVE BID				*				*		
8a	Bill rates consistency										
8b	Pricing all BOQ items										
8c	Receipt of quotation on time										
8d	Having a bid figure										

TABLE 8.2 PERFORMANCE ASSESSMENT OF SUB-CONTRACTORS (SUB-CONTRACTOR'S REF NO 1/90)

CODE	SUB-CONTRACTOR PERFORMANCE CRITERIA EVALUATION	PERFORMANCE ASSESSMENT LEVELS					DEGREE OF IMPORTANCE ATTACHED TO THE CONSTRUCTS				
		EXCELLENT	VERY GOOD	GOOD	SATISFACTORY	AWFUL	EXTREMELY IMPORTANT	VERY IMPORTANT	IMPORTANT	NOT VERY IMPORTANT	UNIMPORTANT
1	FINANCIAL STRENGTH		*				*				
1a	Meeting cash flow requirements										
1b	Financial reference										
1c	Annual turover										
2	WORK AREA EXPERIENCE			*					*		
2a	Labour requirement/availability										
2b	Material availability										
2c	Weather experience										
2d	Plant availability										
3	SAFETY POLICY	*						*			
3a	Safety programme										
3b	Foreman safety experience										
3c	Insurance provision										
3d	Safety equipment										
4	QUALITY OF WORKMANSHIP			*				*			
4a	Quality rated company										
4b	Workmanship record				*			*			
5	WORK REFERENCE										
5a	No of years experience										
6	TECHINICAL COMPETENCE				*						*
6a	Work complexity										
6b	Proposed contract docs knowledge										
6c	Staff experience and knowledge										

TABLE 8.2: cont:- PERFORMANCE ASSESSMENT OF SUB-CONTRACTORS (SUB-CONTRACTOR'S REF. NO 1/90

CODE	SUB-CONTRACTOR PERFORMANCE CRITERIA EVALUATION	PERFORMANCE ASSESMENT LEVELS					DEGREE OF IMPORTANCE ATTACHED TO THE CONSTRUCTS				
		EXCELENT	VERY GOOD	GOOD	SATISFACTORY	AWFUL	EXTREMELY IMPORTANT	VERY IMPORTANT	IMPORTANT	NOT VERY IMPORTANT	UNIMPORTANT
7	RELATIONSHIP WITH OUR COMPANY				*						*
7a	Site staff relationship										
7b	Head office relationship										
8	COMPETITIVE BID				*				*		
8a	Bill rates consistency										
8b	Pricing all BOQ items										
8c	Receipt of quotation on time										
8d	Having a bid figure										

8.12 Validation of SSARC

8.12.1 Approaches to knowledge base validation

As used in this study, the term 'validation' refers to the acceptability of both the recommendations and reasoning of SSARC.
Although validation has been discussed since the time of the early Expert Systems (MYCIN), Buchanan and Shortlife (3), however, as discussed by Green and Keyes (4), there is still no acceptable methodology for conducting validation studies. In addition to validity, validation concerns user acceptability, efficiency, quality of discourse with user, maintainability, and other considerations related to the costs and benefits of implementing a system. This collection of issues is treated at a general level by Gaschnig (5) and Buchanan and Shortliffe (3), and in numerous books on expert system, such as those by Waterman (6) and Walters and Nielsen (7).

In terms of KBS knowledge refinement, validation generally falls into two broad categories:

(a) Informal; and

(b) formal validation

i) Informal validation

Informal validation, is a long term feed-back process which cycles between KE, the domain expert and targeted user which was described in chapter 5. This process begins at project initiation and continues throughout software development.

ii) Formal validation

Formal validation usually begins once a prototype, which is thought to meet design objectives, has been developed.

Some efforts to develop a methodology for KB validation have tried to follow "verification and validation" (V & V) procedures used in conventional software engineering EPRI (8); and Oliver (9).

In a conventional programming context, "verification" involves determining that the code fully and exclusively implements requirements of a Superior specifications, and "validation" tests that the deliverable code correctly implements the original user requirements, Culbert et al. (10). Conventional verification and validation methods rely on user requirements and progress specifications that are articulated before coding takes place. However, using rapid prototyping, systems building proceeds interactively and specifications evolve gradually as increasingly refined prototypes are developed. Thus, conventional verification and validation methods are not well suited for ESs development.

Research on methods for KB validation has also been pursued by those attempting to automate the validation process. Early work in this field is reviewed by Nguyen (11). He also report on a programme that can:

a) Examine rules for syntactical error, such as misspelled names;

b) Identify sets of rules that are in conflict or redundant; and

c) Search for potential rules that may have been overlooked and suggest them to the experts. Stachowitz (12) developed a more ambitious programme that can check the correctness, consistency, and completeness of application written in arbitrary ES shells. Efforts to automate the generation of test cases for use in validation are also reported by Shore, Tu and Fagan (13).

Given the absence of a widely accepted KB validation methodology, case studies of validation exercises provide guidance on advantages and disadvantages of alternative approaches. Among the most thorough case studies are those reported for ESs in medicine, by Hickham (14), Miller (15), and Quaglini (16).
Validation case studies in the engineering literature have also been reported by Schutte (17), Nelson and Blackman (18), and Ludvigsen and Dupont (19), among others.

The validation exercise adopted by the researcher tests the acceptability of the recommendation made by SSARC. The question that significantly influenced the design of the case study was, "What criteria should be used to judge whether the KBS recommendations are similar to the one made by experienced refurbishment contractors?"

The approach used in developing validation factors in SSARC rests on the opinions of the contractors, as a basis for judging system performance. The validation consists of obtaining a high degree of agreement between the recommendations of the systems and those made by the contractors. Where there was a poor agreement, reasons for the differences in recommendations were sought, and they would provide a basis for improving the KBS.

The sub-contractor selection and appointment model for refurbishment contractors (SSARC) was developed based on the combined expertise of refurbishment contractors. Two of the contractors used in this validation exercise participated in creating the KBS. The contractors used were selected based on availability of office computer hardware in the estimating department and willingness to provide the necessary case study data.

8.13 Results from Contractors' Validation Exercise

Although the two contractors validations studies were far from comprehensive, they yielded interesting results from several points of view. From the perspectives of the KB validation, Contractor A and SSARC each arrived at the same recommendation. In contrast, the results from contractor B were different. The results from this contractor revealed an important factor. This contractor admitted that in their company, evaluation of sub-contractor's qualitative factors are usually done after the sub-contractor has put in his bid, and that the lowest bidder is used as a bench mark in assessing other bids, in other words, monetary value does influence the final outcome. This contractor admitted that it was usually very difficult for the lowest bidder not to be used on their contracts, except where he has a criminal record or has been dishonest in the past.

The validation exercise was the first time the refurbishment experts worked with the prototype KBS. In observing the system in operation, the experts were struck by the problems that resulted from their lack of rigours in defining some of the criteria. The overall opinion of the two contractors was that with some minor modifications to the user interface, the prototype systems would be a useful decision support tool for use by them.

The contractors were generally pleased by the level of simplicity and the use of linguistic variables in the system's decision making processes. The contractors believed that SSARC provided a simple but useful decision support tool for use during selection and appointment of sub-contractors. In particular SSARC enabled the contractors to clarify their thinking. It provides a check list to the key criteria they considered when choosing sub-contractors.
The contractors were convinced that SSARC results were both more consistent and objective in its selection and appointment of a sub-contractor than themselves.

Furthermore, the contractors believed that both the development and validation stages of the systems itself assisted in clarifying the organisation's knowledge of the relationships between the key constructs underlying the selection and appointment of sub-contractors.

In conclusion, SSARC has only been evaluated on two refurbishment contractors with reasonable success. However, it must be noted that SSARC was only validated on a relatively small sample of refurbishment contractors and therefore must be used with caution in practice.

8.14 Conclusion

The following conclusions about the usefulness of SSARC which has been set up to explore sub-contractor's selection processes can be drawn:

- The Euclidean distance model along with the fuzzy weighted average were successfully incorporated in the knowledge based decision support system for the sub-contractor's bid evaluation.

- The logic of the SSARC model is correct. Results from SSARC analysis is reasonable.

- Sub-contractor's evaluation can be performed with ease by using SSARC.

- It allows the use of linguistic variables and complete interrogation of the KB and can explain the line of reasoning taken to arrive at a conclusion.

At present the system is restrictive since it incorporates a limited number of case studies. The user must bear this in mind when interpreting conclusions. However, the structure of the knowledge base enables new case studies to be incorporated as they become available.

The knowledge based decision support system described herein is a prototype which is not yet intended for practical use. More work to improve the SSARC model seems to be warranted, especially in dealing with bids quantitative figures. It is noted that the bid quantitative ratings are tentative and may be subjected to changes in future versions of SSARC. This work is now being extended to produce a near commercial system.

- The model is to be used as an advisor and is not intended to replace the human advisors or experienced decision makers' on sub-contractor's selection.
  It facilitates certain actions and encourages the decision maker to examine them. The system therefore clarifies thinking about decision-making and about uncertainty.

CHAPTER NINE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

CHAPTER NINE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

This chapter briefly summarises the material presented in previous chapters of the research and outlines some of the results and the findings reported throughout the thesis. Furthermore, the strengths and weakness of the research methodology and tools used are also outlined. From these observations some tentative conclusions are drawn concerning the appropriateness of SSARC in the selection and the appointment of a suitable sub-contractor for refurbishment contracts. Finally, some thoughts are offered on possible directions in which future research in this area might be pursued.

9.2 Research summary

The foundations of the research arose from a comprehensive review of the literature on the growth of subcontracting in the construction industry with particular reference to refurbishment work and current practices regarding the employment of sub-contractors as reported in chapter two. This review in chapter two showed that the practice of sub-contractor selection and appointment by the refurbishment contractors consists of the use of subjective evaluation to control and analyse sub-contractors risks elements.

Also a comprehensive review of literature on the intelligent knowledge based expert systems and fuzzy set theory was reported in chapters three and four respectively. In chapter three, it was shown that KBS can be used to document expertise thereby making this knowledge transferral to non-experts more effective. It was suggested that both Estimators, Buyers and other senior decision-makers in refurbishment work, who are responsible for choosing sub-contractors, have gained considerable experience and expertise and can be relied upon for their good judgement to make rational and reasonable decisions. This expertise is frequently formulated in the form of simple heuristic rules of thumb and is predominantly qualitative in nature.

Furthermore, experience suggests that sub-contractor selection is an area in which relevant expertise is frequently dispersed or shared within the refurbishment firm's staff.

The development of the knowledge based system would provide a means of consolidating these multiple sources of knowledge within a knowledge base system. This could include combining related views of knowledge within a single system of contrasting different perspectives of the same domain to provide a single standardised perspective. Also the application of the knowledge base systems would mean that human fallibility and bias can be minimised, thereby ensuring that sub-contractor selection is carried out in a more systematic, objective fashion.

It was suggested that knowledge based systems have several characteristics that may lend assistance to improved sub-contractor selection decisions and that the development process promotes a better understanding of both a domain's structure and the relevant expertise. This can be particularly beneficial in non-formal, semi-structured managerial domains such as refurbishment work, which are characterised by multiple expertise. Thus, through the development of the knowledge based systems a contractor can gain a better understanding of their own sub-contractor selection decision-making and the related achievements.

The review in chapter four showed that fuzzy set theory can be useful in modelling linguistic expressions. It was suggested that the use of fuzzy set theory presents a linguistic approach to the uncertainty analysis in linguistic expressions. The use of fuzzy set theory allows precise modelling of imprecise statements such as "good workmanship" or "poor performance" The use of linguistic expressions allows for the easy and natural language specifications of values for imprecise concepts, a specification that had firm theoretical basis for computations that can be performed behind the scenes.

Research over the past decade has established fuzzy set theory on a firm axiomatic base. However, no consensus exists so far on the pragmatic meaning, interpretation and definition of grades of membership. As a result, fuzzy set theory applied to management decision-making lacks the clarity of understanding provided by classical decision analysis. The usefulness and acceptance of the fuzzy logic as a decision-making tool depends on its capacity to enhance the decision-maker's comprehension of the decision problems. Thus, these methodological questions raised by the theory pose problems for the adoption of the approach in most decision making fields. Despite these shortcomings with fuzzy set theory, the concepts are attractive enough to attempt tailoring the technique for the solution of management-decision problems.

In chapter five, the research methodology adopted was discussed. Contact with refurbishment contractors had already been established through the Building Conference Centre in London and with the work of Quah (1) and Teo (2). Also, at the start of the research at Heriot Watt University, in Edinburgh, this researcher was fortunate to have a retired chief estimator with over 40 years experience in one of Britain's biggest construction firms who was used during the knowledge acquisition phase of the research. There were twelve meetings with the chief estimator during the process of knowledge acquisition. The research was transferred to Loughborough University. In order to increase the strength of authority and breadth of expertise of the research, more refurbishment contractors were interviewed. This also enabled the researcher to determine wider perceptions, or facts that other refurbishment contractors had in their possession. A list of 59 refurbishment contractors was supplied by the Builders' Conference. An initial survey of the state of the art regarding the employment of sub-contractors was carried out through a questionnaire survey and seminar given by this researcher to the contractors in London. This was subsequently followed by Repertory Grid interviews of 30 refurbishment contractors.

9.3 Main findings of the research

(1) Questionnaire Analysis

The statistical package for social sciences (SPSS-X) was used in the analysis of the questionnaire. From the questionnaire analysis results, it was possible to draw the following conclusions:

(a) Volume of work sub-contracted

The majority of refurbishment contractors (84.85%) sublet over 90% of their contracts. There were five large contractors who sublet all their contracts.

(b) Sub-contractors policy and data gathering on sub-contractors

Most sub-contractors (63%) operated a written policy for the employment of their sub-contractors. Also, refurbishment contractors (97%) have pools of sub-contractors from which they usually select their sub-contractors. Most contractors keep records of sub-contractors' past performance on their projects.

(c) Data gathering on sub-contractors

Data on sub-contractors' past performance used to make decisions were obtained from the following sources:

i) past and current projects
ii) materials suppliers
iii) references from people who had either engaged them or have worked with them
in the past
iv) interviews
v) grapevine
vi) competitors' references
vii) consultants
viii) clients' references
ix) weekly and monthly work progress reports
x) questionnaires completed by sub-contractors when they first applied for inclusion in the contractors lists
xii) Builders' Conference

(d) The information kept on sub-contractors included:

i) trade type
ii) contact person telephone and facsimile numbers
iii) region of operation
iv) labour size and other resources like plant and financial capability
v) value of work they can undertake
vi) financial capabilities
v) past performance records

(e) Sub-contracting method that offers greatest advantage in terms of:

i) Financial returns

The majority of the contractors (60%) indicated that domestic sub-contractors offered greatest advantage in terms of financial returns.

ii) Effective monitoring

Effective monitoring was achieved by the use of domestic sub-contractors.

iii) Quality of workmanship

Quality of workmanship was achieved with both nominated sub-contractors, domestic sub-contractors and directly employed labour.

iv) Better organisation

Better organisation was achieved by the use of a directly employed labour force.

v) Less administrative worries

Less administrative worries were achieved by the use of nominated sub-contractors.

(g) Criteria which impose greatest constraints on sub-contractor selection decision-making:

i) sub-contractor bid price
ii) information gathering on a particular sub-contractor
iii) meeting the requirements of different interest groups
iv) short time allowed to make the decision
v) quality of workmanship

(2) Repertory Grid analysis result

The Grid Analysis Package (GAP) was used in the analysis of the Repertory Grid. The principal component analysis performed on the combined grid identified the most important constructs used in decision-making by these experts.

(a) Repertory Grid interview for domestic sub-contractors

The most important constructs for the estimators when selecting domestic sub-contractors were:

i) consistency of priced rates in the BOQ
ii) competitive bid

iii) pricing all BOQ items
iv) technical competence
v) reliability and trustworthiness
vi) quality of workmanship
vii) work area experience
viii) client approval
ix) safety records
x) proposed contract document experience

The most important constructs to the buyers were:

i) contract document experience
ii) reliability and trustworthiness
iii) competitive bid
iv) work design experience
v) quality of workmanship
vi) technical competence
vii) consistency of BOQ priced rates
viii) work area experience
ix) safety records
x) client approval

The most important constructs for the contracts director were:

i) technical competence
ii) design experience
iii) safety records
iv) quality of workmanship
v) competitive bid
vi) client approval
vii) priced BOQ consistency
viii) proposed contract document experience
ix) work experience
x) reliability and trustworthiness

(b) For labour only sub-contractors

The most important construct for the estimators were:

i) contact address
ii) competitive bid
iii) prompt start on site
iv) quality workmanship
v) inflationary claims
vi) maintenance of tidy site
vii) attendance at site meetings
viii) Site decisions implementation
ix) work reference
x) experienced site foreman

The most important constructs for the buyers were:

i) competitive bid
ii) quality of workmanship
iii) contact address
iv) work reference
v) prompt start on site
vi) inflationary claims
vii) maintenance of tidy site
viii) experienced site foreman
ix) site decisions implementation
x) site meeting attendance

The most important constructs for the contracts directors were:

i) contract address
ii) site meting attendance
iii) quality of workmanship
iv) competitive bid
v) work reference
vi) prompt start on site
vii) experienced site foreman
viii) reliability and trustworthiness

ix) site decisions implementation
x) maintenance of tidy site

(c) For the materials suppliers

The most important constructs for the estimators were:

i) competitive price
ii) prompt delivery of materials to site
iii) provision of fixing services for materials on site
iv) provision of storage facilities for materials on site
v) nearness to site

The most important constructs for the buyers included:

i) competitive price
ii) prompt delivery of materials to site
iii) provision of fixing services
iv) provision of storage facilities
v) nearness to site

(d) For Plant hirers

The most important constructs for the estimators included:

i) technically qualified and experienced plant operators
ii) prompt repairs of breakdown plant
iii) competitive price
iv) variety of plant
v) nearness to site

The most important constructs for the buyers included:

i) prompt repairs of broken down plant
ii) competitive price
iii) technically qualified and experienced plant operators
iv) variety of plant
v) good maintenance record

The constructs regularly used when selecting domestic sub-contractors were:

i) experience with the proposed contract documentation
ii) consistency of priced rates in the BOQ
iii) technical competence
iv) reliability and trustworthiness
v) competitive bid
vi) work area experience
vii) good safety records
viii) quality of workmanship

The constructs regularly used when selecting labour only sub-contractors were:

i) competitive bid
ii) quality of workmanship
iii) maintenance of work schedule
iv) work area experience
v) safety programme and
vi) contact address

For the material suppliers, the constructs regularly used by contractors included:

i) competitive price
ii) prompt delivery of materials
iii) provision of storage facilities
iv) quality of materials supplied

For the plant hirers the constructs regularly used included:

i) variety of plant
ii) competitive price
iii) prompt replacement of broken down plant
iv) nearness of site

From the principal component analysis it was possible to group the constructs used in the selection of sub-contractors into four categories:

1) technical related constructs

2) cost related constructs
3) relationship related constructs
4) scheduling related constructs

(3) Knowledge representation

Object-oriented frames knowledge representation was found to have an edge over the production rule representation, not only in terms of ease but also in terms of savings in computer memory. The other important advantage of this representation is that the 'slot' for each object is completely separate. Updating of rule-based systems entails the updating of the whole system whereas, in an object-oriented frame representation, only the relevant object has to be changed and the processor remains untouched. The task of updating the objects in object oriented frames is straightforward and does not require any computing skill.

(4) Expert system shell

Using the Leonardo 3 expert system shell helped speed up the implementation of SSARC to a great extent. It is felt that using a language rather than a shell would probably be better as a language may provide more flexibility than a shell but the significant question was the time required to do so. It is worthwhile to spend more time researching the philosophical issues involved rather than programming. The shell used, however, had to be flexible enough to support the requirements of the project. Leonardo 3 proved to be quite a powerful research tool for reasons discussed in section 3.5.1.

9.4 Conclusions and discussions

In recent years, there has been considerable interest in knowledge based systems applications to different areas of the construction industry. When this study started, KBS technology appeared to answer all the questions raised in the application of computer software in the construction industry and, indeed, other areas. With scores of papers written on KBS, the initial reaction was perhaps one of over-enthusiasm. However, the initial over-enthusiastic responses have started to be more meaningful and researchers are starting to take a more mature approach to the new technology.

