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APPLICATIONS OF KNOWLEDGE BASED EXPERT SYSTEMS IN RECURRENT COMPETITIVE BIDDING

by

Gary John Phythian B.Sc. M.Sc.

A Doctoral Thesis Submitted in partial fulfilment of the requirement for the award of Doctor of Philosophy of Loughborough University of Technology.

September 1991

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For my parents
James and Dorothy Phythian
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Throughout this research I have called upon the assistance of a large number of people both within and outside the University. The first debt lies with my supervisor, Professor Malcolm King. Throughout the research his intellectual input was considerable and his instant feedback on the work was invaluable. Moreover, his supervision was given in a very friendly and supportive way which enhanced the enjoyment of what could potentially have been a rather fraught exercise. Hopefully Malcolm's influence can be detected throughout this research and if it can it will be of benefit to the thesis.

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ABSTRACT

Previous bidding studies have focussed on optimum bid pricing and several approaches have been proposed for this problem. Unfortunately, there are problems with each of these approaches and so to date there is no generally accepted approach to bid pricing. Furthermore, bid pricing is only one of a series of interrelated decisions that need to be addressed when formulating an overall bidding strategy. For many organisations decisions concerning whether or not to bid and the level of resources to allocate to bid preparation are equally important. Both of these areas, however, have received scant attention from the academic community. Together these observations suggest that radically different approaches for improving bidding performance should be investigated. Expert systems display several characteristics which suggest that they offer a possible route to further progress in work on bidding and this thesis explores the possible roles and benefits that expert systems can provide in this area.

In particular this thesis describes a case study concerning the development of an expert support system for tender enquiry evaluation. The system was developed for use by the senior management of a large electro-mechanical engineering company to assist with their decisions concerning whether or not to bid and the level of resources to allocate to bid preparation. In the case considered the expertise of two senior managers involved in assessing enquiries was developed into an expert support system. Knowledge was elicited from these managers by asking them to consider previous tenders and specify the factors used in discriminating between them. Their responses were represented in repertory grids.

A subsequent validation study suggested that the system developed provides an appropriate model of the organisation's consensual business perspective regarding its bid versus no bid and bid resourcing decisions. Furthermore, collaboration helped the organisation to clarify its bidding expertise in a changing business environment. In particular, it highlighted the organisation's current bidding policy and forced the organisation to reconsider what its ideal policy should be. It also drew attention to some dissenting views amongst the organisation's senior management and highlighted possible weaknesses within their own expertise. In summary, the resulting expert support system was perceived to improve both the objectivity and consistency of the organisation's enquiry review group and was generally welcomed by the organisation.

It is concluded that expert systems are appropriate tools for modelling competitive bidding situations. However, owing to the nature of bidding domains and non-formal managerial domains in general, the case study suggests that several problems need to be addressed if commercially viable systems are to be developed. Most importantly of which are the identification of appropriate development and validation methodologies in domains characterised by multiple unarticulated experiential based models.
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CHAPTER 1

INTRODUCTION
1. INTRODUCTION

Recent changes in Government legislation have highlighted the important role that competitive bidding or tendering can play in the effective procurement of goods and services. Even before such changes competitive bidding has played an important role in many organisations’ overall business strategies. This is reflected by the extensive interest competitive bidding has evoked within the Management Science/Operational Research (MS/OR) community over the last three decades since the publication of the seminal work by Lawrence Friedman in 1956.

The majority of previous bidding studies have focussed on the problem of determining the optimum price at which to bid. Several quantitative modelling approaches have been proposed for this problem. These have included the decision and game theoretic approaches, and also the probabilistic strategy approach. Unfortunately, there are well established theoretical and/or practical problems with each of these approaches and as a result to date there is no universally acceptable approach to bid pricing.

It is important to realise that bid pricing is only one of a series of interrelated decisions that need to be addressed when formulating an overall bidding strategy. For many organisations an important decision is whether or not to bid at all. This decision is referred to as the bid versus no bid decision and is especially important for those organisations where the cost of bidding is high. This can occur for example, in organisations where bidding involves a significant amount of design work which creates a large front end cost. In such circumstances price may not be a contractor’s major competitive weapon and therefore there is a shift of emphasis from optimal bid pricing towards optimal resourcing of bids. This is an area which has received scant attention from the MS/OR community, but one in which there appears to be significant justification and scope to provide management decision support.

Thus, given the strategic importance of competitive bidding, together with the narrow focus and limited success of the previous approaches in providing management decision support in bid pricing, it can be concluded that radically different approaches for improving bidding performance should be investigated.

In practice managers responsible for preparing competitive bids have gained considerable expertise and intuition and can be relied upon for their good judgement to make rational and reasonable decisions. This suggests that knowledge based
approaches incorporating decision support models based on simple heuristic, experiential rules may be more appropriate and reliable for improving bidding performance.

Expert 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, as for example loosely associated facts and rules, often learnt from experience rather than theory. Therefore, the characteristics of expert systems suggest that they offer a possible route to further progress in providing decision support in competitive bidding. This thesis explores the possible roles and benefits that expert systems can provide in this area.

The thesis is divided into three major sections.

**PART A: LITERATURE SURVEY AND RESEARCH OBJECTIVES**

The first part of this thesis, part A, consists of three chapters. The first two of which provide brief surveys of the literature relating to recurrent competitive bidding and intelligent knowledge based expert systems respectively. The third and final chapter in this section outlines the research objectives and methodology.

Chapter 2 outlines the nature and scope of competitive bidding and defines some of the terminology that is used throughout this thesis. Furthermore, the contributions made by the MS/OR community in the development of quantitative bidding models are briefly discussed and the relative strengths and weaknesses of these previous models are critically summarized.

Chapter 3 outlines the major characteristics of intelligent knowledge based expert systems or expert systems for short. The chapter provides a discussion of the evolution of expert systems which highlights their close relationship to the discipline of artificial intelligence. A working definition of an expert system is provided and their major characteristics and differences from more conventional computer programs are highlighted. The underlying technology, including knowledge representation, methods of inference, and inexact reasoning, that enable expert systems to attain their expert levels or performance is then briefly discussed. Finally, the major benefits, limitations and scope of current expert systems are noted.
Chapter 4 draws together the concepts discussed in chapters 2 and 3. The weaknesses of the previous bidding studies are summarized and the characteristics of expert systems which suggest that they may provide a more appropriate tool for which to provide management decision support in this area are highlighted. Four possible applications of expert systems are identified and the major objectives of the research are outlined. An outline methodological framework for investigating the possible applications of expert systems in competitive bidding is devised. The framework is both exploratory and experimental and is based on in depth case studies requiring extensive collaboration from organisations involved in competitive bidding. The approaches taken to find suitable organisations are discussed; and finally the responses of the organisations approached concerning the possible applications of expert systems in competitive bidding are summarized.

PART B: A CASE STUDY: AN EXPERT SUPPORT SYSTEM FOR TENDER ENQUIRY EVALUATION

The second part of this thesis, part B, describes a case study concerning the development of an expert support system for tender enquiry evaluation. The system was developed for use by the senior management of a large electro-mechanical engineering company to assist in their bid versus no bid and bid resourcing decisions.

Part B consists of eight chapters. Chapter 5 describes the background to the case study. Chapters 6-10 describe the system's development, whilst chapters 11 and 12 describe the system's validation.

Chapter 5 describes the structure, business and bidding activities of the case study organisation. In particular, the organisation's approach to tender enquiry evaluation and the bid versus no bid and bid resourcing decisions are discussed in detail. The organisation's justification for wishing to focus on this part of the bidding process is given and the objectives of collaboration are noted.

Chapter 6 describes the development of an appropriate knowledge acquisition strategy for use within the case study organisation and the domain of tender enquiry evaluation. The nature of the knowledge acquisition process is discussed from which it is concluded that it is important to develop a knowledge acquisition strategy and a set of knowledge acquisition techniques whose properties match the characteristics of the problem domain. The major characteristics of the domain of tender enquiry evaluation are then identified. These are that the domain is characterised by multiple expertise with differing perspectives, that the bid versus no bid and bid resourcing
decisions are classification and co-ordinative type problems, that the domain is semi-structured, and that it can be reasonably assumed that the domain's overall structure is in the form of a hierarchical inference network. These five domain characteristics are compared with the properties of several well researched knowledge acquisition techniques. From this comparison it is concluded that an appropriate strategy would be one based around the technique of repertory grid analysis.

Chapter 7 describes the design and use of the repertory grid based methodology developed for use in the case study. Chapter 7 commences with a discussion of the underlying theory of personal constructs and the issues in the design of repertory grids, with particular emphasis on the development of multiple grid designs which enable comparisons to be made between multiple sources of expertise. Since the domain of tender enquiry evaluation was characterised by multiple expertise with differing perspectives it was agreed with the organisation's senior management that more than one manager should be used throughout the knowledge acquisition process so that a comparison could be made of the expertise of the different managers involved. The managers who were believed to have gained the broadest insight into the tender enquiry evaluation process and the factors that influence the bid versus no bid and bid resourcing decisions are identified, and an appropriate repertory grid design for use with these managers is developed. The experiences and problems of eliciting the managers' respective grids are briefly discussed; and finally the managers' grids are presented and briefly examined.

Chapters 8, 9 and 10 discuss the analysis of the managers' grids. The objective of the analyses was to identify the hierarchical inference network that was assumed to represent the managers' conceptual structure of the domain, and then to develop a model of the managers' reasoning with regard to tender enquiry evaluation.

Chapter 8 describes the first stage of analysis of the managers' grids. Chapter 8 commences with a brief discussion of the methods of analysis for single and multiple grid designs. The characteristics of the domain suggested that FOCUS, a grid analysis method based on an agglomerative hierarchical clustering algorithm, was appropriate for use in the domain of tender enquiry evaluation. The analyses using FOCUS demonstrated that both managers' individual grids were valid. That is, both managers' individual construct systems were capable of discriminating between attractive and unattractive enquiries, and that the discriminations made by their construct systems closely matched their respective overall views. Furthermore, the analyses demonstrated that there was considerable similarity between the two
managers' respective views of the enquiry evaluation process. It was therefore concluded that the managers' construct systems were complementary to each other, and that it was feasible to develop a model of the managers' reasoning based on the managers' combined construct systems.

Chapter 9 discusses the second stage of the grid analysis in which the objective was to arrange the managers' combined construct system into an overall construct hierarchy. The analysis of the grids using FOCUS proved insufficient in revealing the domain's underlying hierarchical structure. A method of analysis based on correlation analysis was therefore devised which enabled the managers' conceptual structure of the domain to be identified and represented in the form of a hierarchical inference network.

Chapter 10 describes the third and final stage of grid analysis in which the objective was to develop a set of "rules" that described the managers' decision processes or reasoning. The hierarchical inference network revealed the presence of relationships between particular constructs, but did not reveal the precise nature of these relationships. Therefore, a methodology was devised to induce a "general rules" or heuristics that described the managers' reasoning. These heuristics expressed how the managers' combined their assessments for sub-ordinate constructs to reach an assessment for a super-ordinate construct. The heuristics were induced from the managers' assessments by fitting appropriate mathematical model forms to express the relationships between the relevant constructs. Taken together the induced set of "general rules" provided a model of the managers' reasoning, expressing how the managers combined their assessments for the relevant constructs in order to evaluate enquiries to reach an overall bid versus no bid decision; and thereby allocate an appropriate level of resources for the preparation of a tender proposal. The rules were developed into a prototype expert support system using the expert system shell Leonardo 3. The resulting system was named TEES for Tender Enquiry Evaluation System.

Chapter 11 describes the development of a formal validation framework for TEES. Chapter 11 commences with a brief survey of the literature in relation to expert system validation which highlights the difference in emphasis between the validation of expert systems and more conventional systems. The key issues in expert system validation are outlined with particular emphasis on the issues relevant to the validation of TEES. From this discussion a formal validation framework for TEES is devised which incorporates a quantitative measure of validity together with a formal
test using the weighted kappa statistic ($\kappa_w$). In recognition that tender enquiry evaluation is characterised by multiple expertise the devised validation framework is based around both intra-expert and inter-expert tests. The validation study involved the use of six managers who together provided a cross section of the different business and functional perspectives. This approach enabled TEES's consensual business perspective to be measured.

Chapter 12 discusses the results from the validation study. In particular the study demonstrated that TEES provides an appropriate model of the organisation's consensual business perspective regarding the important bid versus no bid and bid resourcing decisions. TEES's recommendations could therefore be used as a catalyst for further discussion between the organisation's senior management and in this respect the organisation felt that the system provided a simple but useful decision support tool. Furthermore, senior management's comments suggested that collaboration helped the organisation to clarify its bidding expertise in a changing business environment. In particular, it highlighted the organisation's current bidding policy and forced the organisation to reconsider what its ideal policy should be. The results from the validation study also drew attention to some dissenting views amongst the organisation's senior management and highlighted possible weaknesses within their own expertise. In summary, the resulting expert support system was perceived to improve both the objectivity and consistency of the organisation's enquiry review group and was generally welcomed by the organisation.

**PART C: DISCUSSION AND CONCLUSIONS**

Chapter 13 briefly summarises the material presented in previous chapters of the thesis and discusses in further detail some of the results and findings reported throughout the research. In particular, the methods used to develop and validate TEES are evaluated, as are the results obtained from the validation study.

From these evaluations it is concluded that expert systems are appropriate tools for modelling competitive bidding situations. The research suggests that the principle benefits deriving from the use of expert systems in competitive bidding are the clarification and consolidation of multiple sources of unarticulated experiential 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 bidding decisions. A closely related benefit is the ability to perform sensitivity type
analyses to evaluate the consequences of a variety of scenarios. This is particularly beneficial in bidding situations where the ultimate decision is the result of social interaction between several managers and where it is therefore necessary to reach a consensus decision. In such situations expert systems are beneficial in determining the significance of minor differences of opinion between the managers, and thereby focussing the attention of the group onto the key issues where a consensus is required.

The research suggests, however, that owing to the nature of bidding domains and non-formal managerial domains in general, several problems need to be addressed if commercially viable systems are to be developed. Most importantly of which are the identification of appropriate development and validation methodologies in domains characterised by multiple unarticulated experiential based models. The research also suggests that in some situations purely descriptive models may be inappropriate because experts are themselves unconvinced of the adequacy of their own knowledge; and therefore it is expedient if methods for complementing the traditionally descriptive knowledge bases of expert systems with a normative element are investigated. Together these observations offer possible directions in which future research in the area might be pursued.
PART A

LITERATURE SURVEY AND RESEARCH OBJECTIVES
CHAPTER 2

RECURRENT COMPETITIVE BIDDING - LITERATURE REVIEW
2. Recurrent Competitive Bidding - Literature Review

2.0 Introduction

This chapter provides a brief review of the literature relating to recurrent competitive bidding. Since the seminal work of Lawrence Friedman in 1956 a great deal has been written on competitive bidding, as is demonstrated by a bibliography of bidding literature containing over 500 references published in 1979 (Stark & Rothkopf, 1979). Clearly, it has been beyond the scope of this thesis to review comprehensively all this work and therefore a more recent review of recurrent competitive bidding provided by King & Mercer (1988) has been used as the primary source of reference material.

The chapter commences with a discussion of the nature and scope of competitive bidding and highlights the diverse range of organisations who obtain their business through the competitive bidding process. In spite of its diversity it is possible to abstract a generic model of the bidding process and one such model is presented based on the work of King & Mercer (1988), Ward & Chapman (1988) and the author's own knowledge of the competitive bidding process gleaned from interviews with several organisations involved in bidding. Following this, the contributions made by the Operational Research / Management Science (OR/MS) community in the development of quantitative bidding models are briefly reviewed. This demonstrates that previous work has focussed on one particular problem arising within a specific class of bidding situations. Given the author's thesis, which is that these quantitative bidding models have not been overriding successfull in improving bidding performance and that a knowledge based expert systems approach may be more appropriate, then the discussion of these previous quantitative models is purposefully kept brief and only the major themes underlying the models are presented. Finally, the relative strengths and weaknesses of these previous models are critically summarised.
2.1 The Nature and Scope of Recurrent Competitive Bidding

Recent changes in Government legislation have highlighted the important role that competitive bidding or tendering\(^1\) can play in the effective procurement of goods and services. Examples of such changes include the abandonment of cost plus contracts by the Ministry of Defence and the introduction of compulsory competitive tendering (CCT) within local authorities. These changes have had an effect on a diverse range of organisations, from high profile multinationals bidding for multimillion pound defence contracts to small contractors bidding for refuse disposal, cleaning and maintenance contracts with local authorities. Even before such changes competitive bidding has played an important role in many organisations' overall business strategies; and as noted in the introduction above a great deal has been written on the subject by the OR/MS community, especially within the context of the construction and civil engineering industries which traditionally obtain the majority of their business through this means. However, organisations from a diverse range of economic sectors are dependent on competitive bidding to obtain business and throughout the period of this research the author has had contact with several organisations all of which obtain some, if not all, of their business through competitive bidding. Alongside traditional construction and civil engineering companies, these have included a manufacturer of sophisticated computerised process control equipment, a pharmaceuticals company, an international firm of management consultants and several electrical and mechanical engineering companies.

Although the scope of competitive bidding is diverse a general bidding framework exists. Within this framework there exist two interested parties. These are the customer or contract buyer, who requires some service; and the suppliers, each of whom is willing to provide the service required by the customer at its own price and subject to its own contractual conditions\(^2\). In the present context the word service is used to describe both a tangible product or physical good, as for example the supply of a raw material or the construction of a building, road or bridge; and also to describe

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\(^1\) Throughout this thesis the words bidding and tendering are treated as synonyms, as are also the words tender and bid. The author has noted throughout this research that the words bidding and bid are those preferred throughout the academic literature. However, in discussions with several organisations on the subject the words tendering and tender appear to be preferred.

\(^2\) It should be recognised that in many bidding situations the terms of the contract will be laid down solely by the customer.
an intangible product, as for example a business strategy review. In general the customer decides upon the service required, and then asks a number of suppliers to prepare a competitive bid in order to compete for the business on offer. The competitive bid is in effect a proposal detailing both the supplier’s price and terms under which he is prepared to provide the service. When all bids from interested suppliers have been submitted the customer appraises or evaluates each supplier’s bids; and on the basis of this appraisal chooses one supplier to provide the required service. This sequence of events is referred to as the competitive bidding process and its nature is discussed in further detail in section 2.2.

Within the above framework it is implicitly assumed that there is a single customer with reasonable knowledge of the service that he requires; and furthermore that there are several interested suppliers willing to compete in order to obtain this business. These two assumptions underlie the arguments presented in this thesis. Moreover, throughout this thesis it is assumed that any particular bidding situation is observed from the viewpoint of one supplier referred to as the contractor. This perspective is referred to as the bidders eye view (King & Mercer, 1988). All suppliers other than the contractor are referred to as the competitors, or collectively as the competition.

In order to highlight the diversity of the competitive bidding process it is expedient to describe any given competitive bidding situation in terms of four characteristics that distinguish different bidding situations (King & Mercer, 1988). These are the nature of the bid, the customer’s appraisal criteria, the degree to which the customer specifies his required service, and finally cost uncertainty.

The nature of the bid may be described as either open or closed bidding. Closed bidding is also referred to as sealed bidding. In open bidding each supplier negotiates their own price and terms for providing the service with the customer. The process of negotiation is iterative, suppliers are free to improve upon their previous bids, and moreover they may have knowledge of their competitors’ latest offers. The simplest example of open bidding is a public auction in which each buyer is aware of the other buyers’ offers and is free to raise their bid as many times as they like. In closed

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3 In some competitive bidding situations the roles of customer and suppliers are reversed. In these instances each customer bids to buy a single concession from a sole supplier, as for example to buy an oil lease, or the stock of a bankrupt company (Chapman et al., 1987 pp. 503).

4 Some researchers have studied bidding situations from the perspective of the customer. For example, Turner (1988) considers the customer’s appraisal of the suppliers’ competitive bids.
bidding each supplier is allowed to submit only one bid. Negotiation between the customer and the suppliers is debarred, as is any collusion between the suppliers. Each supplier submits their single bid (that is their price and terms for providing the service) in a sealed envelope to the customer by a specified bid closing date. After this date has passed all the suppliers' bids are opened simultaneously, appraised, and the business or contract awarded to the supplier whose bid the customer considers to be the most attractive. Closed bidding is frequently encountered within the construction and civil engineering industries and also within organisations which obtain business by bidding for contracts issued by government agencies, as for example the property services agency, or other public bodies such as local authorities. The open and closed bidding situations outlined above represent two extremes and in some bidding situations, as for example within the defence industry, the customer adopts a mixture of closed and open bidding. In such situations the suppliers are firstly asked to submit their bids in sealed envelopes, and then after appraising the suppliers' closed bids the customer invites two or three of the most promising suppliers to enter into a phase of negotiation.

In some bidding situations the customer will appraise the suppliers' bids on the sole basis of price with the contract being awarded to the lowest priced bidder. Government agencies and public bodies are often compelled by law to award the contract to the lowest priced responsible supplier. The lowest price wins criterion is also prevalent within the construction and civil engineering industries and as a result the focus of much of the bidding literature assumes a closed bidding situation in which the contract is awarded to the lowest priced bidder (see section 2.3).

The lowest price wins criterion provides an adequate means of bid appraisal in situations where either there is no significant difference between the quality of goods or level of service offered by any of the suppliers (Mercer & Russell, 1969), or where the suppliers' bids can be appraised in an equitable and quantitative manner (Marsh, 1987 pp. 56-57). For example, discounted cash flows can be used to compare different financing schemes and such a situation could occur with the procurement of a raw material. Even in such a simple situation, however, the lowest priced bid adjusted for cash flows may not be an appropriate bid appraisal criteria. Consider the situation of a customer wishing to procure bauxite ore, and suppose that there are several suppliers offering different grades of bauxite at different prices. To compare

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5 In this context responsible means compliant with specification and terms and deemed to be sufficiently technically and managerially competent to provide the service.
these bids equitably not only do the respective aluminium yields of the different grades need to be taken into account, but also the processing costs of the ore. Thus, even in a relatively simple situation, where the customer's requirements are clearly defined, the determination of appropriate bid appraisal criteria can become a relatively complex issue.

When the required service is more complex, or is less clearly defined by the customer, suppliers' bids are likely to differ significantly and as a result their appraisal becomes a much more complex issue. In such situations the customer needs to appraise the suppliers' bids on several dimensions, or criteria, in addition to price. These additional criteria are referred to as the non-price features of bid appraisal (Ward & Chapman, 1988). In some situations it may be possible to quantify the effect of the differences in the suppliers' bids, but in others the relative differences between the suppliers' bids may be essentially qualitative and therefore difficult to quantify. Marsh (1987, pp. 68) cites an example where price takes second place to aesthetics, that of a prestigious office building such as the Hong Kong and Shanghai Bank in Hong Kong.

In some bidding situations each of the suppliers will be provided with detailed specifications of the customer's requirement. This frequently occurs within the construction and civil engineering industries where the customer may use a consultant architect to formalise his requirement and produce detailed specifications and drawings. Each supplier is then asked to be bid against the architect's specification and drawings. Alternatively, the customer may only supply the suppliers with an outline plan of the service, thus giving each supplier the freedom to create his own detailed specification and design to bid against. These two alternatives set out the most extreme situations for the degree to which the service is specified. In several industries it is common for a detailed specification to be provided with each supplier still being required to carry out significant design work. Such a situation arises in industries where each supplier has a standard but modularised product range which is individually tailored to satisfy a customer's precise service requirements. The extent of the suppliers' design input into their competitive bids will influence the customer's bid appraisal criteria. When the supplier's design input is large the suppliers' bids will differ significantly on several dimensions in addition to price. As a result the customer will need to appraise the relevant non-price features of the suppliers' bids to ensure that they are compared in an equitable fashion.
King & Mercer (1988) point out the close relationship between the third and fourth characteristics that distinguish the different bidding scenarios. The customer may have provided a detailed specification of the service that he requires, or he may have provided only an outline plan of the service. In the former case each of the suppliers will be able to estimate the cost incurred in providing the service with a high level of confidence. Whereas in the latter case, due to incomplete knowledge of the service required, each supplier will be uncertain about the exact cost he will incur.
**Figure 2.2 The Competitive Bidding Process**

**STAGE 1:**
CUSTOMER DETERMINES AND ISSUES SERVICE REQUIREMENTS TO SELECTED SUPPLIERS

- Customer Formalises Service Requirements
- Determines Nature of the Bid
- Identifies Suitable Suppliers
- Contacts Suppliers with Service Requirements

**STAGE 2:**
SUPPLIERS PREPARE AND SUBMIT THEIR COMPETITIVE BIDS

- Bid Versus No Bid Decision
- Allocate Appropriate Resources
- Perform Necessary Designs
- Produce A Cost Estimate
- Prepare Prices & Terms
- Forward Bid Proposal to Customer

**STAGE 3:**
CUSTOMER AWARDS CONTRACT TO A SUPPLIER

- Customer Appraises Suppliers' Bids
- Agree Terms with a Supplier

**STAGE 4:**
CHosen SUPPLIER PROVIDES SERVICE
2.2 **The Competitive Bidding Process**

In spite of the diversity of organisations involved in competitive bidding and the numerous bidding situations that arise from the different combinations of the four characteristics discussed above, it is possible to abstract a general model of the competitive bidding process. The model presented in this section is based on the studies of King & Mercer (1988), Ward & Chapman (1988), and the author's own knowledge of the bidding process gleaned from interviews with organisations involved in bidding. The bidding process is illustrated in figure 2.2 and consists of four serial stages. Each of these stages is discussed in the respective sub-sections below.

2.2.1 **Customer Determines and Issues Service Requirements to Selected Suppliers**

As previously noted, the customer may seek assistance from consultant advisers to formalise its service requirements. For example, a customer who wanted a new shopping mall built may commission a firm of architects to produce a set of detailed designs and drawings. These would then be forwarded to each of the selected suppliers and each supplier would be asked to bid against the architects' design.

Alternatively, the customer may provide the suppliers with only an outline plan of the service. In the example of the new shopping mall this corresponds to the customer providing the suppliers with the mall's major requirements, such as the overall floor-space requirements, individual unit requirements and car parking facilities. During this first stage of the bidding process the customer must also decide whether to negotiate with the suppliers, or ask the suppliers to provide sealed bids; and finally, he must select several suppliers from whom to invite bids. Advertising locally or nationally in newspapers or trade press is one means of generating interest from suppliers and in some industries customers are legally obliged to publicly advertise their requirements. In several industries customers are known to vet interested suppliers through a process of pre-qualification. This involves the suppliers producing a statement of their capabilities to provide the service. Often this involves suppliers providing evidence of their past experience with similar work, their current workloading or capacity and their financial position. Furthermore, customers are also known to select suitable suppliers from previously compiled select lists of responsible suppliers. For the suppliers ensuring that their names are on customers' select lists can be a major hurdle and may require the expenditure of significant amounts of resources. For example, the author is aware of one organisation who was required to spend in excess of one million pounds in order to prove themselves technically and
managerially competent before being allowed on one particular blue chip customer's select list.

2.2.2 Suppliers Prepare and Submit their Competitive Bids

After receiving an invitation to bid\(^6\) a supplier must first of all decide whether or not it is worth his while proceeding with the preparation of a competitive bid. That is, each supplier must decide whether or not to bid, a decision referred to as the bid versus no bid decision (Ward & Chapman, 1988). This is an especially important decision for suppliers where the cost of bidding is high. This can occur for example, with suppliers where the preparation of the bid proposal involves a significant amount of design work which creates a large front end cost. The aim of the bid versus no bid decision is to minimise bid preparation costs by identifying potentially unprofitable contracts, and therefore focus a supplier's resources towards profitable and attractive contracts. In determining whether or not to submit a bid the supplier needs to consider several salient factors. These factors may include knowledge of contracts being issued in the near future, his current workload, and present status in reaching organisational objectives. Furthermore, the bid versus no bid decision should not be regarded as binary decision variable. In reality different contracts will warrant different levels of bidding effort depending upon their perceived attractiveness and importance to the supplier. Thus, having decided to bid a supplier needs to consider the level of resources, or tendering effort, to allocate to the preparation of the bid proposal (Ward & Chapman, 1988).