Throughout this study it was felt that KBS might only act as an assistance to the decision-maker and not replace him. Also, as pointed out in section 8.10, the human being's role in decision-making still remains supreme and it is important to have this point clearly understood while making any attempt at developing any intelligent software system for the construction industry.

It was revealed that the current practice of sub-contractor selection fails to take adequate account of the qualitative attributes and in the majority of cases emphasis is primarily on the monetary value alone. It is therefore suggested that radically new approaches for improving management decision-making regarding sub-contractor selection are required and that the characteristics of knowledge based systems suggest that they provide scope for further progress in this area.
Early discussions with the chief estimator led to the conclusion that the problem of defaults, time and cost overruns, poor quality of workmanship and incompetence by some sub-contractors was one of improper evaluation during selection.

The structure of most refurbishment contracting firms is such that several key personnel in different departments influence the decision to use a certain sub-contractor and in this respect, appointments of sub-contractors was seen as coordinating type of decisions requiring the social interaction of several personnel with different vested interests.

In the development of SSARC, a Repertory Grid technique was used which produced what is believed to be a comprehensive set of over 40 constructs for domestic sub-contractors, 25 for labour only sub-contractors, 15 constructs for the materials suppliers and 12 for plant hirers. Chief estimators, buyers and contracts directors assessed for knowledge acquisition were highly educated and experienced and all of them had gained chartered status in their respective professional institutions. They displayed a high degree of intellect and were all extremely articulate.

However, some of them had difficulty in verbalising their knowledge when probed on how some sub-contractors were chosen. This suggested that their knowledge was not open to introspection and that they were not aware of their reasoning. Their knowledge had been refined over many years of experience and therefore deeply compiled. This suggested that indirect knowledge acquisition techniques were more appropriate than more commonly used direct interviewing methods. With this in mind, the Repertory Grid analysis was primarily chosen because of its overall flexibility but also because it enabled comparisons to be made between different perspectives, both systematically and objectively.

Knowledge acquisition is usually regarded as the main bottle-neck in knowledge based systems development. In recognition that experts use different kinds of knowledge and store their knowledge in many different representational forms and that different knowledge acquisition techniques access different types and forms of knowledge, then, when developing an appropriate knowledge acquisition strategy, it is important to match the properties of the knowledge acquisition techniques to the underlying characteristics of the domain. At present, however, there is no uniform technique in the knowledge acquisition for knowledge based systems nor is there any empirical evidence indicating knowledge acquisition techniques most appropriate for such domains.

From the questionnaire and repertory Grid analysis results, it was possible to draw some conclusions regarding the appropriateness of knowledge based systems in the selection of the most suitable sub-contractors for refurbishment contracts.

Before outlining these conclusions, however, it is expedient to highlight several limitations of the research study. Originally it was proposed to use one domain expert for the development of the knowledge based system. However, the time involved and the transfer from Edinburgh to Loughborough meant that it was difficult to use the chief estimator for the full development and the testing of the knowledge based systems.

The time taken to develop SSARC, however, highlighted that there are several problems to be overcome if commercially viable KBS are to be developed for use in the construction industry and other non construction domains.

First and foremost, the experience with SSARC raises the important question of what are the most appropriate methods with which to develop qualitative and descriptive models of expertise in non-formal managerial domains such as sub-contractor selection for refurbishment work. Such domains are characterised by selective multiple expertise and unarticulated experientially, based models and, therefore, there is a need to elicit indirectly and then combine and contrast several experts' or senior managers' knowledge. From the experiences with SSARC, it can be concluded that the Repertory Grid based technique is one such method. In particular, it was shown that although grid based methods can successfully combine similar views and identify conflict between individuals, they cannot resolve such conflict when it arises. Thus, in domains where there is an apparent low level of consensus, grid based methods, at least by themselves, may not prove to be beneficial.

The research suggests that in some situations, knowledge based systems using purely descriptive models may be inappropriate because the experts or managers are themselves unconvinced of the adequacy of their own knowledge. Thus, unless it is

possible to complement the underlying descriptive knowledge base of such systems with normative elements these system may be ultimately unacceptable to managers. Furthermore the research study suggests that fuzzy set theory and statistical techniques can be used successfully to complement standard knowledge acquisition techniques, such as the Repertory Grid, to develop qualitative descriptive models of expertise. The co-operation received from refurbishment contractors during the knowledge acquisition phase suggested that the contractors are highly receptive towards introducing computer based support systems to assist them with their bidding decisions.
The SSARC role is not to replace the estimators' decision making role and does not remove the need for senior management to make qualitative expert assessments on key issues, rather it is to focus the contractor's decision-making process towards an acceptable consensus view.
SSARC standardises the decision approach to sub-contractor's appointment by consolidating multiple sources of unarticulated expertise within a single knowledge base. This improves both the consistency and the objectivity of sub-contractor selection decisions by ensuring that decisions are reached systematically and that tenders are evaluated equitably.

Furthermore, the ability to use linguistic expressions enables contractors to assess the significance of the uncertainty. This is particularly beneficial in refurbishment work where such linguistic expressions are commonplace and also where the ultimate decision is the result of social interaction between several senior managers and where it is, therefore, necessary to reach a consensus decision. In such a situation, fuzzy set theory and knowledge based systems are beneficial in determining the significance of minor differences of opinions between the managers and thereby focussing the attention of the group onto the key issues where a consensus is required. Finally, it assisted the contractors to clarify both their expertise and their current sub-contractor selection policy. In particular, it focussed attention on the key constructs and their inter-relationships influencing their sub-contractor selection decisions. Thus, given the successful experiences with SSARC, it can be concluded that the KBSs are appropriate for modeling sub-contractor selection decisions regarding the employment of the most suitable sub-contractors in refurbishment work.

The experiences with SSARC suggest that beneficial KBSs need not be large or complicated and, as previously noted, SSARC represents the refurbishment contractors at a conceptually high and qualitative level.

It does not remove the need for management to make a qualitative expert assessment on key issues and, indeed, given the operational importance of refurbishment sub-contractors' selection decisions, this could be a pre-requisite for any such system acceptance. If this is the case, then it appears that systems which support senior managers who choose sub-contractors are more appropriate than systems whose role it is to direct the responsibility for sub-contractor selection decisions towards less experienced personnel. Furthermore, the experiences with SSARC indicate that the principal benefits deriving from the use of knowledge based systems in the selection of sub-contractors are the clarification and consolidation of multiple sources of un-articulated experientially based expertise within a single knowledge base. The use, thereafter, of a standardised single knowledge base improves both the consistency and objectivity of a contractor's future sub-contractor selection decisions. A closely related benefit using SSARC is the ability to use linguistic expressions.

9.5 Recommendations for future work

The research presented in this thesis has been both exploratory and experimental in its format. It has raised several important questions, which indicate possible directions in which future work in this area could be pursued.

This research has analysed sub-contractor selection for refurbishment work from the point of view of contractors. SSARC may also be appropriated with some adaptations for developing KBSs in the client domain for the selection of the main contractors. The client also needs to evaluate or appraise the contractors' bid proposals and their problem shares several characteristics with that of a contractor evaluating sub-contractors' tender bids. KBSs could then also prove beneficial in such a role.

In this respect, the methodologies outlined in this thesis are also of interest to those organisations who put out jobs to tender. Moreover, the conclusion also suggests that KBS and the methodologies devised in this research may be appropriate in other non-construction domains which are characterised by selective multiple expertise and which contain classification diagnosis or pre-qualification type problems. Other areas of application include decision to bid on a project and employee performance evaluations.

A similar approach can be adopted within the contractors' organisation to investigate and manage risks in competitive bidding for refurbishment contracts using linguistic variables. The model developed can also be adapted and used to allocate resources at post-contract stages.

The system can be further expanded to analyse risks in refurbishment contracts during tender preparation for the purpose of allocating contingencies.

In summary, this research study has established that it is possible to develop simple but appropriate knowledge based decision support systems for refurbishment contractors for the selection of sub-contractors. However, owing to the characteristics of refurbishment work, several important issues need to be addressed before such systems can be regarded as commercially viable.

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APPENDIX A

REFURBISHMENT CONTRACTORS' SURVEY QUESTIONNAIRE

APPENDIX B

REPERTORY GRID DATA

APPENDICES

APPENDIX A

REFURBISHMENT CONTRACTORS' SURVEY QUESTIONNAIRE

Appendix A

REFURBISHMENT CONTRACTORS' SURVEY QUESTIONNAIRE

Respondent Number [/ /]

Heriot-Watt University
Edinburgh

Construction Management Research Programme

(In conjunction with the Builders' Conference)

Questionnaire

Knowledge Based System to the Selection and Monitoring of Sub-Contractors in Building and Refurbishment Work.

Strictly Confidential

For Comput
Use

1 THE COMPANY

The following questions concerning your company, in relation to the last full accounting year, are asked, in order that we may classify the size of your business.

Please complete the following boxes.

1.1 The last full accounting year/period was from

State the month	State the year	TO	State the month	State the year
	19			19

1
5

By ticking the appropriate box, Please indicate

1.2 Your company turnover per annum for the last full accounting year period (in millions)

Up to £5	£5 - 10	£10 - 15	£15 - 20	£20 - 25	£25 - 30	Over £30
(1)	(2)	(3)	(4)	(5)	(6)	(7)

1.3 The size of the company's total labour force (directly employed)

Up to 100 emp	100-200 emp	200-300 emp	300-400 emp	400-500 emp	500-600 emp	Over 600 emp
(1)	(2)	(3)	(4)	(5)	(6)	(7)

10

1.4 The size of the subcontracting service to your company in percentage terms of volume of turnover.

Less than 20%	20-30%	30-50%	50-70%	70-90%	Over 90%
(1)	(2)	(3)	(4)	(5)	(6)

11

1.5 How many years experience has your company had in building and refurbishment works?

Less than 5 yrs	5-10 yrs	10-15 yrs	15-20 yrs	20-25 yrs	Over 25 yrs
(1)	(2)	(3)	(4)	(5)	(6)

2 SUBCONTRACTING POLICY/METHODS

This section deals with general questions about your company policy to subcontracting.

Please tick the appropriate answer to the questions

2.1.1	Does your company have a written policy or guidelines for the selection of your subcontractors?	YES (1) NO (2)
2.1.2	Do you have a staff member specifically designated to collate information on subcontractors used by your company	YES (1) NO (2)
2.1.3	Does your company have a pool of subcontractors from which you regularly select to carry out your subcontractors jobs?	YES (1) NO (2)
2.1.4	Does your company have any computer system to support data processing with regards to selection and monitoring of subcontractors?	YES (1) NO (2)

2.2 By ticking the appropriate answer please indicate if your company has either worked with or engaged the services of -

2.2.1 Nominated subcontractors	YES (1) NO (2)
2.2.2 Domestic subcontractors	YES (1) NO (2)
2.2.3 Labour-only subcontractors	YES (1) NO (2)
2.2.4 Plant subcontractors (Plant hiring companies, incl operators)	YES (1) NO (2)
2.2.5 Nominated suppliers	YES (1) NO (2)

2.3 By ticking the appropriate box please indicate which method of job execution offers the greatest advantages to your company:

	Nom. Subs.	Dom. Subs.	Own Lab. Force	Lab. Only subcon	Plant Subs.	Nom. Supp.	
2.3.1 Larger financial returns	☐	☐	☐	☐	☐	☐	(1)
2.3.2 More effective monitoring	☐	☐	☐	☐	☐	☐	(2)
2.3.3 Better organisation	☐	☐	☐	☐	☐	☐	(3)
2.3.4 Quality of workmanship	☐	☐	☐	☐	☐	☐	(4)
2.3.5 Less adminstration worries	☐	☐	☐	☐	☐	☐	(5)

2.4 How, when critically examined, is the subcontracting services obtained by your company?

2.4.1 Very good with no complaints ☐ (1)
2.4.2 Good with few complaints ☐ (2)
2.4.3 Could be improved to obtain further advantage ☐ (3)
2.4.4 Fair ☐ (4)
2.4.5 Must be improved to maintain profitability and commercial competitiveness ☐ (5)

3 SUBCONTRACTING INFORMATION

Please tick the appropriate answer to the following questions:

3.1 Are detailed records kept on domestic subcontractors in relation to :

3.1.1 Different trades, for example; do you have separate lists for bricklayers, joiners etc?	YES (1) NO (2)
3.1.2 The area or region of operation, for example - the Inner London area?	YES (1) NO (2)
3.1.3 The size of the subcontractors company, for example - does he have sufficient labour to cope with a large job?	YES (1) NO (2)
3.1.4 His financial status?	YES (1) NO (2)
3.1.5 His past performance?	YES (1) NO (2)

By ticking the appropriate box please indicate:

3.2 Who receives and collates the information? 3

Estimating Department	Buying Department	Planning Department	Sub-contractors Department	Held by each Department	Held on individual basis
☐	☐	☐	☐	☐	☐
(1)	(2)	(3)	(4)	(5)	(6)

By ticking the appropriate box please indicate:

3.3 Do site agents complete written assessment schedules on the performance of subcontractors for feedback? 1

Never	Rarely	Sometimes	Always
☐	☐	☐	☐
(1)	(2)	(3)	(4)

3

By ticking the appropriate box please indicate:

3.4 Does your company supply the following information or documents to domestic subcontractors at pre-tender stage?

Note Each line should have one tick

		Never	Rarely	Sometimes	Always		
3.4.1	A copy of the form of main contract with additions, amendments and exclusions clearly shown	☐	☐	☐	☐	(1)	3
3.4.2	The appropriate section of the bills of quantities	☐	☐	☐	☐	(2)	3
3.4.3	Any relevant drawings or sketches	☐	☐	☐	☐	(3)	3
3.4.4	The preliminaries section of the bills of quantities included	☐	☐	☐	☐	(4)	3
3.4.5	Are subcontractors asked to submit their own work programmes?	☐	☐	☐	☐	(5)	3
3.4.6	Are subcontractors given anticipated start dates, duration, finish dates, phases for their particular work or trades?	☐	☐	☐	☐	(6)	4
3.4.7	Where special attendances are likely are these highlighted or suggested for inclusion in their prices?	☐	☐	☐	☐	(7)	4

	Never	Rarely	Sometimes	Always	
3.4.8 Are supplementary conditions of contract used with subcontractors?	☐	☐	☐	☐	(8)

3.5 By ticking the *appropriate* box, please indicate which conditions of contract are used with domestic subcontractors.

Company's Own Contract	JCT"80"	G.C. Works/1	Other Type of Contract	None
(1)	(2)	(3)	(4)	(5)

3.5.1 If other type of contract, please specify

____

3.6 By ticking the appropriate box, please indicate which members have the responsibility of selecting, monitoring and control of subcontractors

You may use more than one box in each row

Function/ Job Title	Selection	Monitoring	Controlling	
Site Manager				(1)
General foreman				(2)
Buyer				(3)
Contract Manager				(4)
Estimator				(5)
Managing Director				(6)
Quantity Surveyor				(7)
Site Engineer				(8)
Planner				(9)

4 DECISION MAKING

Questions in this section are to determine what methods are used, by your company, to assist decision-making in the selection of subcontractors.

Please indicate the use of each method as it applies to your company by ticking the appropriate box.

NOTE EACH LINE SHOULD HAVE ONE TICK

		In Gen. Use	Used Occas	Rarely Used	Never Used	
4.1.1	Individual decision-making based upon experience and intuition	☐	☐	☐	☐	(1)
4.1.2	Group decision-making based upon informal discussion and using experience and intuition	☐	☐	☐	☐	(2)
4.1.3	The use of computers and decision-making software packages, Expert Systems	☐	☐	☐	☐	(3)
4.1.4	The use of management consultants	☐	☐	☐	☐	(4)
4.1.5	Operational Research Technique, Utility theory, Linear programming, fuzzy sets,	☐	☐	☐	☐	(5)
4.1.6	Bayesian Analysis or Weighted Analysis based upon subcontracting record sheet or similar	☐	☐	☐	☐	(6)

6

Please indicate by ranking from 1 - 5 those items which impose the greatest contraints to decision-making when selecting a subcontractor.

Note 5 is the most important raking down to 1, the least important

4.2.1	Time	☐	(1)
4.2.2	Price of their service to your company	☐	(2)
4.2.3	The lack of information on which to make decisions	☐	(3)
4.2.4	Relationship between all parties on site and between head office staff and director	☐	(4)
4.2.5	Quality of workmanship	☐	(5)
4.2.6	Their management capabilities	☐	(6)
4.2.7	Their performance with regard to their prompt starting and finishing times in accordance with your programme	☐	(7)
4.2.8	The standard of the subcontractors management and administration	☐	(8)

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4.3 Is the person in charge of a site i.e. the Site Agent or General Foreman consulted before the order for subcontractors is placed?
Please tick:

Never	Rarely	Sometimes	Always
☐	☐	☐	☐
(1)	(2)	(3)	(4)

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4.4 In assessing any subcontractor before their selection is it your policy to assess their :

Please tick the appropriate boxes -

		Never	Rarely	Sometimes	Always	
4.4.1	Financial standing	☐	☐	☐	☐	(1)
4.4.2	References, if known, before placing the order	☐	☐	☐	☐	(2)
4.4.3	Ability to submit bona-fide tender figure within the time allowed	☐	☐	☐	☐	(3)
4.4.4	Bid figure within your in-house tender figure	☐	☐	☐	☐	(4)
4.4.5	Labour strength	☐	☐	☐	☐	(5)
4.4.6	Management capabilities and calibre	☐	☐	☐	☐	(6)
4.4.7	Current workload and anticipated future workload	☐	☐	☐	☐	(7)
4.4.8	Tenure in supplying this service	☐	☐	☐	☐	(8)
4.4.9	Transport facilities	☐	☐	☐	☐	(9)
4.4.10	Experience with regard to the proposed size and location, past workmanship	☐	☐	☐	☐	(10)

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		Never	Rarely	Sometimes	Always	
4.4.11	Their safety record and possibility of meeting the prescribed safety measures	☐	☐	☐	☐	(11)
4.4.12	Reliability and trustworthiness	☐	☐	☐	☐	(12)
4.4.13	Working practise - i.e. do they clean up on completion of their work	☐	☐	☐	☐	(13)
4.4.14	Their quality assurance management systems, in accordance with BS5750	☐	☐	☐	☐	(14)

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Please tick the appropriate answer to the questions :

4.6.1	Does your company have the policy of finding and employing new subcontractors <u>whenever</u> possible?	YES (1) NO (2)
4.6.2	Are references sought on similar completed work before engaging a new subcontractor?	YES (1) NO (2)
4.6.3	Are credit bureaux used as a reference source for subcontractor's selection?	YES (1) NO (2)
4.6.4	Do negotiations take place between yourself and a subcontractor before the order is placed?	YES (1) NO (2)
4.6.5	Are subcontractors invited to tender in advance of documents being sent?	YES (1) NO (2)
4.6.6	Is it your policy to notify <u>all</u> tendering firms of sucessful contractor plus details of tendering prices?	YES (1) NO (2)
4.6.7	Are records kept of unsuitable subcontracting organisations?	YES (1) NO (2)
4.6.8	Does your company operate any written assessment for subcontractors at the end of their contract?	YES (1) NO (2)
4.6.9	Would you agree to a personal interview?	YES (1) NO (2)
4.6.10	Would you like a summary of our results?	YES (1) NO (2)

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4.7 Position of respondant in the firm?