Depending upon both complexity of the service and the degree to which it is specified, then the supplier may be required to expend a significant design effort to produce detailed specifications and drawings. After an appropriate design is made available the supplier must produce an estimate of the cost he will incur in providing the service. It is expedient for the cost estimate to be as accurate as possible because in many bidding situations it is the most important factor influencing the bid price (Curtis & Maines, 1973; Mercer, 1983).

After obtaining a cost estimate the supplier must decide upon his bid price and his terms for providing the service. As previously noted in some bidding situations price is the contractor's sole competitive weapon, with the contract being awarded to the lowest priced bidder. In such situations, then when formulating an appropriate bid

\(^6\) In theory this invitation to bid may be no more than a press advertisement.
price the contractor must first and foremost consider his organisational objectives together with his current position with respect to these objectives. The final bid price will then be a compromise between the perceived value of the opportunity to the contractor if the bid is successful, and the probability of the bid being successful, and therefore realising the perceived value, at the given price.

In the simplest situations the perceived value of the contract to the contractor may be purely quantitative in the form of generated profits. Therefore, subject to any constraints the contractor may wish to impose on profits and the probability of success the final bid price is a compromise between profits generated if the bid is successful, and the probability of a bid at a given price being successful. A high bid price will produce generous profits should the bid be successful, but as the supplier's bid price increases the chances of his bid being accepted by the customer decreases. Conversely, a low bid price increases the chances of the supplier's bid being accepted by the customer, but simultaneously reduces the generated profits should the bid be successful. In more complex situations the perceived value may include qualitative dimensions, as for example gaining business with a prestigious customer, or enabling the organisation to diversify its business. In these situations it is much more difficult for a contractor to formalise an overall objective because of the qualitative nature and the difference in relative importance of each of the salient dimensions.

In order to resolve the compromise between perceived value of the contract if the bid is successful, and the probability of the bid being successful the contractor needs to evaluate the effects of several influences. In general, then in addition to his own organisational objectives and current position, the contractor needs to consider general market trends, the nature of the contract, the nature of the competition, in particular its extent and intentions, and finally the nature of the customer.

In more complex bidding situations where non-price features are important then when determining an appropriate bid price the contractor must consider the nature of both the customer and the competition in more detail. The contractor must first attempt to identify those non-price features relevant to the customer, and then attempt to maximise upon their advantages over the competition with respect to these features and minimise the effects of a competitor's advantages over themselves. With the often limited and inaccurate information available this is an extremely difficult problem to address.
2.2.3 **CUSTOMER AWARDS CONTRACT TO A SUPPLIER**

Once all bids have been received the customer must seek to appraise all the suppliers' bids on an equitable basis. This involves identifying any relevant non-price features and assessing their relative importance and equivalent financial value. After this appraisal which may involve a phase of negotiation with two or three suppliers the customer will agree terms with a supplier, and award the contract to that supplier.

2.2.4 **CHosen SUPPLIER PROVIDES SERVICE**

The supplier provides the customer with the required service, and payment is made by the customer. Frequently, both the provision of the service and its payment are made in stages.
### 2.3 MODELLING COMPETITIVE BIDDING SITUATIONS

This section reviews the major contributions made by the OR/MS community in the development of quantitative bidding models. Past models have focused on one particular problem arising within a specific class of bidding situations. This is the problem of providing management support in determining the optimum price at which to bid in order to maximise the expected profit on any given contract within a closed bidding situation in which the contract is awarded to the lowest priced bidder (Boughton, 1987; King & Mercer 1988). This problem is generally reformulated so that the objective is to determine the optimum markup (an allowance for overheads, profit and contingencies such as risk) defined as the ratio of the contractor's bid price to his cost estimate.

To date there is no universally accepted model for determining the optimum markup or bid price. Numerous models have been proposed and these have been classified into three major approaches: the decision theoretic approach (or, basic probabilistic approach), the game theoretic approach, and the probabilistic strategy approach (King & Mercer, 1988). Each of these three approaches differ in their respective assumptions regarding the competitors' bidding behaviour and are reviewed in sub-sections 2.3.1, 2.3.2 and 2.3.3 respectively.

The analysis of the second stage of the bidding process highlighted that bid pricing is only one of a series of interrelated decisions that needs to be addressed by the contractor in his formulation of an overall bidding strategy. In certain bidding situations the related decisions of whether or not to bid and the level of resources, or tendering effort, to allocate to the preparation of the bid proposal are also very important. This is an area which has received considerably less attention from the OR/MS community, but one in which there appears to be significant justification for management support. The work in this area is reviewed in sub-section 2.3.4.
2.3.1 THE DECISION THEORETIC APPROACH

2.3.1 (A) FRIEDMAN'S MODEL

The seminal work on the determination of optimum bid prices was that of Lawrence Friedman published in 1956 (Friedman, 1956). In that paper Friedman proposed a model to determine the optimum price at which a contractor should bid in bidding situations where each supplier submits one sealed bid and the contract is awarded to the lowest priced bidder. Friedman's model, together with its later variants have been grouped together under the heading of the decision theoretic, or the basic probabilistic, approach (King & Mercer, 1988). In this section a brief overview of Friedman's basic model is presented. Its variants are highlighted in section 2.3.1 (C).

After discussing several alternative objectives, Friedman assumes that the contractor's sole objective is to maximise his expected profit on any given contract. The basic decision theoretic model can then be developed as follows:- Let C be the contractor's cost estimate. In reality the estimated and actual cost of providing the service will differ and as a result a contractor is more likely to be the lowest bidder on those contracts where he has underestimated the cost (Feurst, 1976), a phenomenon known as the winners curse. Therefore, in attempting to maximise expected profit it is desirable to derive an unbiased cost estimate. Friedman considers the ratio of actual to estimated cost, $S$. This ratio $S$ is assumed to be a random variable with a probability distribution function, $\mu(S)$. Let $P(m)$ be the probability of the contractor

7 Unless otherwise stated, any reference to Friedman’s work is to his seminal paper published in 1956.

8 The extent and significance of this difference will be dependent upon both the nature of the contract and the industry concerned. Studies by both Curtis & Maines (1973) and King & Mercer (1987a) identified situations in the construction and civil engineering industries respectively where there was significant variation in the contractor’s cost estimates. Whilst studies by Morin & Clough (1969) and King & Mercer (1987a) identify cases within the construction industry where the differences between actual and estimated cost are insignificant.

9 It is recognised that there are several problems with measuring the actual cost of the contract (Feurst, 1976; Ward & Chapman, 1988). In his paper Friedman does not discuss how an estimate for $C$ the actual cost is obtained. Moreover, it is only possible to measure the actual cost for those contracts that the contractor wins, and these necessarily represent a biased sample. However, it is argued that this bias is irrelevant because it is precisely those contracts where cost estimate has been underestimated that the contractor wishes to correct for (Feurst, 1976).
winning the contract at a markup m, then the contractor's expected profit, T(m), at the
given markup m is given by

\[ T(m) = \int_0^\infty P(m)[mC - SC]t(S)\,dS \]

\[ = P(m) \times mC - P(m)C \int_0^\infty S \times t(S)\,dS \quad \text{eq. 2.3.1(A) (i)} \]

Under the assumption that P(m) is independent of S.

By definition, \( \int_0^\infty S \times t(S)\,dS \) is the expected value of S, E(S). Hence,

\[ T(m) = P(m)[Cm - C'] \quad \text{eq. 2.3.1(A) (ii)} \]

where, \( C' = C \times E(S) \), an unbiased estimate of the actual cost.

Equation 2.3.1(A) (ii) expresses Friedman's basic decision theoretic model. The
objective is to determine the optimum markup \( m^* \) that maximises the expected profit
function \( T(m) \). For a small value of m, possibly less than \( C'/C \), the probability of
winning \( P(m) \) equals unity. Furthermore, \( P(m) \) decreases monotonically as the
markup m increases and is asymptotic to zero as m tends to infinity. Therefore from
equation 2.3.1(A) (ii) it can be deduced that, \( T(m)<0 \) when \( m<C'/C \); \( T(m)=0 \) when
\( m=C'/C \); \( T(m)>0 \) when \( m>C'/C \); and \( T(m)\to0 \) as \( m\to\infty \). Thus, a unique optimum
markup \( m^* \) exists.

To determine the probability of the contractor winning the contract at a markup m,
\( P(m) \), Friedman firstly modelled the probability of the contractor beating a single
competitor, that is the probability that the contractor’s bid is lower than that of the
competitor. It is assumed there is sufficient competitive information for a bidding
pattern to be constructed from a competitor’s past bid prices and the contractor’s cost
estimates on those contracts where both contractor and competitor submitted bids. A
competitor's bidding pattern expresses their bidding behaviour. It is the distribution
of their pseudo markups, defined as the ratio of the competitor's bid price and the
contractor's cost estimate. For any competitor j say, it is assumed that their pseudo
markups represent a statistically independent random sample from some probability
distribution, with density function \( f_j(x) \).

One of the most fundamental assumptions underlying the decision theoretic approach
is that when fixing their bid price each competitor randomly selects a markup from
their bidding pattern. The contractor then beats a competitor \( j \) if and only if his markup is less than competitor \( j \)'s pseudo markup. Therefore, the probability of the contractor beating competitor \( j \) with a markup \( m \), \( P_j(m) \), is equal to the probability of competitor \( j \) randomly selecting a markup greater than \( m \). Thus, \( P_j(m) \) is given by

\[
P_j(m) = 1 - F_j(m)
\]

where, \( F_j(x) \) is the cumulative density function of \( f_j(x) \).

If the identity of all the competitors is known and there are \( k \) competitors, then the contractor wins the contract if and only if he beats each of the \( k \) competitors. If it is assumed that there is no collusion between the competitors and that the competitors' bids are statistically independent, then the probability of the contractor winning the contract at a markup \( m \), \( P(m) \), is given by

\[
P(m) = \prod_{i=1}^{k} P_i(m)
\]

where, \( P_i(m) \) is the probability of the contractor beating competitor \( i \) at a markup \( m \) (\( i = 1, \ldots, k \)).

When the number of competitors is known, but not their individual identities, Friedman introduced the concept of an average competitor. A bidding pattern for an average competitor is constructed from all available pseudo markups. To calculate \( P(m) \) it is then assumed that each competitor displays the bidding characteristics of a so called average competitor. Finally, when neither the number nor the identity of the competitors is known Friedman sought either an estimate of the number of competitors, or the distribution of the number of competitors \( g(k) \). In all cases, after appropriate functional forms have been determined for the required probability density functions\(^{10}\), the optimal markup \( m^* \) is found by a search procedure.

\( \text{(B)} \) Assumptions Underlying Friedman's Model

In Friedman's basic decision theoretic model there are several important underlying assumptions whose validity have a significant bearing on the appropriateness of Friedman's model and its variants for modelling bid pricing decisions. This is discussed in further detail in section 2.4 which summarises the relative strengths and

\(^{10}\) In his study Friedman found that the Gamma distribution and the Poisson distribution provided good fits to the competitors' historic pseudo markups and the number of competitors respectively.
weaknesses of the various quantitative bidding models. It is therefore expedient for the assumptions underlying the decision theoretic approach to be made explicit. All the assumptions underlying Friedman's model are thus outlined below.

(i) There is a single objective measure to be optimised, namely the total expected profit on each contract. Therefore, the contractor's marginal utility with respect to profit is constant.

(ii) The contractor can fulfil all contracts that he wins so that he is not resource constrained.

(iii) There is sufficient competitive information regarding the competitors' bid prices on past biddings where both contract and competitor bid to allow competitors' bidding patterns to be constructed.

(iv) For each competitor, their sequence of bids is a statistically independent random sample from their bidding pattern.

(v) Competitors will continue to bid in the future as they have in the past.

(vi) Competitors' bids on each contract are statistically independent.

(vii) There is no significant difference between any of the competitors' cost estimates. This implies that the contractor's probability of winning at a given markup m, P(m) is independent of the error, S, in the contractor's cost estimate.

2.3.1 (C) VARIANTS OF FRIEDMAN'S BASIC DECISION THEORETIC MODEL

Several variants to Friedman's basic decision theoretic approach have been proposed. The major contributions are reviewed in this section.

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11 Together assumptions (iv) and (v) imply that competitors are assumed to bid randomly from fixed bidding patterns with constant parameters.

Hanssman & Rivett (1959) developed a variant of Friedman's model which they argued resulted in gains in accuracy and a reduction in both computational effort and the amount of competitive information required. The optimal markup $m^*$, the probability of winning $P(m^*)$ and the maximum expected profit $T(m^*)$ are all sensitive to the number of competitors submitting bids (Morin & Clough, 1969). Consequently, uncertain knowledge of the competition is one possible source of inaccuracy in Friedman's model. To increase accuracy Hanssman & Rivett (1959) sought to obtain a value for $P(m)$ independently of the number of competitors. They analysed the market lowest bid prices, defined as the lowest priced bid submitted by any of the contractor's competitors, and concluded that the pseudo market's lowest markup, defined as the ratio of the market's lowest bid price to contractor's cost estimate, was a random variable with probability density function independent of the cost estimate. This distribution allowed $P(m)$ to be determined independently of the number of competitors.

Gates (1967) proposed a model which like the earlier study by Hanssman & Rivett (1959) focused on the method for determining $P(m)$. In particular Gates proposed a method for calculating $P(m)$ on the pretext of relaxing the assumption that the competitors' bids be statistically independent. Gates argued that, if a contractor was bidding against $k$ equally matched competitors he could expect to beat each competitor 50 percent of the time. Consequently, the chances of a contractor beating $k$ competitors is $1/(k + 1)$. This led Gates to propose that $P(m)$ should be given by

$$P(m) = \frac{1}{1 + \sum_{i=1}^{k} \{(1 - P_i(m))/P_i(m)\}} \quad \text{eq. 2.3.1(c)(i)}$$

Clearly, the results obtained from Gates' formula for $P(m)$ do not agree with those from Friedman's formula. This has led to a controversy over which, if either, of the two formulas for $P(m)$ is correct. Several papers have been published which have claimed to provide a proof of Gates' formula (see Rosenshine, 1972; Dixie, 1974); but in a more recent paper (Feurst, 1976) it has been demonstrated that Gates' formula is correct only if each $P_j(m)$ is redefined such that it represents the conditional probability that the contractor wins the contract given that either the contractor or competitor $j$ wins. Although Gates' formula has been proven inappropriate many researchers maintain that the results obtained from Gates' model are closer to reality than those obtained from that of Friedman (Gates, 1976; Benjamin & Meador, 1979;)

13 Unless otherwise stated, any reference to Gates' work is to his paper published in 1967.
Carr, 1982) and as a result the controversy is to date is still unresolved. More recently, King & Mercer (1987b) have attempted to change the focus of the debate to that of questioning the underlying assumptions of the Friedman's and Gate's model and the decision theoretic approach (see section 2.4). They demonstrate that Gates' formula does not relax the requirement that the competitors' bids be statistically independent and thus the assumptions underlying both Friedman's and Gates' models are identical.

Perhaps the most interesting and practical variant of Friedman's model is one developed by Morin & Clough (1969). An underlying assumption in Friedman's model is that the competitors bid in the future as they have in the past. In reality, however, competitive environments change over time and therefore so do competitors' bidding behaviours. This suggests that a competitor's recent bidding data should be attributed more weight than their old data in determining the shape of their bidding pattern. By using a probability distribution whose shape and parameters changed over time Morin & Clough (1969) modelled changes in a competitor's bidding behaviour. In their model the bidding patterns were left in form of histograms, and an exponential smoothing weighting scheme was applied to the data to take into account its recency. A further development in their model was that of constructing different bidding patterns for different classes of work. This was based on the premise that competitors' bidding behaviour varied depending upon the nature of the contract, and thus suggested that suppliers discriminate between different contracts (see section 2.3.3).

Simmonds (1969) and Ward & Chapman (1988) discuss an extension of Friedman's model in which the optimal markup $m^*$ is adjusted to take into account the customer's appraisal of any salient non-price features. Their approach involves determining the best combination and level of non-price features for the contractor to include in his bid; and then adjusting the probability of beating a single competitor $j$ with a markup $m$, $P_j(m)$, to take into account the combination of non-price features included in the contractor's and competitor $j$'s bids. Their approach relies upon several restrictive assumptions in addition to the basic assumptions underlying Friedman's model. These are that the customer appraises each non-price feature independently; that there is an increasing marginal cost to the contractor for increasing the level of a non-price feature in his bid and a corresponding decreasing marginal value for the customer; that the contractor can assess the customer's marginal value of each non-price feature; and finally, that the contractor knows the combination and level of non-price features present in the competitors' bids. In reality it is difficult to conceive that the contractor
could obtain such detailed information regarding the marginal value that the customer places on each non-price feature and the combination and level of non-price features included in their competitors' bids. As a result this model is impractical in the majority of bidding situations.

In many bidding situations the observed variation in the suppliers' bid prices is believed to be due mainly to the variation in their respective cost estimates (Curtis & Maines, 1973; Mercer, 1983). This is especially so within the construction and civil engineering industries. So, although it is possible that some suppliers may have some form of competitive advantage that gives rise to lower costs, it is generally conceded that on a given contract the variation in the suppliers' bid prices is created by the probabilistic nature the their cost estimates. In Friedman's model the effect of the probabilistic nature of the cost estimate is ignored. This is because in the evaluation of the integral expression for the expected profit \( T(m) \) (eq. 2.3.1(A) (i)), the probability of winning at a given markup \( P(m) \) is assumed to be independent of the variability in the cost estimate (assumption 2.3.1(B)(vii)). Yet, in reality if a contractor fixes a markup \( m \) to a cost estimate \( C \) his probability of winning must be dependent upon the error in his cost estimate, \( S \). Furthermore, his expected profit will also be dependent upon the error in his cost estimate. In this respect Friedman's model can be seen as an approximation of the bidding situation under consideration.

Recent studies by Carr (1982) and King & Mercer (1990) have investigated the effects of the variability in suppliers' cost estimates in the decision theoretic model. Carr (1982) proposed a "general bidding model" in which the probabilistic nature of the suppliers' cost estimates was taken to influence the probability of winning, but not the expected profit. Carr (1982) assumed that the suppliers' cost estimate, \( t_j(S) \), and markup, \( f_j(m) \), distributions were normally distributed and compared the results from his model to those from the models of Friedman and Gates. From his results he concluded that Friedman's model is appropriate when the variation in the cost estimates is insignificant, but that Gates' model is more appropriate when there is greater variation in the cost estimates. More recently King & Mercer (1990) have generalised Carr's model to investigate effect of the probabilistic nature of the cost estimate on the contractor's expected profit, and not only his probability of winning. They assumed that all the competitors bid with a constant market markup \( M \) and investigated the differences in the optimum markup \( m^* \) obtained from Friedman's Carr's and their own model for several forms of cost estimate distribution, \( t(S) \). From their results they concluded that one of the most critical factors is the relative size of the market markup \( M \) compared to the variability in the cost estimates. However,
their conclusions did not concur with those made by Carr (1982). Their results suggested that when variability in the cost estimates is high Friedman's model may lead to an increase in the markup values used. Yet, when variability in the cost estimates is low it is likely that the optimum markup will lead to lower markups and increased workloads.

2.3.2 THE GAME THEORETIC APPROACH

One of the major limitations of the decision theoretic approach is that it attempts to optimise the contractor's bid price without taking into account the effect of the competitors' reactions to the contractor's behaviour, or indeed the effects of each supplier simultaneously trying to optimise their own bid price. The game theoretic approach attempts to overcome this weakness by constructing models and analysing bid pricing strategies that consider the simultaneous optimality of several bidders.

The pattern of work utilising game theoretic concepts was set by four studies conducted by Griesmer et al (1963a, 1963b, 1963c, 1967). These studies of idealised bidding situations have been recently reviewed by King & Mercer (1988) who argued that many of the derived solutions are not practical. For example, in the first and simplest of the studies analysing a bidding situation modelled by a 2 player constant sum game the optimal solution is for the contractor to bid just under the competitor's cost estimate. Yet, in reality the contractor would not know his competitor's cost estimate!

Since the early work of Griesmer et al (1963a, 1963b, 1963c, 1967) there has been a considerable effort by the OR/MS community to apply game theory to different bidding situations. The situations studied are still those of a closed bidding situation where the lowest priced bidder wins the contract and the contractor's sole objective is to maximise expected profit; but differ in the assumptions they make about the suppliers' bidding behaviour, as for example the form of their bidding strategies (see Rothkopf (1969, 1980a)), or the probabilistic nature of the suppliers' cost estimates. In general these studies have modelled bidding situations as $n$ player non-zero sum games and have attempted to derive equilibrium sets of optimal bid pricing strategies such that no supplier could unilaterally improve upon their expected profit.

In particular several studies have investigated the effects of the probabilistic nature of the supplier's cost estimates (see Wilson, 1969; Rothkopf, 1969, 1980a). In each of these studies by assuming that the suppliers' cost estimates follow well known
probability distributions it has been possible to derive analytical solutions describing the equilibrium set of optimal bid pricing strategies. Often in the solution of these models it has been assumed that the suppliers' cost estimates are equally accurate (that is, that the suppliers' cost estimate distributions are identical) and that on any given contract the suppliers' errors in their cost estimates are statistically independent. In all these models the analytical solutions are defined in terms of the cost estimate distribution's parameters. As a result it has been argued that, since in many bidding situations it difficult for a contractor to determine his own cost estimate distribution regardless of the distributions of the suppliers' cost estimates, these game theoretic models are difficult to apply in practical bidding situations (King & Mercer, 1988). Despite the practical limitations of the game theoretic approach the approach has provided important theoretical insights into the problem of optimal bid pricing. For example, the study conducted by Rothkopf (1980a) demonstrated significant differences in the optimal equilibrium bidding strategies for cases where there is good/poor estimating accuracy, and good/little information regarding the extent of the competition.

Although the underlying concepts of game theory appear well suited to analysing bidding situations, recent studies have cast severe doubt as regards the theory's appropriateness to modelling the bid pricing decision. Rothkopf (1980b) has shown that there is no consistent bidders-eye view when the suppliers adopt multiplicative strategies and adjust their markups in light of the contract's size or value. Thus, the game theoretic approach is inappropriate when suppliers adjust their markup in light of the size of the cost estimate, as for as example when the suppliers are willing to provide quantity discounts or pass on economies of scale to the customer. Furthermore, Palfrey (1980) has shown that in general there is no unique set of optimal equilibrium strategies when the suppliers are constrained to keep the total value of their bid prices on simultaneous bids below a given level. Since in reality all suppliers are limited to the number of contracts they can simultaneously undertake, then the game theoretic approach is inappropriate when the suppliers are constrained by their resources and make different variations in their prices because of their different levels of resources available at the time of bidding.
2.3.3 The Probabilistic Strategy Approach

The probabilistic strategy approach to bid pricing was pioneered by Mercer & Russell (1969). The approach was originally applied within the context of several international oil companies competing to provide a large customer base with their oil requirements, but more recently it has been applied to the provision of more complex goods and services within both the construction and civil engineering industries (see King & Mercer, 1985, 1987a, 1988).

The approach attempts to overcome some of the practical and theoretical weaknesses of both the game and decision theoretic approaches. As previously noted the game theoretic approach is inappropriate when the suppliers adjust their markups in light of the contract's size or value and when suppliers make different variations in their markups because of their different levels of resources available at the time of bidding. In the decision theoretic approach it is assumed that the competitors bid at random from fixed probability distributions with constant parameters, which are independent of the characteristics of the contract. This implies that competitors make no conscious distinction between one contract and another, and therefore that all contracts are of equal value or importance to a given supplier (Mercer & Russell, 1969; King & Mercer, 1985). It is therefore implicitly assumed that neither the contractor nor the competitors rationally discriminate between different contracts on any salient criteria, although the variant proposed by Morin & Clough (1969) started to challenge this assumption by using different bidding patterns for different classes of work. In reality suppliers do not bid randomly, but rather adjust their markup from contract to contract on a rational basis. This is because different contracts vary in their relative attractiveness to the supplier, "depending on such factors as the size of the contract, the bidder's [contractor's] resources available at that time and the location of the contract, if much of the work is to be done away from the bidder's base" (King & Mercer, 1985 pp. 916). As a result all contracts are not equally attractive to a supplier. Furthermore, different suppliers may assess contracts differently to reflect their different corporate objectives and therefore any given contract is not equally attractive to all suppliers.

In neither the game nor the decision theoretic approaches is an attempt made to explicitly model either the contractor's or their competitors' bid pricing strategies. The probabilistic strategy approach attempts to elicit the form of all the suppliers' individual strategies, and then examine the effects of small changes to the contractor's strategy on their bidding performance. The approach therefore represents a move
away from optimal pricing and the concept of simultaneous optimality of several suppliers (King & Mercer, 1988) and seeks to provide a better understanding of the competitors future behaviour and pricing strategies (Mercer & Russell, 1969).

King & Mercer (1988, pp. 9) describe the approach as "essentially a model building and simulation exercise rather than an optimising method". The first step involves the development of a statistical model, derived from an analysis of historic contract data, that explains the contractor's own bid pricing strategy in terms of the key factors that the contractor believes influence their decisions. It is therefore assumed that the contractor's bid prices are based on relatively few key factors with only a limited scope for judgemental factors. Thus provided that these factors can be identified then bid prices can be modelled as being almost deterministic. Insignificant factors are then regarded as contributing to random errors so that bid prices are assumed to have some probability distribution.

Once the contractor's pricing strategy has been determined a similar modelling approach is taken to elicit the form of the contractor's competitors' pricing strategies from the competitors' bid prices on historic contracts. Mercer & Russell (1969) managed to develop strategy models for all of the contractor's major competitors in their study of international oil companies. However, in three studies conducted by King & Mercer (see King & Mercer, 1985, 1987a, 1988) there was insufficient historic competitive information on the competitors' behaviour to determine the competitors' individual strategies. Therefore, they chose to model the market lowest bid strategy, defined as the lowest of all the contractor's competitors bids.

Once the strategy models have been validated simulation experiments are performed in order to try and detect any improvements that could be made to the contractor's bid pricing strategy. This is achieved through small changes in the parameters of the contractor's strategy model. The effects of these changes on key performance criteria such as number of bids won, turnover and profit (King & Mercer, 1985 1987a) are then evaluated by simulating the competitive environment over some fixed time horizon. A key assumption underlying the simulated strategies is that any variation to the contractor's own bid pricing strategy will not be detected by the competitors, or at least is not likely to force the competitors to change their own strategies to compensate for the improved bidding performance of the contractor, thereby changing the market lowest bid strategy. Although at first sight this assumption seems unreasonable, King & Mercer (1988, pp. 14) offer the defence that the assumption is not such "a great restriction as usually only small changes [in the
contractor’s strategy] are likely to be beneficial, since over time most suppliers have developed a reasonably sensible bidding [tender pricing] strategy”.

2.3.4 **Bid Versus No Bid Approaches**

Although the bid versus no bid decision is very important for many organisations involved in bidding, and especially so when the cost of bidding is high, it is an area that has received little attention from the OR/MS community. Goretsky (1987) applies game theory to the bid versus no bid decision. In particular he discusses strategies for whether or not to bid in a bidding situation involving two suppliers bidding for the research and development (R&D) stage of a two stage R&D and production contract for the USA Federal Government. In this bidding situation, in general a single contractor would be funded during the R&D stage, and each supplier has the choice of bidding for the R&D contract as a separate item, and then, later each may bid for the production contract, regardless of whether they bid for or lost the R&D contract.

Under the assumptions that both suppliers consider only binary policies, that is only either to bid or not to bid14, and that an effective strategy is one defined as maximising the return from the contract awards relative to the competition, then the decision as whether or not to bid for the R&D contract can be formulated as a basic zero-sum game between the two suppliers. Goretsky (1987) analysed several scenarios investigating both the relative returns of the R&D contract to the suppliers and the suppliers' relative competitive advantage. Goretsky (1987) conceded that the approach would be difficult to use in practice because of the problems that would be encountered in estimating the input data especially the probabilities of winning a contract. However, the results did provide some useful insights into the decision as to whether or not to bid for the R&D contracts in the two stage bidding scenario outlined. The results emphasised, that in some circumstances it is best to bid even when the expected potential returns are negative, that the suppliers' relative returns had little effect on the decision to bid or not, just on the expected return. Furthermore, that in a relative sense, the larger the gain (or loss) the more necessary it is to compete.

More recently Kidd & Prabhu (1990) have applied the theory of multi-attribute decision making to the bid versus no bid decision. In essence, their approach is based

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14 Thus the effects of allocating different levels of resources to different contracts are not considered.
on similar philosophical grounds as the probabilistic strategy approach to bid pricing with the goal being to explicitly model a contract’s utility (that is, its attractiveness or value) to the contractor in terms of those key factors or attributes that the contractor believes influence whether or not they should bid. The major difference between the two approaches is that whereas in the probabilistic strategy approach the bid pricing strategy is induced from a statistical analysis of historic contract data, in the multi-attribute approach the bid versus no bid decision strategy is inferred from a number of attribute-indifference statements elicited directly from a bidding manager.

Their approach involved extensive and highly structured interviews with a senior marketing manager at director level of a large divisionalised enterprise competing in several overseas countries. The aim of these interviews was to develop a multi-attribute equation that could act as a contract decision filter. The equation is used to generate a contract’s overall utility or attractiveness that will allow for the easy adjudication of the worth of bidding for the contract. Although Kidd & Prabhu (1990) only consider the bid versus no bid decision as a binary decision variable, their multi-attribute approach can be extended to situations where a contractor believes that different contracts warrant different level of resources. This is because the multi-attribute equation is in effect an overall contract utility function that emphasises the relative importance or attractiveness of contracts to the contractor.

2.4 Discussion of Bidding Models

The review of bidding models presented in the previous section demonstrates that the focus of previous studies has been on providing management support in the problem of determining the optimum bid price or markup in closed bidding situations where the contract is awarded to the lowest priced bidder. Three broad approaches have been proposed to tackle this problem. This section discusses the relative strengths and weaknesses of these approaches and furthermore questions the validity of focussing solely on optimal pricing.

Since its development in 1956 the decision theoretic approach has been at the centre of much of the debate on bid pricing models. The study by Gates (1967) questioned the assumption that the competitors’ bid be statistically independent and raised doubts as to the validity of Friedman’s formula for calculating the probability of winning at a given markup m, P(m) (eq. 2.3.1(A) (iv)). More recently King & Mercer (1987b) have argued that there are problems with several of the assumptions underlying the
decision theoretic model, and in particular demonstrate that three of the assumptions are inconsistent. These are the assumptions that the competitors bid randomly from fixed distributions with constant parameters, that the competitors' bids on each contract are statistically independent and that there is no significant difference between any of the suppliers' cost estimates. The inconsistency stems from the assumption about the suppliers' cost estimates and the resulting validity of the competitors' pseudo markups.

At the time of bidding the actual cost of the contract to each supplier is unknown. Therefore, each supplier's cost estimate is best regarded as a random sample from his own cost estimate distribution. Furthermore, it has been argued that in many bidding situations the observed variation in the suppliers' bid prices is due primarily to the variation in the suppliers' cost estimates (Curtis & Maines, 1973; Mercer, 1983). This implies that suppliers do not discriminate between contracts and apply an almost constant markup to their cost estimates from contract to contract. If this is the case then it would explain the observed variation in the suppliers' bid prices and justify the assumption that the competitors' bid randomly from fixed distributions with constant parameters. Unfortunately if this is true, then on any given contract the competitors' pseudo markups are likely to be correlated because they are based upon a single cost estimate, namely the contractor's, and if his cost estimate is low then all the competitors' pseudo markups will be high and visa-versa. The result is that the competitors' bidding patterns are not independently constructed and therefore any sample taken from these bidding patterns will not be statistically independent. So, if this is the case then Friedman's formula for \( P(m) \) is invalid (eq. 2.3.1(A) (iv)) and so is the evaluation of the integral for the expected profit \( T(m) \) which assumes that \( P(m) \) is independent of the error in the cost estimate, \( S \) (eq. 2.3.1(A) (i))

The converse to the above argument is that the variation in the suppliers' cost estimates is insignificant and as result the effect of calculating the pseudo markups on the basis of the contractor's cost estimate is minimal. If this is the case, the competitors' pseudo markups will be statistically independent and Friedman's formula for calculating \( P(m) \) valid. Unfortunately if this is true, the observed variation in the suppliers' bid prices is much more likely to be due to each of the suppliers applying a discriminatory markup strategy rather than a constant markup. For example, the suppliers may alter their markups on contract to contract to reflect their success or failure on previous contracts (Boughton, 1987). As a result a competitor's successive bids will be auto-correlated and the assumption that the competitors bid randomly from fixed bidding patterns with constant parameters invalid. In either case the three
assumptions are inconsistent and irrespective of whether or not there is any significant variation in the suppliers' cost estimates the validity of Friedman's model is questionable.

Further concern has been raised over the use of the decision theoretic approach because of its unilateral perspective. In Friedman's model it is assumed that suppliers will continue to bid in the future as the have in the past, and although the variant developed by Morin & Clough (1969) uses dynamic bidding patterns to reflect the changes in the competitors' behaviour it does not go so far as to consider the effect if each supplier was known to be optimising his own bid prices. It is feared that if each supplier were to simultaneously use a Friedman type model to optimise his bid prices then this would destabilise the market, leading to lower markups and inevitably lower profits for all suppliers. Indeed the studies by both Morin & Clough (1969) and King & Mercer (1990) have shown that when variability in cost estimates is low the use of Friedman type models leads to lower markups and increased workloads.

The game theoretic approach explicitly tries to overcome this last concern with the decision theoretic approach by considering the effect of the suppliers' reactionary behaviour to each others actions. Given its overriding advantage in modelling the simultaneous optimality of several bidders it is unfortunate that the approach is difficult to apply in practice, although the approach has provided significant theoretical insights into the major issues affecting optimal bid price strategies. The most severe limitations of the game theoretic approach derive from the theoretical problems encountered using the approach in bidding situations where suppliers are known to use discriminatory bid pricing strategies. As for example, when suppliers alter their markups in relation to either their cost estimate or their resources available at the time of bidding.

The probabilistic strategy approach attempts to overcome some of the weaknesses of both the decision and game theoretic approaches. In particular the approach is not limited by the restrictive and inconsistent assumptions of the decision theoretic approach and was explicitly developed for use in bidding situations where suppliers were known to use discriminatory bid pricing strategies. The major strengths of the probabilistic strategy approach are that it explicitly models both the contractor's and the suppliers' bid pricing (or market lowest bid) strategies thus promoting a greater understanding of the competition and the market's behaviour. Furthermore, the approach is considerably more flexible than both the decision and game theoretic approaches because there is no requirement to fix a single objective to be maximised.
a priori. Instead several performance measures such as number of bids won, turnover and profit can be considered simultaneously. The approach is not without its weaknesses. The prevalence of cost uncertainty within several industries, as for example with civil engineering contracts, can swamp the more subtle variations due to the suppliers' different strategies (King & Mercer, 1987a). In such circumstances the form of the pricing strategies, especially the competitors' or market lowest bid strategies, can be difficult to elicit. Secondly, like the decision theoretic approach the statistical analyses demand that considerable competitive information is available from both internal and external sources. For example, in the study of a heating and ventilation contractor conducted by King & Mercer (1985) relevant data was collected over a 3 year period for 500 bids.

So, all three approaches have major theoretical or practical limitations; and indeed the game theoretic approach suffers heavily from both. As a result to date there is no universally agreed approach to optimal bid pricing. As a general guide-line it appears that the decision theoretic approach may be the more appropriate when it is known that there is significant variation in the suppliers' cost estimates and it can be assumed that suppliers apply an almost constant markup to their cost estimates. In such circumstances the generalised Friedman's approach developed by King & Mercer (1990) has been advocated. Whilst the probabilistic strategy approach may be the most appropriate method when it is known that there is little variation in the suppliers' cost estimates and it is believed that the suppliers adopt discriminatory bid pricing strategies altering their markups from contract to contract based on the contract's characteristics.

Given the benefits in improved bidding performance that quantitative bid pricing models could provide it is perhaps surprising that none of the three approaches appear to have been put to extensive practical use. This suggests that bidding managers responsible for finalising bid prices have some strong reservations about the appropriateness of these models to the bidding situations that they encounter. There are several reasons why managers may have reservations about the use of the proposed bidding models. These include the models' reliance on historic data, the non-availability of the required data, their myopic outlook in which contracts are considered in isolation to each other, the existence of a single objective which is the same for all contracts; and that the models emphasise the quantitative aspects of bidding and play down the significance of any qualitative aspects.
The models have been criticised for their reliance on historic data and for assuming that competitors will bid in the future as they have in the past (Ward & Chapman, 1988). This seems unduly unfair on any of the proposed bidding models which seek to explain competitors' behaviour from identifying patterns from historic contracts. A bidding manager may argue that his insight, intuition and good judgement allow him to make good pricing decisions, but he must concede that his understanding of their bidding behaviour has been accumulated from many years experience of being exposed to past bidding situations. In this respect a bidding manager's insight, intuition and good judgements is, like the bidding models themselves, inductively derived from patterns emerging from the past.

All the approaches are reliant upon the availability of considerable amounts of competitive information and it could be argued that obtaining detailed information on competitors' prices is impossible. Although it has been argued that this reservation may be more a reflection of a lack of understanding in how to interpret the relevant information (King & Mercer, 1987a; Ward & Chapman, 1988).

In general the models consider contracts in isolation to each other. Therefore, it is assumed that the contractor is not constrained by his resources and can fulfil all the contracts that he wins. Furthermore, in the decision theoretic model it is assumed that all contracts are equally attractive to the contractor. Both Friedman (1956) and Hanssman & Rivett (1959) consider a situation of simultaneous bidding on several contracts when there are resource constraints, but this is a much simpler problem to the problem of sequential bidding which is encountered in reality. For, in sequential bidding the contractor needs to take into account his current workload, his uncertain future workload and possible future contracts coming up for tender. A related cause for concern is the assumption that there is a single objective of maximising expected profit on any contract. This implicitly assumes that contracts are homogeneous, and therefore equally attractive, and furthermore implies there is a steady unending stream of contracts coming up for tender. As a result in general the models do not take into account surges or declines in either the contractor's business or the market as a whole.

Finally, the bidding models emphasise the quantitative aspects of bidding and play down the significance of the qualitative issues such as the relevance of any non-price features. The development of the basic decision theoretic model proposed by Simmonds (1969) addresses the issue of optimum bid pricing when non-price features are prevalent, but his approach would be extremely difficult to apply in practice. Furthermore, when non-price features are prevalent price may not be a contractor's
major competitive weapon. In such circumstances quality of service, as for example quality of design and manufacture, or reputation may have a greater significance than price upon the probability of winning. As a result a contractor's emphasis may change from one of optimal pricing towards that of optimal resourcing of tenders. This may occur for example in bidding situations where the cost of tendering is high due to a significant design effort creating a large front end cost. In such circumstances the related decisions concerning whether or not to bid and the level of resources to allocate to the preparation of the bid proposal become important managerial decisions. With the exception of a few studies this is an area which has received scant attention from the OR/MS community. The author has, however, had discussions with two organisations both involved in the design and manufacture of complex electronic and electro-mechanical equipment respectively who felt that tender, or bid, resourcing was a more significant issue than final pricing (see section 4.6). This suggests that in some bidding situations there is a greater need for management support in deciding what business to bid for and how committed an organisation should be to obtaining that business than there is for optimal bid pricing.

2.5 Summary

The nature and scope of the competitive bidding process has been outlined highlighting the diversity of the organisations involved in competitive bidding and the many different bidding situations that can arise.

The major contributions made by OR/MS community in the development of quantitative bidding models have been briefly reviewed. This has demonstrated that the focus of the previous work has been on providing management support in the determination of the optimal bid price in closed bidding situations in which the contract is awarded to the lowest priced bidder. Three major approaches have been proposed to provide support in this area. These are the decision theoretic approach, the game theoretic approach and the probabilistic strategy approach. All three approaches have widely accepted limitations, none have gained widespread use, so to date there is no universally agreed approach to optimal bid pricing.

One criticism which can be levelled at these models is that they all emphasise the quantitative issues in bidding, namely the probability of winning, expected profit and price, and play down the significance of many of the qualitative aspects. In many bidding situations non-price features are prevalent and the final bid price may not be a
contractor's major competitive weapon. In such cases the emphasis for a contractor may change from optimal pricing towards optimal resourcing of tenders. In such a case the related decisions concerning whether or not to bid and the level of resources to allocate to bid preparation may be of equal significance to that of final bid pricing. This is an area that has received scant attention from the OR/MS community but one which justifies management support and further investigation.
CHAPTER 3

INTELLIGENT KNOWLEDGE BASED EXPERT SYSTEMS (IKBES) - LITERATURE REVIEW
3. **INTELLIGENT KNOWLEDGE BASED EXPERT SYSTEMS (IKBES) - LITERATURE REVIEW**

3.0 **INTRODUCTION**

This chapter provides a brief review of the literature relating to Intelligent Knowledge Based Expert Systems (IKBES), or Expert Systems (ES) for short. The chapter commences with a discussion of the evolution of expert systems and highlights their close relationship to Artificial Intelligence (AI). A definition of an expert system is provided and their major characteristics and differences from more conventional computer systems highlighted. Following this, the basic underlying technology of expert systems is briefly described; and finally the benefits, limitations and scope of expert systems are noted.

3.1 **THE EVOLUTION OF ARTIFICIAL INTELLIGENCE AND EXPERT SYSTEMS**

From the very dawn of the computer age researchers have strived towards the development of tools exhibiting Artificial Intelligence (AI). The term AI dates from a two month study at Dartmouth College, New Hampshire in 1956, and describes a multi-disciplinary field comprising of areas from computer science, cognitive science and linguistics. Research into AI is concerned with two major objectives: developing models of human cognition and building intelligent systems.

Models of human cognition represent the methods by which humans store and manipulate knowledge to solve problems. Present research in this area focuses on knowledge representation and reasoning which can be regarded as the building blocks for intelligent systems (see sections 3.4.1 and 3.4.2 respectively).

Building intelligent systems can be thought of as applied AI research. An intelligent system can be thought of as any computer program that displays intelligent behaviour; that is, behaviour that would be considered intelligent if it were exhibited by a human. Intelligent systems therefore emulate or simulate aspects of human behaviour. Over the last 30 years interest in AI has grown to the extent that there are now several areas of on going applied AI research. These include Natural Language Processing, Robotics, Human Computer Interaction, Exploratory Programming and Intelligent Knowledge Based Expert Systems (IKBES) or Expert Systems (ES).
In the formative years of AI, researchers held the romantic view that they would be able to produce intelligent systems that would equal and perhaps surpass human levels of performance, and that ultimately all tasks requiring intelligence would be automated. In retrospect, this perspective is referred to as the hard AI philosophy: its underlying assumption was that intelligent behaviour was primarily a function of high powered domain-independent reasoning techniques such as the predicate calculus or means end analysis. This approach had some successes; for example in 1957 a system known as the General Problem Solver was developed which could solve puzzles and prove logic theorems. The protagonists of the hard AI philosophy argued that to create more powerful systems all that was required was to increase the number of generic high powered reasoning techniques.

Time proved the hard AI philosophy to be flawed. Firstly, because it assumed that it was known which reasoning techniques to add, that is how humans reason; and secondly, because it assumed that generic reasoning techniques would be powerful enough to solve many different classes of problem.

A significant breakthrough was made in 1964 with the development of DENDRAL (see Lindsay et al., 1980) a system to identify chemical compounds from their mass spectrometer frequency distributions. Whereas other developers sought domain-independent techniques for solving problems, the developers of DENDRAL sought domain-dependent techniques and incorporated considerable amounts of domain-specific knowledge into their system. This shift in emphasis proved to be a great success and by the late 1960's DENDRAL had identified a legitimate molecular structure with which the chemists were unaware.

In retrospect, the protagonists of the hard AI philosophy had failed to recognise the significance of domain-specific knowledge in problem solving and the success of DENDRAL led to the soft AI philosophy which emphasised the importance such knowledge. This paradigm shift from seeking domain-independent powerful reasoning techniques to the inclusion of domain-specific knowledge is now regarded as one of the major conceptual breakthroughs in AI.

The inclusion of large amounts of domain-specific knowledge is one of the most important characteristics of an expert system; and therefore in retrospect DENDRAL can be regarded as one of the first expert systems.
After DENDRAL, several other successful expert systems were developed in the USA during the 1970's and early 1980's. These included MYCIN (see Shortclifffe, 1976) a system used for the diagnosis and treatment of bacteremia infections; PROSPECTOR (see Duda et al., 1979) designed to aid geologists in their search for valuable mineral reserves; and XCON/R1 (see McDermott, 1982), probably the most commercially successful expert system to date, developed by the Digital Corporation in conjunction with Carnegie-Mellon University to configure computer systems to meet customer specific requirements.

Interest in expert systems has grown dramatically since the early 1980's, as is demonstrated by the government funded Alvey and Esprit project initiatives in Britain and Europe; and several authors have argued for expert systems as levers for competitive advantage (Aeh, 1988; Keller, 1988; Ryan, 1988; Leonard-Barton & Sviokla, 1988).

3.2 AN EXPERT SYSTEM - A DEFINITION

There are many different definitions of an expert system provided in the relevant literature, but in general they all emphasise three major features. These are that expert systems are primarily knowledge based, that they solve complex problems normally solved by human experts; and finally that they attain levels of performance comparable with their human counterparts. The definition given below is a simplified version of one of the most cited definitions proposed by one of the pioneers of expert systems Edward Feigenbaum, as cited by Aeh (1988).

"... An Expert System is an intelligent computer program that uses knowledge and inference procedures which have been elicited from an expert, to solve problems that are difficult enough to require significant human expertise for their solution, and is designed in such a way so that it can act as a cost effective expert consultant ..."

Expanding upon this definition several important points arise. First and foremost is that expert systems use knowledge and inference procedures. The precise constituents of knowledge are difficult to define, but for the purpose of this chapter knowledge shall be regarded as any body of information that experts have found

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1 Three excellent review papers of expert systems are those provided by Kastner & Hong (1984), Assad & Golden (1986) and Fordyce et al. (1987).

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useful in solving problems within their area of expertise. So, knowledge may comprise of "rules, facts, truths and reasons" used by experts (Sell, 1985 pp. 14). Inference procedures may be regarded as any strategies or rules of thumb, often referred to as heuristics (Kastner & Hong, 1984; Fordyce et al. 1987), that experts have found useful in dictating the best approach to follow in tackling problems within their area of expertise. These inference procedures are often described as meta-knowledge because they convey knowledge about how to use knowledge (Jackson, 1986 pp. 37-38; Zahedi, 1987).

The second point that arises is that expert systems act as cost effective expert consultants. The knowledge and inference procedures outlined above can be thought of as a model of expertise in the problem area. Expert systems simulate the actions of the human expert. An expert system offers a recommendation based upon the information available and can justify its recommendations to the user. That is, expert systems are capable of explaining their conclusions and reasoning. Furthermore, expert systems produce results consistent with leading experts in the area and like human experts are capable of offering recommendations in light of a combination of incomplete, uncertain and conflicting information (see Kastner & Hong, 1984; Assad & Golden, 1986; Fordyce et al., 1987).
Figure 3.2  A Basic Expert System Architecture
Figure 3.2 shows a basic expert system architecture in relation to the expert, the expert system developer, who is normally referred to as the knowledge engineer, and the system user.

A basic expert system comprises of four components: the knowledge base, the inference engine, the explanation module and the user interface. The expert's knowledge is stored, or represented, in the system's knowledge base. The various methods by which an expert's knowledge can be represented within an expert system are discussed in section 3.4.1. The knowledge base is constructed by the knowledge engineer through close liaison with the expert and with the aid of the developer interface. In general, the inference engine consists of one or more generic reasoning, or inferencing, methods whose purpose is to control how the expert's knowledge is manipulated to solve the user's problem. The various reasoning methods used in expert systems are discussed in section 3.4.2. The user interface allows the user to communicate with the system in a natural dialogue; and the explanation module enables the user to obtain justification of the system's reasoning and explanation of its recommendations.
3.3 CHARACTERISTICS OF EXPERT SYSTEMS: THEIR DIFFERENCES FROM MORE CONVENTIONAL SYSTEMS

Many authors have commented on the differences between expert systems and more conventional computer systems; but in truth since both technologies have evolved in parallel over the last 30 or so years their differences are primarily one of emphasis with many so-called conventional systems making use of AI concepts. Bearing this in mind the major dimensions upon which expert systems and more conventional systems differ are summarised in table 3.3 below.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Expert System</th>
<th>Conventional Program</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Representation</td>
<td>Primarily Symbolic</td>
<td>Primarily Numeric (Algebraic)</td>
</tr>
<tr>
<td>2. Solution Method</td>
<td>Heuristic</td>
<td>Algorithmic</td>
</tr>
<tr>
<td>3. Knowledge Level</td>
<td>Judgmental</td>
<td>Definitional</td>
</tr>
<tr>
<td>4. Software Architecture</td>
<td>Separation of Knowledge from Inference &amp; Control (Declarative)</td>
<td>Integration of Knowledge with Inference &amp; Control (Imperative)</td>
</tr>
<tr>
<td>5. Results</td>
<td>Satisficing</td>
<td>Optimising</td>
</tr>
</tbody>
</table>

3.3.1 REPRESENTATION

All computer programs model some aspect of the real world and as a result those concepts, or entities, central to the system being modelled need to be represented. These concepts are represented by program constructs known as identifiers. An identifier consists of a sequence of characters referred to as a symbol (Waterman, 1986b pp. 16). In conventional systems the majority of concepts will assume a single numeric value; and as a result, conventional systems are primarily concerned with processing large volumes of numeric data (Harmon & King, 1985 pp. 7). As such they make full use of the

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arithmetic operators and high level mathematical functions and are therefore well suited to modelling quantitative aspects of real world problems. In expert systems the majority of the concepts being modelled will assume non-numeric values, so that a concept's value will itself be represented by a symbol; and furthermore, concepts may be multi-valued. As a result expert systems are primarily concerned with manipulating concepts represented as complex symbol structures; and as such they make limited use of the arithmetic operators and much more use of the logical operators. So, whereas conventional systems emphasise the quantitative aspects of real world problems, expert systems are more suited to modelling the qualitative aspects of problems; and in this respect are better suited to modelling many aspects of human expertise.

3.3.2 Solution Method

Conventional programs use complex algorithms to determine a solution. These are procedures that define precisely how the task should be performed and which guarantee that a solution is found. In contrast, expert systems use much less rigorous solution methods known as heuristic search procedures. These heuristics are experientially based rules of thumb that have been shown to provide good solutions.

3.3.3 Knowledge Level

Conventional systems are normally applied to problems arising in well structured domains. In such domains the relevant knowledge is clearly defined in that the precise relationships between the domain concepts are known with a high degree of certainty and are often openly examinable. Consequently, these relationships are largely definitional or structural. Whereas expert system domains are normally less structured and therefore there is less certainty of the precise relationships between domain concepts. This is because many areas of human expertise are characterised by experiential knowledge; and consequently, the relationships are largely judgemental, not open to direct examination and are often unarticulated. This difference has a significant bearing on the development of expert systems which is discussed in further detail in chapter 6.
3.3.4 Software Architecture

As illustrated in figure 3.2 in an expert system the inference and control mechanisms that dictate what the program is to do next are stored in the inference engine and are kept separate from the domain knowledge stored in the knowledge base. In stark contrast to this approach, in conventional systems the control mechanisms are integrated with the domain knowledge making it difficult to distinguish the two apart. Moreover, in conventional systems the control mechanism is implicitly determined by the sequential order of the domain knowledge within the program. As a result the correctness of the program is highly sensitive to the ordering of the program statements. In expert systems, then in theory at least, the ordering of the domain knowledge within the knowledge base is largely irrelevant. Such programs are said to be declarative which means that provided that each piece of knowledge is correctly declared then the program will function correctly. This separation of knowledge and control is regarded as one of the major breakthroughs in AI research.

The separation of knowledge and control ensures that the domain knowledge is both transparent and modular. These properties suggest that expert systems are easier to modify than their conventional counterparts. Furthermore, the separation of knowledge and control opens up the possibilities for system development by experts rather than programmers, thus following the pattern of many spreadsheet applications (Harmon et al., 1988 pp. 8).

3.3.5 Results

The nature of the different solution methods used by expert and conventional systems influences the nature of the respective systems' results. Due to their algorithmic nature conventional systems always produce the correct result, so that their solutions are optimal. Expert systems do not guarantee to produce optimal results, even when an optimal solution is known to exist. Rather, expert systems are said to be "satisficing" (Grant, 1986) in that they produce results that are generally acceptable because they are comparable to those produced by human experts. Indeed like humans expert systems may produce some incorrect recommendations, or at least recommendations that ultimately lead to unfavourable outcomes!
As previously noted, many so-called conventional systems make use of AI concepts. Thus the differences between expert and conventional systems outlined above have been somewhat overstated. Indeed it may be expedient to consider the expert/conventional system division as a continuous space in the five dimensions listed in table 3.3. In this space a system that predominantly emphasises the characteristics listed under the column headed expert system in table 3.3 can be regarded as an expert system; whereas, a system that predominantly emphasises the characteristics listed under the column headed conventional program can be regarded as a conventional system.

For example, in database management systems the primary form of representation is symbolic rather than numeric and correspondingly such systems manipulate concepts with almost sole use of the logical operators. In addition, the architecture of such systems is declarative. In a database management system, however, the knowledge level is wholly definitional and structural; and furthermore the solution method is algorithmic thereby providing optimised results.

Furthermore, heuristic search is a technique used extensively within conventional systems by the OR/MS community to tackle non-polynomial (NP) hard problems. Grant (1986) argues that the nature of the heuristics used in OR/MS and AI are different because OR/MS type heuristics are generic domain-independent heuristics capable of tackling a wide range of problems, as for example branch and bound methods for integer programmes. Although in fact several fields of study have involved the development of domain-specific heuristics, as for example multi-level production planning. For such problems, however, the OR/MS community have developed heuristics for problems whose underlying form of representation is numeric and whose knowledge level is predominantly definitional or structural. Furthermore, they have developed such heuristics using imperative rather than declarative programming languages.

Finally, the spreadsheet is perhaps the most widely used software tool where the domain knowledge and control mechanisms are separated. Essentially a spreadsheet package can be regarded as a declarative programming language because the underlying software determines the natural order in which the cells should be evaluated. In spreadsheet applications, however, the underlying form of representation is numeric, the solution methods are algorithmic providing optimised results and the knowledge level is primarily definitional, although there is considerable scope for incorporating judgemental relationships.
So, although database management systems, OR/MS type heuristic applications and spreadsheet applications all make use of AI concepts, they all predominantly emphasise the characteristics of conventional systems and should therefore not be mistaken for expert systems.

Decision support systems, however, operate in semi-structured, or ill-structured, domains and rely primarily on the use of judgmental relationships (Finlay et al., 1988). Moreover, although decision support systems primarily make use of a numeric form of representation, they are declarative, heuristic and thereby satisficing. As a result conventional decision support systems share several similarities with expert systems (see section 3.5.1(2)).

3.4 Basic Expert Systems Technology

The previous two sections have summarised the major characteristics of expert systems and their differences from more conventional systems. Apart from noting that expert systems primarily process symbolic information and use judgemental relationships which together suggest that they are well suited to modelling many aspects of human expertise, scant attention was paid to the underlying technology which allows them to attain their expert performance. The following sub-sections summarise several key areas of expert systems technology, namely knowledge representation, methods of inference and inexact reasoning.

3.4.1 Knowledge Representation

An expert system is primarily knowledge based and as a result its expert performance derives from the amount and quality of domain knowledge stored within its knowledge base. Knowledge representation is concerned with how large bodies of domain knowledge can be organised into data structures that facilitate symbolic manipulation within an expert system's knowledge base.

Various knowledge representation schemes have been proposed for use within expert systems. Winfield (1982) lists seven schemes including logic, procedural

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3 Another key area knowledge acquisition, the process of gathering domain knowledge from the human expert or experts, is discussed explicitly within the context of the case study in part B of this thesis (see chapter 6).
representations, production systems which are more generally referred to as production rules, direct (or analogue) representations, semantic networks, and frames and scripts. Jackson (1986, pp. 29) classifies all the major schemes into three broad categories. These are mathematical logic including the propositional and first order predicate calculus; production rules; and finally structured objects which include semantic networks and slot and filler methods such as frames and scripts.