Director ☐ (1)
Estimator ☐ (2)
Quantity Surveyor ☐ (3) 11
Site Manager ☐ (4)
Others *(please specify)* .... ☐ (5)

I am most grateful for your help in completing this questionnaire.
Please return in the envelope provided to:-

Prof. V. B. Torrance
Dept. of Building
Heriot-Watt University
Riccarton
Edinburgh
EH14 4AS

APPENDIX B

REPERTORY GRID DATA

REPERTORY GRID DATA

Buyer Repertory grid (**Materials supplier** constructs)

	CONSTRUCTS	ELEMENTS						CONSTRUCTS	
		S1	S2	S3	S4	S5	S6		
CR1	Competitive price	4	2	5	4	5	4	Nit picking	CR1
CR2	Prompt replacement of defective materials	3	1	5	3	2	4	Delay in replacement of defective materials	CR2
CR3	Bulk Purchase discount	2	3	5	5	5	4	Small supplier	CR3
CR4	Consistency in quoting for our firm	3	2	5	2	4	5	Inconsistency in quoting for our firm	CR4
CR5	Prompt treatment of invoice	5	4	2	5	4	4	Delay in treatment of invoice	CR5
CR6	Membership of trade association	4	3	5	4	4	4	Non membership of trade association	CR6
CR7	Prompt delivery on site	4	1	4	4	4	5	Late delivery on site	CR7
CR8	Availability of credit facilities	3	1	4	2	4	1	Unavailable credit facilities	CR8
CR9	Provision of storage facilities	3	2	3	3	4	2	Unavailable storage facilities	CR9
CR10	Good working relationship with our firm	3	2	4	1	4	5	Poor working relationship with our firm	CR10
CR11	Nearness to site	3	4	2	1	3	3	Long haulage of materials	CR11
CR12	Provision of fixing services	4	1	5	3	4	3	Unavailable skilled labour for fixing services	CR12
CR13	Correct type of materials and quality	4	3	4	5	5	4	Incorrect type of material and poor quality	CR13
CR14	Receipt of quotation on time	3	2	5	4	4	3	Persistently late in sending his bid	CR14

Estimators Repertory grid (**Materials supplier** constructs)

CONSTRUCTS		ELEMENTS						CONSTRUCTS	
		S1	S2	S3	S4	S5	S6		
CR1	Competitive Price	5	4	4	5	4	3	Uncompetitive bid	CR1
CR2	Discount for bulk purchase	4	4	5	4	3	3	Small supplier	CR2
CR3	Prompt delivery on site	3	4	4	2	2	3	Late delivery on site	CR3
CR4	Availability of credit facility	2	1	3	1	2	1	Unavailable credit facility	CR4
CR5	Provision of storage facilities	4	3	4	3	3	3	Unavailable storage facilities	CR5
CR6	Prompt replacement of defective materials	3	2	4	4	4	4	Delay in replacement of defective materials	CR5
CR7	Good working relationship with our firm	3	3	4	5	4	3	Poor working relationship with our firm	CR7
CR8	Prompt treatment of invoice	4	1	2	4	1	3	Long delay in treating invoice	CR8
CR9	Nearness to site	3	2	3	1	1	2	Far away from site	CR9
CR10	Provision of fixing services	1	4	2	3	3	3	Inability to provide fixing services	CR10
CR11	Membership of trade association	3	3	5	3	4	5	Non membership of trade association	CR11
CR12	Correct type of materials and quality	3	4	4	3	5	1	Incorrect type of material and poor quality	CR12

Estimators Repertory grid (**Plant hirer** constructs)

CONSTRUCTS		ELEMENTS						CONSTRUCTS	
		S1	S2	S3	S4	S5	S6		
CR1	Competitive price	3	4	2	5	4	3	Uncompetitive price	CR1
CR2	Prompt treatment of invoice	4	1	4	4	3	3	Delay in treatment of invoice	CR2
CR3	Good working relationship with our fir	3	3	4	5	4	3	Poor working relationship with our coy	CR3
CR4	Delivery of plant to site on time	4	2	3	1	3	2	Late delivery of required plant on site	CR4
CR5	Good maintenance record	3	5	4	2	1	3	Poor maintenance record	CR5
CR6	Prompt repair of breakdown plant	3	4	5	1	2	3	Late repair of breakdown plant	CR6
CR7	Long lease arrangement of plant	4	3	5	2	3	4	Short lease arrangement available	CR7
CR8	Large selection of plant	2	4	3	2	5	5	Small selection of plant	CR8
CR9	Nearness to site	3	4	5	4	2	4	Long distance from site	CR9
CR10	Provision of fitters and plant operators	3	4	4	4	4	4	Non-availability of plant operators	CR10

Buyer Repertory grid (**Plant hirer** constructs)

CONSTRUCTS		ELEMENTS						CONSTRUCTS	
		S1	S2	S3	S4	S5	S6		
CR1	Competitive price	2	4	3	5	2	3	Uncompetitive price	CR1
CR2	Good maintenance record	1	5	4	3	3	3	Poor maintenance record	CR2
CR3	Prompt repair of breakdown plant	3	4	4	2	2	3	Late repair of breakdown plant	CR3
CR4	Receiving quotation in good time	2	3	5	2	4	4	Late receipt of quotation	CR4
CR5	Large selection of plant	2	4	3	3	3	5	Small selection of plant	CR5
CR6	Credit facility availability	1	4	4	5	3	3	Unavailable credit facility	CR6
CR7	Nearness to site	3	2	5	4	2	4	Long distance from site	CR7
CR8	Good working relationship with our firm	3	3	4	5	5	3	Poor working relationship with our coy	CR8
CR9	Banksmen and drivers availability	3	4	3	4	5	4	Non provision of drivers and banksmen	CR9
CR10	Prompt treatment of invoice	4	3	2	4	1	3	Delay in treatment of invoice	CR10
CR11	Passing of security checks	3	2	3	1	3	2	Failing security checks	CR11

Estimators Repertory grid (**Labour only** sub-contractor)

CONSTRUCTS		ELEMENTS								CONSTRUCTS
		S1	S2	S3	S4	S5	S6	S7	S8	
CR1	Competitive bid	1	1	5	4	4	5	2	4	Uncompetitive bid
CR2	Attendance of site meetings	2	1	3	2	5	2	1	4	Non attendance of site meetings
CR3	Good experience on project size	2	1	3	2	5	4	5	4	Inexperienced on project size
CR4	Adequate size of labour force	4	3	4	5	4	4	3	5	Inadequate labour force
CR5	Implementation of decisions	3	4	4	4	4	3	1	4	Ignored all decisions reached
CR6	Good quality of workmanship	2	2	4	4	3	4	3	4	Poor quality of workmanship
CR7	Contact address	3	3	4	4	4	4	5	5	No fixed address
CR8	Good work reference	2	4	1	2	3	4	1	3	Poor work reference
CR9	Prompt response to calls	3	3	4	1	2	4	3	5	Late response to calls
CR10	Maintenance of tidy site	2	4	4	4	3	3	2	4	Untidy work habit.
CR11	Good experienced site foreman	1	2	4	4	5	5	2	4	Poor experienced site foreman
CR12	Good Financial capability	1	3	5	2	4	5	2	5	Poor financial standing
CR13	Consistency of priced rates	2	4	4	3	3	4	1	3	Overloading of priced rates
CR14	Good relationship with site staff	1	3	4	3	4	5	2	5	Poor relationship with site staff
CR15	Receipt of quotation on time	3	4	5	1	1	2	2	5	Late receipt of priced bills
CR16	Consistency in quoting for us	2	3	4	2	2	3	2	4	Inconsistent in quoting for us
CR17	Correct claims	3	4	4	3	4	4	2	4	Inflated claims
CR18	Technical competence	3	4	3	5	4	4	5	4	Technical incompetence
CR19	Prompt start on site	2	1	2	4	3	4	4	3	Late start on site
CR20	Good work programme	3	2	3	4	3	4	2	5	Poor work programme
CR21	Possession of recent tax payment papers	4	5	4	5	4	5	4	4	Dodge tax payments
CR22	Keen to work for our firm	5	4	5	4	3	4	3	3	Persuaded to send in quotation

Buyer Repertory grid (**Labour only** sub-contractor constructs)

CONSTRUCTS	ELEMENTS								CONSTRUCTS
	S1	S2	S3	S4	S5	S6	S7	S8	
CR1 Contact address	3	3	4	5	4	4	5	5	Unregistered company
CR2 Attendance of site meetings	2	1	3	2	5	2	4	4	Ignored all meetings
CR3 Good Financial capability	1	3	5	2	4	5	2	5	Poor financial standing
CR4 Implementation of decisions	3	4	4	4	4	3	5	4	Ignored all decisions reached
CR5 Good relationship with site staff	1	3	4	3	4	5	5	5	Poor relationship with site staff
CR6 Good work reference	2	4	1	2	3	4	4	3	Poor work reference
CR7 Competitive bid	1	1	5	4	4	5	4	4	Uncompetitive bid
CR8 Good quality of workmanship	2	2	4	4	3	4	5	4	Poor quality of workmanship
CR9 Good safety programme	1	3	5	2	4	5	5	5	Poor safety programme
CR10 Consistency of priced rates	2	4	4	3	3	4	5	3	Inconsistency of priced rates
CR11 Receipt of quotation on time	3	4	5	1	1	2	3	4	Late receipt of priced bills
CR12 Consistency in quoting for us	2	3	4	2	2	3	5	4	Inconsistent in quoting for us
CR13 Tidy working practice	3	4	4	3	4	4	4	4	Untidy work practice
CR14 Experience site foreman	1	2	4	4	5	5	4	4	Inexperienced site foreman
CR15 Experience on project type	2	1	3	2	5	4	5	3	Inexperience project size
CR16 Geographical area work experience	3	4	3	5	4	4	5	4	No work experience in the area
CR17 Keen to work for us	4	3	1	2	4	5	3	4	Not keen to work for us
CR18 Pricing all bills of quantities work items	3	1	2	3	1	4	4	4	Pricing only few items
CR19 Good union relationship	1	4	4	3	2	4	5	5	Poor union relationship
CR20 Prompt start on site	2	1	2	4	3	4	4	3	Late start on site
CR21 Has sufficient men on site for the project	4	5	4	5	4	5	4	4	Put insufficient men on site
CR22 Availability of plant and equipment	5	3	5	5	1	2	4	3	Unable to obtain plant and machinery
CR23 Technical competence	3	4	3	5	4	4	5	4	Technical incompetence
CR24 Genuine assessment of work claims	5	4	5	3	2	5	3	4	Inflationary claims

Contracts Director Repertory grid (**Labour only** sub-contractor constructs)

CONSTRUCTS		ELEMENTS								CONSTRUCTS
		S1	S2	S3	S4	S5	S6	S7	S8	
CR1	Attendance of site meetings	2	1	3	2	5	2	4	4	Ignored all meetings
CR2	Implementation of decisions	3	4	4	4	4	3	5	4	Ignored all decisions reached
CR3	Good relationship with site staff	1	3	4	3	4	5	5	5	Poor relationship with site staff
CR4	Good work reference	2	4	1	2	3	4	4	3	Poor work reference
CR5	Competitive bid	1	1	5	4	4	5	4	4	Uncompetitive bid
CR6	Good quality of workmanship	2	2	4	4	3	4	5	4	Poor quality of workmanship
CR7	Good working practice on site	3	3	4	1	2	4	5	3	Untidy working practice
CR8	Possession of current tax papers	2	4	4	4	3	3	5	4	Tax dodger
CR9	Good safety programme	1	3	5	2	4	5	5	5	Poor safety programme
CR10	Consistency of priced rates	2	4	4	3	3	4	5	3	Put few men on site
CR11	Has sufficient men on site	2	3	4	2	2	3	5	4	Inconsistent in quoting for us
CR12	Experience on project type	3	4	4	3	4	4	4	4	Inexperience on project type
CR13	Experience site foreman	1	2	4	4	5	5	4	4	Inexperienced site foreman
CR14	Experience on project size	2	1	3	2	5	4	5	3	Inexperience project size
CR15	Correct claims	2	3	2	3	4	4	4	4	Inflated claims
CR16	Good work programme	3	2	3	4	3	4	5	5	Poor work programme
CR17	Geographical area work experience	3	4	3	5	4	4	5	4	No work experience in the area
CR18	Technical competence	4	3	1	2	4	5	3	4	Technical incompetence
CR19	Pricing all bills of quantities work items	3	1	2	3	1	4	4	4	Pricing only few items
CR20	Consistently bid for us	1	4	4	3	2	4	5	5	Occasional bidder
CR21	Prompt start on site	2	1	2	4	3	4	4	3	Late start on site
CR22	Contact address	3	3	4	5	4	4	5	5	Unregistered company
CR23	Understand contract documents	4	5	5	5	4	5	5	5	Cannot interpret contract docs
CR24	Good financial standing	4	4	5	4	2	4	3	3	Poor financial standing
CR25	Plant & equipment availability	3	5	4	5	3	5	4	4	Unable to provide plant & equipment
CR26	Receipt of quotation on time	4	5	3	4	2	1	2	3	Persistent late quote

Table 7.1: **Estimators** Repertory Grid(**Domestic Sub-contractors** constructs)

CONSTRUCTS		ELEMENTS										CONSTRUCTS
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
CR1	Competitive bid	5	5	4	1	5	4	2	3	3	2	Uncompetitive priced rates
CR2	Consistency of priced rates	5	5	4	4	5	2	1	1	1	3	Overloading of priced rates
CR3	Early quotation	4	4	3	4	4	2	1	1	3	5	Late quotation
CR4	Pricing all items in BOQ	3	5	1	1	4	5	2	3	5	5	Lump sum quotation
CR5	Keen to work for us	4	2	4	2	1	4	3	5	5	3	Persuaded to send in quotation
CR6	Capable of financing his contract	5	3	5	2	2	1	1	1	4	3	Likely to go into liquidation
CR7	Project type experience	5	4	3	4	2	2	1	1	5	5	Inexperience on project type
CR8	Project size experience	3	2	2	1	3	4	5	5	3	4	Inexperience on project complexity
CR9	Geographical area work experience	2	5	2	3	5	5	1	2	1	4	No work experience in the area
CR10	Technical competence	3	4	3	3	3	2	1	2	5	5	Technical incompetence
CR11	Prompt commencement site work	3	4	3	5	4	3	5	1	2	5	Late start on site
CR12	Good record of schedule maintenance	3	4	3	2	3	5	4	2	3	4	Late completion of work schedule
CR13	Good quality of workmanship	4	3	4	3	2	3	4	5	1	1	Poor quality of workmanship
CR14	Quality rated firm	3	3	3	3	4	2	2	1	5	5	Quality unrated firm
CR15	Experienced site foreman	2	2	1	1	1	2	2	2	3	4	Inexperienced site foreman
CR16	Properly registered company	3	3	4	5	4	5	5	4	4	5	Unregistered company
CR17	Agreement on work programme	4	5	2	4	3	1	4	3	4	5	Unacceptable work programme
CR18	Capable site management	4	4	4	4	3	5	4	3	4	5	Incapable of managing his work
CR19	Adequate cashflow	3	5	1	3	2	1	1	2	1	3	Unstable firm
CR20	Good financial reference	3	4	3	1	2	1	4	2	4	3	Poor financial reference
CR21	Reasonable claims	3	4	3	1	2	1	4	2	4	3	Inflated claims
CR22	Reasonable work valuations	4	2	4	1	2	2	4	5	5	3	Inflated work valuations
CR23	Reliable and honest firm	3	4	5	3	3	1	2	4	5	3	Unreliable and untrustworthy firm
CR24	Good trade reference	4	4	2	1	2	5	2	4	2	3	Poor trade reference
CR25	Good relationship with our firm	3	4	4	4	2	3	1	2	3	3	Poor relationship with our firm
CR26	Adequate plant and equipment	5	5	4	5	3	4	5	4	5	3	Inadequate plant and equipment
CR27	Good safety records	4	3	5	4	3	3	2	4	1	1	Poor safety records
CR28	Good safety programme	3	4	4	5	5	4	4	2	1	1	Poor safety programme
CR29	Client approval	4	5	3	3	1	1	2	4	5	4	Client disapproval

Estimators cont:- Repertory Grid(**Domestic Sub-contractors** constructs)

CONSTRUCTS		ELEMENTS										CONSTRUCTS
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
CR30	Experienced safety foreman	5	3	2	1	3	2	1	1	4	5	Cow boy firm
CR32	Quick response to calls	1	2	3	5	5	4	4	5	2	4	Slow to respond to calls
CR33	Good communicator	3	1	1	4	4	5	5	1	2	3	Poor communicator
CR34	Attendance of site meetings	4	4	4	5	2	2	1	4	4	3	Never bothered to attend meetings
CR35	Implementation of decisions	3	5	2	4	4	5	5	3	1	3	Ignored all decisions reached
CR36	Adequate turnover	1	2	3	3	2	5	1	4	3	4	Unacceptable turnover
CR37	Approval by client	3	2	2	1	1	5	5	4	2	3	Unapproved by the client
CR38	Proper trade registration	4	1	2	4	1	3	2	4	3	5	Unregistered firm
CR39	Plant and equipment availability	4	2	1	3	4	1	2	4	2	5	Incapable of meeting matls specs
CR41	Provision of bonds and warranties	3	3	4	3	5	4	2	2	1	1	Incapable of providg bonds & warran
CR42	Experience on contract document	3	4	2	4	4	5	3	1	1	3	Inexperience on contract documents

Contracts Director Repertory Grid(Domestic Sub-contractors constructs)												
CONSTRUCTS		ELEMENTS										CONSTRUCTS
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
CR1	Keen to work for us	4	2	4	4	4	4	3	5	5	3	Persuaded to send in quotation
CR2	Project type experience	4	3	1	2	1	1	1	1	1	2	Inexperience on project type
CR3	Geographical area work experience	2	5	4	3	3	2	1	2	1	4	No work experience in the area
CR4	Good record of schedule maintenance	3	4	3	5	4	3	4	3	4	5	Late completion of work schedule
CR5	Experience on contract documents	4	2	3	5	3	3	2	5	4	3	Inexperience on contract documents
CR6	Good quality of workmanship	3	4	5	2	3	5	4	5	4	4	Poor quality of workmanship
CR7	Attendance of site meetings	1	1	1	2	4	5	1	4	3	4	Never bothered to attend meetings
CR8	Experienced site foreman	3	3	3	3	4	4	4	2	5	5	Inexperienced site foreman
CR9	Pricing all items in BOQ	3	1	2	4	5	2	5	3	2	4	Lump sum quotation
CR10	Agreement on work programme	3	3	4	5	4	5	5	4	4	5	Unacceptable work programme
CR11	Job size experience	3	2	3	2	4	5	4	3	3	4	Inexperience on project complexity
CR12	Capable site organisation	4	4	4	4	3	5	4	3	4	5	Poor site organisation
CR13	Consistency of priced rates	3	2	1	2	3	3	3	4	4	5	Inconsistent priced rates
CR14	Adequate cashflow	3	5	1	3	2	1	1	2	1	3	Unstable firm
CR15	Good financial reference	3	4	3	1	2	1	4	2	4	3	Poor financial reference
CR16	Approval by client	1	2	1	3	1	1	3	1	1	3	Unapproved by the client
CR17	Reasonable claims	4	2	4	4	5	2	4	5	5	3	Inflated claims
CR18	Consistently bid for us	1	3	3	3	2	3	4	1	4	3	Only occasional bidder
CR19	Reliable and honest firm	4	4	2	3	3	5	2	4	2	3	Unreliable and untrustworthy firm
CR20	Good trade reference	3	4	4	4	2	3	3	3	3	3	Poor trade reference
CR21	Capable of managing his own work	4	2	1	3	3	4	4	4	3	5	Incapable of managing his own work
CR22	Good relationship with our firm	4	5	4	5	3	4	3	4	5	3	Poor relationship with our firm
CR23	Prompt site work commencement	4	4	4	5	4	4	5	3	4	4	Late start on site
CR24	Adequate plant and equipment	4	3	3	3	3	3	3	4	4	3	Inadequate plant and equipment
CR25	Good safety records	3	4	4	5	5	4	4	4	4	2	Poor safety records
CR26	Competitive bid	2	1	2	2	5	2	4	3	5	5	Uncompetitive priced rates
CR27	Good safety programme	4	5	3	3	3	3	4	4	5	4	Technical incompetence
CR28	Technical competence	3	4	3	3	3	2	2	3	3	3	Incompetent and unskilled workforce
CR29	Keeping tidy site	5	3	2	1	3	4	5	5	3	5	Untidy site work practice
CR30	Materials specification compliance	3	3	4	3	2	4	2	2	1	1	Incapable of meeting matls specs

Contracts Director cont- Repertory Grid(**Domestic Sub-contractors** constructs)

CONSTRUCTS	ELEMENTS										CONSTRUCTS
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
CR31 Contact address	3	3	3	4	4	4	4	3	5	3	Cow boy firm
CR32 Quick response to calls	4	4	4	5	2	2	4	4	4	3	Slow to respond to calls
CR33 Good communicator	3	5	2	4	4	3	3	3	1	3	Poor communicator
CR34 Implementation of decisions	3	4	4	4	4	3	5	4	2	3	Ignored all decisions reached
CR35 Reasonable work valuations	3	4	5	3	3	3	3	3	5	3	Inflated work valuations
CR36 Adequate turnover	4	5	5	4	5	3	2	4	3	5	Unacceptable turnover
CR37 Experienced safety foreman	4	2	3	4	5	2	5	5	5	4	Inexperienced safety foreman
CR38 Proper trade registration	1	3	1	5	4	5	3	4	2	5	Unregistered firm
CR39 Client approval	2	2	4	5	4	3	3	5	3	4	Client disapproval
CR40 Plant and equipment availability	4	1	3	5	3	3	2	2	3	4	Incapable of providg reqd. plant & eqpmt.
CR41 Quality rated firm	4	3	4	3	2	3	4	4	3	1	Quality unrated firm
CR42 Provision of bonds and warranties	3	4	2	4	4	5	3	3	5	3	Incapable of providg bonds & warranties
CR43 Correct design of work	4	4	5	3	2	4	2	3	3	4	Incorrect design of work
CR44 Prompt design of variations	3	3	5	4	4	4	3	4	4	5	Late design of variations
CR45 Transporting workforce to site	4	2	1	3	5	5	2	2	3	5	Transportation unavailability

Buyer Repertory Grid(Domestic Sub-contractors constructs)

CONSTRUCTS		ELEMENTS										CONSTRUCTS
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
CR1	Competitive bid	2	1	2	2	5	2	4	3	5	5	Uncompetitive priced rates
CR2	Pricing all items in BOQ	3	1	2	4	5	2	5	3	2	4	Lump sum quotation
CR3	Consistently bid for us	1	3	3	3	2	3	4	1	4	3	Only occasional bidder
CR4	Project type experience	4	3	1	2	1	1	1	1	1	2	Inexperience on project type
CR5	Good relationship with our firm	4	5	4	5	3	4	3	4	5	3	Poor relationship with our firm
CR6	Geographical area work experience	2	5	4	3	3	2	1	2	1	4	No work experience in the area
CR7	Skilled and competent workforce	3	4	3	3	3	2	2	3	3	3	Incompetent and unskilled workforce
CR8	Prompt site work commencement	4	4	4	5	4	4	5	3	4	4	Late start on site
CR9	Good record of schedule maintenance	3	4	3	5	4	3	4	3	4	5	Late completion of work schedule
CR10	Capable site management staff	1	1	1	2	4	5	1	4	3	4	Incapable of managing his work
CR11	Good quality of workmanship	3	4	5	2	3	5	4	5	4	4	Poor quality of workmanship
CR12	Experience on contract documents	4	2	3	5	3	3	2	5	4	3	Inexperience on contract documents
CR13	Quality rated firm	4	3	4	3	2	3	4	4	3	1	Quality unrated firm
CR14	Experienced site foreman	3	3	3	3	4	4	4	2	5	5	Inexperienced site foreman
CR15	Never defaulted in the past	2	2	4	5	4	3	3	5	3	4	Previous default experience
CR16	Agreement on work programme	3	3	4	5	4	5	5	4	4	5	Unacceptable work programme
CR17	Technical competence	4	4	4	4	3	5	4	3	4	5	Technical incompetence
CR18	Early quotation	4	2	1	3	3	4	4	4	3	5	Late quotation
CR19	Adequate cashflow	3	5	1	3	2	1	1	2	1	3	Unstable firm
CR20	Good financial reference	3	4	3	1	2	1	4	2	4	3	Poor financial reference
CR21	Reasonable work valuations	3	4	5	3	3	3	3	3	5	3	Inflated work valuations
CR22	Consistency of priced rates	3	2	1	2	3	3	3	4	4	5	Inconsistent priced rates
CR23	Reliable and honest firm	4	4	2	3	3	5	2	4	2	3	Unreliable and untrustworthy firm
CR24	Good trade reference	3	4	4	4	2	3	3	3	3	3	Poor trade reference
CR25	Adequate plant and equipment	4	3	3	3	3	3	3	4	4	3	Inadequate plant and equipment
CR26	Keen to work for us	4	2	4	4	4	4	3	5	5	3	Persuaded to send in quotation
CR27	Work design capability	3	4	4	5	5	4	4	4	4	2	Poor work design
CR28	Keeping tidy site	5	3	2	1	3	4	5	5	3	5	Untidy site work practice
CR29	Experienced safety foreman	4	2	3	4	5	2	5	5	5	4	Inexperienced safety foreman
CR30	Contact address	3	3	3	4	4	4	4	3	5	3	Cow boy firm

Buyer Repertory Grid cont:-(**Domestic Sub-contractors** constructs)

CONSTRUCTS		ELEMENTS										CONSTRUCTS
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	
CR31	Quick response to calls	4	4	4	5	2	2	4	4	4	3	Slow to respond to calls
CR32	Good safety programme	4	5	3	3	3	3	4	4	5	4	Poor safety programme
CR33	Implementation of decisions	3	4	4	4	4	3	5	4	2	3	Ignored all decisions reached
CR34	Project size experience	3	2	3	2	4	5	4	3	3	4	Inexperience on project complexity
CR35	Adequate turnover	4	5	5	4	5	3	2	4	3	5	Unacceptable turnover
CR36	Approval by client	1	2	1	3	1	1	3	1	1	3	Unapproved by the client
CR37	Registered company	1	3	1	5	4	5	3	4	2	5	Unregistered firm
CR38	Plant and equipment availability	4	1	3	5	3	3	2	2	3	4	Incapable of providg reqd. plant & eqpmt.
CR39	Materials specification compliance	3	3	4	3	2	4	2	2	1	1	Incapable of meeting matls specs
CR40	Reasonable claims	4	2	4	4	5	2	4	5	5	3	Inflated claims
CR41	Provision of bonds and warranties	3	4	2	4	4	5	3	3	5	3	Incapable of providg bonds & warranties

APPENDIX C

SURVEY QUESTIONNAIRE SPSS-X DATA ENTRY FORMAT

Appendix C

SURVEY QUESTIONNAIRE SPSS-X DATA ENTRY FORMAT

```
DATA LIST FILE ='sky.dat5' RECORDS=3
  /1 CONCODE 1-3 ACCTYR 4-11 TURNOVER 12 DIRLAB 13 SUBPER 14 REFUBEX 15
     SUBPOCY 16 STAFFIN 17 SUBPOOL 18 COMPUTER 19 NSC 20 DOM 21 LOSC 22
     PLANTSUB 23 SUPPLR 24 FINRTR 25 MONITR 26 ORGAN 27 WKMANSHP 28
     ADMIN 29 SERV 30 REGISTA 31 LOCATN 32 SIZE 33 FINREC 34 PEFOREC 35
     INFOCOL 36 ASMENT 37 MAINCON 38 BOQ 39 DRWG 40 PRELIM 41 WKPROG 42
     STDATE 43 SPATTEN 44 SUPCOND 45 CONTRACT 46
  /2 SELECTSM 4-6 SELECTGF 7-8 SELECTBY 9-10 SELECTCM 11-12 SELECTES 13-14
     SELECTMD 15-16 SELECTQS 17-18 SELECTSE 19-20 SELECTPL 21-22 MONITSM 22-23
     MONITGF 24-25 MONITBY 26-27 MONITCM 28-29 MONITES 30-31 MONITMD 32-33
     MONITQS 34-35 MONITSE 36-37 MONITPL 38-39 CONTRSM 40-41 CONTRGF 42-43
     CONTRBY 44-45 CONTRCM 46-47 CONTRES 48-49 CONTRMD 50-51 CONTRQS 52-53
     CONTRSE 54-55 CONTRPL 56-57 INDECI 58  GPDECI 59 COMDICI 60
     MANAG 61 FUZZY 62 BAYES 63 TIME 64 PRICE 65 INFOLAK 66 RELATN 67 WKQUA 68
     MGTCAP 69 PROSTAT 70 SUBMGT 71 SITECON 72
  /3 FINSTAN 4 REF 5 BID 6 INHSE 7 LABSTR 8 MGTABL 9 WKLOAD 10 TENSER 11
     TRANSFA 12 EXPLOCA 13 SAFE 14 TRUST 15 TIDYSITE 16 QUASUR 17 SUBEPLO 18
     PASTWK 19 CREDBU 20 NEGO 21 ADVDOC 22 TENNOT 23 RECUN 24 COYASS 25
     INTER 26 RESULT 27 POSITN 28
VARIABLE LABELS CONCODE 'CONTRACTORS REFERENCE NUMBER'
                /ACCTYR  'ACCOUNTING YEAR'
                /TURNOVER 'ANNUAL TURNOVER'
                /DIRLAB 'DIRECTLY EMPLOYED LABOUR'
                /SUBPER 'PERCENTAGE OF SUBCONTRACTORS USED'
                /REFUBEX 'YEARS OF EXPERIENCE IN REFURBISHMENT WORKS'
                /SUBPOCY 'COY WRITTEN POLICY ON SUB SELECTION'
                /STAFFIN  'STAFF  SPECIFICALLY DESIGNATED TO COLLATE INFO'
                /SUBPOOL 'POOL OF SUB TO CHOOSE FROM'
                /COMPUTER 'USE OF COMPUTER IN THE SELECTION OF SUBS'
                /NSC  'DO YOU WORK WITH NOMINATED SUBS'
                /DOM  'DO YOU WORK WITH DOMESTIC SUBS'
                /LOSC  'DO YOU WORK WITH LABOUR-ONLY SUBS'
                /PLANTSUB  'DO YOU HIRE PLANT SUPPLIERS'
                /SUPPLR 'DO YOU HIRE MATERIAL SUPPLIERS'
                /FINRTR 'SUBS THAT GIVE LARGER FINAN RETURNS'
                /MONITR  ' SUBS THAT OFFERS EFFECTIVE MONITORG'
                /ORGAN 'SUBS THAT OFFERS BETTER ORGANISATION FOR THE COY'
                /WKMANSHP 'SUBS THAT OFFERS QUALITY OF WORKMANSHIP'
                /ADMIN 'SUB THAT OFFERS LESS ADMIN WORRIES'
                /SERV 'HOW IS QUALITY OF SERVICES PROVIDED BY SUBS'
                /REGISTA 'DO YOU KEEP RECORD OF DSC ACCORDING TO TRADE'
                /LOCATN 'RECORD ACCORDING TO AREA OF OPERATN'
                /SIZE 'RECORD ACCORDING TO STAFF CAPABILITY'
                /FINREC 'RECORD ACCORDING TO FINANCIAL STATUS'
                /PEFOREC 'RECORD ACCORDING TO PAST PERFORMANCE'
                /INFOCOL 'WHO RECEIVES AND COLLATE INFO'
                /ASMENT 'SITE AGENTS ASSESEMENT OF SUBS ON SITE'
                /MAINCON 'DO YOU GIVE INFO ON MAIN CONTRACT CONDITIONS'
                /BOQ 'DO YOU GIVE BOQ TO SUBS'
                /DRWG 'DO YOU GIVE DRWG TO SUBS'
                /PRELIM 'DO YOU GIVE PRELIM SECTN OF BOQ'
                /WKPROG 'DO SUBS SUBMIT WKPROG'
                /STDATE 'DO YOU GIVE START AND FINISHG DATES TO SUB'
                /SPATTEN 'DO YOU HIGHLIGHT SPECIAL ATTENDANCE'
                /SUPCOND 'DO YOU GIVE SUPPLIMENTARY CONDITION OF CONTRACTS'
                /CONTRACT 'CONDITN OF CONTRACTS USED BY DSC'
                /SELECTSM 'SITE MANAGER BEING RESPONSIBLE FOR  SELECTN'
                /SELECTGF 'GENERAL FOREMAN BEING RESPNSIBLE FOR SELECTN'
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                /SELECTCM 'CONTRACT MANAGER BEING RESPNSIBLE FOR SELECTN'
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               /MONITBY 'BUYER BEING RESPONSIBLE FOR MONITORG'
               /MONITCM 'CONTRACT MANAGER BEING RESPONSIBLE FOR MONITORG'
               /MONITES 'ESTIMATOR BEING RESPONSIBLE FOR MONITORG'
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               /CONTRCM 'CONTRACT MANAGER BEING RESPONSIBLE FOR CONTROLG'
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               /CONTRMD 'MANAGING DIRECTOR BEING RESPONSIBLE FOR CONTROLG'
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               /MANAG 'USE OF MGT CONSULTANTS'
               /FUZZY 'USE OF FUZZY SET THEORY'
               /BAYES 'USE OF BAYES & WGHTED INDEX'
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               /PRICE 'PRICE CRITERION IN SUB SELECTN'
               /INFOLAK 'INFORMATION LACK IN SELECTION'
               /RELATN 'SITE & OFFICE AGGREMENT IN THE SELECTN'
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               /MGTCAP 'MGT CAPABILITY'
               /PROSTAT 'PROMPT START ON SITE'
               /SUBMGT 'SUB STD & MGT ADIM'
               /SITECON 'CONSULTATN OF SITE AGENT B4 SELECTION'
               /FINSTAN 'DO YOU ASSESS FINANCIAL STANDG'
               /REF 'DO YOU ASSESS WORK REFERENCE'
               /BID 'ABILITY TO SUBMIT REALISTIC BID'
               /INHSE 'SUB BID WITH IN-HSE BID'
               /LABSTR 'SUB LAB STRENGHT'
               /MGTABL 'SUB MGT CAPABILITY'
               /WKLOAD 'SUB WORKLOAD'
               /TENSER 'SUB TENURE IN SERVICE SUPPLIER'
               /TRANSFA 'SUB TRASPORT FACILITY'
               /EXPLOCA 'SUB REGION OF OPERATN & WKMANSHP'
               /SAFE 'SUB SAFETY RECORD'
               /TRUST 'SUB HONESTY'
               /TIDYSITE 'SUB SITE TIDYNESS'
               /QUASUR 'SUB QA & QC RECORD'
               /SUBEPLO 'EMLOYMT OF NEW SUBS'
               /PASTWK 'PAST WK EXPERIENCE'
               /CREDBU '[BSUB CREDIT BUREAUX'
               /NEGO 'NEGOTIATN BW SUB B4 EMPLOYMT'
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               /TENNOT 'NOTIFICATN OF TENDER RESULT'
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               /COYASS  'OPERATION OF WRITTEN ASSESSMT'
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0023433444434444411111211111
0340789069073462211111112233331112113444433332
034    030405  07  0910    13    16  181920          26  114444221511343
0343344334334444331111211111
0570489049074461211111112111131112211444322342
05701    04  0607    10    13    16    19    22    25    414444352132524
0573334433323432321212212111
0291289129021562212111112333331111113444444431
029      04050607    10    13  1516    1920  22  2425    214444151344543
0293344444334443111212211111
0470989099072561111111114333231111113444444441
047    0304050607   9101112131415161718192021  23  2526  114444233454443
0474433444334444411111111111
```

APPENDIX D

INGRIDA COMPUTER OUTPUT FOR DOMESTIC AND LABOUR ONLY SUB-CONTRACTORS ANALYSIS RESULTS

Appendix D

INGRIDA COMPUTER OUTPUT FOR DOMESTIC AND LABOUR ONLY SUB-CONTRACTORS ANALYSIS RESULTS

Domestic Sub-contractor - Estimator's Analysis Result

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                              CONSTRUCT MEANS AND DEVIATIONS
                              ==============================
INTRODUCTION
------------
THE MEAN VALUES FOR THE CONSTRUCT SHOW WHETHER YOU TEND TO MARK
HIGH OR LOW ON THAT CONSTRUCT. IF YOU ARE USING A 7 POINT SCALE
THE MEANS SHOULD BE ABOUT 4  THE PERCENTAGE OF VARIATION SHOWS
HOW WELL YOU ARE USING THE SCALE  IN GENERAL  THE HIGHER THE
PERCENTAGE THE BETTER YOUR DISCRIMINATION ON THE CONSTRUCT. ONE
IMPORTANT EXCEPTION TO THIS RULE IS WHEN YOU ONLY USE THE EXTREME
POINTS (EITHER 1 OR 7 ON A 7 POINT SCALE;  IN THIS CASE, THE
PERCENTAGE VARIATION WILL BE HIGH EVEN THOUGH YOUR
DISCRIMINATION IS CRUDE.

0CONSTRUCT      MEAN        VARIATION      AS PER CENT
     1          3.400        24.4000          2.77
     2          3.000        24.0000          4 05
     3          3.100        15.9000          2.54
     4          3.200        23.6000          3.67
     5          3.300        14 1000          2.42
     6          2.700        12.1000          3.33
     7          3.200        17.6000          3.55
     8          3.200        15.6000          2.35
     9          3.300        19.6000          3.61
    10          2.900        22.9000          2.24
    11          3.500        15.5000          2.48
    12          3.300        16 1000          1.22
    13          2.700        20.1000          2.41
    14          3 100        17 9000          2.24
    15          2.000        16.0000          1.20
    16          3.300         8 1000          2.04
    17          3.100        16 9000          2.54
    18          4 200         5 6000          2.39
    19          2.700        12.1000          1.82
    20          3.200         7.6000          2.65
    21          3.300        16.1000          2.12
    22          2 900        15 9000          2.24
    23          2.700        22.1000          1.34
    24          4 300        16 1000          0.92
    25          3.000        16.0000          2.41
    26          3.300        15 1000          3.02
    27          3.200        19.5000          2.95
    28          2.700        19.1000          3.33
    29          3.200        16.6000          2.78
    30          2.900        16.5000          3.45
    31          3.300        15.1000          2.12
    32          3.500        16.5000          2.48




    33          2 800        17 6000          2.35
    34          2.800        16.6000          2.95
    35          2.900        16.9000          2.54
    36          2.400        18.4000          2.77
    37          3.300        14.1000          2.42
    38          2.800        15.6000          2.35
    39          3.000        16.0000          2.41
    40          3.400        18.4000          2.77
0TOTAL VARIATION ABOUT CONSTRUCT MEANS        664.5969

                              BIAS
                              ====
INTRODUCTION
------------
BIAS SHOWS HOW LOPSIDED YOUR MARKS ARE IN GENERAL  THE FURTHER
CONSTRUCT MEANS DEVIATE FROM THE MID POINT OF THE GRADING SCALE.
 THE HIGHER THE BIAS WILL BE  VARIABILITY GIVES AN
OVERALL IMPRESSION OF HOW WELL YOU ARE USING THE SCALES  THE
HIGHER THE VARIABILITY THE BETTER - EXCEPT OF COURSE WHEN YOU
ARE ONLY USING THE EXTREME VALUES  VARIABILITY NORMALLY EQUALS
ABOUT .50 TO  TO

0                          BIAS        . 0.2171
                           VARIABILITY  0 6794
```

Domestic Sub-contractor - Buyer's Analysis Result

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INTRODUCTION
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THE MEAN VALUES FOR THE CONSTRUCT SHOW WHETHER YOU TEND TO MARK
HIGH OR LOW ON THAT CONSTRUCT. IF YOU ARE USING A 7 POINT SCALE
THE MEANS SHOULD BE ABOUT 4. THE PERCENTAGE OF VARIATION SHOWS
HOW WELL YOU ARE USING THE SCALE. IN GENERAL, THE HIGHER THE
PERCENTAGE THE BETTER YOUR DISCRIMINATION ON THE CONSTRUCT. ONE
IMPORTANT EXCEPTION TO THIS RULE IS WHEN YOU ONLY USE THE EXTREME
POINTS (EITHER 1 OR 7 ON A 7 POINT SCALE). IN THIS CASE, THE
PERCENTAGE VARIATION WILL BE HIGH EVEN THOUGH YOUR
DISCRIMINATION IS CRUDE.

0CONSTRUCT     MEAN       VARIATION     AS PER CENT
     1         3.200       23.6000          2.63
     2         3.600       19.3999          2.91
     3         3.500       12.5000          1.94
     4         3.200       19.6000          3.37
     5         2.300       18.1000          2.56
     6         3.300       22.1000          3.37
     7         3.500       19.5000          2.64
     8         3.500       15.5000          1.78
     9         3.000       11.0000          0.80
    10         2.500       12.4000          1.94
    11         3.200       23.6000          1.78
    12         3 600       26.4000          3.58
    13         3.900       12 9600          2.63
    14         2.600       18.4000          2.63
    15         3.700       18.1000          1.16
    16         3.900       19.9000          1.84
    17         3.200       23.6000          1.84
    18         3.800        5.6000          1.77
    19         3.900       12.9000          2.23
    20         3 400       18.4000          2.63
    21         2.300       17.1000          1.84
    22         3.300       22.6000          2.80
    23         3.000       24.0000          2.76
    24         3.200       18.6000          3.37
    25         2.900       17.9000          2.70
    26         2.900       12.9000          3.15
    27         3.200       23.6000          2.64
    28         3.200       16.5999          3.37
    29         3.000       19.0000          2.86
    30         3.600       16.4000          3.77
    31         3.000       15.0000          3.43
    32         3.300       20.1000          2.23
    33         3 300       19 1000          3.18
    34         3.200       19.6000          2.80
    35         3.000       16.0000          2.86
    36         3.300       20.1000          2.97



    37         2.800       15.6000          2.23
    38         3.300       16.1000          2.30
    39         2.900       17.9000          3.27
    40         3.400       12.8000          2.41
0TOTAL VARIATION ABOUT CONSTRUCT MEANS        700.4973

                              BIAS
                              ----
INTRODUCTION
------------
BIAS SHOWS HOW LOPSIDED YOUR MARKS ARE IN GENERAL. THE FURTHER
CONSTRUCT MEANS DEVIATE FROM THE MID POINT OF THE GRADING SCALE,
 THE HIGHER THE BIAS WILL BE. VARIABILITY GIVES AN
OVERALL IMPRESSION OF HOW WELL YOU ARE USING THE SCALES. THE
HIGHER THE VARIABILITY THE BETTER - EXCEPT OF COURSE WHEN YOU
ARE ONLY USING THE EXTREME VALUES  VARIABILITY NORMALLY EQUALS
ABOUT .50 TO .70.

0                          BIAS          0.2298
                           VARIABILITY   0.6975
```

Domestic Sub-contractor - Contract Director's Analysis Result

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INTRODUCTION
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THE MEAN-VALUES FOR THE CONSTRUCT SHOW WHETHER YOU TEND TO MARK
HIGH OR LOW ON THAT CONSTRUCT. IF YOU ARE USING A 7 POINT SCALE
THE MEANS SHOULD BE ABOUT 4. THE PERCENTAGE OF VARIATION SHOWS
HOW WELL YOU ARE USING THE SCALE. IN GENERAL, THE HIGHER THE
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IMPORTANT EXCEPTION TO THIS RULE IS WHEN YOU ONLY USE THE EXTREME
POINTS (EITHER 1 OR 7 ON A 7 POINT SCALE). IN THIS CASE, THE
PERCENTAGE VARIATION WILL BE HIGH EVEN THOUGH YOUR
DISCRIMINATION IS CRUDE.