The choice of knowledge representation scheme used in an expert system is dependent upon the domain knowledge characteristics, as each scheme has its own strengths and weaknesses. For example, the first order predicate calculus upon which the AI language Prolog is based does not explicitly deal with inexact reasoning, that is reason with uncertain knowledge (for details of the Prolog language see Clocksin & Mellish, 1987; Bratko, 1986; Bharath, 1986). It would therefore be difficult to represent the knowledge that "blond haired people often have blue eyes" using this scheme.

Determining the most appropriate scheme or schemes is a significant problem in expert systems development. The majority of PC based expert system development tools, or "shells", make use of only one or two representational schemes although experts may use several different ways to structure their knowledge (see section 6.1). As a result the knowledge representation schemes available in many PC based tools are overly restrictive because they require the knowledge engineer to "bend" or "engineer" the domain knowledge to fit the representational formalism of the development tool (Pollitzer & Jenkins, 1985; Cullen & Bryman, 1988; King, 1989).

By far the most commonly used knowledge representation scheme used in expert systems is production rules (Kastner & Hong, 1984; Fordyce et al., 1987; Doukidis & Paul, 1990). Production rules were used in both MYCIN and XCON/R1 and are the predominant scheme employed in most expert system shells.

Frames, originally developed by Marvin Minsky in 1975, have recently become en vogue, and are currently employed alongside production rules in several of the more expensive and sophisticated shells such as Leonardo 3 and Personal Consultant Plus. Frames provide a more transparent representation of a domain's overall structure than production rules and are closely related to semantic networks which were used in PROSPECTOR.
These three schemes are briefly reviewed in the following sub-sections.  

### 3.4.1 PRODUCTION RULES (PRODUCTION SYSTEMS)  

A production rule, or rule for short, consists of a condition-action pair and is normally expressed in the form of an if *condition* then *action* type rule. In rule-based expert systems these if ... then rules represent the bulk of the domain-dependent knowledge in the system's knowledge base. A separate domain-independent control or inference strategy stored in the inference engine (see section 3.4.2) is used to manipulate the rules to infer new information in order to solve a specific problem. Rules are particularly appropriate for expressing experiential or judgmental knowledge between domain concepts and for expressing an expert's heuristics or meta-knowledge; but they can also be used to express causal and definitional type knowledge.

The semantics of a rule are that whenever the condition component of a rule is true, or is satisfied, then the action component of the rule can be taken or inferred. When this happens the rule is said to have "fired". In general, the condition component of a rule is a logical proposition comprising of a set of facts or statements connected by logical operators which is required to be true for the rule to be fired.

The facts are generally represented by ordered 3-tuples known as Object-Attribute-Value (O-A-V) triplets (Harmon & King, 1985 pp. 38-39; Fordyce et al., 1987). Objects represent physical or conceptual domain entities; attributes general characteristics or traits possessed by the object; the final component of the ordered 3-tuple represents the value assumed by the corresponding attribute.

The syntactical structure of a production rule outlined above is much simpler than that found in all but the cheapest and most unsophisticated expert system shells. Most rule-based implementations incorporate the concepts of existential and universal quantification over values and objects from the first order predicate calculus which enables rules to be used to express more general, or universal, knowledge such as "all

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5 Production rules were originally developed by the mathematician E. Post in 1943.
men are mortal". Furthermore, most implementations allow meta-rules, expressing the expert's meta-knowledge, to be encoded within the system's knowledge base. These meta-rules are used to control or focus the search of the inference engine (see section 3.4.2(1)).

Production rules have many strengths. First and foremost rules are easy to understand. Secondly, they are highly modular because 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 rule based expert systems are, at least in theory, especially 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 (Rich, 1983 pp. 201-202). Moreover, rules are a powerful representational scheme because they have been shown to be Turing complete (Sell, 1985 pp. 33) and as such display the property of representational adequacy (Rich, 1983 pp. 201-202) or logical adequacy (Jackson, 1986 pp. 29).

Production rules also have their weaknesses. The forward and backward chaining inferencing mechanisms used to manipulate rules (see section 3.4.2(1)) mean that a system's reasoning can be difficult to follow and as a result 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 that rule based systems become rapidly "inferentially inefficient" (Rich, 1983 pp. 201-202), that is slow to manipulate, as the number of rules increases. To overcome this difficulty the more sophisticated rule based shells allow the developer to structure the domain knowledge into "hierarchical rule sets" or "context trees" (Harmon & King, 1985 pp. 40-41, 258) to create so-called "blackboard" architectures (Nii, 1986). These improve both the transparency of the overall domain structure and the inferential efficiency of rule based systems.
3.4.1(2) **Semantic Networks**

A semantic network is a digraph consisting of nodes and arcs (or links) which maps out the expert's conceptual structure of the problem domain. The graph's nodes represent the concepts central to the domain being modelled; and the graph's links represent associations or relations between the concepts represented as nodes. The links are frequently used to represent domain-independent associations or relations such as is_a and a_k_o (a kind of) thus emphasising the hierarchical structure of a domain; and are also used to represent relations such as part_of and has_a thus emphasising attributes or traits of domain concepts: but equally, the links may be used to represent causation, either empirical or theoretical, through links such as influences or affects. This was the case with the development of CASNET, a disease diagnosis system, in which a causal semantic network was used to represent the experts' knowledge (see Kulikowski & Weiss, 1982).

One of the major strengths of semantic networks is their overall "flexibility" (Assad & Golden, 1986 pp. 310). 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 is defined by the expert and knowledge engineer and therefore semantic networks can be used to represent many different types of knowledge; and like production rules, semantic networks are Turing complete (Sell, 1985 pp. 33). Furthermore, unlike production rules, in a semantic network the overall domain structure is transparent and a system's reasoning is easy to follow because associations can be traced through the graph. Finally, in a semantic network concepts can inherit properties of others through the transitive associational links in the network; and as such they are storage efficient representational schemes.

One of the most notable weaknesses with semantic networks is modelling exceptions to the norm. For example, consider a semantic network in relation to fruit. Then, the node apple could be linked to the node fruit with the link a_k_o (or is_a), the node fruit could be linked to the node seeds with the link has and the node seeds could be linked to the node inside with the link where. The interpretation being that an apple is a fruit with seeds inside. A problem arises if one tries to add the node strawberry to the network because a strawberry is a fruit with seeds on the outside! Furthermore, semantic networks have been criticised because their node semantics can be ambiguous (Jackson, 1986 pp. 57; Assad & Golden, 1986). In the above example it is not readily apparent whether the node apple represents the class of all apples or a particular apple, as for example a golden delicious owned by the student Rachel.
Finally, although they are storage efficient, semantic networks are inferentially inefficient and this problem is heightened by the fact that it is not generally possible to incorporate meta-knowledge within a semantic network (see section 3.4.2(2)).

3.4.1(3) Frame Based Representations

The frame concept was originally developed by Marvin Minsky in 1975 to facilitate reasoning based on interpretation of stored past situations. In this respect frame based systems attempt to emulate reasoning by analogy (Fordyce et al., 1987). A frame is a data structure that collects together knowledge about a particular concept and provides expectations or default knowledge about that concept. A frame therefore represents a standard stereotypical situation.

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. 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; and is also similar to a set of O-A-V triplets with a common object.

There are some notable differences between a frame and a database record or a collection of O-A-V triplets. Firstly, a frame's slot value may be a frame itself. Thereby, by using slots such as \textit{is} \_ \textit{a} or \textit{a} \_ \textit{k} \_ \textit{o} it is possible to link frames together into hierarchical networks creating instance and class frames to represent different levels of abstraction. For example, a frame representing an apple could be regarded as an instance of the class frame representing a typical fruit. 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. For example, the instance frame strawberry could have a slot named \textit{seeds} and a value "outside"; whereas the class frame fruit could have the value "inside" for the slot named \textit{seeds}.

Furthermore, it is possible to have "procedural attachments" (Harmon & King, 1985 pp. 44), also referred to as "demons" (Fordyce et al., 1987 pp. 74), associated with a frame's slot which invoke either a set of 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 representation 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 so-called "default" values (Harmon & King, 1985 pp. 44; Fordyce et al, 1987 pp. 73) which allow for weak reasoning to be performed. These default values allow for probable values for a concept's traits to be used when the information available is incomplete.

Although the concept of multiple-level inheritance is intuitively very appealing it can give rise to several drawbacks with frame based representations. Firstly, if there is unrestrained overriding of inherited properties, then it becomes impossible to represent either definitional conditions, as for example "all squares are right angled, equal sided, quadrilaterals", or contingent, that is conditionally dependent, universal truths, as for example "all the flowers in my garden are roses" (Jackson, 1986 pp. 67). Secondly, complex mechanisms are required to reason with frame based representations (see section 3.4.2(3)) and these can rapidly become inferentially inefficient if there are several levels of inheritance within the hierarchical frame based network.

### 3.4.2 Methods of Inference

The inference engine (see figure 3.2) 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 and sensors, to solve the problem at hand. Various search strategy approaches are available for controlling the manipulation of the knowledge. These approaches as known as inference methods or mechanisms, and are generally dependent upon the representation scheme being deployed. In the following three sub-sections the inference mechanisms used for production rules, semantic networks and frames are briefly described.  

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6 For more detailed accounts of these inference mechanisms see Rich (1983, pp 201-244); Kastner & Hong (1984); Harmon and King (1985, pp. 49-60); Jackson (1986, pp 32-38, 56); Ramsey et al (1986); Frost (1986, pp. 423-426, 467-479) and Fordyce et al (1987).
3.4.2(1) INFERENCE METHODS FOR PRODUCTION RULES

In a rule-based expert system, it is the responsibility of the inference engine to select which rules to "fire" at the appropriate time during the user's consultation in order to solve the problem at hand. 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. The local mechanisms correspond to the expert's meta-knowledge and are used to focus the attention of the global mechanism down more promising search paths. At a global level, production rules are normally manipulated using either a forward chaining or backward chaining inferencing strategy; although in some rule-based implementations bidirectional strategies are deployed. Forward chaining strategies are also referred to as event or data driven strategies; backward chaining strategies are also known as goal driven strategies.

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 is known as the recognise and act cycle. The existing information consists of data supplied by the user, data from any 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" using a conflict resolution strategy. Conflict resolution strategies include reactivity, recency and specificity (see Jackson, 1986 pp. 34 for further details). The selected rule is "fired"; that is, its action component is inferred, which terminates the present cycle. This cycling process is repeated until either no more rules can "fire", or the inference engine receives an explicit directive to stop.

In those rule-based systems which employ a backward chaining strategy, in addition to the rules in the knowledge base, there exists a primary goal. It is then 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 conditions. Since, if the truth of these conditions could be established, then the rule can "fire" 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 truth are unknown are put onto 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.

Backward chaining is the more appropriate inference strategy in domains where there
is a small number of possible solution outcomes that can be enumerated \textit{a priori}; and
is therefore appropriate for use in diagnostic and classification type expert systems
(see section 3.6). Whereas, forward chaining is better suited to domains where there
are a large number of possible solution outcomes, or where it is not be possible to
enumerate\(^7\) all the solution outcomes \textit{a priori}. Forward chaining is therefore
appropriate for use in design and configuration type expert system applications (see
section 3.6), as was the case in the XCON/R1 system.

In several rule based implementations so called meta-rules or control rules enable the
expert's meta-knowledge to be incorporated within the system's knowledge base. In a
backward chaining strategy these meta-rules are used to set up an agenda of sub-goals
to be performed by the inference engine, and can therefore be used to encode the
expert's generic problem solving approach. Whereas, in a forward chaining or
bidirectional strategy these meta-rules can be used to dynamically change the focus of
the inference engine depending on the problem context being encountered.

\textbf{3.4.2(2) INFERENCE METHODS FOR SEMANTIC NETWORKS}

Inference mechanisms for semantic network based representations are based on graph
traversal, or set covering, algorithms (Jackson, 1986 pp. 56). These algorithms draw
inferences by proving that domain concepts are related, or associated, by identifying a
path within the network that joins the respective concepts' nodes. If the inference
engine was trying to establish that the domain concepts \(X\) and \(Y\) were related it would
initiate "activation" through the network in all directions from both nodes \(X\) and \(Y\).
At some point, if the concepts \(X\) and \(Y\) are related this spreading activation will
intersect and arrive at a common node. At this point a relationship between the
concepts \(X\) and \(Y\) has been established because a transitive associational path has
been identified between the nodes \(X\) and \(Y\).

Like rule based expert systems, systems using a semantic network based
representation can be reasoned with using both forward and backward chaining

\(^7\) That is, enumerate the possible solution outcomes in a finite polynomial time.
strategies. One of the major problems with inference mechanisms based on an "intersection search" (Rich, 1983 pp. 218) is the problem of combinatorial explosion, because the global inference strategy cannot be focussed by incorporating meta-knowledge. As a result semantic networks are inferentially inefficient because their inference mechanisms are not themselves knowledge based.

3.4.2 Inferring Methods for Frames

Frame based inference mechanisms are typically based on hypothesize and test cycles (Ramsey et al., 1986). In such systems the inference engine's reasoning proceeds as follows: Given some of the problem's features the inference engine generates an agenda of potential hypotheses which can explain the problem's features. Each of these hypotheses is then tested using procedures which measure their ability to account for the problem's features and questions are generated that help to discriminate between the most likely hypotheses. The cycle is then repeated with the additional information required.

In several respects this process is similar to a bidirectional search strategy that firstly involves forward chaining to generate appropriate hypotheses from the available information, and then initiates backward chaining in order to discriminate between the most likely hypotheses. This analogy type reasoning from observed facts to best explaining hypothesis is referred to as "abduction" (Ramsey et al., 1986 pp. 479). Like backward chaining inference mechanisms in rule based systems frame based abduction is particularly appropriate for diagnostic and classification type applications.

The form, strengths, weaknesses and inference mechanisms of production rules, semantic networks and frames are summarised in table 3.4.2.
<table>
<thead>
<tr>
<th>Knowledge Representation Scheme</th>
<th>Form</th>
<th>Strengths</th>
<th>Weaknesses</th>
<th>Inference Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production Rules</td>
<td>Condition-Action pairs in the form of if...then rules. Use of hierarchical rule sets, or context trees, to create so-called blackboard architectures.</td>
<td>Easy to understand. Modular - rules almost self contained. Easy to modify enhance, acquisitionally efficient. Logically adequate. Meta-knowledge easy to incorporate - inferentially efficient.</td>
<td>System's reasoning difficult to follow. Domain structure opaque. Can become inferentially inefficient with large rule sets unless meta-knowledge or context trees used.</td>
<td>Forward and backward chaining.</td>
</tr>
<tr>
<td>Semantic Networks</td>
<td>Directed graph. Nodes represent domain concepts, links represent associations or relations between concepts.</td>
<td>Very flexible. Easy to modify enhance, acquisitionally efficient. Domain structure transparent. Represent hierarchies. Inheritance of properties.</td>
<td>Node semantics can be ambiguous. Cannot handle exceptions. Inferentially inefficient due to inability to add meta-knowledge.</td>
<td>Graph traversal algorithms that spread activation through network. Search for a common node to establish a relation.</td>
</tr>
</tbody>
</table>
3.4.3 Inexact Reasoning Methods

As part of their ability to perform at human expert levels of performance, expert systems are expected to provide appropriate recommendations in light of a mixture of incomplete, uncertain and conflicting information. Frame based systems through the use of "default" values enable systems to perform weak reasoning by making reasoned assumptions in light of incomplete information; and even some predominantly rule based shells, as for example Leonardo 3 and Xi-Plus release 3, incorporate "default" values.

Inexact reasoning methods allow expert systems to make reasoned inferences with uncertain and conflicting information; and alongside the knowledge acquisition process (see section 6.1) is one of the most controversial issues in expert systems research and development.

The earliest expert systems to incorporate inexact reasoning methods were MYCIN and PROSPECTOR. The MYCIN system incorporated an ad-hoc inexact reasoning mechanism based on the use of certainty factors. Whilst, in PROSPECTOR probabilities were propagated throughout the semantic network using bayesian inference. Since these early systems several alternative mechanisms for inexact reasoning have been proposed. The have included mechanisms based on fuzzy logic theory (see Zadeh, 1965), the Dempster-Shaffer theory of evidence and impossibility theory (see Frost 1986, pp. 406-420 for further details).

None of these methods have received universal acceptance. Indeed it has been argued that inexact reasoning methods do not necessarily improve a system's performance, and that it may be better to ignore quantitative inexact reasoning mechanisms and model uncertainty both qualitatively and explicitly within the knowledge base (Welbank, 1983 pp. 28). It is beyond the scope of this thesis to thoroughly review these inexact reasoning mechanisms and therefore only a summary of the more commonly adopted fuzzy logic, certainty factor and bayesian inference approaches is provided (see table 3.4.3).
### Table 3.4.3  Summary of Three of the Major Approaches to Inexact Reasoning used in Expert Systems

<table>
<thead>
<tr>
<th>Inexact Reasoning Method</th>
<th>Fuzzy Logic</th>
<th>Certainty Factors MYCIN</th>
<th>Bayesian Probabilities PROSPECTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Uncertainty in Statements</strong></td>
<td>Relevant statements, evidence or hypotheses are not finite, instead there exists a fuzzy set (F) of values between 0 and 1. Eg. F(patient is anoxeric) = 0.8</td>
<td>A certainty factor cf(E) between -1 and 1 is associated with each statement. cf(E) is the difference between a measure of belief in E, mb(E), and a measure of disbelief in E, md(E). Therefore, conflicting evidence is kept separate.</td>
<td>A probability P(E) is associated with each statement, evidence or hypothesis. These are normally converted to odds O(E) for easier manipulation O(E) = P(E)/(1-P(E))</td>
</tr>
<tr>
<td><strong>Uncertainty in Knowledge</strong></td>
<td>In a rule such as if E then H, theory fails to define a mapping g such that P(H) = g(F(E))</td>
<td>A single certainty factor CF(H/E) in the range [-1,1] is associated with each rule, if E then H. if CF(H/E) &gt; 0 then mb(H/E) = CF(H/E)xcf(E) if CF(H/E) &lt; 0 then md(H/E) = -CF(H/E)xG(E)</td>
<td>A least sufficiency (LS&gt;1) value and a least necessity value (LN&lt;1) is associated with each rule. LS measures the sufficiency of E in establishing the truth of H; and LN measure the necessity of E in establishing the truth of H. O(H/E) = LSxO(E) and O(H/E) = LNxO(E)</td>
</tr>
<tr>
<td><strong>Compound Premises</strong></td>
<td>Use of Fuzzy Boolean Operators P(E1 and E2) = min {P(E1), P(E2)}. P(E1 or E2) = max {P(E1), P(E2)}. P(not E) = 1 - P(F(E)).</td>
<td>Weakest and strongest evidence, similar to Fuzzy Logic cf(E1 and E2) = min {cf(E1), cf(E2)}, cf(E1 or E2) = max {cf(E1), cf(E2)}. cf(not E) = - cf(E).</td>
<td>Weakest and strongest evidence similar to Fuzzy Logic P(E1 and E2) = min {P(E1), P(E2)}. P(E1 or E2) = max {P(E1), P(E2)}. P(not E) = 1-P(E).</td>
</tr>
<tr>
<td><strong>Combining Evidence</strong></td>
<td>Suppose that g is id, so that P(H) = F(E). Then theory fails to define a mapping h to combine P(H/E1) and P(H/E2) such that P(H/E1,E2) = h(F(H/E1),F(H/E2)).</td>
<td>mb(H/E1,E2) = mb(H/E1) + mb(H/E2)x[1-mb(H/E1)]. Similarly for md(H/E1,E2).</td>
<td>It is assumed that the pieces of evidence E1 and E2 are statistically independent so that their effect on P(H) can be treated independently.</td>
</tr>
<tr>
<td><strong>General Comments</strong></td>
<td>Fuzzy logic has firm theoretical foundations, but system designer must complement theory by defining mappings g and h.</td>
<td>Absolute truth can only be proved from a single piece of confirming evidence.</td>
<td>Bayesian approach has firm theoretical foundations. Unrealistic assumption that evidence is statistically independent to avoid finding joint distributions. Problems in estimating prior probabilities.</td>
</tr>
</tbody>
</table>
Table 3.5 The Benefits and Limitations of Expert Systems

<table>
<thead>
<tr>
<th>BENEFITS</th>
<th>LIMITATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) General Benefits</td>
<td>(1) Domain Driven Limitations</td>
</tr>
<tr>
<td>* Solutions to problems in knowledge-rich, non-quantitative domains</td>
<td>* Well established area of expertise</td>
</tr>
<tr>
<td>* Competitive Advantage through improved decision making at lower cost</td>
<td>* Narrow, deep, relatively well structured domains</td>
</tr>
<tr>
<td>* Clarification of domain structure and relevant expertise</td>
<td>- Lack of consensus</td>
</tr>
<tr>
<td>** (2) Benefits Intrinsic to Systems that Simulate Expert Behaviour**</td>
<td>* Human senses</td>
</tr>
<tr>
<td>* Enhance performance of experts, improved productivity</td>
<td>- Vision (Eg. pattern recognition or spatial orientation of objects)</td>
</tr>
<tr>
<td>- Minimise human fallibility</td>
<td>- Touch</td>
</tr>
<tr>
<td>- Frees experts to concentrate on more problematic or important tasks</td>
<td>- Smell</td>
</tr>
<tr>
<td>- Enumerate more alternatives</td>
<td>* Domain expertise relatively stable with respect to time</td>
</tr>
<tr>
<td>- Take into account more data</td>
<td>** (2) Technology Driven Limitations**</td>
</tr>
<tr>
<td>* Increased capabilities of non-experts, delegate tasks to less qualified, less experienced and cheaper personnel</td>
<td>* Majority of PC based expert system development tools, or shells, use limited knowledge representation schemes and inference mechanisms</td>
</tr>
<tr>
<td>- Relieve expert in simple cases</td>
<td>- Require the knowledge engineer to &quot;bend&quot; or engineer the expert's domain knowledge</td>
</tr>
<tr>
<td>- Less dependence on scarce expertise</td>
<td>- Do not facilitate reasoning by analogy</td>
</tr>
<tr>
<td>- Expertise is more accessible</td>
<td>- Lack flexibility in changing goals and plans</td>
</tr>
<tr>
<td>** (3) Benefits Due to &quot;Harnessing&quot; an Organisational Knowledge Base**</td>
<td>- Do not support non-monotonic reasoning</td>
</tr>
<tr>
<td>* Maintain and increase organisational knowledge base</td>
<td>* Lack robustness</td>
</tr>
<tr>
<td>- Archive critical expertise</td>
<td>- Performance said to be &quot;brittle&quot;</td>
</tr>
<tr>
<td>- Purchase proven expertise</td>
<td>* Poor explanation facilities</td>
</tr>
<tr>
<td>- Disseminate scarce and valuable expertise</td>
<td>- Often limited to a simple &quot;trace&quot; of the rules used by the inference engine</td>
</tr>
<tr>
<td>- Draw together related areas of expertise within a single knowledge base</td>
<td>* Poor self-learning capabilities</td>
</tr>
<tr>
<td>** (4) Benefits Due to Underlying AI/ES Technology**</td>
<td>- Can not use their own experience to update and restructure their own knowledge base</td>
</tr>
<tr>
<td>* Explicit representation of domain knowledge which is separated from inference mechanisms</td>
<td></td>
</tr>
<tr>
<td>- Increase developer productivity</td>
<td></td>
</tr>
<tr>
<td>- Scope for development by expert/users</td>
<td></td>
</tr>
<tr>
<td>- Easier to maintain, modify and enhance</td>
<td></td>
</tr>
<tr>
<td>- Largely self-documenting</td>
<td></td>
</tr>
</tbody>
</table>
3.5 The Benefits and Limitations of Expert Systems

The rapid growth of interest in expert systems can be partly accounted for by the highly publicised organisational benefits that their development and use provide. These benefits are discussed in sub-section 3.5.1 below and are summarised in table 3.5. Although expert systems have many commercially realisable benefits, their use represents no panacea. Current expert systems technology has many widely accepted limitations. These are discussed in sub-section 3.5.2 and are summarised in table 3.5.

3.5.1 The Benefits

In outlining the organisational benefits that expert systems can provide it is expedient to consider the benefits along four major dimensions. Firstly, there are those general benefits that this new generation of computer systems can provide; secondly, are those benefits that are intrinsic to systems that simulate expert behaviour; thirdly, are those benefits due to the capability to "harness" the organisational knowledge base; and finally those benefits due to the underlying technology of expert systems.

3.5.1(1) General Benefits

Perhaps the singly most significant benefit of expert systems is that they enable the boundaries of computer based applications to be expanded. Conventional systems have proved successful in efficiently performing complex but routine tasks often involving extensive numerical manipulation in highly structured domains. Expert systems are beginning to prove themselves capable of providing computer based solutions in less structured, knowledge-rich, qualitative rather than quantitative, domains that have thwarted solution by traditional methods (Pollitzer & Jenkins, 1985; Simon, 1987; Aeh, 1988; Keller, 1988; O'Keefe, 1988). Their capabilities to model qualitative aspects of problems mean that expert systems are well suited to modelling many aspects of human expertise; and in particular, since qualitative decision making characterises the work of senior management, then expert systems provide the capability of increasing the degree of automation at higher levels of organisational decision making (Simon, 1987).

Expert systems can be used as levers for competitive advantage (Aeh, 1988; Keller, 1988; Ryan, 1988; Leonard-Barton & Sviokla, 1988); and in particular their use can improve the quality of decision making and reduce its cost. For example, the XCON/R1 system is reported to save the Digital Corporation several million dollars.
each year because it reduces the need for final systems testing before shipment of customers' orders. Furthermore, the system has helped to support Digital's strategic policy to provide computer systems satisfying customer specific requirements. Another example is AMEX developed by the American Express Company for use as a credit authorisers assistant. AMEX is reported to have raised productivity by 20% whilst simultaneously reducing losses from over extension of credit. Furthermore, AMEX supports the company's product differentiation strategy of offering individualised credit limits (see Leonard-Barton & Sviokla, 1988).

One of the most understated general benefits of expert systems is that their development can be used to promote a better understanding of both the domain's structure and the relevant expertise (Bobrow et al., 1986; Keim & Jacobs, 1986; Leonard-Barton & Sviokla, 1988). Much human expertise is tacit and unarticulated and as such it is difficult to examine and review. The expert system development process, and in particular the knowledge acquisition process (see section 6.1), provides an explicit model of the domain and the relevant expertise. Once the expertise is revealed it can be reviewed and refined in light of any observed weaknesses or inconsistencies. This process enables the knowledge or expertise to be clarified and formalised. This may be particularly important in domains characterised by multiple experts with differing perspectives.

3.5.1(2) Benefits Intrinsic to Systems that Simulate Expert Behaviour

Traditionally, expert systems have been developed to capture scarce and valuable, or critical, areas of expertise. Once captured the expertise could be disseminated throughout the organisation so that less qualified personnel could have access to the expert's decision making capabilities without the expert being present. Both the systems MYCIN and PROSPECTOR were developed for this purpose. For such systems the overriding objective is to increase the capabilities of non-experts, by delegating tasks to less qualified, less experienced and therefore cheaper personnel. Such systems can relieve the expert in simple cases (Holroyd et al., 1985; Ernst & Ojha, 1986) and ensure that the organisation is less dependent on scarce expertise because the expertise is more accessible (Martin, 1985); as for example, any time day or night, or in any geographical location.

More recently, it has been recognised that expert systems can be used by experts themselves to enhance their own performance, thus changing the emphasis from that of replacing the decision maker to that of aiding or supporting the decision maker.
Expert systems can therefore be developed to be used as decision support tools rather than as consultant/advisory systems: an empirical study of 67 expert system projects by Doukidis (1988) concludes that several fundamental decision support concepts have been explicitly applied to expert systems. As with conventional decision support systems (DSS) the expert user has overriding control and does not totally surrender his own judgment to the system. The expert user can direct the system in its problem analysis and evaluate different alternatives through sensitivity type analyses. These decision support type expert systems are referred to as expert support systems (ESS) (Luconi et al 1986; Kerschberg & Dickenson, 1988; Finlay et al, 1988), or expert decision support systems (EDSS) (Lee, 1988).