0CONSTRUCT       MEAN        VARIATION       AS PER CENT
     1           3.350        4.9000           3.29
     2           3.300       12.1000            5.62
     3           3.600       14.4000            3.36
     4           4.400       10.9000            2.54
     5           2.200       15.5000            4.10
     6           3.900       10.0000            2.92
     7           3.200       13.6000            3.17
     8           3.400       12.4000            2.89
     9           3.000       11.0000            4.20
    10           3.600        9.4000            1.49
    11           4.000       10.0000            2.33
    12           2.200       11.6000            2.71
    13           3.300       16.1000            5.15
    14           3.300        4.1000            1.96
    15           4.000       10.0000            1 40
    16           3.800       12.6000            1.31
    17           3.800       11.6000            2.71
    18           4.200        5.6000            2.33
    19           3.700       10.1000            0.96
    20           3.600       12.4000            1.96
    21           2.900        2.9000            1.14
    22           3.500       12.5000            3.85
    23           3.100       10.9000            2.08
    24           3.500        6.5000            1.52
    25           3.800       18.5000            3.75
    26           3.800       17.6000            2.08
    27           3.500       18.1000            2.54
    28           3.300       24.1000            2.24
    29           3.300       12.1000            1.09
    30           3.500       12.5000            4.31
    31           2.900       12.5000            0.60
    32           3.800       11.6000            1.31
    33           3.900       13.9000            2.08
    34           3.400       14.0000            1.03
    35           3.500       12.5000            1.98
    36           3.500       13.5000            2.45



    37           4.200       13.6000            1.31
    38           3.500        6.5000            0.93
    39           3.800       16.1000            3.64
    40           3.300       22.1000            2.82
0TOTAL VARIATION ABOUT CONSTRUCT MEANS          426.7981

                                   BIAS
                                   ----
INTRODUCTION
------------
BIAS SHOWS HOW LOPSIDED YOUR MARKS ARE IN GENERAL. THE FURTHER
CONSTRUCT MEANS DEVIATE FROM THE MID POINT OF THE GRADING SCALE,
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HIGHER THE VARIABILITY THE BETTER - EXCEPT OF COURSE WHEN YOU
ARE ONLY USING THE EXTREME VALUES. VARIABILITY NORMALLY EQUALS
ABOUT .50 TO .70.

0                            BIAS          0.3328
                             VARIABILITY   0.5457
0
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Labour only Sub-contractor - Estimator's Analysis Result

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                                        ==============================
 INTRODUCTION
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 THE MEAN VALUES FOR THE CONSTRUCT SHOW WHETHER YOU TEND TO MARK
 HIGH OR LOW ON THAT CONSTRUCT. IF YOU ARE USING A 7 POINT SCALE
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 POINTS (EITHER 1 OR 7 ON A 7 POINT SCALE). IN THIS CASE, THE
 PERCENTAGE VARIATION WILL BE HIGH EVEN THOUGH YOUR
 DISCRIMINATION IS CRUDE.

0CONSTRUCT      MEAN         VARIATION      AS PER CENT
     1          3.125         18.8750          6.53
     2          2.500         14.0000          4.84
     3          3.250         10.5000          5.36
     4          3.625         11.6750          4.11
     5          3.380         13.8750          3.46
     6          2.380         11.8750          3.46
     7          3.125         18.8750          4.80
     8          2.375         17.3750          3.46
     9          3.125         10.8750          3.76
    10          3.250         15.5000          1.90
    11          3.375         10.8750          5.49
    12          2.625          7.8750          6.18
    13          3.000         11.2000          2.77
    14          3.125         11.5000          6.53
    15          2.250          5.0000          6.53
    16          2.875          8.8750          2.72
    17          2.875         18.8750          3.07
    18          3 500         11.0000          3.46
    19          3.375         15.8750          3.07
    20          2 375         11.5000          4 11



    21          3.250         11.5000          3.98
    22          2.000          3.0000          3.07
    23          2.750          7.5000          2.59
    24          1 750          4.2750          0.65
0TOTAL VARIATION ABOUT CONSTRUCT MEANS        289.1250

                                     BIAS
                                     ====
 INTRODUCTION
 ------------
 BIAS SHOWS HOW LOPSIDED YOUR MARKS ARE IN GENERAL. THE FURTHER
 CONSTRUCT MEANS DEVIATE FROM THE MID POINT OF THE GRADING SCALE.
  THE HIGHER THE BIAS WILL BE. VARIABILITY GIVES AN
 OVERALL IMPRESSION OF HOW WELL YOU ARE USING THE SCALES  THE
 HIGHER THE VARIABILITY THE BETTER - EXCEPT OF COURSE WHEN YOU
 ARE ONLY USING THE EXTREME VALUES  VARIABILITY NORMALLY EQUALS
 ABOUT .50 TO  70

0                                BIAS          0.2233
                                 VARIABILITY   0.6427
0
```

Labour only Sub-contractor - Buyer's Analysis Result

```
                                   CONSTRUCT MEANS AND DEVIATIONS
                                   ==============================
 INTRODUCTION
 ------------
 THE MEAN VALUES FOR THE CONSTRUCT SHOW WHETHER YOU TEND TO MARK
 HIGH OR LOW ON THAT CONSTRUCT  IF YOU ARE USING A 7 POINT SCALE
 THE MEANS SHOULD BE ABOUT 4  THE PERCENTAGE OF VARIATION SHOWS
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 PERCENTAGE THE BETTER YOUR DISCRIMINATION ON THE CONSTRUCT. ONE
 IMPORTANT EXCEPTION TO THIS RULE IS WHEN YOU ONLY USE THE EXTREME
 POINTS (EITHER 1 OR 7 ON A 7 POINT SCALE)  IN THIS CASE, THE
 PERCENTAGE VARIATION WILL BE HIGH EVEN THOUGH YOUR
 DISCRIMINATION IS CRUDE.

0CONSTRUCT      MEAN        VARIATION      AS PER CENT
     1          2.380        15.8750          5.50
     2          3.125        14.8810          4.20
     3          3.125         5.5770          4.55
     4          3.130        14.8750          5.50
     5          3.375        12.1750          4.05
     6          3.000        15.0000          4.36
     7          3.125        18 8750          4.05
     8          3.000        18.0000          3.50
     9          3.125        12.8750          3.19
    10          3.250        11.5000          3.37
    11          2.250         5.0000          4.07
    12          2.750         8.8000          4.69
    13          2.750        15.5000          4.07
    14          3.125        14 5750          4.36
    15          2.250         7.5000          5.54
    16          2.750        15.5000          4.55
    17          3.120        10.8750          4.07
    18          3.375        13.8750          4 07
    19          3 250        12.5000          3.37
    20          3 375        17.8750          5.54



    21          3 625        13 8750          4.66
    22          3.625        12.8750          1.72
    23          2.750        13.5000          2.20
    24          3.875        11.8750          3.15
    25          3.625        11.8750          3.48
0TOTAL VARIATION ABOUT CONSTRUCT MEANS          340.8750

                                   BIAS
                                   ====
 INTRODUCTION
 ------------
 BIAS SHOWS HOW LOPSIDED YOUR MARKS ARE IN GENERAL. THE FURTHER
 CONSTRUCT MEANS DEVIATE FROM THE MID POINT OF THE GRADING SCALE.
  THE HIGHER THE BIAS WILL BE. VARIABILITY GIVES AN
 OVERALL IMPRESSION OF HOW WELL YOU ARE USING THE SCALES. THE
 HIGHER THE VARIABILITY THE BETTER - EXCEPT OF COURSE WHEN YOU
 ARE ONLY USING THE EXTREME VALUES  VARIABILITY NORMALLY EQUALS
 ABOUT .50 TO .70.

0                             BIAS           0.2004
                              VARIABILITY    0.6987
0
0
```

Labour only Sub-contractor - Contract Director's Analysis Result

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                              [illegible]
                              ==============================
 INTRODUCTION
 ------------
 THE MEAN VALUES FOR THE CONSTRUCT SHOW WHETHER YOU TEND TO MARK
 HIGH OR LOW ON THAT CONSTRUCT. IF YOU ARE USING A 7 POINT SCALE
 THE MEANS SHOULD BE ABOUT 4. THE PERCENTAGE OF VARIATION SHOWS
 HOW WELL YOU ARE USING THE SCALE  IN GENERAL. THE HIGHER THE
 PERCENTAGE THE BETTER YOUR DISCRIMINATION ON THE CONSTRUCT  ONE
 IMPORTANT EXCEPTION TO THIS RULE IS WHEN YOU ONLY USE THE EXTREME
 POINTS (EITHER 1 OR 7 ON A 7 POINT SCALE). IN THIS CASE, THE
 PERCENTAGE VARIATION WILL BE HIGH EVEN THOUGH YOUR
 DISCRIMINATION IS CRUDE.

0CONSTRUCT      MEAN         VARIATION      AS PER CENT
     1          2.630         21.8750          4.43
     2          2.750         15.5000          4.12
     3          3.250         14.5000          5.96
     4          3.500         16.0000          5.23
     5          3.130         18.8750          4.85
     6          3.260         21.5000          2.77
     7          2.875         18.8750          1.91
     8          2.625         12.8750          6.06
     9          3.125         12.8750          3.01
    10          3.250         15.5000          3.88
    11          3.500         13.0000          6.65
    12          3.000         12.0000          2.22
    13          3.000         16.0000          3.84
    14          2.500         14.0000          1.66
    15          3.375         13.8750          3.84
    16          3.125         14.8750          4.12
    17          3.000         15.0000          4.43
    18          3.250         15.5000          3.19
    19          3.375         13.8750          3.84
    20          3 000          5.0000          4.30




    21          2 750         17.5000          2.46
    22          3.500         24.0000          3.84
    23          2.500          6.0000          5.23
    24          2.500         10.0000          3.84
    25          2.750         10.8750          3.45
0TOTAL VARIATION ABOUT CONSTRUCT MEANS        360.8750

                               BIAS
                               ====
 INTRODUCTION
 ------------
 BIAS SHOWS HOW LOPSIDED YOUR MARKS ARE IN GENERAL. THE FURTHER
 CONSTRUCT MEANS DEVIATE FROM THE MID POINT OF THE GRADING SCALE.
  THE HIGHER THE BIAS WILL BE  VARIABILITY GIVES AN
 OVERALL IMPRESSION OF HOW WELL YOU ARE USING THE SCALE:  THE
 HIGHER THE VARIABILITY THE BETTER - EXCEPT OF COURSE WHEN YOU
 ARE ONLY USING THE EXTREME VALUES. VARIABILITY NORMALLY EQUALS
 ABOUT .50 TC  T0.

0                            BIAS          0.2183
                             VARIABILITY   0.6180
0
```

APPENDIX E

FUZZY SET THEORY COMPUTER PROGRAMME FOR SSARC IMPLEMENTATION

Appendix E

FUZZY SET THEORY COMPUTER PROGRAMME FOR SSARC IMPLEMENTATION (Implemented in Pascal)

```
program SSARC (input, marks_defs, ratings);

uses   crt,printer;

const
  max_mark_len = 300;    {max number of components in a mark descriptior


type

  mark = record len        : integer;
           contents       : array [1..max_mark_len] of record
                                 mark   : real;
                                 index  : integer;
                                end;


        end;
    markarray = array ['A'..'E'] of mark;
    name = string[80];
   string20 = ARRAY [1..20] OF STRING[20];

var

{Declare the main work-space variables }
     marks1,weights : markarray;
   m ,      { Individual mark for a single criterion }
   w ,      { Its corresponding weight }
   product ,  { This is m.w for each mark, weight read in }
   N ,      { The 'running total numerator }
   D ,      { The running total denominator }  { That should do }
   Q : mark;     { Quotient of N by D }

   mc, wc : char;     { Indicates marks and weights read from keybd. }

   area : real;      { This is where the answer goes before being
                     obliterated by the next set of opinions }
   ans, m_idx: char;
   distance : array ['A'.. 'E'] of real;
   NumRec, i : integer;
   a,b : string20;
```

```
{**********************************************************************}

Function LTrim( Str : string) : string ;
var
  I : integer ;

begin
  I := 0 ;
   Repeat
    I := I + 1 ;
  Until str[I] <> ' ' ;
  LTrim := Copy( Str, I, Length(Str) ) ;
End;

{**********************************************************************}

Function RTrim( Str : string) : string ;
var
  I,l : integer ;

begin
  I := 0 ; l := length(str);
  Repeat
   I := I + 1 ;
  Until (i > L) or (str[I] = ' ');
 I := I - 1 ;
  RTrim := Copy( Str, 1, I ) ;
end;

{**********************************************************************}

procedure   read_marks  (filename  :  name;
                   var marks : markarray;lower,upper : char);

{ The marks are stored in a file called marks.dat. There are five
  rows defining the constants lower to  upper }

var
 i         : integer;
 m_idx     : char;
  marks_defs: text;

begin
     assign   (marks_defs, filename);
    reset    (marks_defs);
```

```
        for  m_idx :=  lower to upper do begin

            { read a line defining the marks  the format of a line is:
                 mark index mark index ... eol. NB. subsequent indices
               must increase along a line ... }

          i := 0;
             while not (eoln(marks_defs)) do begin
              i := i + 1;
                    read (marks_defs, marks[m_idx].contents[i].mark);
                    read (marks_defs, marks[m_idx].contents[i].index);
          end;

           { Set length field for this mark }
           marks[m_idx].len := i;
            readln (marks_defs);

        end;

 end;

 procedure  read_file;
 var fyle : Text;
     str  : string;

 begin
        assign  (fyle,'d:\mio\subcont.dat');
       assign  (fyle,'d:subcont.dat');
     reset (fyle);
      numrec := 0;
           while  (not(eof(fyle)))  do begin
              numrec := numrec + 1;
              readln(fyle, str);
                a[numrec] :=copy(str,1,20);
                b[numrec] :=copy(str,21,20);
          end;
              writeln('numrecs =',numrec);
end;

procedure convert1( rating : string; var mc : char);
Var
   i : integer;
   s: string;

begin
    mc := ' '; s := rtrim(ltrim(rating));
```

```
      if s = 'Excellent' then  mc:= 'A';
      if s = 'Good' then mc:= 'B';
      if s = 'Satisfactory' then mc := 'C';
      if s = 'Fair' then mc:= 'D';
      if s = 'Awful' then mc:= 'E';
   {    writeln('This is :',rating, mc);}
    end;

   procedure  report_results(var  mc:char);
   begin
        case mc of
            'A'  : begin
                        writeln('This subcontractor has an excellent chance');
                         writeln('of meeting the performance requirement of the project
                  end;
            'B'  :begin
                        writeln('This subcontractor has a good chance');
                         writeln('of meeting the performance requirement of the project
                  end;
            'C'  :begin
                        writeln('This subcontractor has a 50-50 chance');
                         writeln('of meeting the performance requirement of the project
                  end;
            'D'  :begin
                       writeln('This subcontractor has a fair chance');
                         writeln('of meeting the performance requirement of the project
                  end;
           'E'  : begin
                      writeln('This subcontractor is not likely  to meet ');
                        writeln('the performance requirement of the project');
                 end;
      end;
  end;

  procedure  convert2(weight : string; var wc : char);
  var
     i : integer;
     s :string;
  begin
     wc:= ' '; s := rtrim(ltrim(weight));
     if s = 'Extremely_important' then wc:= 'A';
     if s = 'Very_important' then wc:= 'B';
     if s = 'Important' then wc:= 'C';
     if s = 'Not_very_important' then wc:= 'D';
     if s = 'Unimportant' then wc:= 'E';
  {    writeln('This is :',weight, wc);}
```

```
 end;


 procedure   print_vector  (m  :  mark;  s:name);

 var
   i : integer;

 begin

     write  ('Definition for ' +  s  +  '<', m.len:1,'> {');
       for i := 1 to m.len do
                         write(m.contents[i].mark:5:2,'/',m.contents[i].index:1,',');

       writeln ('}');


end;


procedure   sum(v1,v2: mark; var sum_total : mark);

{Do the sum of all the normalised items, sum involves the addition
  of two denominators only (Also do the sum of the weights entries}

var
     x1,x2 :integer;
     index_sum   : integer;  {Sum of 'denominators'}
     min_mark    : integer;  {min of 'numerators'  }
    rt_idx  : integer;
      temp_total: array[1..max_mark_len] of real;
    min : real;
begin

    {Initialise the temp_workspace(-1.0 is an invalid value)}
      for x1 :=1 to max_mark_len do temp_total[x1] := -1.0;

   {CROSS PRODUCT all items with indices}
       for x1 :=1 to v1.len do
       for x2 :=1 to v2.len do
    begin
              index_sum:= v1.contents[x1].index + v2.contents[x2].index;

     {Find the min 'numerators'}
     begin
         min := v1.contents[x1].mark;
```

```
         if v2.contents[x2].mark < min then
         min := v2.contents[x2].mark;

          if temp_total[index_sum] = -1.0 then
           temp_total[index_sum] := min
           else if min > temp_total[index_sum] then
           temp_total[index_sum] := min;
     end;
    end;
      {Now pack the sum_total vector}
      rt_idx := 0;
       for x1 := 1 to max_mark_len do
        begin
             if temp_total[x1] <> -1.0 then
           begin
              rt_idx := rt_idx + 1;
                  sum_total.contents[rt_idx].mark := temp_total[x1];
                 sum_total.contents[rt_idx].index:= x1;
           end;
       end;
      sum_total.len := rt_idx;

end;
procedure  multiply (v1, v2 : mark; var running_total:mark);

var
 x1, x2       :integer;
   index_sum     : integer;          { sum of 'denominators' }
   min_mark      : integer;          { min of 'numerators'   }
   rt_idx       : integer;
    temp_total     : array [1..max_mark_len] of real;
   min : real;

begin

    { Initialiase the temp workspace  (-1.0 is invalid value) }
    for x1 := 1 to max_mark_len do temp_total[x1] := -1.0;

   { CROSS PRODUCT discards all items with 'odd' indices  }
   for x1 := 1 to v1.len do
    for x2 := 1 to v2.len do
  begin

        index_sum := v1.contents[x1].index * v2.contents[x2].index;
   begin
     { Find the min 'numerator' }
```

```
         min := v1.contents[x1].mark;
         if v2.contents[x2]. mark < min then
          min := v2. contents[x2].mark;

          if temp_total[index_sum] = -1.0 then
            temp_total[index_sum] := min
         else if min > temp_total[index_sum] then
          temp_total[index_sum] := min;

      end;
    end;
    { Now pack the running_total vector }
    rt_idx := 0;
    for x1 := 1 to max_mark_len do
    begin
       if temp_total[x1] <> -1.0 then
      begin
         rt_idx := rt_idx + 1;
            running_total.contents[rt_idx].mark := temp_total[x1];
           running_total.contents[rt_idx].index := x1;
      end;
    end;
    running_total.len := rt_idx;

end;

procedure divide(v1, v2 : mark; var result : mark);

var    i,j : integer;
     min :real;

 begin
     { Initialise the result as a work space }
    for i := 1 to 9 do
    begin
       result.len := 9;
        result.contents[i].mark := -1.0;
        result.contents[i].index := i;
    end;

    for i := 1 to 9 do
    begin

      for j := 1 to v2.len do
      begin
          { Find the min numerators in the sub-set of
```

```
            elements for this value of i. }

           if j*i <= v1.len then
          begin
                 min := v2.contents[j].mark;
                  if (v1.contents[j*i].mark < min) then
                 min := v1.contents[j*i].mark;

                   if (min > result.contents[i].mark) then
                     result.contents[i].mark := min;
          end;
        end;
     end;
 end;

procedure  normalise(n:mark;  var  result:mark);
        {Applies to all multiplications, all summation and divisions}

{Do the normalisation of the result obtained,  Normalisation involves the
 division of all numerators with the highest numerator, and writing
 all missing denominators and inserting zero value (0.0) as the numerator
 of all the missing denominators}

var
   nom_total      : array[1..max_mark_len] of real;
  j,i,v,w       : integer;
  max           : real;
   current_denominator   : integer;
   previous_denominator  : integer;
  x1, x2                 : integer;
  rt_idx                 : integer;
  ch           : char;
begin
      {Initialise the temp_work_space (-1.0) is an invalid value}

  for i := 1 to max_mark_len do
     nom_total[i] := -1.0 ;
    max := 0;

  for i := 1 to n.len do
    begin


       if n.contents[i].mark > max then max := n.contents[i].mark;
```

```
    end;


     for i := 1 to n.len do
      begin
          {Divide all numerators with the maximum numerator}
          n.contents[i].mark := n.contents[i].mark / max;
     end;

 { Include all missing denominators and insert zero (0.0) as their
   numerators}
   previous_denominator := 0;
  for v := 1 to n.len do
   begin
       current_denominator := n.contents[v].index;
       if current_denominator - previous_denominator > 1  then
     begin
         for i := previous_denominator + 1 to current_denominator - 1 do
       begin
         nom_total[i] := 0.0;
       end;
     end;
        nom_total[current_denominator]  := n.contents[v].mark;
        previous_denominator := current_denominator;
  end;


   {Now pack the normalised vectors}
     rt_idx := 0;
      for x1 := 1 to max_mark_len do
     begin
         if nom_total[x1] <> - 1.0 then
       begin
           rt_idx := rt_idx + 1;
               result.contents[rt_idx].mark := nom_total[x1];
             result.contents[rt_idx].index := x1
     end; end;
      result.len := rt_idx;
end;


function  distance_map(x,  f:mark):real;

var   sum,mark:real;
    i,j:integer;
```

```
 begin
     sum:=0.0;
     for i:=1 to x.len do
    begin
         mark:=0.0;
         if f.len>0 then
        begin
           j:=0;
            repeat
               j:=j+1;
                until (f.contents[j].index=x.contents[i].index) or (j>=f.len);
               if f.contents[j].index=x.contents[i].index then
                mark:=f.contents[j].mark;
        end;
            sum:=sum+sqr(x.contents[i].mark-mark);
   end;
     distance_map:=sqrt(sum);
end;


procedure  initialise_N_and_D;
var i : integer;

begin
    convert1(a[1],mc);
    convert2(b[1],wc);
   N.len := marks1[mc].len;
   D.len := weights[wc].len;
   for i := 1 to N.len do begin
        N.contents[i].mark := marks1[mc].contents[i].mark;
        N.contents[i].index := marks1[mc].contents[i].index;
   end;
   for i := 1 to D.len do begin
        D.contents[i].mark := weights[wc].contents[i].mark;
        D.contents[i].index := weights[wc].contents[i].index;
  end;
end;

var  mini:real;
    midx:char;

begin
    read_file;
     read_marks('MARKS.DAT',marks1, 'A', 'E');
{      Display_marks(marks1, 'A', 'E');}
     read_marks('WEIGHTS.DAT',weights, 'A', 'E');
```

```
     for  i := 1 to numrec do
     begin
          convert1(a[i] , mc);
          convert2(b[i] ,wc);
    end;
{      Display_marks(weights, 'A', 'E');}
           { Read the 1st mark/ weight pair into N and D initially }
          initialise_N_and_D;      { Take the 1st pair to N and D }
           multiply(marks1[mc], weights[wc], M);
{            print_vector(M,concat(mc,'*',wc));}
          normalise(M,M);
{            print_vector(M,'Normalised_first_mult is : ');}
          sum(D, weights[wc], D);
 {          print_vector(D,'D : ');}
          normalise(D, D);
        i := 0 ;
         repeat
          i := i+1  ;
               multiply(marks1[mc], weights[wc], product);
{                print_vector(product, concat('Second_mult is: ' ));}
              normalise(product, product);
 {                print_vector(product, concat('Normalised Second_mult is: '));}
            sum(D, weights[wc], D);
{            print_vector(D, concat(wc,'+',wc));                                   }
            normalise(D,D);
 {            print_vector(D, 'normalise D: ');}
             sum(N,product,M);
{               print_vector(M, concat('SumMult is: '));}
            normalise(M,M);
 {                print_vector(M, concat('Mult_Normalised 2nd_round is: '));}
        Until i = NumRec;


        divide (D,M,Q);
{           print_vector(Q, 'result of division: ');}
         normalise(Q,Q);
        m_idx:= 'A';
            distance[m_idx] := distance_map(marks1[m_idx], Q);
         mini := distance[m_idx];
        midx := m_idx;
          write('The distance to ', m_idx);
          writeln(' is : ',distance[m_idx]:9:6 );
        For m_idx := 'B' to 'E' do
       begin
```