Expert support systems enhance experts' performance by increasing their productivity. In particular expert support systems minimise experts' human fallibility because they are consistent, complete and comprehensive. Consistency refers to a system's ability to produce the same (or similar) recommendation given the same (or similar) set of inputs. Completeness refers to a system's ability to ensure that all information that may be relevant to the problem is sought; and comprehensiveness refers to a system's ability to ensure that all the available relevant information is taken into account during the problem analysis. Sadly, these are all qualities that are lacking in human experts!

Furthermore, expert support systems increase the speed with which tasks can be performed. This means that routine tasks can be performed quickly, thereby freeing the expert to concentrate on more problematic or important tasks. Similarly, the increase in speed means that the expert can use the system to evaluate a greater number of alternatives, thereby enabling the expert to conduct a more comprehensive analysis of the problem. Finally, the processing power of a computer means that an expert support system can take into account more information, as for example from on-line databases, than the unsupported human expert, thereby enabling the expert to perform the problem analysis in greater depth or detail.

3.5.1(3) BENEFITS DUE TO "HARNESSING" THE ORGANISATIONAL KNOWLEDGE-BASE

Expert systems are of value because they enable organisations to "harness" their knowledge bases. In particular expert systems enable organisations to archive their critical areas of expertise so that expertise is not lost when personnel retire or die. Expert systems enable organisations to purchase proven standard areas of expertise,
Expert systems enable scarce and valuable expertise to be disseminated throughout an organisation thereby increasing its accessibility, and finally they enable related and dispersed areas of expertise to be drawn together within a single knowledge base (Bobrow et al., 1986).

3.5.1 Benefits due to the underlying technology

Expert systems are characterised by their explicit, transparent representation of domain knowledge within the knowledge base, and the separation of this knowledge from the inference mechanisms used to manipulate it which are stored in the inference engine. Together these characteristics provide several benefits. Firstly, the declarative knowledge representation schemes used increase developer productivity and facilitate "rapid prototyping" which can be used both to evaluate different ideas, as for example alternative design strategies, and to validate and refine the domain knowledge. Secondly, the availability of numerous "high level" PC based development tools, or shells, provide scope for the development of small scale systems by expert users (Harmon et al., 1988 pp. 8). Although King (1989) concludes that it is unlikely that these shells will ever be as "user friendly" and as acceptable to users as the ubiquitous spreadsheet. Finally, the explicit, declarative knowledge representation schemes suggest that expert systems are easier to maintain and modify than more conventional systems. In particular the modularity and independence of the knowledge structures suggest that expert systems are easier to enhance because new knowledge structures, as for example additional rules or frames, can be added largely independently of the existing knowledge structures.

3.5.2 The limitations

In outlining the limitations of current expert systems it is expedient to consider their limitations along two dimensions. Firstly, there are those limitations imposed by the types of domain for which expert systems are, or are not, appropriate. These are referred to as domain driven limitations in table 3.5. Secondly, there are those limitations due to the capabilities of the current technology underlying expert systems. These are referred to as technology driven limitations in table 3.5.
3.5.2(1) Domain Driven Limitations

First and foremost an expert system can only be developed for use in a domain where there is a well established area of expertise. That is, the scope of expert systems is limited to performing tasks that human experts can already perform. Therefore one should not be misled into thinking that expert systems can solve problems that defy human solution (Sell, 1985; Keim & Jacobs, 1986). Secondly there are many tasks where human capabilities are far superior to those of a computer (Keim & Jacobs, 1986). This is true of tasks that involve extensive use of the humans senses, such as tasks that involve the use of vision, touch and smell. For example, expert systems are not appropriate for tasks which involve the recognition of shapes or patterns, or the spatial orientation of objects.

Furthermore, expert systems have proved themselves more successful in narrow deep domains that are relatively well structured than they have in wide shallow unstructured domains (Pollitzer & Jenkins, 1985; Martin, 1985; Bobrow et al, 1986; Keim & Jacobs, 1986). As a result expert systems have been more successful in domains where there is a single source of expertise, as for example in domains where there is documented expertise or a general consensus of opinion amongst several human experts, than in domains where there is a lack of consensus amongst several human experts.

Finally, although expert systems are easy to modify and enhance (see section 3.5.1(4)), unlike human experts their self-learning capabilities, that is their ability to learn from their experiences and mistakes and to restructure their own knowledge base, is currently very poor (see section 3.5.2(2)). As a result expert systems are more appropriate for domains where the relevant expertise is relatively stable over time.

3.5.2(2) Technology Driven Limitations

Current PC based expert systems development tools, or shells, have been criticised for being overly restrictive in their limited use of knowledge representation schemes and inference mechanisms (Pollitzer & Jenkins, 1985). In particular, it has been noted that these tools frequently require the knowledge engineer to bend or engineer the expert's domain knowledge to fit the representational formalisms of the chosen tool (Cullen & Bryman, 1988; King 1989), and as a result the richness of the expert's knowledge structures can be lost. Furthermore, in the main, shells do not facilitate analogy type reasoning and are poor at changing their goals or plans mid-consultation.
and as such do not provide non-monotonic reasoning. That is, unlike human experts, the inference mechanisms do not generally allow for the retraction of intermediate conclusions if subsequent information proves them to be invalid.

Expert systems lack robustness, their performance is said to be "brittle" (O'Keefe, 1988). So unlike human experts whose performance tends to degrade slowly as the boundaries of their knowledge are reached, an expert system's level of performance rapidly falls as it reaches the boundaries of its knowledge because it is unaware of the limitations of its own knowledge.

Furthermore, in current expert systems the explanation facilities incorporated in the explanation module (see figure 3.2) are very rudimentary and are largely inadequate apart from use for debugging and systems testing purposes. For example, in many rule based expert systems the explanation module provides nothing more than a trace of the rules that were used, or are currently being used, by the inference engine to solve the problem.

Finally, current expert systems have extremely poor self-learning facilities, in that they are not capable of updating and restructuring their own knowledge bases in light of their experience.

3.6 Scope and Application of Expert Systems

The rapid growth of interest in expert systems technology has resulted in the development of expert systems in a diverse range of disciplines. Expert systems have found application in science (E.g. medicine, chemistry and statistics), industry (E.g. engineering and production/manufacturing), commerce (E.g. banking and accountancy), business (E.g. marketing and human resource management) and education (E.g. teaching and training). This diverse range of application has resulted in several classifications of expert systems being proposed which aim to define the scope of their application.

Expert systems have been classified by their underlying technology creating a differentiation between rule base systems and frame based systems, and between small scale PC based expert systems developed using shells and large scale expert systems running on dedicated AI workstations and developed using state-of-the-art development environments (Harmon & King, 1985 pp. 173-207).
Secondly, expert systems have been classified by the role they were designed to perform. So, it is possible to have consultant-advisory type systems and decision support type expert systems depending upon both the expertise of the user and the degree of judgement the user surrenders to the system (Luconi et al, 1986; Lee, 1988; Kerschberg & Dickinson, 1988; Finlay et al, 1988).

Thirdly expert systems have been classified by the types of task they were designed to perform. Expert systems can perform interpretation, prediction, diagnosis, planning, monitoring, debugging, repair, instruction, control, classification and design (Hayes-Roth et al, 1983; Stefik et al, 1982). Meanwhile other researchers, rather than attempt to classify expert systems, have investigated the scope and appropriateness of current expert system technology in relation to a problem domain's underlying characteristics such as size, complexity, structuredness, degree of judgement and rate of change (Holroyd et al, 1985; Ernst & Ojha, 1986).

Two types of task for which expert systems appear to be particularly appropriate are classification/diagnosis and design/planning. In essence diagnostic or classification type systems are designed to measure a situation or object along several dimensions, or attributes, and then classify the situation or object into generally only one of a small number of categories. Furthermore, the rule based backward chaining paradigm described in sections 3.4.1(1) and 3.4.2(1) is believed to be particularly appropriate in domains where the final categories are mutually exclusive and exhaustive and where different situations or objects differ markedly along all the salient dimensions (Holroyd et al, 1985).

There are numerous successful applications of diagnostic/classification type expert systems. These include medical systems for diagnosing diseases, as for example MYCIN for the diagnosis and prognosis of bacterema infections; diagnostic "fault finding" systems for computer networks and process control equipment (King, 1989); and systems for use in human resource management designed to screen or vet personnel prior to interview (Edwards & Bader, 1988; Finlay & King, 1989).

In design and planning type expert system applications the aim is to construct an object with given properties and subject to certain constraints. For such tasks the major benefit of the artificial intelligence / expert system (AI/ES) approach is that using heuristic search the system can intelligently enumerate and evaluate more quickly and reliably a much greater number of alternate designs or plans than their
human counterparts. The most well known example of a design type expert system is XCON/R1 developed to configure computer systems to meet specific customer requirements. Another domain in which design/planning type expert systems have had success is in production scheduling where an AI/ES approach is capable of tackling more complex problems than traditional mathematical programming approaches (Simon, 1987).

3.7 SUMMARY

Expert systems have evolved from research into artificial intelligence. In essence an expert system is a computer program that emulates the performance of one or more human experts in a narrow domain of expertise.

Expert systems are characterised by their dependence upon large quantities of qualitative domain-specific knowledge, their use of heuristic search procedures rather than algorithms to determine solutions and the separation of the domain knowledge from the inference mechanisms that are used to manipulate the knowledge to solve problems.

Expert systems have many realisable organisational benefits. In particular their use expands the boundaries of computer based applications; and furthermore can create competitive advantage by increasing the quality of organisational decision making at lower cost. However, their use represents no panacea and current expert systems technology has many widely accepted limitations that restricts their wider use. Two tasks with which expert systems have proved themselves particularly capable are classification/diagnosis and design/planning.
CHAPTER 4

EXPLORING THE POSSIBLE APPLICATIONS OF

EXPERT SYSTEMS IN COMPETITIVE BIDDING
4. **Exploring the Possible Applications of Expert Systems in Competitive Bidding**

4.0 **Introduction**

This chapter draws together the concepts discussed in the previous two chapters and devises a framework for investigating the possible applications of expert systems in competitive bidding. The chapter commences by summarising the weaknesses of previous bidding studies and outlines the characteristics of expert systems which suggest that they may provide a more appropriate tool for which to provide management with decision support in this area. Four possible applications of expert systems in competitive bidding are identified, and the scope and objectives of the proposed research are outlined. Following this the aforementioned framework is outlined. It is one based on in depth case studies requiring extensive collaboration from organisations involved in competitive bidding. The approaches taken to find suitable organisations are then briefly discussed; and finally the responses of the organisations are summarised.

4.1 **Why Expert Systems are Appropriate for Modelling Competitive Bidding Situations**

As previously noted in chapter 2, many organisations from a diverse range of economic sectors obtain the majority, if not all, of their business through the process of competitive bidding. For these organisations both their survival and prosperity are dependent upon the *success* of their competitive bids; and the implementation of successful bidding strategies is therefore of paramount importance. This is reflected by the attention given to the subject by the MS/OR community over the last three decades since the seminal work of Lawrence Friedman in 1956.

The focus of previous bidding studies has been to provide managerial support in the determination of the optimum price at which to bid in order to maximise the expected profit on any given contract in a closed bidding situation, and where the contract is awarded to the lowest priced bidder. Several quantitative modelling approaches have been proposed for this problem: these include the decision and game theoretic approaches, and also the probabilistic strategy approach.
Unfortunately, as previously noted in section 2.4, there are well established theoretical and/or practical limitations with both the decision and game theoretic approaches. Even the more flexible probabilistic strategy approach has its limitations, and all three approaches have received criticism from academics and bidding managers alike. In particular criticism from academics has been levelled at the validity of the underlying assumptions on which the models are based (King & Mercer, 1987b). Whilst criticism from bidding managers has been levelled at the models' dependence upon historical data. It has been argued that quantitative models cannot be reliable because their use of historical data requires the unrealistic assumption that competitors will exhibit the same behaviour as they have in the past; and furthermore that the models are impractical because of the difficulties encountered in collating the required data models (Ward & Chapman, 1988).

It is important to realise that bid pricing is only one of a series of interrelated decisions that need to be addressed when formulating an overall bidding strategy. In many bidding situations equally important decisions are the related decisions as whether or not to bid at all, a decision referred to as the bid versus no bid decision, and the level of resources to allocate to bid preparation. These decisions are especially important in bidding situations where the cost of bidding is high, as for example in situations where a significant amount of design work needs to be performed and therefore where qualitative features are prevalent. In such circumstances the final bid price may not be a contractor's major competitive weapon, and therefore the emphasis for a contractor may change from optimal bid pricing towards optimal resourcing of bids. These two related decisions have, however, received scant attention from the OR/MS community, but are areas in which there appears to be significant justification and scope to provide management decision support.

So, in general previous bidding models have not taken into account the qualitative features important in many bidding situations, and have not recognised that the contractor is constrained by his resources and further needs to balance these resources. Furthermore, previous studies have focused on bid pricing, whereas for many organisations the bid versus no bid decision and the resourcing of bids are equally important managerial decisions. Given the strategic importance of competitive bidding it can be concluded that radically different approaches for improving bidding performance should be investigated.
As previously noted in chapter 3, expert systems are a relatively new area of computing technology which have evolved from research into artificial intelligence. In essence an expert system (ES) is a computer program that aims to capture the expertise and emulate the performance of one or more human experts in a problem domain. This expertise consists of knowledge and judgement, as for example loosely associated facts and rules, often learnt from experience rather than theory. This expertise is frequently formulated in the form of simple heuristics, or rules of thumb, and is predominantly qualitative in nature rather than quantitative. Thus, ES are characterised by their dependence upon large quantities of qualitative domain-specific knowledge. However, through the use of powerful hybrid representation schemes ES can support models incorporating both the qualitative and quantitative features of a problem domain. ES simulate the actions of the human experts. An ES offers a recommendation based upon the information available and can justify its recommendations to the user. That is, ES are capable of explaining their conclusions and reasoning. Furthermore, ES produce results consistent with leading experts in the domain and like human experts are capable of offering recommendations in light of a combination of incomplete, uncertain and conflicting information.

In practice managers responsible for preparing competitive bids have gained considerable expertise and intuition, and can be relied upon for their good judgement to make rational and reasonable decisions. This is at least true for those organisations who remain in business and are profitable! The managers' expertise has both quantitative and qualitative aspects. Customers, contracts and competitors are effectively diagnosed and various experiential rules of thumb are used to arrive at an appropriate decision, whether this be a decision whether or not to bid, or a final price at which to bid. Furthermore, experience suggests that bidding is an area in which relevant expertise or knowledge is frequently dispersed or shared between several managers, and where the information available with which to make decisions is often both limited and inaccurate.

Together these characteristics suggest that the modelling capabilities of ES closely match the type of reasoning carried out by managers preparing bids; and therefore that knowledge based approaches incorporating decision support models based on simple heuristic, experiential, rules may be more appropriate and reliable for improving bidding performance. Thus, one further possible approach to providing management decision support in competitive bidding is through the use of expert systems (ES), and in particular the use of expert support systems (ESS) by the bidding managers themselves.
ES and ESS have several characteristics that may lend assistance to improved bidding performance. Firstly, as noted above experience suggests that bidding is an area where relevant expertise or knowledge is generally dispersed among several managers. ES and ESS therefore provide a means of consolidating these multiple sources of expertise within a single knowledge base. This could include combining related areas of knowledge within a single system or contrasting different perspectives of the same domain to provide a single consensual or standardised perspective.

Secondly, the consistent, complete and comprehensive nature of ES and ESS means that human fallibility and bias can be minimised, thereby ensuring the bidding decisions are made in a more systematic, objective and equitable fashion. Thirdly, the ES and ESS development process promotes a better understanding of both a problem domain's structure and the relevant expertise. This can be particularly beneficial in domains characterised by multiple expertise. Therefore, through the development of an ES or ESS a contractor can gain a better understanding of their own bidding strategies and related performance. Finally, an additional and related benefit from the use of ES and ESS, but as yet largely unresearched, is their use as experimental management tools, as akin to simulation techniques. With an ES and ESS there is scope for changing or adding new parameters to the system's knowledge base, and investigating the effects in a safe simulated environment.

Given the strategic importance of competitive bidding, together with the narrow focus and limited success of previous approaches in providing management decision support in bid pricing, there is obvious scope and value in investigating the possible uses of knowledge based expert system techniques in competitive bidding. The aim of this thesis is to explore the possible applications and benefits that ES technology can provide in this area.

ES and ESS should not, however, be viewed as a panacea for competitive bid management. Each of the previous modelling approaches were normative approaches and were also predominantly data driven generic approaches. The models that are incorporated in ES and ESS are descriptive rather than normative, and furthermore are knowledge based rather than data based. Although in theory through the use of hybrid representational schemes it may be possible to combine descriptive and normative approaches (Kastner & Hong, 1984). Together these characteristics imply that the models are specific to the bidding situations for which they were developed. Consequently, an ES or ESS developed for one contractor has no functional purpose for any other contractor. That is, that the model embedded within an ES or an ESS
for bid management for one contractor cannot be transferred for use by another contractor or to another industry. At best suitable development methodologies and modelling frameworks may be recognised.

4.2 RESEARCH OBJECTIVES

The overall objective of the research program was to explore the possible roles and benefits that expert systems (ES) can provide in competitive bidding. The devised research paradigm described in section 4.3 is case driven involving the extensive collaboration of organisations involved in competitive bidding. In this respect the proposed research paradigm was both exploratory and experimental in its nature, and therefore it was neither feasible nor appropriate to limit the scope of the research by an a priori defined set of formal research hypotheses.

Instead the exploratory and experimental paradigm aimed to provide informative insights into three main sub-themes regarding the use of ES in competitive bidding and which therefore underlay the overall research objective. These included:

1. Role and Scope of Application of ES in Competitive Bidding

2. Benefits Associated with the use of ES in Competitive Bidding

3. Implications of 1. and 2. above on the Role of ES in other Managerial Domains

The nature of each of these sub-themes is described in further detail in each of the three subsequent sub-sections respectively.
4.2.1 Role and Scope of Application of ES in Competitive Bidding

The research aimed to address where in the contractor's bidding process can the use of ES be most beneficial, and how this is influenced by the characteristics of the bidding situation under consideration.

From the analysis of the competitive bidding process discussed in chapter 2 and the characteristics of ES outlined in chapter 3 four possible areas for ES applications in bidding can be identified. These include:

1. Assisting with decisions concerning whether or not to bid
2. Assisting with decisions concerning the amount of bidding effort
3. Assisting with decisions concerning the most appropriate design
4. Assisting with decisions concerning an appropriate bid price and overall package to offer the customer

Furthermore, the research aimed to address what types of ES are most appropriate and beneficial for use in competitive bidding situations. Is it consultant/advisory type ES whose role is to redistribute the responsibility of a contractor's more simple bidding decisions to less experienced bidding function personnel? Alternatively, is it support type systems (ESS) whose role is to assist highly experienced senior bidding managers in their bidding decisions?
4.2.2 Benefits Associated with the Use of ES in Competitive Bidding

Another aspect of the research aims was to identify what are the principle benefits to be derived from the use of ES in competitive bidding; or alternatively, how the ES can be used to improve a contractor's bidding performance. Several possible benefits were identified in section 4.1: these included:-

1. Consolidating multiple sources of a contractor's bidding expertise within a single knowledge base.

2. Improving the objectivity and consistency of a contractor's future bidding decisions.

3. In ESS using sensitivity analysis to evaluate consistently, completely and comprehensively a range of possible scenarios that the contractor might encounter.

4. Enhancing a contractor's understanding of the key issues, and their inter-relationships, affecting its bidding decisions.

5. Using ES as an experimental tool to enable a contractor to evaluate different bidding strategies.

6. Combining qualitative and quantitative approaches to complement a contractor's descriptive knowledge base with a normative component.

4.2.3 Implications of 4.2.1 and 4.2.2, Above on the Role of ES in Other Managerial Domains

At present there is very little epistemological knowledge regarding the scope of application of ES in managerial domains. Empirical studies describing the success or otherwise of ES in managerial domains can therefore be regarded as an important contribution to knowledge in this area. Thus, if ES are found to be appropriate for modelling competitive bidding situations, then part of the research project would be to identify the factors or characteristics of bidding domains (or those of ES) which lead to their success. Alternatively, if ES are found to be inappropriate for modelling competitive bidding situations, then the research would seek to identify the factors or characteristics of bidding domains (or those of ES) which lead to their failure. A further aim was to match the characteristics of bidding domains against those of other...
managerial domains and therefore provide further empirical evidence as to where ES are appropriate for use in management in general.

Similarly, there is very little epistemological knowledge regarding which ES development paradigms and knowledge acquisition techniques are appropriate for which domains (see chapter 6). The research also aimed therefore to provide further empirical evidence as to which ES paradigms, as for example rules or frames, and which knowledge acquisition techniques are appropriate for bidding and other managerial domains. In particular the research aimed to highlight the factors or characteristics which lead to a paradigm's or technique's success or failure.

4.3 EXPLORATORY RESEARCH METHODOLOGY

The overall objective of this research project was to investigate the possible roles and benefits of ES and ESS in competitive bidding. To achieve these objectives an outline methodological framework was devised based on a small number of in depth case studies with organisations involved in competitive bidding.

It was planned that each case study would involve extensive collaboration from an organisation involved in competitive bidding, and it was envisaged that each study would take place over a 6 to 9 month period. Each study would commence with the identification of an appropriate ES or ESS application within the case study organisation's bidding function. Following this relevant bidding knowledge and expertise would be acquired and developed into an appropriate system using a suitable ES development tool. Finally, the system's performance would be measured and its benefits to the organisation evaluated. The overall research paradigm was therefore both exploratory and experimental. Tentative conclusions about the benefits that ES and ESS provide for competitive bidding would be drawn from a discussion of the case studies.
It was appreciated that many of the precise details regarding the systems' development would be case dependent. However, it was possible to envisage each case study following a general 6 stage process. This process is outlined below.

1. General Familiarisation
2. Problem Identification
3. Knowledge Acquisition
4. Model and System Development
5. Repeat 3 & 4 above
6. System Validation, and Evaluation

The nature and purpose of each of these 6 stages are discussed in further detail in the respective sub-sections below.

4.3.1 General Familiarisation

The overall aim of this stage was to gain a general overview of the case study organisation's business and their approach to competitive bidding. It was envisaged this would involve approximately 3 semi-structured 2 hour interviews with key personnel from the organisation's bidding function. From these interviews it was hoped to learn about the individual and collective responsibilities of the bidding function personnel, and in particular the organisation's approach to the various stages of the competitive bidding process outlined in chapter 2.

Furthermore, this first stage would enable the researcher to build up a rapport with the key personnel in the bidding function and thereby gain respect and credibility. This was considered to be of vital importance in ensuring that collaboration could be maintained over several months.

4.3.2 Problem Identification

The objective of this stage of the case study methodology was to identify a suitable area within the organisation's bidding process where an ES or ESS could be beneficial. In order to maintain the organisation's interest and commitment to the research, then a central facet of this stage was to involve the organisation closely in a suitable problem area's identification and definition. It was hoped that this approach would ensure that the organisation believed some tangible benefits would result from long term collaboration.
The chosen problem area therefore needed to display several characteristics. Firstly, the problem needed to be important to the organisation, so that the development of an ES or ESS was perceived to be of high value. Secondly, the project needed to be supported internally, especially by those managers who would need to become extensively involved during the knowledge acquisition stage. It was therefore important to identify an application where managers were enthusiastic, optimistic of some success, and would be available and willing to co-operate with their time. Finally, but by no means least, it was important to ensure that the problem area was one in which expertise did indeed exist!

It was envisaged that this stage would involve approximately two 2 hour interviews with key personnel from the organisation's bidding function.

4.3.3 Knowledge Acquisition

The objective of the knowledge acquisition stage would be to gather data or information relevant to the case study organisation's bidding decisions. This material would be subsequently analysed and structured (see section 4.3.4) in order to reveal insights into the organisation's decision processes.

It was planned that this stage would commence with the identification of all possible sources of relevant information. These could include documented material, as for example company procedures, or previously documented bids. However, it was envisaged that the richest sources of material would lie with the key managers responsible for preparing bids themselves. Therefore, an important step in the knowledge acquisition stage would be the identification of the organisation's best experts.

Once all sources of relevant information were identified, an appropriate overall knowledge acquisition strategy would be developed that was an appropriate match for the characteristics of the case study. Again the precise details of this strategy would be case dependent. However, it was envisaged that any strategy would involve interviews with key bidding managers, which would probably be based around either historic or current bids. Various techniques drawn from the knowledge acquisition literature would be used to both structure and focus these interviews.

It was estimated that approximately 12 hours of interviews would be sufficient to enable a rudimentary prototype system to be developed. This estimate provided the
collaborating organisation with an initial and limited level of commitment. Whilst the rudimentary system would enable both the researcher and the case study organisation to quickly ascertain the probability of a successful outcome to the project, and could therefore serve as a basis for negotiating further collaboration.

4.3.4 **MODEL AND SYSTEM DEVELOPMENT**

It was envisaged that this stage would involve no collaborative effort from the case study organisation.

This stage would involve the analysis and structuring of the information gleaned through the knowledge acquisition interviews. Furthermore, it would be performed partly in parallel to the knowledge acquisition interviews, so that the resulting insights into the managers' decision processes could be used to focus and structure further knowledge acquisition sessions with the managers. The precise nature of the analysis and structuring methods used would be case dependent, and are therefore only discussed in detail in part B of this thesis.

The overall aim of the analysis and structuring process would be to develop a model of the organisation's bidding decision processes, or reasoning, with regard to the problem under discussion. This model would then be developed into an appropriate ES or ESS using a suitable ES development tool.

4.3.5 **REPEAT 3 & 4**

Stage 5 was inserted to illustrate that the systems' development was envisaged to be an iterative process.

The overall approach taken in this stage would be to demonstrate the prototype system developed in stage 4 above to key personnel in the organisation's bidding function. The objective of these demonstrations would be to informally assess whether or not the system's results and reasoning were consistent with those derived and used by the managers themselves.

It was envisaged that this stage would involve the case study organisation in several ways. In particular they would be charged with providing suitable test data, commenting on the system's reasoning and results, especially identifying errors in the system's reasoning and suggesting the possible cause of these errors, and generally
discussing the system's weaknesses and recommending changes and possible improvements to the system.

4.3.6 Validation and Evaluation

The objective of this stage would be to measure the system's level of performance, and hence evaluate the system's benefits to the case study organisation.

During this stage it was hoped to carry out some form of parallel trial study lasting approximately 3 months. During this period the system's recommendations and reasoning would be formally compared with those decisions made by the managers within the organisation's bidding function. It was hoped that a Turing type test, as recommended by Blanning (1984), would be used in conjunction with a formal test-statistic, as recommended by O'Keefe et al (1987), to develop a quantitative measure of the system's level of performance, and therefore a formal measure of its validity.

It was envisaged that this approach would involve the researcher visiting the case study organisation on a regular basis, perhaps once a week, to run cases through the system, and to collect and collate relevant data in order to construct an appropriate validation database.

Again the precise details of how this stage would be approached would be case dependent, and are therefore only discussed in detail in part B of this thesis.
### Table 4.4 Summary of the Characteristics of Several ES Development Tools

<table>
<thead>
<tr>
<th>Representation Scheme</th>
<th>Xi-Plus Prolog</th>
<th>Leonardo 2</th>
<th>Xi-Plus 3</th>
<th>Leonardo 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inference Mechanisms</strong></td>
<td>Simple flat file of production rules.</td>
<td>First order predicate calculus.</td>
<td>Rules and Frames organised into hierarchical rule sets.</td>
<td>Rules organised into hierarchical rules sets</td>
</tr>
<tr>
<td></td>
<td>Backward chaining. Limited forward chaining invoked through the use of &quot;demon&quot; rules.</td>
<td>Depth first backward chaining.</td>
<td>Backward chaining with opportunistic forward chaining.</td>
<td>As Xi-Plus</td>
</tr>
<tr>
<td><strong>General Comments</strong></td>
<td>Flat file structure means that systems are inferentially inefficient. This puts an upper limit on the number of rules that can be included in a single knowledge base. No facilities to devise customised user interfaces. Limited facilities for linking applications to other software products such as spreadsheets or databases.</td>
<td>Concise and flexible. Powerful predicates can be coded quickly resulting in improved productivity. Flexibility enables developer to devise expressive problem oriented knowledge structures. Slower to program with than an ES shell, and the creation of acceptable user interfaces is both difficult and time consuming.</td>
<td>Hierarchical rule sets mean that systems are inferentially efficient. No upper limit on number of rules within a knowledge base. Powerful hybrid representation scheme enables knowledge to be represented in a more natural and efficient manner than with rules alone. In built procedural programming language enables easy interfaces to other software products. Developer has full control over the user interface with a screen designer utility and the procedural language.</td>
<td>A much improved version of Xi-Plus. Knowledge bases can be organised into hierarchical rule sets. This improves transparency, inferential efficiency and therefore the complexity of the domain that can be modelled. No upper limit on number of rules within a knowledge base. Interfaces to other software products are supported, and a screen designer utility provides the developer with control over the user interface.</td>
</tr>
</tbody>
</table>
4.4 CONSTRAINTS ON PROPOSED METHODOLOGY

The overall environment in which the research was performed imposed certain restrictions on both the depth and manner in which the case studies could be pursued. In particular these included the availability of both human resources and appropriate computing facilities.

Firstly, the researcher’s time was limited, and it was envisaged that there were at maximum only 21 months in which to complete the case studies. (In fact it was later discovered that it was only possible to pursue one case study to any depth in the time available.) Similarly, there were limitations on the level of organisational commitment that one could reasonably expect. Consequently, the objective of each case study was to develop a prototype ES or ESS to demonstrate the feasibility, or otherwise, of knowledge based techniques in competitive bidding. Only limited effort was put into the design of an appropriate user interface; and therefore the emphasis was on the validation and evaluation of the model, rather than on the system as a whole.

Secondly, the proposed research was constrained by the availability of appropriate hardware and ES development software. Loughborough University Business School (LUBS) had standardised on the use of IBM-PC "clones" and the MS-DOS operating system. The prototype systems were therefore constrained to be designed and developed to run on IBM-PC "clone" machines. This also placed a constraint on the development software that could be used during the research.

At the start of the research LUBS was in possession of one expert system shell, Xi-Plus, and a PC version of PROLOG. During the course of the research LUBS obtained three further expert system shells: Leonardo 2, Xi-Plus 3 and Leonardo 3. Throughout the course of this research each of these five tools were thoroughly evaluated. (A summary of these tools major features in provided in table 4.4) From this evaluation it was concluded that there is a clear convergence among the features available in the ES shells currently available in the UK. It is the researcher’s opinion that Leonardo 3 is one of the most versatile of the popular ES shells available in the UK. It combines ease of use with flexibility and representational power, and was therefore chosen for use during the proposed research.
4.5 WEAKNESSES OF PROPOSED METHODOLOGY

The proposed outline methodology described in section 4.3 suffers from several weaknesses. First and foremost, being based on a limited number of in depth case studies the methodology is both exploratory and experimental in its nature. As a result there are problems associated with the generalisation of any research findings. Within the proposed methodology, only tentative conclusions concerning the benefits and appropriateness, or otherwise, of ES and ESS in competitive bidding can be drawn.

Secondly, the proposed methodology is weak in its overall control of the research design for each case study. In particular, in order to gain and maintain long term collaboration, it was necessary to provide the case study organisations with a strong influence in both the areas of study to be investigated and the manner in which the studies were approached. This implied that, *a priori*, the researcher could not determine which of the 4 application areas identified in section 4.2 would be explored, nor the precise approaches that were to be taken. Furthermore, many exogenous factors could influence the success, or otherwise, of collaboration. For example, the case study organisation's level of commitment and cooperation would be likely to influence the research findings, as would the nature of the personal relationships developed between the researcher and the key bidding personnel within each case study organisation.

Finally, when seeking suitable collaborators it proved impossible to target specific industrial sectors, as for example the construction and/or civil engineering industries. Each industries' individual characteristics would therefore compound the difficulties in comparing and generalising any of the research findings. (Although in retrospect because only one case study was pursued this weakness is largely irrelevant.)

4.6 SEARCH FOR ORGANISATIONS

The feasibility of the outlined research program was dependent upon gaining the collaboration of organisations involved in competitive bidding and who were based in the East Midlands. These organisations would need to provide extensive commitment over a period of some 6-9 months. This would be especially true during the knowledge acquisition stages of the project. Gaining the necessary level of
collaboration proved problematic and therefore when searching for suitable organisations several different approaches were adopted.

The first method of approaching organisations involved the use of contacts in the Department of Civil Engineering at Loughborough University. These contacts proved unhelpful, however, for it was clear that they wished to protect their relationships with construction and civil engineering organisations.

The second method of gaining collaboration involved approaching organisations through past and present students of LUBS’s part-time MBA programme. Many, if not most, of the large organisations in the East Midlands area sponsor their more promising managers through LUBS’s MBA, and several of these organisations were known to be involved in competitive bidding.

Before contacting these organisations a 5 page written research proposal (together with a 2 page summary) outlining the possible uses and benefits of expert systems in competitive bidding was produced (see Appendix A). Firstly, this proposal outlined the background to the research highlighting the importance of competitive bidding and the limitations of the previous bidding models. Secondly, it outlined the benefits of ES and ESS and the 4 possible areas of application identified in section 4.2. Thirdly, it outlined the nature of collaboration highlighting the problem definition, system development and validation and evaluation stages discussed in section 4.4. In particular, the proposal emphasized those areas of the research where the collaborating organisation would need to be actively involved, as for knowledge acquisition, and those areas where they would only need to be passively involved, as for example validation. Estimates of the time required from the organisation’s personnel during each of these stages were included in the proposal summary. Fourthly, the proposal outlined the type of factors that were believed to influence the managers’ bidding decisions. Finally, due to the commercial sensitivity of competitive bidding strategies, several guarantees of confidentiality were made.

The organisations were approached by sending the proposal to the manager who had completed, or was currently undertaking, the MBA. A covering letter outlined the nature of the research, and stressed that it was University sponsored so that collaboration would not involve any direct funding from the organisations themselves.

Eight organisations were approached via contacts identified through LUBS’s MBA. Of these 6 were large engineering companies involved in the design and manufacture
of medium to high technology mechanical, electrical and electronic products. In part this reflected both the scope of competitive bidding and the catchment area of LUBS's MBA. Of the 8 organisations approached 3 responded positively and with these organisations an initial meeting was arranged. The purpose of which was to discuss the nature of the outlined research in further detail, and in particular the level of commitment required by the organisation.

Approaching organisations known through LUBS's MBA produced 3 useful leads. However, 2 organisations wanted more time to consider the implications of collaboration in further detail, and the third organisation although very enthusiastic was considered unsuitable (see section 4.7). It was therefore decided that next course of action should involve writing to a large number of senior executives. Furthermore, it was believed that the level of commitment expected from the collaborating organisations could be off-putting. It was therefore decided that it might be expedient to attempt to perform some less involved pilot studies, whilst more suitable long term collaborators could be found.

LUBS had several years previously compiled a data base of companies in the Loughborough, Leicester, Derby and Nottingham areas from which list of approximately 50 companies who were thought to be involved in competitive bidding was compiled. Each of these organisations were then contacted by telephone, they were asked about their involvement in competitive bidding and the name of a suitable contact was sought. Through these conversations some organisations were ruled out from consideration and those remaining on the list were separated into two groups depending upon how good a target they were perceived to be. The first group were termed high profile organisations and these were those organisations most likely to result in long term collaboration. The second group were termed low profile, these were those organisations less likely to result in long term collaboration, but could be useful candidates for piloting the work whilst more suitable organisations were sought. This process ultimately resulted in a list of 13 high profile and 19 low profile organisations.

The contact in each organisation was then sent the proposal together with a covering letter. In the case of the low profile organisations, however, the proposal differed in the level of commitment required and the organisation's time input was reduced by the order of 30%. Of the 13 high profile organisations approached 3 responded positively, and of the 19 low profile organisations approached 6 responded positively.
As before with each of these organisations an initial meeting was arranged to discuss the nature of collaboration in further detail.

In addition a further 2 organisations were approached via personal contacts. So, in summary, in total 42 organisations were approached of which 14 responded positively. With each of these organisations a meeting was arranged to discuss in further detail the scope for developing ES for use within their bidding functions. The organisation's responses are summarised in the next section.
Table 4.7  Summary of the 14 Organisation’s Responses to Research Proposal

<table>
<thead>
<tr>
<th>Company Industry/Market</th>
<th>Initial Contact</th>
<th>Size of Company</th>
<th>Response from Company</th>
<th>Company’s Area of Interest</th>
<th>Access Gained</th>
<th>Result of Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Toxic Waste Disposal</td>
<td>MBA</td>
<td>Medium</td>
<td>Initially positive, but domain was a highly sensitive area.</td>
<td>Bid versus no bid &amp; pricing decisions</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>2 Telecommunications Equipment</td>
<td>MBA</td>
<td>Large</td>
<td>Very Positive. Research complemented their own initiatives.</td>
<td>Design + budget costing &amp; pricing</td>
<td>Yes</td>
<td>Proposed system outside scope of research</td>
</tr>
<tr>
<td>4 Computerised Process Control Equipment</td>
<td>High Profile Proposal</td>
<td>Large</td>
<td>Very Positive. Research complemented their own initiatives.</td>
<td>Bid versus no bid &amp; allocation of resources.</td>
<td>Yes</td>
<td>Concern over confidentiality of material. Project now run internally</td>
</tr>
<tr>
<td>5 Civil Engineering Contractor</td>
<td>High Profile Proposal</td>
<td>Large National</td>
<td>Positive</td>
<td>Pricing</td>
<td>Yes</td>
<td>Problems with gaining access to relevant experts</td>
</tr>
<tr>
<td>6 Construction Contractor</td>
<td>High Profile Proposal</td>
<td>Large National</td>
<td>Positive</td>
<td>Pricing</td>
<td>Yes</td>
<td>Expert unenthusiastic and sceptical of project’s success</td>
</tr>
</tbody>
</table>

+ This is a subjective assessment based on annual turnover and number of employees.
<table>
<thead>
<tr>
<th>Company Industry/Market</th>
<th>Initial Contact</th>
<th>Size of Company</th>
<th>Response from Company</th>
<th>Company’s Area of Interest</th>
<th>Access Gained</th>
<th>Result of Collaboration</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 Electro-Mechanical Engineering</td>
<td>Low Profile Proposal</td>
<td>Medium</td>
<td>Positive, but in a rather ill-defined area.</td>
<td>Design, Costing and Pricing</td>
<td>Yes</td>
<td>Unable to agree upon a suitable area for system.</td>
</tr>
<tr>
<td>8 Electro-Mechanical Engineering</td>
<td>Low Profile Proposal</td>
<td>Medium</td>
<td>Interested, but sceptical of feasibility in given time estimates.</td>
<td>Pricing</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>9 Electro-Mechanical Engineering</td>
<td>Low Profile Proposal</td>
<td>Medium</td>
<td>Interested, but sceptical of feasibility in given time estimates.</td>
<td>Pricing</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>10 Electro-Mechanical Engineering</td>
<td>Low Profile Proposal</td>
<td>Medium</td>
<td>Interested in idea, but not convinced of practical feasibility.</td>
<td>None identified</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>11 Construction Work</td>
<td>Low Profile Proposal</td>
<td>Small Local</td>
<td>Interested in idea, but not convinced of practical feasibility.</td>
<td>None identified</td>
<td>No</td>
<td>-</td>
</tr>
<tr>
<td>12 Medical Supplies</td>
<td>Low Profile Proposal</td>
<td>Medium</td>
<td>Positive</td>
<td>Pricing</td>
<td>Yes</td>
<td>Company responded to late to collaborate.</td>
</tr>
<tr>
<td>13 Civil Engineering</td>
<td>Personal Contact</td>
<td>Medium National</td>
<td>Positive</td>
<td>Pricing</td>
<td>Yes</td>
<td>Problems with gaining access to relevant experts</td>
</tr>
<tr>
<td>14 Scientific Equipment</td>
<td>Personal contact</td>
<td>Medium</td>
<td>Positive</td>
<td>Pricing</td>
<td>Yes</td>
<td>Company responded to late to collaborate.</td>
</tr>
</tbody>
</table>
4.7 Organisations' Responses to the Research Proposal

Of the 42 organisations approached 14 responded positively to the research proposal and this section briefly summarises their responses. (Table 4.7 summarises the major characteristics of these 14 organisations and also their responses to the research proposal.) The 14 organisations were involved in a variety of different activities and thereby highlighted the diverse scope of competitive bidding. Of the 14 organisations 4 were involved in construction and/or civil engineering. Two of these were national civil engineering contractors, although one was also involved to a minor extent in construction work, whilst the other 2 were solely involved in the construction industry. A further 3 organisations were involved in high technology markets, and of these one was a manufacturer of sophisticated computerised process control equipment, another a manufacturer of telecommunications equipment; whilst the third was involved in the disposal of toxic waste. Of the remaining 7 organisations, 5 were traditional electro-mechanical engineering companies, whilst 2 were involved in the supply of scientific and medical equipment.

In the overwhelming majority of cases the managers seemed enthusiastic of learning more about the nature of ES and their characteristics which would enable them to assist the managers in their bidding decisions. This was taken to suggest not only that competitive bidding is an important managerial issue for many organisations, but also it is one where greater management support is welcomed.

The interviews with the 14 organisations suggested that the six generic factors included in the research proposal (organisational objectives, current position, market trends, nature of contract, nature of customer and nature of competition, see Appendix A) provided a comprehensive list of the types of factors that are likely to influence a contractor's bidding decisions. Many managers, however, remained unconvinced that it was feasible to capture and replicate their bidding expertise. In their defence the managers stressed that assessing and combining each of these factors was a difficult and complex task involving numerous different sub-factors. These comments suggested that much bidding expertise is conceptually organised into some kind of hierarchical structure in which different factors operate at different conceptual levels. Most managers accepted that this was a reasonable model of their expertise, and it was therefore put to the managers that the role of the knowledge acquisition would be to identify the natural hierarchical structure of their bidding expertise. Some managers still remained sceptical, however, that there was any structure to their expertise, and in retaliation they put forward the argument that for any factor the
method of assessment may vary from one bid to the next. This argument, however, could only imply that the managers' expertise was complex in the sense that in a relationship between a set of sub-factors and a higher level factor there were many possible combinations to consider. For, if this argument was taken to imply anything other than this, it could only imply that the managers were inconsistent in their assessments! At this point most managers were convinced that their bidding expertise did obey some form of natural structure, even if the structure itself was very complex; and therefore were convinced that, in theory, it was feasible to investigate developing ES for use in bidding. Some managers from the low profile organisations did, however, question the feasibility of collaboration given numerous sub-factors and the optimistic time estimates in the research proposal.

From the meetings it was evident that the larger, higher technology organisations were more enthusiastic of long term collaboration than were the smaller organisations. This could have been due to one or more of several reasons. Firstly, without exception, these organisations were already sophisticated users of Information Technology (IT) and therefore the introduction of IT based tools into the workplace was not an uncommon occurrence. Indeed two of the high technology organisations were already involved to a small extent in the development and use of ES applications. Whilst the third together with one of the larger electro-mechanical engineering organisations were aware of ES technologies and were keen to bring ES expertise into their respective organisations. Secondly, for at least two of these organisations there was significant design element within their often drawn out bidding processes. Their bidding activities were therefore seen as an extensive, time consuming drain on resources where small improvements could be very beneficial. Finally, these organisations were probably less antagonistic towards discussing their problems with university academics. The managers of these organisations were all highly educated, very few did not hold a university degree or equivalent, and some held post graduate qualifications. In these respects these organisations may have felt the they had more to gain than the smaller organisations from collaborating with university based research.

Indeed three of the four organisations considered above had developed strong ideas of their own as to where and how ES could be most beneficial to their bidding performance. In particular, both the manufacturer of computerised process control equipment and one of the higher technology electro-mechanical engineering organisations believed that use of ES could be of greatest benefit during the front end of their respective bidding processes, namely the bid versus no bid decision and the
allocation of bidding resources to bid preparation. In many respects their interest in the early stages of the bidding process reflected the characteristics of their respective bidding situations. Firstly, relative to the majority of the remaining 12 organisations interviewed their bidding activities were characterised by a low volume of high value tenders. Secondly, there was an extensive design element to each of their bids, requiring a significant expenditure of bidding resources, thereby creating a large front end cost. Furthermore, although both organisations were asked to submit sealed bids, there was inevitably a second stage of negotiation. As a result the final bid price (that is, the price included in the sealed bid) was not regarded as such an important issue. In light of these characteristics both organisations placed considerable emphasis and effort into identifying suitably attractive tenders to pursue. However, both organisations felt that their respective bid versus no bid and bid resourcing policies were in need of review. Consequently, both organisations were keen to collaborate with the research, as they both felt that it would complement their own initiatives.

In both organisations relevant expertise was highly dispersed amongst several managers. Both organisations, therefore, held regular review meetings where the relevant managers would discuss tenders and projects in progress in order to reach appropriate bid versus no bid and bid resourcing decisions. Even so both organisations showed considerable concern over the lack of a formal basis for their bidding decisions. Both expressed concern that their decisions were made unsystematically and were possibly inconsistent. In both cases the greatest perceived benefits of a resulting ES were the clarification and drawing together of related multiple sources of expertise within a single knowledge base. The aim of the ES was therefore to provide a single standardised approach to each organisations' respective bidding decisions. The use thereafter of such a system would enable future bidding decisions to be made both more objectively and consistently, and thereby enable scarce and valuable bidding resources to be more fruitfully allocated.

The manufacture of telecommunications equipment was also keen to collaborate and had identified a role for which it felt an ES would prove beneficial. It envisaged a lap-top based system that would assist the sales engineers in the design, costing and pricing of its communications systems. The role of the system was to produce budget bid proposals in the customers' offices in response to the customers' requirements. The organisation believed that such an ES would provide them with competitive advantage because it would enable them to respond to their customers' requirements more quickly than their competitors. However, even though the organisation were very keen to collaborate it was felt that its envisaged system was outside the scope of
the proposed research, and furthermore would not be feasible within the time available. Consequently, a collaborative project was not pursued with this organisation.

Three of the four construction / civil engineering organisations, although less enthusiastic than the larger higher technology organisations, agreed to collaborate with projects to develop ES to assist their respective bidding managers' in their final pricing decisions. Again, as with the larger higher technology organisations, this reflected these organisations' respective bidding situations. The bidding activities of all three organisations were characterised by a large volume of low value tenders. (In one organisation the order of 250 bids were submitted each year, and in all three case the highest value bids were only of the order of 1 million pounds.) None of the organisations placed a great deal of emphasis on the bid versus no bid and bid resourcing decisions. One manager summarised his organisation's no bid versus no bid policy in one line, "if the [contracts] value is more than 250,000 and we have capacity available we will take our chances and submit a bid". Furthermore, in all three cases the overwhelming majority of bids (90-95%) were build only contracts, where detailed architects specifications and drawings were provided by the customer to be costed and priced by the contractor. Their business was further characterised by a high proportion of public sector work (~70%), all three organisations were asked to submit sealed bids, there was very little post bid negotiation and the lowest priced bidder was believed to be the winner in all but the most exceptional cases. Consequently, the these organisations' respective interest in developing ES to assist during the latter stages of the bidding process was a reflection of the extent to which the final bid price influences the outcome of the customers' appraisal of the suppliers' bids.

So, initially five case studies were started. Two of these studies involved the development of ES to assist managers in the bid versus no bid and bid resourcing decisions; whilst three studies involved the development of ES to assist managers in the final bid pricing decision.

Given the limitations on the researcher's time it was clearly not feasible to pursue all five case studies through to completion. The rationale, however, for starting with the five studies was the fear that some organisations might find the level of collaboration overbearing in light of other more important demands on their resources, and may therefore wish to withdraw from collaboration mid project. Furthermore, it was possible that many other problems could arise that would influence the successful
completion of the case studies. Indeed throughout the course of the case studies several such problems did arise, and to such an extent that only one study was performed through to completion. However, the excellent cooperation from the organisation concerned enabled the single study to be performed to a much greater depth than was originally anticipated.

Problems arose very early in the studies involving the civil engineering contractors and in both cases the principle problem was gaining access to the relevant expert bidding managers. In one of these organisations the final bid price was determined at a meeting between one of the two business managers and the chief cost estimator (although on smaller value contracts a more junior estimator may be involved). The company was, however, in a process of considerable reorganisation after a recent merger and access to the two business managers could not be obtained. In the second civil engineering contractor pricing decisions were without exception referred to the board of directors, and again repeated access to the board's members could not be obtained. These two studies were therefore terminated amicably at the end of their respective problem definition stages.

In the study involving the construction contractor the major problem was that the chief estimator (one of the two managers responsible for the bid pricing decision) whom had been nominated by the organisation as its main expert was unenthusiastic and sceptical about the project's success. The reasons behind his feelings were uncertain, but the most likely reason was that he felt that his status would be threatened by a computer system whose role was to emulate his own area of expertise. The manager habitually postponed meetings the day they were due to take place, and then refused to arrange an alternative date until several weeks in advance. Furthermore, it was apparent that the manager had reservations about discussing commercial decisions and providing relevant documented material. Although in fairness to the manager these seemed to stem more from the manager's uncertainty regarding whether he had appropriate authorisation to do so rather than purely from a lack of desire to cooperate. The organisation's lack of cooperation was unfortunate because all the early signs indicated that a simple system could be developed, however, owing to the expert's lack of enthusiasm, in due course this study was also terminated during the knowledge acquisition stage.

So, ultimately it was two of the larger, higher technology organisations with whom collaboration was most successful. Even in one of these cases, however, the managers showed concern regarding the confidentiality of their bidding expertise. In
particular, they were unwilling to provide any relevant documented material or
discuss on going and recent bids in sufficient depth with an external party. The
organisation were, however, keen to pursue the development of an ES to assist the
managers in their bid versus no bid and bid resourcing decisions. Therefore, to
overcome the confidentiality problem, an arrangement was made for one of LUBS's
part-time MBA students from the organisation to continue with the project under the
direction of the researcher and his supervisor using the development and validation
methodologies devised throughout part B of this thesis.

Therefore, in the end only one case study was pursued through to completion,
however, as previously noted it was pursued to a much greater depth than was
originally anticipated. This case study is described in detail in part B of this thesis.

4.8 SUMMARY

This chapter has reiterated the weaknesses of previous bidding studies and has
outlined the characteristics of expert systems (ES) which suggest that they may
provide a more appropriate tool with which to provide management decision support
in this area. These characteristics include consolidating multiple sources of expertise
within a single knowledge base and minimising human fallibility by ensuring that
future bidding decisions are made in a more systematic, objective and equitable
fashion.

From an analysis of the competitive bidding process discussed in chapter 2, four
possible roles for ES in bidding have been identified. These include: assisting with
decisions concerning whether or not to bid; assisting with decisions concerning the
amount of bidding effort; assisting with decisions concerning the most appropriate
design; and assisting with decisions concerning an appropriate bid price and package.

A simple six stage framework for investigating the roles and benefits of ES in
competitive bidding has been devised. The framework is based on a small number of
in depth case studies involving organisations involved in competitive bidding.

To find suitable collaborators 42 organisations believed to be involved in competitive
bidding in the East Midlands were approached with a formal research proposal. Of
these 42 organisations 14 responded positively, and an initial meeting was arranged
with these to discuss the nature of collaboration in further detail. Of these 14
organisations, 3 had very strong ideas as to where and how ES could be most beneficial to their bidding performance and were very enthusiastic about collaboration. For one of these organisations, however, it was felt that the envisaged system was outside the scope of the proposed research, and furthermore would not be feasible within the time available. Of the remaining 11 organisations a further 3, although less enthusiastic, agreed to some form of collaboration; and as a result five case studies were initially started.

Several of these case studies ran into problems. These included the inaccessibility of the relevant expert bidding managers and lack of cooperation due to fears over commercial confidentiality. These problems suggested that in the end only one study could be pursued through to completion, however, with the extra time available it was then pursued to a much greater depth than was originally anticipated. This case study is described in detail in the subsequent chapters in part B of this thesis.
PART B

A CASE STUDY: AN EXPERT SUPPORT SYSTEM FOR TENDER ENQUIRY EVALUATION
CHAPTER 5

COMPANY BACKGROUND AND PROBLEM DEFINITION
5. **COMPANY BACKGROUND AND PROBLEM DEFINITION**

5.0 **INTRODUCTION**

This chapter describes both the background to the case study organisation and the scope of the collaborative project that was undertaken. The chapter commences with a brief overview of the organisation's business activities and its structure. The chapter then focuses on one of the organisation's two major operating divisions and its activities, structure and approach to tendering are described. The division's response to the research proposal is noted, which led to the definition of a collaborative project exploring the possibility of developing an expert support system (ESS) to assist in the bid versus no bid decision and the allocation of bidding resources. Finally, the division's approach to these decisions is described in detail and the project objectives outlined.

5.1 **ORGANISATIONAL BACKGROUND**

The case study organisation is a prestigious engineering company, specializing in the design, manufacture and commissioning of large multimillion pound electro-mechanical products. It is one of the world's foremost organisations within its industrial sector with over 150 years experience and has earned an international reputation for the quality of its products with sales in over 30 countries. The organisation competes for all of its major business through the process of competitive tendering against both fierce UK and overseas competition. In the year ending March 1989 its sales were in excess of 350 million pounds.

5.2 **ORGANISATIONAL STRUCTURE**

The board of directors consists of seven members. These are the Managing Director, the directors of the four corporate functions Finance, Information Technology, Marketing and Personnel; and the directors of the two major divisions who control the organisation's business activities. These are the New Products Division (NPD) and the Manufacture and Repair Division (MRD) respectively.
The NPD is involved in the design, manufacture and commissioning of new products; whilst the MRD manufactures components for inclusion in new products and is also responsible for the maintenance and repair of products in service. This case study focuses solely on the business, and in particular the tendering, activities of the NPD. The following two sections provide a brief overview of both its structure and tendering activities.

5.3 The Structure of the New Products Division (NPD)

The New Products Division (NPD) operates as a largely autonomous business unit through a matrix structure. The NPD is divided into five business groups each responsible for a distinct product range. Each business group is headed by a Business Group Manager who is responsible for achieving that group's performance targets. In addition there are four functions supporting the activities of these managers; these are Engineering, Manufacturing, Procurement and Sales & Commercial. Together these four functions provide the necessary resources to both obtain business via tender proposals, and then to manage those contracts that result from successful tenders during the design, manufacture and commissioning stages. Ultimately, the five Business Group Managers and the managers of the supporting functions report directly to the NPD's director who has overall responsibility for the division's operations.

5.4 The NPD's Tendering Process

The NPD's tendering process closely matches the tendering process models described by King & Mercer (1988), Ward & Chapman (1988), and the hybrid model outlined in section 2.2. The NPD's approach to tendering can be divided into four serial stages. These are as follows:-

1. Receipt of Enquiry or Invitation to Tender (ITT)
2. Bid Versus No Bid Decision - Tender Action Group (TAG)
3. Design and Cost Estimation
4. Putting the Tender Proposal Together - Tender Pricing

The nature of each of these stages is outlined in the following sub-sections respectively.
5.4.1 Receipt of Enquiry or Invitation to Tender (ITT)

The NPD responds to two types of enquiry. These are known as unsolicited and solicited enquiries respectively. Unsolicited enquiries are those where the customer has identified a specific requirement and has then forwarded details of the requirement, in the form of an enquiry document or ITT, to several suitable suppliers. Whereas, for solicited enquiries the organisation plays a far more pro-active role in obtaining the enquiry. Solicited enquiries are normally obtained through the marketing function. Rather than the customer identifying a specific requirement, the marketing function identifies the customer's needs and then through a dialogue with the customer attempts to solicit an enquiry, or alternatively suggests to the NPD that they should submit a pre-emptive bid, that is prepare a tender proposal without being asked by the customer.

5.4.2 Bid Versus No Bid Decision - Tender Action Group (TAG)

All enquiries received by the NPD are vetted by the Tender Action Group (TAG) which comprises of a committee of senior managers. The TAG decides whether or not to proceed with the preparation of a tender proposal in response to the enquiry; and if so the level of bidding resources to allocate to the preparation of the proposal. The nature and role of the TAG is described in detail in section 5.5.1.