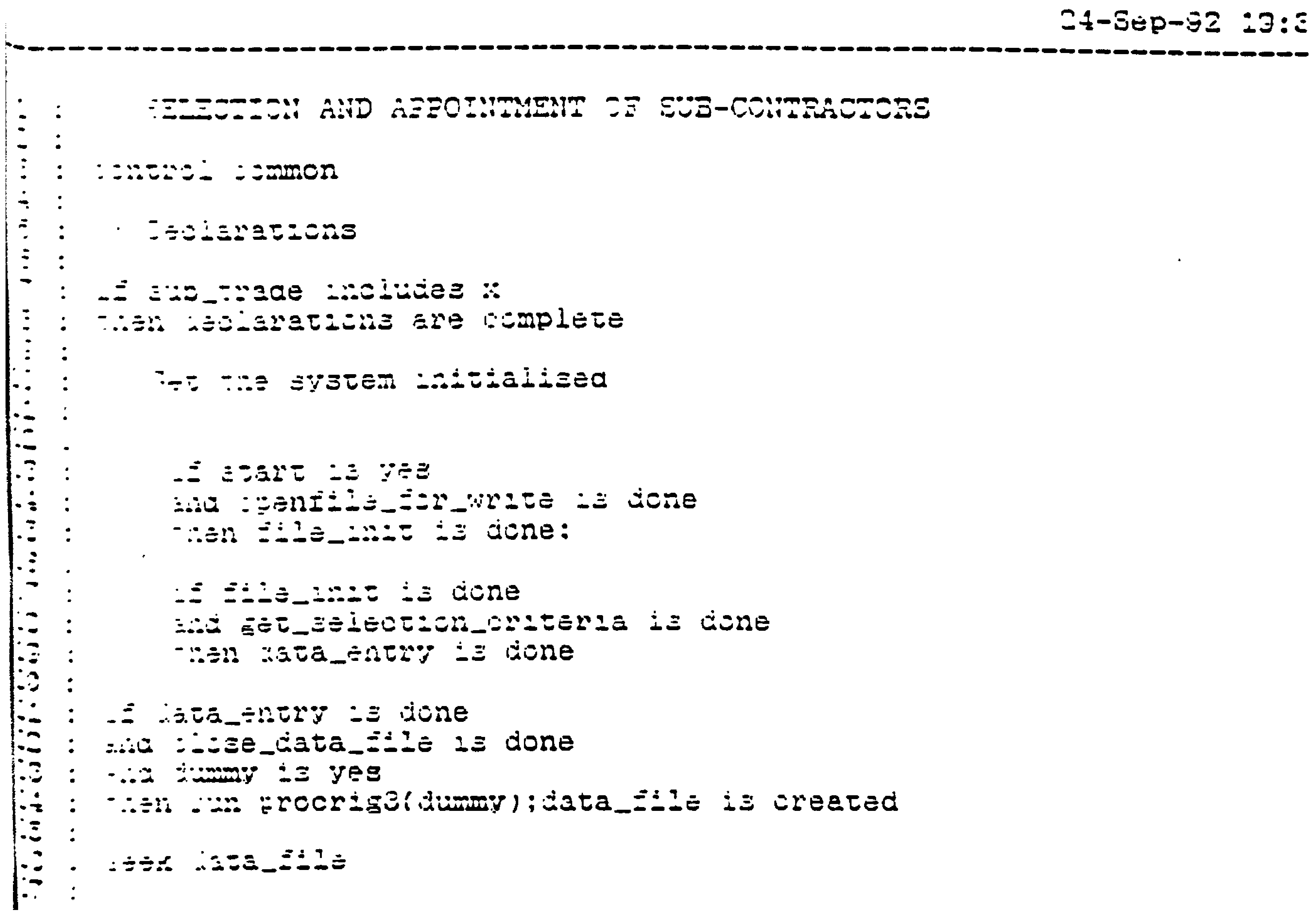
```
            distance[m_idx] := distance_map(marks1[m_idx], Q);
         if  mini  > distance[m_idx] then
       begin
             mini := distance[m_idx];
           midx :=m_idx;
     end;

           write('The distance to ', m_idx);
           writeln(' is : ',distance[m_idx]:9:6 );
     end;
     writeln('The minimum distance is for ',midx,' = ',mini:9:6);

    report_results(midx);

end.
```

APPENDIX F

SSARC KNOWLEDGE BASED DECISION SUPPORT SYSTEM CODED IN LEONARDO EXPERT SYSTEM SHELL FORMAT EXAMPLE

Appendix F

SSARC KNOWLEDGE BASED DECISION SUPPORT SYSTEM CODED IN LEONARDO EXPERT SYSTEM SHELL FORMAT EXAMPLE



```
                                                                  24-Sep-92 13:3
--------------------------------------------------------------------------------

: :      SELECTION AND APPOINTMENT OF SUB-CONTRACTORS
  :
  : control common
  :
  :   Declarations
  :
  : if sub_trade includes x
  : then declarations are complete
  :
  :      Get the system initialised
  :
  :
  :       if start is yes
  :       and openfile_for_write is done
  :       then file_init is done:
  :
  :       if file_init is done
  :       and get_selection_criteria is done
  :       then data_entry is done
  :
  : if data_entry is done
  : and close_data_file is done
  : and dummy is yes
  : then run procrig3(dummy);data_file is created
  :
  . seek data_file
  :
```

```
 1 : sub_trade                            List
 2 : declarations                         Text
 3 : start                                Text
 4 : openfile_for_write                   Text
 5 : file_init                            Text
 6 : get_selection_criteria               Text
 7 : data_entry                           Text
 8 : close_data_file                      Text
 9 : dummy                                Text
10 : procrig3                             Procedure
11 : data_file                            Text
12 : Openfile                             Procedure
13 : sub                                  Class
14 : safety_policy_rating                 Text
15 : safety_policy_weight                 Text
16 : n_rating                             Text
17 : n_weight                             Text
18 : write_to_file_proc                   Procedure
19 : sub_buffer                           Text
20 : SP_rating:                           Slot referent Text
21 : SP_weight:                           Slot referent Text
22 : trade_reference_rating               Text
23 : trade_reference_weight               Text
24 : TR_rating:                           Slot referent Text
25 : TR_weight:                           Slot referent Text
26 : workmanship_records_rating           Text
27 : workmanship_records_weight           Text
28 : WR_rating:                           Slot referent Text
29 : WR_weight:                           Slot referent Text
30 : close_file_proc                      Procedure
31 : Sub1                                 Undefined
32 : Sub2                                 Undefined
33 : Sub3                                 Undefined
```

```
Object Number :     1     Name: sub_trade                        24-Sep-92 1
------------------------------------------------------------------------------

            Name:  sub_trade
        LongName:
            Type: List
           Value:
       Certainty:
     DerivedFrom:
    DefaultValue:
      FixedValue:
    AllowedValue:
    Joinery,Bricklayer,Plunber,Carpentery,Plasterer,Electrical,Roofe
    Slater,Air conditioner
    ComputeValue:
         OnError:
     QueryPrompt: Indicate your list of preference
    QueryPreface:
         Please slect the subcontractor trade you want to select. Us
         cursor keys to point at selected option. and then the Ins k
         add  any other option you may wish to include to the list.
         Del key can be used to remove an option.

       Expansion:
      Commentary:
    Introduction:
      Conclusion:
```

```
          Name:  get_selection_criteria
      LongName:
          Type: Text
         Value:
     Certainty:
   DerivedFrom:

RuleSet:



FOR ALL sub
    if start is yes
    then ask safety_policy_rating;
         ask safety_policy_weight;
         m_rating is safety_policy_rating;
         m_weight is safety_policy_weight;
         run write_to_file_proc(m_rating, m_weight. sub_buffer);
         SP_rating: of sub is safety_policy_rating;
         SP_weight: of sub is safety_policy_weight;
         ask trade_reference_rating;
         ask trade_reference_weight;
         m_rating is trade_reference_rating;
         m_weight is trade_reference_weight;
         run write_to_file_proc(m_rating, m_weight, sub_buffer);
         TR_rating: of sub is trade_reference_rating;
         TR_weight: of sub is trade_reference_weight;
         ask workmanship_records_rating;
         ask workmanship_records_weight;
         m_rating is workmanship_records_rating;
         m_weight is workmanship_records_weight;
         run write_to_file_proc(m_rating, m_weight, sub_buffer);
         WR_rating: of sub is workmanship_records_rating;
         WR_weight: of sub is workmanship_records_weight;
         get_selection_criteria is done
```

```
Object Number :    8     Name: close_data_file                 24-Sep-92
---------------------------------------------------------------------------

        Name:  close_data_file
    LongName:
        Type: Text
       Value:
   Certainty:
 DerivedFrom:
DefaultValue:
  FixedValue:
AllowedValue:
ComputeValue:
     OnError:
 QueryPrompt:
QueryPreface:
   Expansion:
  Commentary:
Introduction:
  Conclusion:

  RuleSet:

if start is yes
then run close_file_proc();
    close_data_file is done

```

```
Object Number :    10     Name: procrig3                          24-Sep-92 19:
-------------------------------------------------------------------------------

  1 :          Name:  procrig3
  2 :      LongName:
  3 :          Type: Procedure
  4 :   AcceptsReal:
  5 :   AcceptsText: dummy
  6 :   AcceptsList:
  7 :   ReturnsReal:
  8 :   ReturnsText:
  9 :   ReturnsList:
 10 :     LocalReal:
 11 :     LocalText:
 12 :     LocalList:
 13 :     Rollout:
 14 :     Externals: d:\mio\mike.exe
 15 :          Body:
 16 :
 17 :             call d:\leo324\mike
 18 :
 19 :  return
 20 :
 21 :
 22 :
 23 :
```

```
Object Number :   20     Name: safety_prog_weight               13-Sep-92 16:.
------------------------------------------------------------------------------

        Name:  safety_prog_weight
    LongName:Safety programme
        Type: Text
       Value:
   Certainty:
 DerivedFrom:
DefaultValue: Unimportant
   ForbidUnk:
  FixedValue:
AllowedValue:Extremely_important,Very_important,Important
Not_very_important,Unimportant
ComputeValue:
     OnError:
 QueryPrompt:How important is safety programme?

QueryPreface:
Degree of importance of Safety programme to the
sub-contractor's project.

Please use the cursor up or cursor down arrow
select your answer, use the <RETURN> key to enter your
answer.

    Boxwidth:12
   Expansion:
  Commentary:
Introduction:
  Conclusion:

```

```
ect Number :    4     Name: openfile_for_write            24-Sep-92 19:36
--------------------------------------------------------------------------

 :          Name:  openfile_for_write
 :      LongName:
 :          Type: Text
 :         Value:
 :     Certainty:
 :   DerivedFrom:
 :  DefaultValue:
 :    FixedValue:
 :  AllowedValue:
 :  ComputeValue:
 :       OnError:
 :   QueryPrompt:
 :  QueryPreface:
 :     Expansion:
 :    Commentary:
 :  Introduction:
 :    Conclusion:
 :
 :       RuleSet:
 :
 : if start is yes
 : then run Openfile();
 :      Openfile_for_write is done
```

```
ct Number :    27      Name: work_reference_rating         13-Sep-92 16:12
---------------------------------------------------------------------------

:          Name:  work_reference_rating
:      LongName:
:          Type: Text
:         Value:
:     Certainty:
:   DerivedFrom:
:  DefaultValue:
:       OnError:
:     ForbidUnk:
:    FixedValue:
:  AllowedValue:Excellent,Good,Satisfactory,Fair,Awful
:   QueryPrompt:Please indicate your rating for work reference
:
:  QueryPreface:
:  Sub-contractor's work reference rating. Which of these
:  ratings reflect your assesment of the sub-contractor's
:  work reference.
:
:  Please use the cursor up or cursor down arrow to select
:  your answer, use the <RETURN> key to enter your answer.
:
:  AVexpansion:
:  -
:  Indicates outstanding work reference.Usually given to a
:  a sub-contractor who has worked for our company.
:  There is a high probability that the sub-contractor
:  would be able to sucessfully complete his project.
:  -
:  Indicates the ability to meet specified objectives. Very
:  much above average.
:  -
:  Indicates average, that is meet most
:  objectives. Weakinesses can be corrected. However, areas of concern
:  or risks should be noted..
:  -
:  Awful indicates that the sub-contractor fail to meet kev
:  requirments for this
```

```
t Number :   32      Name: quality_of_work_weight          13-Sep-92 16:15
--------------------------------------------------------------------------

          Name:  quality_of_work_weight
      LongName:
          Type: Text
         Value:
     Certainty:
   DerivedFrom:
  DefaultValue:Unimportant
     ForbidUnk:
  AllowedValue:Extremely_important,Very_important,Important
  Not_very_important,Unimportant
  ComputeValue:
       OnError:
   QueryPrompt:Degree of importance for quality of workmanship

  QueryPreface:Please indicate the level of importance for this
  criterion on the proposed project?
  Please use the cursor up or cursor down arrow to select
  your answer. use the <RETURN> key to enter your answer

      BoxWidth: 12
     Expansion:
    Commentary:
  Introduction:
    Conclusion:
```