5.4.3 Design and Cost Estimation

If the TAG recommends a "go ahead" bid decision then a highly complex design and cost estimation process is called into action. The process involves several small teams responsible for producing detailed designs, manufacturing costs, project programmes, project financing plans and quality assurance programmes.

5.4.4 Putting the Tender Proposal Together - Tender Pricing

Eventually all the design and costing information is brought together by the Proposals function (which is part of the Sales & Commercial function) to produce the tender proposal. The final stage of the process is concerned with tender pricing. A standard tender price is calculated using a spreadsheet model based on corporate guide-lines relating to return on capital employed, return on sales and percentage profit levels. Depending upon the value of the tender the final price has to be authorised at various
levels starting with the relevant Business Group Manager, followed by the NPD Director and then finally the Managing Director. During this process the price is "tweaked" in light of a number of salient factors.

5.5 Problem Definition

Contact was initially established with the case study organisation to explore the possibility of a collaborative project using expert systems technology. Senior managers in the organisation were impressed with the research proposal discussed in chapter 4 outlining the problems with the previous approaches to modelling tendering situations and the possible applications and benefits that expert systems could provide (see appendix A). As a result an initial meeting was arranged with the NPD's Sales & Commercial Manager and the Proposals Manager to discuss the nature of collaboration in more detail. At this meeting it transpired that the NPD was particularly enthusiastic about exploring the prospect of developing an ESS to assist in the second stage of its tender process, namely the bid versus no bid decision and the allocation of resources for bid preparation. The managers' cited two principle reasons for wanting to concentrate on these particular managerial tendering decisions. These were as follows:-

Firstly, there was a growing concern within the NPD that the bid versus no bid and bidding resource allocation decisions were being made unsystematically in a somewhat "ad-hoc fashion" rather than on a formal basis. The organisation believed that a collaborative project investigating the application of expert systems technology would prove beneficial to the NPD because its success would be dependent upon the clarification of its criteria for deciding whether or not to bid and the related allocation of bidding resources; and also because the resulting ESS would enable future bid versus no bid and bid resourcing decisions to be made in a more systematic, objective and equitable fashion.

Secondly, the organisation was looking closely at the effects of the removal of trade barriers in Europe after 1992. The organisation's industrial sector is presently a protected category within the European Economic Community (EEC) and therefore customers within the EEC are not obliged to publicly advertise their requirements in a European journal. Consequently, it is difficult for the NPD to pursue business with customers within the large industrialised EEC countries with their own indigenous industries, as for example Germany, France, Italy, Holland and Spain. By 1992,
however, it will be illegal for any customer within the EEC not to make its requirements known publicly; and so post 1992 the organisation will have free access to the European market. In the meantime the NPD only tender for business on the fringes of the European market in the smaller countries without well developed indigenous industries, as for example Denmark, Greece and Yugoslavia. Several of the NPD's UK customers have, however, pre-empted the 1992 legislation and have begun to invite tenders from the EEC thus increasing the competition within the NPD's home market. The changing business environment has led the NPD to review its current tendering practices, and in particular to review its criteria for deciding which enquiries to pursue. The NPD believed that a collaborative project would help to clarify its current tender strategies; and as a result of which, it would be better positioned to develop tendering strategies for its changing environment and for Europe after 1992.

A combination of these two concerns led the organisation's senior managers to believe that a collaborative project to develop an expert support system (ESS) to assist with the bid versus no bid and bid resourcing decisions would prove beneficial to the NPD and complement their own initiatives. The NPD's mechanism for reviewing enquiries (or ITT) to decide whether or not to bid, and if so the level of tendering effort, is outlined in sub-section 5.5.1 below.

5.5.1 THE ROLE OF THE TENDER ACTION GROUP (TAG) - THE BID VERSUS NO BID DECISION

Each year the NPD receives about 80 tender enquiries inviting the organisation to prepare a tender proposal and compete for the offered business via a competitive bid. The nature of the organisation's business dictates that for every enquiry a significant input of design resources is required to produce a high quality tender proposal. As a result the overall cost of tendering or pursuing a particular enquiry is high because the design component of a proposal creates a large front end cost. Therefore, due to the high input of resources necessary in preparing high quality tender proposals it is not the organisation's policy to tender for all prospective business. Tender enquiries are therefore evaluated against a number of salient criteria to identify their relative merits and demerits, and hence filtered in order to target the organisation's resources towards the most attractive business opportunities. As a result the bid versus no bid and bid resourcing decisions are referred to collectively as tender enquiry evaluation.
All tender enquiries received by the NPD are vetted by a committee referred to as the Tender Action Group (TAG). This group meets regularly every fortnight and provides a mechanism for deciding whether or not to proceed with the preparation of a tender proposal in response to an enquiry (or ITT). The TAG is a committee of senior managers who review the current status of enquiries and ongoing projects and represents the interests of the Business Group Managers and the four functions who support their activities.

The TAG exists in an advisory capacity and its decisions are reached by management consensus. Its role is to inform the relevant Business Group Manager of the implications of pursuing a particular enquiry. For example, the TAG would discuss the demands that the enquiry would place on existing resources and aim to highlight any potential difficulties in the product's design and manufacture. Ultimately the TAG's role is to recommend appropriate action concerning whether or not to bid; and consequently an appropriate level of resources to allocate to the preparation of the tender proposal.

Each enquiry reviewed by the TAG is awarded one of five bid decision categories. The bid versus no bid decision can therefore be regarded as a classification type problem. This is because in effect the role of the TAG is to consider enquiries along a number of salient dimensions and then classify them into one of the five *a priori* defined mutually exclusive classes. Each category indicates the level of resources to be allocated to the preparation of the tender proposal in response to the enquiry. In descending order of resource allocation these five bid decision categories are Bid A, Bid B, Bid C, Referral and No Bid respectively.

A Bid A decision signifies the NPD's commitment to produce a fully responsive tender proposal with "100% effort", the aim being to offer the customer a fully documented tender proposal with "firm", that is guaranteed prices. The NPD refer to enquiries awarded Bid A decisions as "high profile" enquiries. Bid A decisions are awarded to those enquiries that the NPD believe represent highly attractive business opportunities.

Enquiries awarded Bid B and Bid C decisions represent business opportunities that the NPD consider to be worth pursuing, but are not as attractive as those enquiries which are awarded Bid A decisions. As a result less resources are allocated to the preparation of tender proposals for enquiries awarded either of these two bid decisions than for those enquiries awarded Bid A decisions. A Bid B decision
signifies "50% effort", the overall aim only to produce a tender proposal with budget prices so that in effect the NPD's response is non-committal. A Bid C decision signifies the allocation of even less resources, "25% effort"; its aim is primarily to "keep things ticking over", or "keep a foot in the door", and is therefore often awarded to projects that are in their infancy where the customer is seeking "rough" cost estimates for inclusion in an investment appraisal.

Since the TAG discusses both solicited and unsolicited enquiries it is possible that it does not have a formal ITT or enquiry document from the customer. As a result the TAG may feel that there is not sufficient information to award the enquiry an appropriate bid decision. In such circumstances the NPD can postpone making its decision by awarding the enquiry a Referral decision thus placing the enquiry on the agenda of the next TAG meeting so that further information can be sought before an appropriate decision is made. Finally an enquiry can be awarded a No Bid decision signifying that the NPD wishes to decline the invitation to tender. No Bid decisions are awarded to those enquiries that are believed to represent very unattractive business opportunities.

The initial discussion with the NPD's Sales & Commercial Manager and the Proposals Manager (together with later individual discussions with the Proposals Manager) led to the conclusion that management consensus and therefore appropriate bid versus no bid decisions are generally easily reached on both the highly attractive and very unattractive enquiries respectively; but that medium attractiveness enquiries are much more difficult to evaluate.

5.5.2 AIMS OF PROJECT

Once collaboration was agreed, two objectives of the case study were identified. These were firstly, to test the hypothesis that knowledge based expert systems technology could provide a useful medium for providing decision support in the bid versus no bid and bid resourcing decisions by developing a prototype ESS to assist the NPD's management in the evaluation of tender enquiries. Secondly, due to the forthcoming legislative changes taking place in the NPD's business environment, to enhance managements' understanding of the key factors and their inter-relationships underlying the tender evaluation process and the bid versus no bid and bid resourcing decisions.
5.6 Summary

The case study organisation is a large engineering company specialising in the design, manufacture and commissioning of multimillion pound electro-mechanical products. The organisation is split into two major operating divisions and this study focuses solely on the tendering activities of the New Products Division (NPD).

The organisation was enthusiastic about the possible benefits that expert systems could provide the NPD in its tendering activities; especially the benefits relating to consistent advice drawn in a systematic fashion and the clarification of management's knowledge. As a result the NPD consented to take part in a collaborative project to develop an expert support system (ESS) to assist the Tender Action Group (TAG), a multi-functional committee of senior managers, in its evaluation of tender enquiries and the important bid versus no bid and bid resourcing decisions.
CHAPTER 6

KNOWLEDGE ACQUISITION - SELECTING AN APPROPRIATE TECHNIQUE
6. Knowledge Acquisition - Selecting An Appropriate Technique

6.0 Introduction

This chapter describes the selection of an appropriate knowledge acquisition technique for use within the case study organisation and the domain of tender enquiry evaluation. The chapter commences with a brief discussion of the knowledge acquisition process and of the various techniques which are currently available to improve both the process' effectiveness and efficiency. It is concluded that it is important to develop an overall knowledge acquisition strategy and to choose a set of knowledge acquisition techniques whose properties closely match the characteristics of the domain. Therefore, following this conclusion the most significant characteristics of the domain are discussed. These characteristics are then compared to the properties of several knowledge acquisition techniques and on this basis an appropriate technique is selected for use within the case study organisation.

6.1 Knowledge Acquisition (KA) - A Definition and Overview

The process of knowledge acquisition (KA), which at this juncture is defined both simply and tautologically as - the process of acquiring an expert's knowledge relevant to the domain of discourse, is central to expert systems (ES) development. Unfortunately, experience suggests that the KA process is both time consuming and fraught with difficulties (Kidd, 1987 pp. 1; Berry & Broadbent, 1986). Indeed, for several years it has been the traditional view of the ES community that KA is the critical bottle-neck in ES development (Feigenbaum & McCorduck, 1984 pp. 107). Furthermore, this view-point is supported by two recent surveys of parties involved in the development of ES (see O'Neill & Morris, 1989; Doukidis & Paul, 1990).

O'Neill & Morris's (1989) survey concluded that the major problems encountered during KA were the time consuming nature of analysing, interpreting and abstracting relevant knowledge from the vast amount of information available, usually in the form of an unstructured interview transcript. This suggests that the KA process is poorly understood and that many developers of expert systems are using ad-hoc

1 O'Neill & Morris (1989) surveyed UK software houses specialising in artificial intelligence and UK businesses who are actively involved in expert systems development to examine their development methodologies.
methods in an attempt to circumvent the process' inherent difficulties. Although Doukidis & Paul's (1990) survey\(^2\) does not explicitly highlight problems with KA, the authors conclude that the two most significant constraints affecting more widespread ES development are the time taken and costs involved (constraints which are clearly correlated) in implementing these systems. Again these two characteristics may be interpreted as being symptomatic of a poor understanding of the KA process.

There are those, however, who challenge the traditionalist blanket view that KA is both difficult and time consuming per se. For example, Cullen & Bryman (1988) from their survey of 70 ES projects in the UK and USA suggest that the time has come for a new perspective on KA. They regard KA as an intervening variable in the process of ES development; and the results from their survey suggest that choosing a wrong KA strategy can lead to a project's eventual failure, but very rarely can the failure of a project be traced directly to problems encountered during KA. They report that problems concerned with managerial support and the restrictive representation formalisms in currently available software tools are more likely to lead to a project's failure. Cullen & Bryman (1988, pp. 222-223) conclude that the KA bottleneck is a selective phenomenon and it is expedient to differentiate between acquisition critical applications and acquisition independent applications, a differentiation based upon the characteristics of the application domain. For acquisition independent applications, characterized by narrow, shallow knowledge domains and where the system's function is low level and routine, then the choice of KA strategy is largely irrelevant. For acquisition critical applications, however, characterised by wider, more ill-structured domains and where the system's function is further towards emulating the expert, then the choice of KA strategy is more likely to be a significant variable in governing the success of the project. In such circumstances development difficulties are likely to arise if inappropriate KA strategies and techniques are adopted which are incompatible with the characteristics of the domain. Therefore in these circumstances it is important to develop an overall KA strategy and adopt a set of KA techniques whose properties are well matched to the domain's characteristics. This recommendation to develop a KA strategy that matches the domain's characteristics to the properties of a set of KA techniques has been proposed by several other researchers (see Kidd, 1987 pp. 11; Gammack & Young, 1985 pp. 105-112; Berry & Broadbent, 1986). Moreover, the consensus of opinion suggests that this matching should be performed irrespective of whether or

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\(^2\) Doukidis & Paul (1990) surveyed the British Operational Research Society to examine the membership's degree of involvement in artificial intelligence and expert systems.
not the application domain is acquisition critical as measured by Cullen & Bryman's (1988) criteria.

The above recommendation of matching the domain's characteristics to the properties of a KA technique has been applied in the case study under discussion; and the next two sections in this chapter discuss the characteristics of the domain of tender enquiry evaluation and the matching of these characteristics to an appropriate KA technique respectively. Before proceeding to discuss these issues, however, the nature of the KA process is described in more detail.

The KA process is one that is difficult to define, a result of the limited understanding of the nature of knowledge and expertise itself. Over the last 10 or so years, however, two quite distinct schools of thought concerning KA have emerged. The first of these has its origins in computer science and with the pioneers of artificial intelligence and ES. The advocates of this school of thought regard KA as a process involving the extraction, mining or elicitation of jewels, nuggets or chunks of knowledge. For example, Sell (1985) in his book Expert Systems - A Practical Introduction defines KA as follows:-

"Knowledge acquisition is the process of building the knowledge content of expert systems, the so-called knowledge base. It is a process that carries on throughout the life of the system. It has several tasks to perform: it has to elicit knowledge, organise it, encode it, validate it and tune it." (Sell, 1985 pp. 26)

Other definitions from this school of thought are:-

Feigenbaum & McCorduck (1984, pp. 107) - "Knowledge acquisition - mine those jewels of knowledge out of [the experts'] heads one by one"

Olsen & Reuter (1987, pp. 152) - "Knowledge acquisition is the extraction of knowledge from the expert"

Kim & Courtney (1988, pp. 269) - "Knowledge acquisition is the process of gathering knowledge about a domain usually from an expert, and incorporating it into a computer program"

This first school of thought has recently been referred to as a functionalist approach (Whitley, 1990). The underlying assumption of the functionalist approach is that there is "one reality ... that is essentially the same for everyone" (Hirschheim & Klein, 1989 pp. 1203); that is, there is only one view or version of the truth. This arises
from the belief that ES operate in formal domains rather than in non-formal or semi-formal domains. Formal domains are those where knowledge is clearly defined and openly examinable. In such domains knowledge may be largely definitional or structural. Moreover, there is a single view of truth and a unique correct solution exists. Consequently, it is believed that knowledge is atomic and can be transferred atom by atom from the expert to the knowledge engineer. Under this paradigm the ES's knowledge base becomes an isomorph of the expert's reality or knowledge. These atomic and transferable properties of knowledge are reinforced by Sell (1985) who suggests that "elicitation delivers single items of knowledge that need to be organised into a unified whole" (Sell, 1985 pp. 27). So, this first school of thought regards the KA process as one whose objective is to re-create reality.

Furthermore, in the definitions of the KA process proposed by Sell (1985) and Kim & Courtney (1988) the product or result of the process is the ES itself, at least in some skeletal form. Thus, the scope of the KA process has increased; for not only does it involve the gathering and organisation of knowledge, but it also involves the encoding of this knowledge into some chosen representational formalism. Many researchers believe that the inclusion of the encoding of the knowledge within the KA process has detrimental effects. For example, Pollitzer & Jenkins (1985) argue that the most appropriate knowledge representation scheme and inference strategies are dependent upon the characteristics of the domain. Therefore, imposing a particular representational formalism on the KA process will dictate to the knowledge engineer the types of knowledge structures and reasoning processes to look for, this may result in an underestimation of the complexity of the knowledge and reasoning processes, and subsequently the loss of significant facets of expertise. As Breuker & Wielenga (1983, pp. 6) assert "nothing is so detrimental to the acquisition of insight than an underestimation of the complexity of the knowledge and reasoning in a particular domain". These arguments suggest that KA and the subsequent encoding of the knowledge in an appropriate representational formalism should be regarded as two independent processes; and therefore the product of the KA process should be an implementation independent representation of the expert's knowledge.

The second more recent school of thought concerning the KA process has emerged from the recognition that in semi or non-formal domains absolute truth or a single view of reality does not necessarily exist. Instead reality is believed to be personally or socially constructed, a product of individuals who give it meaning and create different versions of same domain. In such domains there may be many views of the truth. Furthermore, knowledge is often unarticulated and is seldom, if ever, openly
examinable. This school of thought has been termed the socio-technical approach (Whitley, 1990) and its advocates regard KA as a modelling process (Neale, 1987 pp. 155; Kidd, 1987 pp. 11; Breuker & Wielinga, 1987). Under this hypothesis knowledge is not regarded as a completely transferable collection of atomic structures. As Neale (1990, pp. 447) asserts "there are obvious difficulties in assuming that one human can ever entirely share another's knowledge". The objective is thus not to create an isomorph of the expert's (or experts') reality or knowledge, but to develop a conceptual homomorphic model of the domain incorporating the salient domain concepts and their inter-relationships. Neale (1987) in his review of KA for ES offers the following definition.

"Knowledge acquisition involves the creation of a conceptual model of the expert's knowledge and reasoning, from the analysis of data elicited by various techniques" (Neale, 1987 pp. 155)

The KA process by which such a conceptual model is developed is outlined by Kidd (1987, pp. 3). In her methodology the process is assumed to consist of three phases. These are:-

1. Employing a technique to elicit data (usually verbal from the expert)

2. Interpreting these verbal data (more or less skilfully) in order to infer what might be the expert's underlying knowledge and reasoning processes

3. Using this interpretation to guide the construction of some model or language that describes (more or less accurately) the expert's knowledge and performance. Interpretation of further data is guided in turn by this evolving model.

Similar three phase approaches to KA are also described by Welbank (1983, pp. 6-7), Grover (1983) and Breuker & Wielenga (1987). The above three phase KA methodology has been adopted for use within the case study organisation and it's application is described in the subsequent chapters 7, 8, 9, and 10.

Welbank (1983, pp. 8-15) provides a comprehensive review of the major problems encountered during the KA process. Some of these problems can be seen to result from the socio-politico relations between the knowledge engineer, the expert and the system's or project's sponsor; and Welbank (1983) offers some advice on how these problems can be alleviated. Welbank (1983) also highlights a set of problems that are
more indicative of the fundamental difficulties in modelling knowledge. These problems are related to awareness and articulation, black box models and mis-leading models, and each of these are worthy of further note. Neale (1990, pp. 450) succinctly summarises the KA problem in the assertion that "the key problem in knowledge acquisition is the derivation of the domain concepts and the relationships between them". The problem of awareness and articulation arises because experts need not be necessarily aware of their own internalized conceptual structures; and therefore they may find great difficulty in being introspective and analysing their own knowledge to abstract the salient domain concepts and their inter-relationships. As experts become more expert they become less aware of the own reasoning processes, it is said that there knowledge becomes compiled (Chandrasekran & Mittal, 1983). Their judgements no longer rely upon reasoning from first principles, but rather tend to rely more upon experience and analogy by recognising patterns, features or characteristics. This phenomenon can lead to the development of so called black box models because experts articulate their knowledge at a very shallow level missing out the important intermediate steps to their reasoning. The problem with mis-leading models arises because their is no justifiable reason to believe that an expert's first conceptualization of the domain is the right one (if indeed a right conceptualization does exist), thus the concepts and their inter-relationships may appear unstable over time as the expert re-analyses and re-evaluates his or her conceptual structure of the domain.

The field of cognitive psychology has provided numerous techniques or methods that can benefit the KA process. Primarily these techniques are geared to provide assistance with the first phase of the KA process. However, since the objective of many of the techniques is to provide more effective and efficient data elicitation, then they also benefit the subsequent stages of analysis/interpretation and model construction. The most comprehensive overviews of these techniques are those provided by Ian Neale of ARIES at City University (see Neale, 1987, pp. 49-106; Neale, 1988).

The importance of matching the characteristics of the domain to the properties of a particular KA technique was stressed earlier in this section. However, this raises the important question concerning which characteristics and properties should be matched? With the current state of art as it is there is no definitive answer to this question. Some research has been conducted to provide empirical evidence from a controlled environment to suggest which techniques are most appropriate for which domains (see Schweickert et al., 1987), although the results from this small study are
inconclusive: more promisingly ESPRIT initiatives are attempting to provide a proper epistemological foundation for KA. For the time being, however, both Kim & Courtney (1988) and Olsen & Reuter (1987) have provided theoretical frameworks which assist in the selection of appropriate KA techniques for use in a particular domain. In both of these frameworks the matching is based principally upon the characteristics of the knowledge used within the domain.

It is important to recognise that knowledge is not homogeneous; and it is generally recognised that there are two types of knowledge: so called declarative knowledge and procedural knowledge (Kim & Courtney, 1988). Declarative knowledge is knowledge about the domain concepts and their inter-relationships: whereas procedural knowledge is knowledge about how to reason with the declarative knowledge to solve problems. Not only are there different types of knowledge, but experts store knowledge in different representational forms or structures, as for example lists, tables, hierarchies, inferential flows and networks, and in general different KA techniques access different representational structures and reveal different types of knowledge (Olsen & Reuter, 1987). Olsen & Reuter (1987) review 12 KA techniques and match each one to both the knowledge structures that they can access and the knowledge types that they can reveal. Whereas, Kim & Courtney (1988) focus on choosing a KA technique for use in management domains which they regard as being generally wider, shallower and less formalised than that of most ES domains. They provide a conceptual contingency model matching the characteristics of several knowledge acquisition techniques to the managerial decision categories outlined in Mintzberg's (1979) theory of the organisation.

These two frameworks have been used as a basis within the case study organisation in order to develop an appropriate KA strategy for use within the domain of tender enquiry evaluation. The starting point for using both these frameworks was the identification of the most significant domain characteristics and in particular the identification of the principal knowledge types and underlying knowledge structures. These issues are discussed in the next section.

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3 Declarative and procedural knowledge are also referred to as content and process knowledge (Garg-Janardan & Salvendy, 1987 pp. 522), and also as object and meta-knowledge (Jackson, 1986 pp. 37) (Cf. Knowledge and Inference Procedures section 3.2)
6.2 IDENTIFICATION OF THE DOMAIN OF TENDER ENQUIRY EVALUATION'S CHARACTERISTICS

The initial discussions with the Sales & Commercial and the Proposals Managers (see section 5.5) during the general familiarisation and problem definition stages (see sections 4.3.1 and 4.3.2) enabled the most important domain characteristics to be identified. These characteristics are as follows:

1. Multiple Expertise
2. Classification Type Problem
3. Co-ordinative Type Decision
4. Semi-Structured Managerial Domain
5. Underlying Hierarchical Inference Network

Each of these 5 characteristics is described in the following sub-sections 6.2.1-6.2.5 respectively. The implication of these characteristics on the choice of an appropriate KA technique (or KA techniques) for use in the domain of tender enquiry evaluation is then discussed in section 6.3.

6.2.1 MULTIPLE EXPERTISE

The nature and impact of multiple expertise on the KA process is beautifully illustrated in the following quote by Shaw & Gaines (1987).

"Much expertise only resides within the social context of a cooperating group of individuals and requires elicitation across the group" (Shaw & Gaines, 1987 pp. 277)

This quote has a significant bearing on the case study under discussion. The decisions made by the TAG are reached at by consensus. This consensus structure is one in which several managers with different business perspectives influence the ultimate recommendations of the committee. The presence of this consensus based multi-functional approach to tender enquiry evaluation suggests that no one manager is considered an expert (or is knowledgeable) in all the aspects that can influence the decision. The purpose the TAG committee is such that each manager contributes beneficial judgements from their own functional specialism. Therefore, the domain of tender enquiry evaluation is characterised by multiple and selective expertise; and as a consequence the KA strategy developed for use in the domain needs to provide a framework in which both knowledge or expertise can be combined from different managers and any observed differences between managers' views reconciled. This requirement is discussed in more detail in sections 6.3, 7.1.4, 7.2.1 and 7.2.2.
Furthermore, since within the case study organisation knowledge or expertise is socially constructed between the functional managers, then the socio-technical approach to KA is a more appropriate paradigm than the functionalist paradigm within the current context. Therefore the objective of the KA process is to develop a homomorphic conceptual model of the TAG decision processes (see section 6.1).

6.2.2 Classification Type Problem

The domain of tender enquiry evaluation can be regarded as a classification type domain (see section 3.5). In effect the role of the TAG is to consider enquiries along a number of dimensions and then classify them into one of the 5 bid decision categories (see section 5.5.1).

6.2.3 Co-ordinative Type Decision

In Mintzberg’s (1979) organisational model co-ordinative decisions are defined as follows:-

"Co-ordinative decisions are decisions which assure that resources are obtained and used effectively and efficiently in the accomplishment of the organisation's objectives. This kind of decision involves interpersonal interaction and consideration of a larger number of factors within the context of policies and objectives developed in strategic planning" (Kim & Courtney, 1988 pp. 280)

This quote has a significant bearing on the case study under discussion. The ultimate bid decision made by the TAG results in the assignment of various levels of functional resources to the preparation of a tender proposal. That is, the process of evaluating tender enquiries is primarily concerned with the effective allocation of the organisation's resources in order to achieve their organisational goals. Furthermore, the presence of multiple expertise (see section 6.2.1) ensures the involvement of personal interaction in the evaluation process; so that the organisation's bid versus no bid and bid resourcing decisions can be regarded as a co-ordinative type decisions.

Kim & Courtney (1988) suggest that the type of knowledge required for co-ordinative type decisions is predominantly conceptual and heuristic experiential knowledge; that is, such decisions are characterised by declarative rather than procedural knowledge. As a consequence, the principal knowledge type within the domain of tender enquiry
evaluation was assumed be declarative rather than procedural. The impact of this assumption on the selection of appropriate KA techniques is discussed in section 6.3.

6.2.4 SEMI-STRUCTURED MANAGERIAL DOMAIN

Dhar (1987) argues that the type of knowledge required to solve a problem is influenced by the degree to which the task has been formalised. Level of formalisation goes hand in hand with the level of understanding of the domain. Dhar (1987) argues that in the absence of formalisation problem solving and understanding are more likely to depend on informal, intuitive, and possibly unarticulated models. Dhar's (1987) observations are relevant in the context of the case study under discussion. One of the organisation's primary motivations when agreeing to collaborate with the research project was their strong desire to ensure that bid versus no bid and bid resourcing decisions are made in a systematic and consistent manner, thereby clarifying why particular decisions are taken to all parties involved. This suggested that the organisation's approach to tender enquiry evaluation was an informalised process. As noted above relevant expertise is dispersed throughout several managers; the role of the proposed expert system was to draw together this expertise and consolidate it within a single knowledge base to deliver the objectives of systematicity and consistency, and therefore increase the process' level of formalisation. Dhar's (1987) observations suggest that the relevant managers' knowledge is shallow heuristic knowledge, where relationships between domain concepts have been built from empirical associations observed from many years experience. Furthermore, lack of formalisation implicitly implies low dependency upon procedural or meta-knowledge, thus providing further support to the conclusion that the principle type of knowledge used in the domain of tender enquiry evaluation is declarative. So the domain of tender enquiry evaluation is characterised by shallow heuristic declarative knowledge.