APPENDIX G

FUZZY SET THEORY COMPUTER OUTPUT RESULTS EXAMPLE

Appendix G

FUZZY SET THEORY COMPUTER OUTPUT RESULTS EXAMPLE

```
 0.00/8. 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.00/13. 0.00/14. 0.00/15. 0
0.00/17. 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23. 0.00/24.
 0.00/26. 0.00/27. 0.00/28. 0.00/29. 0.00/30. 0.00/31. 0.50/32. 0.00/33.
, 0.00/35. 0.50/36. 0.00/37. 0.00/38. 0.00/39. 0.50/40. 0.50/41. 0.00/42
3. 0.50/44. 0.50/45. 0.50/46. 0.00/47. 0.50/48. 0.50/49. 1.00/50. 0.00/5
52. 0.00/53. 0.50/54. 0.50/55. 0.50/56. 0.00/57. 0.00/58. 0.00/59. 0.50/
/61. 0.00/62. 0.00/63. 0.00/64. 0.00/65. 0.50/66. 0.00/67. 0.00/68. 0.00
0/70. 0.00/71. 0.50/72. 0.00/73. 0.00/74. 0.00/75. 0.00/76. 0.00/77. 0.0
00/79. 0.00/80. 0.00/81. 0.00/82. 0.00/83. 0.00/84. 0.00/85. 0.00/86. 0.
.00/88. 0.00/89. 0.00/90. 0.00/91. 0.00/92. 0.00/93. 0.00/94. 0.00/95. 0
0.00/97. 0.00/98.}
Enter another pair of data (Y/N) ?
Enter linguistic value for this criteria (A..E) ? A
Enter linguistic value for weight for this criteria (A..E) ? C
Definition for Second_mult is: <15> { 0.00/21. 0.00/24. 0.00/27. 0.00/28
3. 0.00/35. 0.50/36. 0.50/40. 0.00/42. 1.00/45. 0.50/48. 0.00/49. 0.50/5
55. 0.00/63.}


/37. 0.00/38. 0.00/39. 0.00/40. 0.00/41. 0.00/42.}


Definition for normalise D: <42> { 0.00/1. 0.00/2. 0.00/3. 0.00/4. 0.00/
5. 0.00/7. 0.00/8. 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.00/13. 0.00/14.
 0.00/16. 0.00/17. 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23.
, 0.50/25. 0.50/26. 0.50/27. 0.50/28. 0.50/29. 1.00/30. 0.50/31. 0.50/32
3. 0.50/34. 0.50/35. 0.50/36. 0.00/37. 0.00/38. 0.00/39. 0.00/40. 0.00/4
42.}
Definition for SumMult is: <125> { 0.00/2. 0.00/3. 0.00/4. 0.00/5. 0.00/
7, 0.00/8. 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.00/13. 0.00/14. 0.00/15.
. 0.00/17. 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23. 0.00/24
5. 0.00/26. 0.00/27. 0.00/28. 0.00/29. 0.00/30. 0.00/31. 0.00/32. 0.00/3
34. 0.00/35. 0.00/36. 0.00/37. 0.00/38. 0.00/39. 0.00/40. 0.00/41. 0.00/
/43. 0.00/44. 0.00/45. 0.00/46. 0.00/47. 0.00/48. 0.00/49. 0.00/50. 0.00
0/52. 0.00/53. 0.00/54. 0.00/55. 0.00/56. 0.00/57. 0.00/58. 0.00/59. 0.0
00/61. 0.00/62. 0.00/63. 0.50/64. 0.00/65. 0.00/66. 0.00/67. 0.50/68. 0.
.00/70. 0.00/71. 0.50/72. 0.00/73. 0.00/74. 0.00/75. 0.50/76. 0.50/77. 0
0.00/79. 0.50/80. 0.50/81. 0.00/82. 0.00/83. 0.50/84. 0.50/85. 0.50/86.
 0.50/88. 0.00/89. 1.00/90. 0.00/91. 0.00/92. 0.50/93. 0.50/94. 0.00/95.
. 0.00/97. 0.00/98. 0.50/99. 0.00/100. 0.00/101. 0.50/102. 0.00/103. 0.0
.00/105. 0.00/106. 0.00/107. 0.50/108. 0.00/109. 0.00/110. 0.00/111. 0.0
.00/113. 0.00/114. 0.00/115. 0.00/116. 0.00/117. 0.00/118. 0.00/119. 0.0
.00/121. 0.00/122. 0.00/123. 0.00/124. 0.00/125. 0.00/126.}


.00/70. 0.00/71. 0.50/72. 0.00/73. 0.00/74. 0.00/75. 0.50/76. 0.50/77. 0
0.00/79. 0.50/80. 0.50/81. 0.00/82. 0.00/83. 0.50/84. 0.50/85. 0.50/86.
 0.50/88. 0.00/89. 1.00/90. 0.00/91. 0.00/92. 0.50/93. 0.50/94. 0.00/95.
. 0.00/97. 0.00/98. 0.50/99. 0.00/100. 0.00/101. 0.50/102. 0.00/103. 0.0
.00/105. 0.00/106. 0.00/107. 0.50/108. 0.00/109. 0.00/110. 0.00/111. 0.0
.00/113. 0.00/114. 0.00/115. 0.00/116. 0.00/117. 0.00/118. 0.00/119. 0.0
.00/121. 0.00/122. 0.00/123. 0.00/124. 0.00/125. 0.00/126.}


Definition for A*C<126> { 0.00/1. 0.00/2. 0.00/3. 0.00/4. 0.00/5. 0.00/6
. 0.00/8. 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.00/13. 0.00/14. 0.00/15.
. [illegible] 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23. 0.00/24.
4. 0.00/35. 0.00/36. 0.00/37. 0.00/38. 0.00/39. 0.00/40. 0.00/41. 0.00/3
43. 0.00/44. 0.00/45. 0.00/46. 0.00/47. 0.00/48. 0.00/49. 0.00/50. 0.00
```

```
                                        ..., 0.00/101, 0.00/102, 0.00/10
00/105, 0.00/106, 0.00/107, 0.00/108, 0.00/109, 0.00/110, 0.00/11
00/113, 0.00/114, 0.00/115, 0.00/116, 0.00/117, 0.00/118, 0.00/11
00/121, 0.00/122, 0.00/123, 0.00/124, 0.00/125, 0.00/126,}
Enter another pair of data (Y/N) ?

0.50/88, 0.00/89, 0.50/90, 0.00/91, 0.00/92, 0.00/93, 0.00/94, 0.
 0.00/97, 0.00/98, 0.00/99, 0.00/100, 0.00/101, 0.00/102, 0.00/10
00/105, 0.00/106, 0.00/107, 0.00/108, 0.00/109, 0.00/110, 0.00/111
00/113, 0.00/114, 0.00/115, 0.00/116, 0.00/117, 0.00/118, 0.00/119
00/121, 0.00/122, 0.00/123, 0.00/124, 0.00/125, 0.00/126,}
Enter another pair of data (Y/N) ?
Enter linguistic value for this criteria (A..E) ? B
Enter linguistic value for weight for this criteria (A..E) ? C
Definition for Second_mult is: <20> { 0.00/15, 0.00/18, 0.00/20, 0
4, 0.00/25, 0.00/27, 0.50/28, 0.50/30, 0.50/32, 1.00/35, 0.50/36,
42, 0.00/45, 0.50/48, 0.00/49, 0.00/54, 0.00/56, 0.00/63,}


Definition for Normalised Second_mult is: <63> { 0.00/1, 0.00/2, 0.
 0.00/5, 0.00/6, 0.00/7, 0.00/8, 0.00/9, 0.00/10, 0.00/11, 0.00/12,
0/14, 0.00/15, 0.00/16, 0.00/17, 0.00/18, 0.00/19, 0.00/20, 0.00/21
00/23, 0.50/24, 0.00/25, 0.00/26, 0.00/27, 0.50/28, 0.00/29, 0.50/3
.50/32, 0.00/33, 0.00/34, 1.00/35, 0.50/36, 0.00/37, 0.00/38, 0.00/
0.00/41, 0.50/42, 0.00/43, 0.00/44, 0.00/45, 0.00/46, 0.00/47, 0.50
 0.00/50, 0.00/51, 0.00/52, 0.00/53, 0.00/54, 0.00/55, 0.00/56, 0.0
, 0.00/59, 0.00/60, 0.00/61, 0.00/62, 0.00/63,}
Definition for C+C<20> { 0.00/4, 0.00/5, 0.00/6, 0.00/7, 0.00/8, 0.
, 0.00/11, 0.00/12. 0.00/13, 0.50/14. 0.50/15, 0.50/16, 1.00/17, 0.
9, 0.50/20, 0.00/21, 0.00/22, 0.00/23,}
```

```
, 0.00/59, 0.00/60, 0.00/61, 0.00/62, 0.00/63,}
Definition for C+C<20> { 0.00/4, 0.00/5, 0.00/6, 0.00/7, 0.00/8, 0.
, 0.00/11. 0.00/12, 0.00/13, 0.50/14, 0.50/15, 0.50/16, 1.00/17, 0.
9, 0.50/20, 0.00/21, 0.00/22, 0.00/23,}
```

```
Definition for normalise D: <23> { 0.00/1, 0.00/2, 0.00/3, 0.00/4, 0
6, 0.00/7, 0.00/8. 0.00/9. 0.00/10, 0.00/11, 0.00/12, 0.00/13. 0.50/
 0.50/16, 1.00/17, 0.50/18, 0.50/19, 0.50/20, 0.00/21. 0.00/22. 0.00
Definition for SumMult is: <125> { 0.00/2, 0.00/3, 0.00/4, 0.00/5, 0
7. 0.00/8, 0.00/9, 0.00/10, 0.00/11, 0.00/12, 0.00/13. 0.00/14. 0.00
, 0.00/17. 0.00/18. 0.00/19, 0.00/20. 0.00/21, 0.00/22. 0.00/23, 0.0
5, 0.00/26. 0.00/27. 0.00/28. 0.00/29, 0.00/30, 0.00/31, 0.00/32. 0.
34, 0.00/35, 0.00/36, 0.00/37, 0.00/38, 0.00/39, 0.00/40. 0.00/41. 0
/43, 0.00/44. 0.00/45. 0.00/46, 0.00/47, 0.50/48, 0.00/49, 0.00/50,
0/52, 0.00/53, 0.50/54, 0.00/55, 0.50/56, 0.00/57, 0.50/58, 0.50/59,
00/61, 0.50/62, 0.50/63, 0.50/64, 0.50/65, 0.50/66, 0.50/67, 0.50/68
.00/70, 0.50/71, 0.50/72, 0.00/73, 0.50/74, 0.50/75, 0.50/76, 0.50/7
0.00/79, 0.50/80, 0.00/81, 0.50/82, 0.50/83, 0.50/84, 0.00/85, 0.00/
 0.50/88, 0.00/89, 0.50/90, 0.00/91, 0.00/92, 0.00/93, 0.00/94, 0.00/
, 0.00/97, 0.00/98, 0.00/99, 0.00/100, 0.00/101, 0.00/102, 0.00/103,
.00/105, 0.00/106, 0.00/107, 0.00/108, 0.00/109, 0.00/110, 0.00/111,
.00/113, 0.00/114, 0.00/115, 0.00/116, 0.00/117, 0.00/118, 0.00/119,
.00/121, 0.00/122, 0.00/123, 0.00/124, 0.00/125, 0.00/126,}
```

```
 0.50/88, 0.00/89, 0.50/90, 0.00/91, 0.00/92, 0.00/93, 0.00/94, 0.00/
, 0.00/97, 0.00/98, 0.00/99, 0.00/100, 0.00/101, 0.00/102, 0.00/103,
.00/105, 0.00/106, 0.00/107, 0.00/108, 0.00/109, 0.00/110, 0.00/111,
.00/113, 0.00/114. 0.00/115, 0.00/116, 0.00/117, 0.00/118, 0.00/119,
.00/121, 0.00/122, 0.00/123, 0.00/124, 0.00/125, 0.00/126,}
```

```
, 0.50/35, 0.50/36, 0.00/37, 0.50/38, 0.50/39, 0.50/40, 0.00/41, 0.50/42
3, 0.50/44, 0.00/45, 0.00/46, 0.00/47, 0.50/48, 0.00/49, 0.00/50, 0.00/5
52, 0.00/53, 0.00/54, 0.00/55, 0.00/56, 0.00/57, 0.00/58, 0.00/59, 0.00/
/61, 0.00/62, 0.00/63, 0.00/64, 0.00/65, 0.00/66, 0.00/67, 0.00/68, 0.00
0/70,}
Enter another pair of data (Y/N) ?
```

```
, 0.50/35, 0.50/36, 0.00/37, 0.50/38, 0.50/39, 0.50/40, 0.00/41, 0.50/42
3, 0.50/44, 0.00/45, 0.00/46, 0.00/47, 0.50/48, 0.00/49, 0.00/50, 0.00/5
52, 0.00/53, 0.00/54, 0.00/55, 0.00/56, 0.00/57, 0.00/58, 0.00/59, 0.00/
/61, 0.00/62, 0.00/63, 0.00/64, 0.00/65, 0.00/66, 0.00/67, 0.00/68, 0.00
0/70,}
```

```
Enter another pair of data (Y/N) ?
Enter linguistic value for this criteria (A..E) ? C
Enter linguistic value for weight for this criteria (A..E) ? C
Definition for Second_mult is: <15> { 0.00/9, 0.00/12, 0.00/15, 0.50/16,
, 0.50/20, 0.00/21, 0.50/24, 1.00/25, 0.00/28, 0.50/30, 0.00/35, 0.50/36
2, 0.00/49,}


Definition for Normalised Second_mult is: <49> { 0.00/1, 0.00/2, 0.00/3,
 0.00/5, 0.00/6, 0.00/7, 0.00/8, 0.00/9, 0.00/10, 0.00/11, 0.00/12, 0.00
0/14, 0.00/15, 0.50/16, 0.00/17, 0.00/18, 0.00/19, 0.50/20, 0.00/21, 0.0
00/23, 0.50/24, 1.00/25, 0.00/26, 0.00/27, 0.00/28, 0.00/29, 0.50/30, 0.
.00/32, 0.00/33, 0.00/34, 0.00/35, 0.50/36, 0.00/37, 0.00/38, 0.00/39, 0
0.00/41, 0.00/42, 0.00/43, 0.00/44, 0.00/45, 0.00/46, 0.00/47, 0.00/48,
}
Definition for C+C<32> { 0.00/4, 0.00/5, 0.00/6, 0.00/7, 0.00/8, 0.00/9,
, 0.00/11, 0.00/12, 0.00/13, 0.00/14, 0.00/15, 0.00/16, 0.00/17, 0.00/18
9, 0.50/20, 0.50/21, 0.50/22, 0.50/23, 0.50/24, 1.00/25, 0.50/26, 0.50/2
28, 0.50/29, 0.50/30, 0.00/31, 0.00/32, 0.00/33, 0.00/34, 0.00/35,}
```

```
}
Definition for C+C<32> { 0.00/4, 0.00/5, 0.00/6, 0.00/7, 0.00/8, 0.00/9,
, 0.00/11, 0.00/12, 0.00/13, 0.00/14, 0.00/15, 0.00/16, 0.00/17, 0.00/18
9, 0.50/20, 0.50/21, 0.50/22, 0.50/23, 0.50/24, 1.00/25, 0.50/26, 0.50/2
28, 0.50/29, 0.50/30, 0.00/31, 0.00/32, 0.00/33, 0.00/34, 0.00/35,}
```

```
Definition for normalise D: <35> { 0.00/1, 0.00/2, 0.00/3, 0.00/4, 0.00/
6, 0.00/7, 0.00/8, 0.00/9, 0.00/10, 0.00/11, 0.00/12, 0.00/13, 0.00/14,
 0.00/16, 0.00/17, 0.00/18, 0.00/19, 0.50/20, 0.50/21, 0.50/22, 0.50/23,
, 1.00/25, 0.50/26, 0.50/27, 0.50/28, 0.50/29, 0.50/30, 0.00/31, 0.00/32
3, 0.00/34, 0.00/35,}
Definition for SumMult is: <97> { 0.00/2, 0.00/3, 0.00/4, 0.00/5, 0.00/6
, 0.00/8, 0.00/9, 0.00/10, 0.00/11, 0.00/12, 0.00/13, 0.00/14, 0.00/15,
 0.00/17, 0.00/18, 0.00/19, 0.00/20, 0.00/21, 0.00/22, 0.00/23, 0.00/24,
, 0.00/26, 0.00/27, 0.00/28, 0.00/29, 0.00/30, 0.00/31, 0.50/32, 0.00/33
4, 0.00/35, 0.50/36, 0.00/37, 0.00/38, 0.00/39, 0.50/40, 0.50/41, 0.00/4
43, 0.50/44, 0.50/45, 0.50/46, 0.00/47, 0.50/48, 0.50/49, 1.00/50, 0.00/
/52, 0.00/53, 0.50/54, 0.50/55, 0.50/56, 0.00/57, 0.00/58, 0.00/59, 0.50
0/61, 0.00/62, 0.00/63, 0.00/64, 0.00/65, 0.50/66, 0.00/67, 0.00/68, 0.0
00/70, 0.00/71, 0.50/72, 0.00/73, 0.00/74, 0.00/75, 0.00/76, 0.00/77, 0.
.00/79, 0.00/80, 0.00/81, 0.00/82, 0.00/83, 0.00/84, 0.00/85, 0.00/86, 
0.00/88, 0.00/89, 0.00/90, 0.00/91, 0.00/92, 0.00/93, 0.00/94, 0.00/95,
 0.00/97, 0.00/98,}
```

```
00/70, 0.00/71, 0.50/72, 0.00/73, 0.00/74, 0.00/75, 0.00/76, 0.00/77, 0.
.00/79, 0.00/80, 0.00/81, 0.00/82, 0.00/83, 0.00/84, 0.00/85, 0.00/86, 
0.00/88, 0.00/89, 0.00/90, 0.00/91, 0.00/92, 0.00/93, 0.00/94, 0.00/95,
 0.00/97, 0.00/98,}
```

```
Definition for Mult_Normalised 2nd_round is: <52> { 0.00/1. 0.00/2. 0.00/
/4. 0.00/5. 0.00/6. 0.00/7. 0.00/8. 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.
0.00/14. 0.00/15. 0.00/16. 0.50/17. 0.50/18. 0.00/19. 0.00/20. 0.50/21.
 0.00/23. 0.00/24. 0.50/25. 1.00/26. 0.50/27. 0.00/28. 0.00/29. 0.00/30.
 0.50/32. 0.00/33. 0.00/34. 0.00/35. 0.00/36. 0.50/37. 0.50/38. 0.00/39.
0. 0.00/41. 0.00/42. 0.00/43. 0.00/44. 0.00/45. 0.00/46. 0.00/47. 0.00/48
49. 0.00/50. 0.00/51. 0.00/52.}
This is :D
This is :Not_very_importantD
Definition for Second_mult is: <14> { 0.00/1. 0.00/2. 0.00/3. 0.50/4. 0.0
50/6. 0.50/8. 1.00/9. 0.00/10. 0.50/12. 0.00/15. 0.50/16. 0.00/20. 0.00/

Definition for Normalised Second_mult is: <25> { 0.00/1. 0.00/2. 0.00/3.
 0.00/5. 0.50/6. 0.00/7. 0.50/8. 1.00/9. 0.00/10. 0.00/11. 0.50/12. 0.00/
0/14. 0.00/15. 0.50/16. 0.00/17. 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.00
00/23. 0.00/24. 0.00/25.}
Definition for D+D<59> { 0.00/2. 0.00/3. 0.00/4. 0.00/5. 0.00/6. 0.00/7.
 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.00/13. 0.00/14. 0.00/15. 0.00/16.
 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23. 0.00/24. 0.00/25.
 0.00/27. 0.00/28. 0.00/29. 0.00/30. 0.00/31. 0.00/32. 0.00/33. 0.00/34.
 0.00/36. 0.00/37. 0.50/38. 0.50/39. 0.50/40. 0.50/41. 0.50/42. 0.50/43
44. 0.50/45. 1.00/46. 0.50/47. 0.50/48. 0.50/49. 0.50/50. 0.50/51. 0.50/5
53. 0.00/54. 0.00/55. 0.00/56. 0.00/57. 0.00/58. 0.00/59. 0.00/60.}
```

```
Definition for Normalised Second_mult is: <25> { 0.00/1. 0.00/2. 0.00/3.
 0.00/5. 0.50/6. 0.00/7. 0.50/8. 1.00/9. 0.00/10. 0.00/11. 0.50/12. 0.00/
4/14. 0.00/15. 0.50/16. 0.00/17. 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.0
00/23. 0.00/24. 0.00/25.}
Definition for D+D<59> { 0.00/2. 0.00/3. 0.00/4. 0.00/5. 0.00/6. 0.00/7.
```

```
 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.00/13. 0.00/14. 0.00/15. 0.00/16.
 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23. 0.00/24. 0.00/25.
 0.00/27. 0.00/28. 0.00/29. 0.00/30. 0.00/31. 0.00/32. 0.00/33. 0.00/34
 0.00/36. 0.00/37. 0.50/38. 0.50/39. 0.50/40. 0.50/41. 0.50/42. 0.50/4
44. 0.50/45. 1.00/46. 0.50/47. 0.50/48. 0.50/49. 0.50/50. 0.50/51. 0.50/
53. 0.00/54. 0.00/55. 0.00/56. 0.00/57. 0.00/58. 0.00/59. 0.00/60.}
```

```
Definition for normalise D: <60> { 0.00/1. 0.00/2. 0.00/3. 0.00/4. 0.00/
 0.00/7. 0.00/8. 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.00/13. 0.00/14.
 0.00/16. 0.00/17. 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23.
 0.00/25. 0.00/26. 0.00/27. 0.00/28. 0.00/29. 0.00/30. 0.00/31. 0.00/32.
 0.00/34. 0.00/35. 0.00/36. 0.00/37. 0.50/38. 0.50/39. 0.50/40. 0.50/4
2. 0.50/43. 0.50/44. 0.50/45. 1.00/46. 0.50/47. 0.50/48. 0.50/49. 0.50/5
51. 0.50/52. 0.50/53. 0.00/54. 0.00/55. 0.00/56. 0.00/57. 0.00/58. 0.00/
0/60.}
Definition for SumMult is: <27> { 0.00/2. 0.00/3. 0.00/4. 0.50/5. 0.50/6.
 0.50/8. 0.50/9. 1.00/10. 0.50/11. 0.00/12. 0.50/13. 0.50/14. 0.00/15.
 0.50/17. 0.50/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23. 0.00/24.
 0.00/26. 0.00/27. 0.00/28.}
```

```
/53. 0.00/54. 0.00/55. 0.00/56. 0.00/57. 0.00/58. 0.00/59. 0.00/60.}

Definition for normalise D: <60> { 0.00/1. 0.00/2. 0.00/3. 0.00/4. 0.00/
6. 0.00/7. 0.00/8. 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.00/13. 0.00/14.
 0.00/16. 0.00/17. 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23.
 0.00/25. 0.00/26. 0.00/27. 0.00/28. 0.00/29. 0.00/30. 0.00/31. 0.00/3
```

```
34. 0.00/35. 0.00/36. 0.00/37. 0.50/38. 0.50/39. 0.50/40. 0.50/41. 0.50/
1/43. 0.50/44. 0.50/45. 1.00/46. 0.50/47. 0.50/48. 0.50/49. 0.50/50. 0.50
0/52. 0.50/53. 0.00/54. 0.00/55. 0.00/56. 0.00/57. 0.00/58. 0.00/59. 0.0

on for Summult is: <27> { 0.00/2. 0.00/3. 0.00/4. 0.50/5. 0.50/6. 0.50/7
. 0.50/9. 1.00/10. 0.50/11. 0.00/12. 0.50/13. 0.50/14. 0.00/15. 0.00/16.
. 0.50/18. 0.50/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23. 0.00/24. 0.00/25
26. 0.00/27. 0.00/28.}

on for Mult Normalised 2nd round is: <28> { 0.00/1. 0.00/2. 0.00/3. 0.00
0/5. 0.50/6. 0.50/7. 0.50/8. 0.50/9. 1.00/10. 0.50/11. 0.00/12. 0.50/13.
 0.00/15. 0.00/16. 0.50/17. 0.50/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22.
. 0.00/24. 0.00/25. 0.00/26. 0.00/27. 0.00/28.}
:E
:importantC
on for Second_mult is: <28> { 0.00/15. 0.00/18. 0.00/20. 0.00/21. 0.50/2
/25. 0.00/27. 0.50/28. 0.50/30. 0.50/32. 1.00/33. 0.50/36. 0.50/40. 0.50/
0/45. 0.50/48. 0.00/49. 0.00/54. 0.00/56. 0.00/63.}


 0.00/15. 0.00/16. 0.50/17. 0.50/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22.
. 0.00/24. 0.00/25. 0.00/26. 0.00/27. 0.00/28.}
:E
:importantC
on for Second mult is: <28> { 0.00/15. 0.00/18. 0.00/20. 0.00/21. 0.50/2
/25. 0.00/27. 0.50/28. 0.50/30. 0.50/32. 1.00/33. 0.50/36. 0.50/40. 0.50/
0/45. 0.50/48. 0.50/49. 0.00/54. 0.00/56. 0.00/63.}

on for Normalised Second mult is: <63> { 0.00/1. 0.00/2. 0.00/3. 0.00/4.
. 0.00/6. 0.00/7. 0.00/8. 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.00/13. 0.0
.00/15. 0.00/16. 0.00/17. 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.
.50/24. 0.00/25. 0.00/26. 0.00/27. 0.50/28. 0.00/29. 0.50/30. 0.00/31. 0
0.00/33. 0.00/34. 0.00/35. 0.50/36. 0.00/37. 0.00/38. 0.00/39. 0.50/40.
 0.50/42. 0.00/43. 0.00/44. 0.00/45. 0.00/46. 0.00/47. 0.50/48. 0.00/49.
. 0.00/51. 0.00/52. 0.00/53. 0.00/54. 0.00/55. 0.00/56. 0.00/57. 0.00/58
9. 0.00/60. 0.00/61. 0.00/62. 0.00/63.}
on for ... 64  0.00/4. 0.00/5. 0.00/6. 0.00/7. 0.00/8. 0.00/9. 0.00/10
1. 0.00/12. 0.00/13. 0.00/14. 0.00/15. 0.00/16. 0.00/17. 0.00/18. 0.00/1
20. 0.00/21. 0.00/22. 0.00/23. 0.00/24. 0.00/25. 0.00/26. 0.00/27. 0.00/



0/29. 0.00/30. 0.00/31. 0.00/32. 0.00/33. 0.00/34. 0.00/35. 0.00/36. 0.00
00/38. 0.00/39. 0.00/40. 0.00/41. 0.50/42. 0.50/43. 0.50/44. 0.50/45. 0.5
.50/47. 0.50/48. 0.50/49. 0.50/50. 1.00/51. 0.50/52. 0.50/53. 0.50/54. 0.
0.50/56. 0.50/57. 0.50/58. 0.50/59. 0.00/60. 0.00/61. 0.00/62. 0.00/63. 0
 0.00/65. 0.00/66. 0.00/67.}


1. 0.00/12. 0.00/13. 0.00/14. 0.00/15. 0.00/16. 0.00/17. 0.00/18. 0.00/1
/20. 0.00/21. 0.00/22. 0.00/23. 0.00/24. 0.00/25. 0.00/26. 0.00/27. 0.00/
0/29. 0.00/30. 0.00/31. 0.00/32. 0.00/33. 0.00/34. 0.00/35. 0.00/36. 0.00
00/38. 0.00/39. 0.00/40. 0.00/41. 0.50/42. 0.50/43. 0.50/44. 0.50/45. 0.5
.50/47. 0.50/48. 0.50/49. 0.50/50. 1.00/51. 0.50/52. 0.50/53. 0.50/54. 0.
0.50/56. 0.50/57. 0.50/58. 0.50/59. 0.00/60. 0.00/61. 0.00/62. 0.00/63. 0
 0.00/65. 0.00/66. 0.00/67.}

ion for normalise D: <67> { 0.00/1. 0.00/2. 0.00/3. 0.00/4. 0.00/5. 0.00/
0/7. 0.00/8. 0.00/9. 0.00/10. 0.00/11. 0.00/12. 0.00/13. 0.00/14. 0.00/15.
6. 0.00/17. 0.00/18. 0.00/19. 0.00/20. 0.00/21. 0.00/22. 0.00/23. 0.00/24
25. 0.00/26. 0.00/27. 0.00/28. 0.00/29. 0.00/30. 0.00/31. 0.00/32. 0.00/3
0/34. 0.00/35. 0.00/36. 0.00/37. 0.00/38. 0.00/39.
```

```
Definition for B*C<126> { 0.00/1, 0.00/2, 0.00/3, 0.00/4, 0.00/5, 0.00/6.
, 0.00/8, 0.00/9, 0.00/10, 0.00/11, 0.00/12, 0.00/13, 0.00/14, 0.00/15,
 0.00/17, 0.00/18, 0.00/19, 0.00/20, 0.00/21. 0.00/22, 0.00/23, 0.00/24.
, 0.00/26. 0.00/27, 0.00/28, 0.00/29, 0.00/30. 0.00/31, 0.00/32. 0.00/33.
4, 0.00/35. 0.00/36, 0.00/37, 0.00/38, 0.00/39, 0.00/40. 0.00/41. 0.00/4
43, 0.00/44, 0.00/45, 0.00/46, 0.00/47, 0.50/48, 0.00/49. 0.00/50. 0.00/
/52, 0.00/53, 0.50/54. 0.00/55, 0.50/56, 0.00/57, 0.50/58, 0.50/59. 0.50,
0/61, 0.50/62, 0.50/63, 0.50/64, 0.50/65, 0.50/66, 0.50/67, 0.50/68. 0.0
00/70, 0.50/71, 0.50/72, 0.00/73, 0.50/74, 0.50/75, 0.50/76. 0.50/77, 0.
.00/79, 0.50/80, 0.00/81, 0.50/82, 0.50/83, 0.50/84. 0.00/85, 0.00/86. 0
0.50/88. 0.00/89, 0.50/90, 0.00/91, 0.00/92, 0.00/93, 0.00/94, 0.00/95,
 0.00/97, 0.00/98, 0.00/99, 0.00/100, 0.00/101, 0.00/102, 0.00/103, 0.00
00/105, 0.00/106, 0.00/107, 0.00/108, 0.00/109, 0.00/110, 0.00/111. 0.00
00/113, 0.00/114, 0.00/115, 0.00/116, 0.00/117, 0.00/118, 0.00/119, 0.00
00/121, 0.00/122, 0.00/123, 0.00/124, 0.00/125, 0.00/126,}
Enter another pair of data (Y/N) ?
Enter linguistic value for this criteria (A..E) ? C
Enter linguistic value for weight for this criteria (A..E) ? D

00/70, 0.50/71, 0.50/72, 0.00/73, 0.50/74, 0.50/75, 0.50/76. 0.50/77, 0..
.00/79, 0.50/80, 0.00/81, 0.50/82, 0.50/83, 0.50/84, 0.00/85, 0.00/86, 0
0.50/88. 0.00/89, 0.50/90, 0.00/91, 0.00/92, 0.00/93, 0.00/94. 0.00/95.
 0.00/97, 0.00/98, 0.00/99, 0.00/100, 0.00/101, 0.00/102, 0.00/103, 0.00
00/105. 0.00/106, 0.00/107, 0.00/108, 0.00/109, 0.00/110, 0.00/111. 0.00
00/113, 0.00/114, 0.00/115, 0.00/116, 0.00/117. 0.00/118. 0.00/119, 0.00
00/121, 0.00/122, 0.00/123, 0.00/124, 0.00/125, 0.00/126,}
Enter another pair of data (Y/N) ?
Enter linguistic value for this criteria (A..E) ? C
Enter linguistic value for weight for this criteria (A..E) ? D
Definition for Second_mult is: <20> { 0.00/3, 0.00/4, 0.00/5. 0.00/6. 0.
50/8. 0.00/9, 0.50/10. 0.50/12, 0.00/14, 1.00/15, 0.50/16, 0.50/18, 0.50
0/21, 0.50/24, 0.00/25, 0.00/28, 0.00/30, 0.00/35,}


Definition for Normalised Second_mult is: <35> { 0.00/1, 0.00/2. 0.00/3.
 0.00/5. 0.00/6, 0.00/7. 0.50/8, 0.00/9, 0.50/10, 0.00/11. 0.50/12. 0.00
0/14. 1.00/15, 0.50/16. 0.00/17, 0.50/18, 0.00/19, 0.50/20. 0.00/21. 0.0
00/23, 0.50/24. 0.00/25, 0.00/26, 0.00/27, 0.00/28, 0.00/29. 0.00/30, 0.
.00/32, 0.00/33, 0.00/34, 0.00/35,}
Definition for D+D<27> { 0.00/2, 0.00/3. 0.00/4, 0.00/5, 0.00/6. 0.00/7.
 0.00/9. 0.00/10, 0.00/11, 0.00/12, 0.00/13. 0.00/14, 0.00/15. 0.50/16.
 0.50/18. 0.50/19, 1.00/20, 0.50/21, 0.50/22. 0.50/23, 0.50/24. 0.00/25.
, 0.00/27, 0.00/28,}


Definition for normalise D: <28> { 0.00/1, 0.00/2, 0.00/3. 0.00/4. 0.00/
6. 0.00/7. 0.00/8, 0.00/9. 0.00/10. 0.00/11, 0.00/12, 0.00/13. 0.00/14.
 0.50/16, 0.50/17, 0.50/18. 0.50/19, 1.00/20, 0.50/21, 0.50/22, 0.50/23.
, 0.00/25, 0.00/26. 0.00/27, 0.00/28,}
Definition for SumMult is: <69> { 0.00/2, 0.00/3, 0.00/4, 0.00/5, 0.00/6
, 0.00/8. 0.00/9, 0.00/10, 0.00/11, 0.00/12, 0.00/13. 0.00/14, 0.00/15,
 0.00/17, 0.50/18. 0.00/19, 0.50/20, 0.00/21, 0.50/22, 0.50/23. 0.50/24.
, 0.50/26. 0.50/27. 0.50/28, 0.00/29, 1.00/30. 0.50/31, 0.50/32. 0.50/33
4, 0.50/35. 0.50/36. 0.00/37, 0.50/38, 0.50/39, 0.50/40, 0.00/41, 0.50/4
43, 0.50/44, 0.00/45, 0.00/46, 0.00/47, 0.50/48. 0.00/49, 0.00/50. 0.00/
/52, 0.00/53, 0.00/54, 0.00/55, 0.00/56, 0.00/57, 0.00/58, 0.00/59. 0.00
0/61, 0.00/62, 0.00/63, 0.00/64, 0.00/65, 0.00/66, 0.00/67, 0.00/68, 0.0
00/70,}


Definition for C*D<70> { 0.00/1, 0.00/2, 0.00/3, 0.00/4, 0.00/5. 0.00/6.
 0.00/8. 0.00/9, 0.00/10, 0.00/11, 0.00/12, 0.00/13, 0.00/14, 0.00/15,
0.00/26, 0.00/27, 0.50/28. 0.00/29, 1.00/30, 0.50/31. 0.50/32, 0.50/33.
```

```
0.50/64, 0.00/65, 0.00/66. 0.00/67, 0.50/68. 0.0
00/70, 0.00/71, 0.50/72, 0.00/73, 0.00/74, 0.00/75, 0.50/76, 0.50/77, 0.
.00/79, 0.50/80, 0.50/81, 0.00/82, 0.00/83, 0.50/84, 0.50/85. 0.50/86, 0
0.50/88, 0.00/89, 1.00/90, 0.00/91, 0.00/92, 0.50/93, 0.50/94, 0.00/95,
 0.00/97, 0.00/98, 0.50/99, 0.00/100, 0.00/101, 0.50/102, 0.00/103, 0.00




00/105, 0.00/106, 0.00/107, 0.50/108, 0.00/109, 0.00/110. 0.00/111, 0.00
00/113, 0.00/114, 0.00/115, 0.00/116, 0.00/117, 0.00/118, 0.00/119, 0.00
00/121, 0.00/122, 0.00/123, 0.00/124, 0.00/125, 0.00/126,}
Enter another pair of data (Y/N) ?

00/113, 0.00/114, 0.00/115, 0.00/116, 0.00/117, 0.00/118, 0.00/119, 0.00
00/121, 0.00/122, 0.00/123, 0.00/124, 0.00/125, 0.00/126,}
Enter another pair of data (Y/N) ?
Enter linguistic value for this criteria (A..E) ? B
Enter linguistic value for weight for this criteria (A..E) ? C
Definition for Second_mult is: <20> { 0.00/15, 0.00/18, 0.00/20. 0.00/21
4, 0.00/25, 0.00/27. 0.50/28. 0.50/30, 0.50/32, 1.00/35, 0.50/36. 0.50/4
42, 0.00/45, 0.50/48, 0.00/49, 0.00/54, 0.00/56, 0.00/63,}


Definition for Normalised Second_mult is: <63> { 0.00/1, 0.00/2. 0.00/3.
 0.00/5, 0.00/6, 0.00/7, 0.00/8, 0.00/9, 0.00/10. 0.00/11. 0.00/12. 0.00
0/14. 0.00/15, 0.00/16, 0.00/17, 0.00/18, 0.00/19, 0.00/20. 0.00/21. 0.0
00/23. 0.50/24, 0.00/25. 0.00/26, 0.00/27. 0.50/28, 0.00/29, 0.50/30. 0.
.50/32, 0.00/33. 0.00/34, 1.00/35, 0.50/36, 0.00/37. 0.00/38. 0.00/39, 0
0.00/41, 0.50/42, 0.00/43, 0.00/44, 0.00/45, 0.00/46, 0.00/47. 0.50/48, .
 0.00/50, 0.00/51. 0.00/52, 0.00/53. 0.00/54, 0.00/55. 0.00/56, 0.00/57.
, 0.00/59, 0.00/60. 0.00/61, 0.00/62. 0.00/63,}
Definition for C+C<46> { 0.00/4, 0.00/5, 0.00/6, 0.00/7, 0.00/8. 0.00/9.
. 0.00/11. 0.00/12, 0.00/13, 0.00/14, 0.00/15, 0.00/16, 0.00/17, 0.00/18
9, 0.00/20, 0.00/21, 0.00/22, 0.00/23, 0.00/24. 0.00/25, 0.00/26. 0.00/2
28, 0.50/29, 0.50/30, 0.50/31, 0.50/32, 0.50/33, 0.50/34, 1.00/35. 0.50/
/37, 0.50/38. 0.50/39, 0.50/40. 0.50/41, 0.50/42. 0.00/43, 0.00/44, 0.00
0/46, 0.00/47. 0.00/48, 0.00/49,}


0/46. 0.00/47, 0.00/48, 0.00/49,}


Definition for normalise D: <49> { 0.00/1. 0.00/2, 0.00/3. 0.00/4. 0.00/
6, 0.00/7. 0.00/8. 0.00/9, 0.00/10, 0.00/11. 0.00/12. 0.00/13. 0.00/14.
 0.00/16, 0.00/17, 0.00/18. 0.00/19, 0.00/20, 0.00/21. 0.00/22. 0.00/23.
, 0.00/25. 0.00/26, 0.00/27, 0.50/28. 0.50/29, 0.50/30. 0.50/31. 0.50/32
3. 0.50/34, 1.00/35. 0.50/36, 0.50/37, 0.50/38, 0.50/39. 0.50/40. 0.50/4
42. 0.00/43. 0.00/44, 0.00/45. 0.00/46, 0.00/47, 0.00/48. 0.00/49,}
Definition for SumMult is: <125> { 0.00/2. 0.00/3. 0.00/4. 0.00/5. 0.00/
7, 0.00/8. 0.00/9, 0.00/10, 0.00/11, 0.00/12, 0.00/13. 0.00/14. 0.00/15.
. 0.00/17, 0.00/18. 0.00/19, 0.00/20, 0.00/21, 0.00/22. 0.00/23. 0.00/24
5, 0.00/26. 0.00/27. 0.00/28, 0.00/29, 0.00/30. 0.00/31. 0.00/32. 0.00/3
34, 0.00/35, 0.00/36, 0.00/37, 0.00/38, 0.00/39, 0.00/40. 0.00/41. 0.00/
/43, 0.00/44, 0.00/45, 0.00/46. 0.00/47, 0.50/48. 0.00/49. 0.00/50. 0.00
0/52, 0.00/53, 0.50/54. 0.00/55, 0.50/56, 0.00/57. 0.50/58. 0.50/59. 0.5
00/61, 0.50/62, 0.50/63, 0.50/64. 0.50/65, 0.50/66, 0.50/67. 0.50/68. 0.
.00/70. 0.50/71, 0.50/72, 0.00/73, 0.50/74, 0.50/75, 0.50/76. 0.50/77, 0
0.00/79, 0.50/80, 0.00/81, 0.50/82, 0.50/83, 0.50/84, 0.00/85. 0.00/86,
 0.50/88. 0.00/89, 0.50/90, 0.00/91, 0.00/92, 0.00/93, 0.00/94, 0.00/95.
, 0.00/97, 0.00/98, 0.00/99, 0.00/100, 0.00/101, 0.00/102, 0.00/103, 0.0
.00/105, 0.00/106, 0.00/107, 0.00/108, 0.00/109, 0.00/110, 0.00/111. 0.0
.00/113, 0.00/114, 0.00/115, 0.00/116, 0.00/117, 0.00/118, 0.00/119. 0.0
.00/121, 0.00/122, 0.00/123, 0.00/124, 0.00/125, 0.00/126,}
```