In their paper Kim & Courtney (1988) classify managerial problem domains along three dimensions: size, complexity and structuredness. Size refers to the number of concepts in the domain; complexity to the number of inter-relationships between the concepts; and finally structuredness to the uncertainty regarding the precise nature of these relationships. As part of their contingency model (see section 6.1) Kim & Courtney (1988) provide a mapping between a domain characterisation as measured along these three dimensions and appropriate KA techniques. Therefore, it was expedient to characterise the domain of tender enquiry evaluation by the dimensions of size, complexity and structuredness. This characterisation is described below.
Potentially the size of the domain of tender enquiry evaluation is large. This is because the managers believe that there is an inherent uniqueness about each enquiry, and therefore also in the concepts that are used in its evaluation. Many of the concepts, however, that the Proposals Manager revealed during the general familiarisation process could be regarded as a specific instance of a more generic or super-ordinate concept. For example, on many overseas projects in the third world the organisation see significance in the availability of government to government aid, but closer analysis reveals that this concern is a manifestation of their concern over the more generic concept relating to the prospects of the customer being able to secure finance for the project. Similarly, several overseas countries impose tariff barriers on imported goods to protect their indigenous industries. This is a manifestation of the organisation's concern over their relative competitiveness. This raised the question of at what level of detail the tender enquiry evaluation process should be modelled? Since the proposed system was to be used by the managers themselves as a support system rather than by less qualified personnel as consultative system, then a beneficial system could still result from modelling the enquiry evaluation process at a relatively conceptually high level. In this respect the system would not remove the need for the managers to make qualified judgements when using the system. Thus, by choosing to model enquiry evaluation at conceptually high level it was possible to restrict the number of concepts, and therefore the size of the domain.

Assessing the complexity and structuredness of a managerial domain appears to require considerable subjective judgement. What is apparent is that the domain of tender enquiry evaluation is not well-structured. If it were, then the precise nature of the relationships between the domain concepts would be known, and the organisation would have therefore formalised the enquiry evaluation process! Therefore, arguing by contradiction, since the domain has not been formalised it cannot be well-structured. During the familiarisation process the Proposals Manager touched upon the nature of the relationships between certain domain concepts. For example, the manager stated that the prospects of the customer being able to secure finance for the project would influence the chances of the project going ahead, which in turn would influence whether or not the organisation "sat up and took notice". Therefore, it was concluded that the managers are probably aware of the existence of several relationships between the domain concepts, but that they are not aware of the precise nature of these relationships. For example, the Proposals Manager (quite justifiably) did not know the precise significance of the prospects of the customer being able to
secure finance for the project on the chances of the project going ahead. Therefore, the domain of tender enquiry evaluation was assumed to be semi-structured. Furthermore, the Proposals Manager when probed about the relevance of particular domain concepts answered with multi-reasoned explanations, thus suggesting that the domain of tender enquiry evaluation was of at least moderate complexity.

As a consequence of these observations the domain of tender enquiry evaluation was assumed to be moderately complex and semi-structured. The significance of this characterisation on the choice of an appropriate KA technique is discussed in section 6.3.

6.2.5 Inferential Hierarchical Network

This is not so much an observed characteristic but a basic modelling assumption or hypothesis. It is believed that to classify an enquiry into one of the 5 bid decision categories the managers are required to make trade-offs between an enquiry’s attractive and unattractive traits. In a model this sort of trade-off is frequently represented by combining the concepts being traded-off against each other into a composite dimension or concept. Indeed there is empirical evidence to support this approach, for it has been shown that people can simultaneously handle no more than about 7 concepts (Miller, 1956). Therefore, if the managers believe that there are more than 7 domain concepts that influence the bid versus no bid and bid resourcing decisions, then the managers must necessarily have some method of combining these concepts together so that ultimately there are at most about 7 concepts being traded-off against each other. Therefore, it has been assumed or hypothesized that the managers combine the salient domain concepts into composite concepts, and then ultimately into a single conceptual structure that represents an enquiry’s overall attractiveness.

These beliefs give rise to the first modelling assumption or hypothesis.

(i) The domain concepts are organised into a hierarchical inference network (or directed graph). Each node in the network represents a single domain concept, the directed arcs illustrate both the existence and direction of a relationship between two concepts. Each arc is assigned a weight that indicates the relative importance of the sub-ordinate concepts in a particular relationship.
Furthermore, if enquiries are to be evaluated in an equitable systematic and consistent manner then the same concepts must be used in the same way to evaluate all enquiries now and in the future. This gives rise to the second modelling assumption or hypothesis.

(ii) The network in (i) above is static. That is, the nodes, arcs and weights are all constant with respect to all enquiries and time.

6.2.6 Domain Characterisation Summary

The case study organisation's bid versus no bid and bid resourcing decisions are coordinative, classification type problems which require judgements from multiple expert sources for their solution. Furthermore, the domain is informal and is considered to be moderately complex and semi-structured. The type of knowledge used to evaluate enquiries is believed to be shallow, heuristic, experiential declarative knowledge, and its underlying structure is believed to be in the form of a hierarchical inference network. The implication of these characteristics on the selection of appropriate KA techniques for use in the domain of tender enquiry evaluation is discussed in the next section.
**Figure 6.3(i) Various Kinds of Knowledge that Direct and Indirect Knowledge Acquisition Methods Can Reveal**

<table>
<thead>
<tr>
<th></th>
<th>Concepts</th>
<th>Relationships</th>
<th>Inference Rules</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DIRECT METHODS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interviews</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Questionnaires</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Observation</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Protocol Analysis</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Interruption</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Closed Curves</td>
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<td>X</td>
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<tr>
<td>Inferential Flow Analysis</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td><strong>INDIRECT METHODS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDS</td>
<td></td>
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<td>X</td>
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<tr>
<td>Hierarchies</td>
<td></td>
<td></td>
<td>X</td>
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<tr>
<td>GWN</td>
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<td></td>
<td>X</td>
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<tr>
<td>Ordered Tree</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Repertory Grid</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Card Sort*</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Matrix Technique*</td>
<td></td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rule Induction*</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>


* Not originally included in Olsen & Reuter (1987)
### Figure 6.3(ii) Various Representational Structures that Indirect Knowledge Acquisition Methods can Reveal

<table>
<thead>
<tr>
<th>Method</th>
<th>Lists</th>
<th>Tables</th>
<th>Hierarchies</th>
<th>Flow</th>
<th>Networks</th>
<th>Physical Space</th>
<th>Physical Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>MDS</td>
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<td>+</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
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<tr>
<td>Hierarchy</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
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<tr>
<td>GWN</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td>X</td>
<td></td>
<td>+</td>
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<tr>
<td>Ordered Tree</td>
<td>+</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repertory Grid</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Card Sort</td>
<td>+</td>
<td>+</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Matrix Technique</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td></td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Rule Induction</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>+</td>
</tr>
<tr>
<td>Closed Curves</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inferential Flow</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>+</td>
</tr>
</tbody>
</table>


* Not originally included in Olsen & Reuter (1987).
* Direct techniques which make assumptions about underlying representational structures, and are therefore included in the table.
6.3 SELECTING A KNOWLEDGE ACQUISITION TECHNIQUE - JUSTIFYING THE USE OF REPERTORY GRIDS

Olsen & Reuter (1987) classify KA techniques into the two broad categories: these are direct methods and indirect methods. Direct methods\(^4\) ask the expert to report directly what he or she knows - such methods are generally interview based, and therefore rely upon the availability of the knowledge to both introspection and articulation, and a subsequent analysis of large quantities of verbal data. In contrast, indirect methods\(^5\) do not rely upon the ability of the expert to articulate their knowledge directly; instead indirect methods collect other behaviours, such as recall or scaling of responses, from which the knowledge engineer can make inferences about what the expert must have known to respond the way he or she did. In general direct methods make no assumptions about the underlying knowledge structures used by the expert, and as such their free-form format means that they are capable of revealing all types of declarative knowledge (see figure 6.3(i)). Whereas indirect methods involve assumptions about the underlying representational structure of the concepts and their inter-relationships, and therefore are more limited in the types of knowledge they can reveal. So care must be taken when using indirect methods to ensure that their assumptions about the domain's underlying representational structure are validated.

The major drawback with the use of direct methods arises from the KA problem related to awareness and articulation (see section 6.1). Thus, since experts are not necessarily aware of their internalized conceptual structures they may have difficulty in reporting directly what they know to the knowledge engineer. This observation is particularly relevant in the context of the case study under discussion, because the domain of tender enquiry evaluation has been characterised as a semi-structured domain in which the managers have difficulty in identifying the precise nature of the relationships between the salient domain concepts (section 6.2.4). This suggested that the managers' knowledge was not open to introspection and articulation. In addition, research suggests that in general people have great difficulty in providing reliable estimates of probabilities (Welbank, 1983 pp. 26; Olsen & Reuter, 1987). Thus,

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\(^4\) Examples of direct methods include focused and structured interview techniques such as the distinction of goals and the laddered grid respectively, and protocol analysis (see Neale, 1987 pp. 62-67 and pp. 80-84, 1988; Olsen & Reuter, 1987).

\(^5\) Examples of indirect methods include repertory grid analysis, card sorts, proximity analysis and the matrix technique (see Neale, 1987 pp. 74-80, 1988; Olsen & Reuter, 1987).
given the modelling assumption concerning the underlying hierarchical network structure of the domain (see section 6.2.5 (i)), it was unlikely that the managers would have been able to provide reliable estimates for the relative weights associated with the network's arcs. Although this second observation could be simply a further manifestation of the problem relating to the unavailability of the managers' knowledge to introspection and articulation. Taken together these two observations suggested that indirect KA methods were more appropriate for use within the domain of tender enquiry evaluation than were the more commonly adopted interview based direct methods. As a result of this conclusion several indirect KA techniques were surveyed to identify those whose properties best matched the characteristics of the domain identified in section 6.2.

Olsen & Reuter (1987) review 5 indirect methods. These are multidimensional scaling (MDS), Johnson hierarchical clustering, general weighted network (GWN)\(^6\), ordered tree, and repertory grid analysis. This is not an exhaustive list and other indirect methods derived from the literature were also surveyed. These included the card sort (see Neale, 1987 pp. 74-76, 1988, and 1990; Schweickert et al., 1987), rule induction (Hart 1985a, 1985b, 1986 pp. 109-131, Mingers, 1986, 1987a, 1987b, Neale, 1987 pp. 99-103, 1988), and the matrix technique which is an extension of GWN to reveal inference rules (Gammack, 1987b; Neale, 1987 pp. 86, 1988).

Figures 6.3(i) and 6.3(ii) show the types of knowledge that the techniques mentioned above can reveal, and the underlying representational knowledge structures that the techniques access respectively. The properties highlighted in these two figures suggest that repertory grid analysis is one of the most versatile indirect KA techniques. Repertory grid analysis can reveal domain concepts, relationships and inference rules; whereas, with the exception of the card sort, rule induction and the matrix technique, the other techniques only reveal the existence of relationships between concepts without highlighting the precise nature of these relationships. Furthermore, repertory grid analysis and card sorts are the only two techniques that reveal domain concepts, all the other methods rely upon the concepts being given or provided \textit{a priori} by some other method. It is expedient to make a distinction between the elicitation of a repertory grid and its subsequent analysis. The elicitation process produces a multidimensional data set that can be used as a basis for several other indirect techniques including Johnson hierarchical clustering, GWN, and therefore the matrix technique. This suggests that repertory grid analysis can be used

\(^6\) The GWN technique is referred to as proximity analysis by Gammack (1987a), Neale (1987, pp. 85-86), and Neale (1988).
as basis for several of the other indirect techniques, and therefore that the technique is particularly appropriate when the expert's underlying knowledge structures are believed to include hierarchies, inferential flows and networks (see figure 6.3(ii)). In the case study under discussion the underlying structure of the domain of tender enquiry evaluation has been hypothesized to be in the form of a hierarchical inference network (section 6.2.5). Therefore, there is a close correspondence between the knowledge structures accessed by repertory grid analysis and those that the managers are believed to use. Furthermore, inspection of figure 6.3(ii) reveals that both rule induction and to a slightly lesser extent card sorts are also appropriate techniques when the expert's underlying knowledge structures are believed to include hierarchies, inferential flows and networks. Therefore, there is also a close correspondence between the knowledge structures accessed by rule induction and card sorts, and those that the managers are believed to use. As a consequence it was expedient to evaluate the relative appropriateness of these three techniques for use in the case study under discussion.

The three techniques repertory grid analysis, card sorts and rule induction are all closely related. All three techniques are inductive approaches to KA where general relationships between domain concepts are revealed from relationships between concepts observed in specific instances, in addition they all require the analysis of a multidimensional data set. Furthermore, all three techniques are better suited to analysis type problems than to synthesis type problems. As a result of this last observation all three techniques are particularly appropriate to classification type domains, and therefore appear well suited to the domain of tender enquiry evaluation (see section 6.2.2).

The major difference between the three techniques is in the assumed scales of measurement for the domain concepts, and this has a significant bearing on their relative appropriateness for use in the domain of tender enquiry evaluation. In the card sort technique the elements of the domain are assumed to show marked differences on the concept dimensions, and as a result the scales of measurement used for the concept dimensions are generally nominal or categorical. Whereas, in a repertory grid the elements are not necessarily assumed to show marked differences on the concept dimensions and the scales of measurement used for the concept dimensions are either ordinal or interval; and finally in rule induction there is no restriction on the scales of measurement used, and the concept dimensions can be

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7 By elements of the domain one is referring to the particular outcomes or recommendations that can arise in a classification type problem.
measured on any of a nominal, ordinal, interval or ratio scale of measurement. Furthermore, in repertory grid analysis relationships between concepts are identified by comparing the concepts with one another directly and this requires that the concepts must all be measured on the same scale of measurement (see section 7.1.2). This restriction does not apply to the use of concepts in either the card sort technique or rule induction, and Mingers (1987a) provides an example using rule induction where the concept dimensions are measured on different scales. The categorical based analysis of card sorts suggests that the technique is most appropriate for use in well-structured domains characterized by definitional or structural relationships, as for example a categorical hierarchy or taxonomy. This is markedly different from the semi-structured domain hierarchy which is assumed to exist within the context of the case study under discussion, where the managers are required to make trade-offs between the concept dimensions. Consequently the card sort technique was not considered to be appropriate for use in the domain of tender enquiry evaluation.

Rule induction is a cunningly deceptive technique because although there is no restriction on the scales of measurement used for the concept dimensions the ID3 algorithm underpinning the technique assumes that all the concepts dimensions are nominal (see Mingers, 1986 for further explanation). As a consequence rule induction is best suited to well-structured domains. A view also supported by Kim & Courtney (1988), although Mingers (1987a, 1987b) has had some success applying the technique to less structured domains where there is significant levels of noise in the data. There is also some disagreement as to whether repertory grid analysis is best suited to well-structured or ill-structured domains. Kim & Courtney (1988) and Blanning (1984) maintain that repertory grids are best suited to well-structured analysis domains where there is a high level of certainty regarding the relationships between the concepts. Whereas, Neale (1988) argues that repertory grid analysis is best suited to domains characterised by a low level of consensus among experts and a high degree of perceived subjectivity, and in a later paper asserts that "it [repertory grid analysis] is particularly relevant to the initial modelling of ill-structured managerial domains like marketing" (Neale, 1990 pp. 451); but, perhaps more significantly the majority of studies using repertory grid analysis in disciplines other than ES development have involved the analysis of ill-structured domains (see for example: Stewart & Stewart (1981) Part Two: Uses of the Repertory Grid in Industry pp. 73-208).
Since the domain of tender enquiry evaluation was characterised as semi-structured (section 6.2.4), it was not possible to choose between repertory grid analysis and rule induction on the basis of their appropriateness for use in well/ill-structured domains. However, one of the major advantages of repertory grid analysis is that it provides a framework for combining knowledge from multiple sources. Repertory grid analysis can be used to reconcile and combine the expertise of two or more experts in the same domain, and used to combine the expertise of different experts in different aspects of the same general domain (Boose, 1986); and as co-ordinative decisions are characterised by interpersonal interaction then they are believed to be appropriate for such domains (Kim & Courtney, 1988). Therefore, in the context of the case study under discussion repertory grid analysis provides a framework for contrasting and combining the views of the different managers who influence the co-ordinative type decisions made by the TAG.

To summarise the properties of repertory grid analysis closely matches the characteristics of the domain of tender enquiry evaluation identified in the previous section (section 6.2), and therefore it was the technique chosen for use in the case study.

It is important to note the repertory grid analysis is no panacea and it has widely recognised limitations. It is not suited to synthesis type problems, nor to the elicitation of deep or process knowledge (Blanning, 1984). However, since the type of knowledge used to evaluate enquiries is believed to be shallow heuristic knowledge, then these limitations do not affect the technique's suitability for use in the case study.
6.4 SUMMARY

KA is widely regarded as the major bottle-neck in the development of ES. Various techniques taken from the field of cognitive psychology are available which aim to improve both the effectiveness and the efficiency of the KA process. Some of these techniques are generally applicable because they make no assumptions about the form of the underlying knowledge structures within the domain; however, they do rely upon the availability of the knowledge to introspection and articulation. Whereas several of the techniques are less generally applicable because of their restrictive assumptions about the form of the underlying knowledge structures; however these later techniques do not rely on the availability of the knowledge to introspection and articulation. For these reasons it is generally acknowledged that it is important to adopt a knowledge acquisition technique whose properties match the characteristics of the domain.

The characteristics of the domain of tender enquiry evaluation have been drawn from initial interviews with the Sales & Commercial and the Proposals Managers. These characteristics were then compared with the properties of several well researched knowledge acquisition techniques, and based on this comparison the technique known as repertory grid analysis was selected as being the most appropriate technique for use in the domain of tender enquiry evaluation.
CHAPTER 7

KNOWLEDGE ACQUISITION STAGE 1-
DATA ELICITATION USING REPERTORY GRIDS
7. KNOWLEDGE ACQUISITION STAGE 1 - DATA ELICITATION USING REPERTORY GRIDS

7.0 INTRODUCTION

This chapter describes the methodology adopted during the first stage of the knowledge acquisition process. That is, the data elicitation stage outlined by Kidd (1987, pp. 3). Justification for using repertory grid techniques in the domain of tender enquiry evaluation was provided at the end of the previous chapter, and therefore this chapter commences with a brief overview of repertory grids and their relationship to the theory of personal constructs. Following this overview issues in the development of the basic single grid technique to the design of multiple grids are discussed, and the relevance of multiple grid designs to modelling multiple expertise for expert system development is highlighted. General principles in grid designs are noted; and then based on these principles an appropriate grid design for use in the domain of tender enquiry evaluation is developed. Finally, the experiences of using grid based techniques within the case study organisation are briefly described.

7.1 AN OVERVIEW OF REPERTORY GRIDS

7.1.1 KELLY'S PERSONAL CONSTRUCT THEORY

The use of repertory grid techniques was pioneered by the clinical psychologist George Kelly (1955) to support his model of human thinking called personal construct theory. George 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; and in particular he devised the repertory grid technique as an instrument to gather data about the ways an individual construes or views the environment or world around them (Vyakarnam, 1989). 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 especially within management education) and most recently as a formal basis for knowledge acquisition for expert systems (Cooke & McDonald, 1987).

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1 For studies of the use of repertory grid techniques in management education see for example: Honey (1979), Smith (1978), and Easterby-Smith (1980).
Unlike many psychological theories whose underlying axiomatic principles are often implicit or latent as a result of the theory having evolved over a period of time, personal construct theory is stated both explicitly and formally in a fundamental postulate and 11 corollaries (For a full discussion of these see Bannister & Fransella, 1971 pp. 19-31; or Vyakaranam, 1989). The underlying assumption on which the theory rests is that knowledge of an individual's attitude towards an aspect of their world will enable predictions to be made of that individual's behaviour towards that same aspect of their world. To develop his theory Kelly regarded man as a scientist with his own personal view of the world. As a scientist man classifies and categorises about the world, developing theories about it, and based on these theories the scientist is able to anticipate and make predictions based on these anticipations. The theory suggests that as a scientist, man makes sense of the world through contrast and similarity (Eden & Jones, 1984). Thus, meaning and significance to the events and experiences in an individual's life are provided by the individual seeking to recognise the differences and similarities between past and present events and experiences. In personal construct theory this meaning and significance is believed to be obtained through the application of an individually unique set of constructs\(^2\) that the individual has erected to make sense of their world. Meaning and significance through the interpretation of contrast and similarity gives rise to Kelly's dichotomy corollary; this states that an individual's construct system is composed of a finite number of dichotomous bipolar constructs (Bannister & Fransella, 1971 pp. 24)\(^3\). 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, 1980). 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 (Vyakaranam, 1989).

\(^2\) Hence the name Personal Construct Theory - each individual's construct system is thought to be unique. This is expressed in Kelly's individuality corollary which states that individuals differ from each other in their construction of events (Bannister & Fransella, 1971 pp. 22)

\(^3\) 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 (see for example: Bannister, 1962; Shaw, 1980). 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 (see sections 6.3, 7.1.2, 7.2.2(2)).
To summarize, repertory grid techniques are based on Kelly's personal construct theory. A theory in which the underlying assumption is that each individual can express their conceptual structure as a unique system of bipolar dimensions known as personal constructs through which they experience life and categorize their experiences (Shaw, 1981).

7.1.2 Repertory Grids - A Working Definition

A repertory grid has three components: these are its elements, its constructs (an abbreviation for personal constructs) and its linking mechanism (see Easterby-Smith, 1981 pp. 10; Hassard, 1987). The grid's elements correspond to events or experiences in the individual's life. It is important to note that these elements define the material upon which the grid will be based, and therefore the scope of the problem to be considered. The grid's constructs represent the various ways in which the individual differentiates between these experiences; that is, the ways in which the individual differentiates between the elements in the grid. Each construct is a bipolar characteristic or attribute (elicited from the individual during an interview) which each element displays to some degree (Hart 1986, pp. 134; see section 7.1.1). The degree to which each element displays a particular characteristic is provided by the linking mechanism. The linking mechanism is some kind of rating scale. Therefore, each element is assigned to each construct using either a binary, ordinal or interval scale of measurement4.

4 As previously noted in section 6.3 it is necessary that the same linking mechanism or rating scale is used for all the constructs in the grid.

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Based on these observations the following formal definition of a repertory grid is given.

**Definition - A Repertory Grid**

A repertory grid is a subjective data based representation of an individual's view of a particular problem or topic of discourse. A repertory grid consists of a matrix of data that provides a finite system of cross references between events or experiences in an individual's life and those personal constructs (or factors) that the individual has erected to make sense of (or differentiate between) those events and experiences (This definition is based on those given by Hart (1986, pp. 134-135) and Shaw (1981 pp. 33))\(^5\).

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\(^5\) A direct comparison has been made between repertory grid techniques and rule induction (Hart, 1985a; 1986 pp. 109-131; for an overview of rule induction see Hart, 1985b; 1986 pp. 109-131; Mingers, 1986). The elements of a grid can be compared with the training set used in rule induction and the constructs can be compared with the attributes. However, as previously noted in section 6.3, there are fewer restrictions on the scales of measurement used for attributes than there are for constructs.
### Figure 7.1  A Repertory Grid Drawn up by a Course Tutor Considering Different Types of Students on a Course

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**Comparison of Students on a Course**

- **school-leaver**
- **poor qualifications**
- **unsure**
- **asks questions**
- **good qualifications**
- **confident**
- **quiet**
- **good attendance**
- **poor attendance**
- **does work**
- **does not work**
- **joins in socially**
- **does not join in**
- **not organised**
- **organised**
- **scruffy**
- **tidy**

7.1.3 AN EXAMPLE REPERTORY GRID

Figure 7.1 shows a repertory grid taken from Anna Hart's book *Knowledge Acquisition For Expert Systems* (Hart, 1986 pp. 142). The grid has been constructed by an expert, in this case a course tutor, to compare different students on a course. In this grid 7 students (Brian, Kim, Terry, Ian, Steve, Nadia, and David) are being compared. Together these students form the 7 elements of the grid, \(E_1, \ldots, E_7\), and following what appears to be the standard convention these 7 elements are taken to form the columns of the grid. The expert has identified 9 constructs, \(C_1, \ldots, C_9\), which he (or she) uses to differentiate between the 7 students. (Again in line with the standard convention these 9 constructs are taken together to form the rows of the grid). In this example a 3 point interval rating scale has been used to assign each of the students (or elements) to each of the 9 constructs. A rating of 1 corresponds to the verbal label given at the left hand side of the grid; and conversely a rating of 3 corresponds to the verbal label given at the right hand side of the grid. For example, it can be seen that the course tutor regards Brian and Terry as mature students, whereas the tutor regards the other five students as school leavers.

7.1.4 MULTIPLE GRIDS

Personal construct theory recognises that different individuals may construe events or experiences in different ways. This is reflected in the individuality corollary which states that each individual's construct system is thought to be unique (see Bannister & Fransella, 1971 pp. 22). This is not suggesting that each individual's construct system is necessarily distinct (or that individuals' construct systems are mutually exclusive); indeed as a converse to the individuality corollary Kelly formulated the commonality corollary to reflect that individuals may construe events or experiences in similar ways. The commonality corollary states that -

"To the extent that one person employs a construction of experience which is similar to that of another, his processes are psychologically similar to that of the other person" (Bannister & Fransella, 1971 pp. 30).

The principle ideas underlying repertory grids have been developed so that comparisons between construct systems represented by two or more grids (that is, multiple grids) can be made (see Shaw, 1980, 1981; Shaw & Thomas, 1978; Thomas et al., 1976). Such comparisons appeal to both the individuality and commonality
corollaries to determine the differences and similarities respectively between the construct systems of multiple grids.

There are various reasons why it may be expedient to make comparisons between multiple grids. By comparing two grids elicited from the same individual it is possible to identify an individual's so-called core structure, defined as the set of elements and constructs that are central to the individual's psychological maintenance processes (see Shaw, 1981). Alternatively, if the two 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 (see Shaw 1980, 1981). Finally, multiple grids elicited from a small group of individuals can be compared to determine the consensus of opinion and to identify those individuals of the group whose views are the most dissenting (see Thomas et al., 1976). It is in these respects 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 (see section 6.3).

In order to make effective comparisons of the underlying construct systems between multiple repertory grids it is necessary that either the elements corresponding to the events or experiences in the individual's life (or individuals' lives) and/or the constructs are identical in all of the grids (Easterby-Smith, 1981 pp. 27). This practical constraint on the design of multiple grids (and in particular on the methods used to generate the elements and constructs) raises important theoretical considerations. Duck (1975) suggested that two constructs could be regarded as similar if they satisfied one of either two criteria. These criteria were literal similarity - satisfied if the individuals used precisely the same verbal labels; and conceptual similarity - satisfied if the individuals used different verbal labels to convey the same idea. However, the results of a study of magistrates decision making show that two individuals can use radically different verbal labels to convey the same idea, and yet may use the same verbal labels to convey different ideas (see McKnight, 1976).

6 Strictly speaking there is no difference between the nature of elements and constructs (see Easterby-Smith, 1981 pp. 11). So although we have spoken of the individuality and commonality corollaries as applying to constructs they can equally apply to elements. Therefore when we speak of making comparisons between underlying construct systems, then elements should also be regarded as part of an individual's personal construct system.

7 In light of footnote 5 the conclusions drawn from McKnight's (1976) study are equally applicable to elements as well as constructs.
Therefore, given the practical constraint outlined above these findings suggest that great care needs to be taken in the design and comparison of multiple grids.

MINUS and CORE (Shaw 1980, 1981) are two approaches for making comparisons between two grids which have identical element and construct labels. Two identically designed grids can be compared with respect to the similar and different uses of the elements and constructs by examining the differences in the rating patterns in each grid. MINUS identifies the difference and similarities between the two grids by superimposing one grid on top of the other. This superimposed grid shows the differences in the ratings in every equivalent position in the grids. The superimposed grid is then analysed to identify those elements and constructs which have been used in the same way, thereby revealing either an individual's core structure, or the extent of shared understanding between two individuals. CORE provides an alternative, more flexible, approach to either identifying an individual's core structure, or the extent of shared understanding between two individuals. In order to measure a change or difference in meaning in the two dimensions of elements and constructs, each is held constant whilst a change in the other is calculated. Therefore the two grids are processed by successively deleting the element whose usage is the most different on all constructs and the construct whose usage is the most different on all the elements. The resulting unchanged diminished grid is referred to as the core grid and displays either an individual's core structure, or the extent of shared understanding between the two individuals.

If in the MINUS and CORE approaches the two grids are elicited from the same individual it is reasonable to assume that the verbal labels used for the elements and constructs held the same meaning on the two occasions that the grid was completed. As a result it is reasonable to conclude that those elements and constructs which remain the least unchanged on the two occasions form part of the individual's core structure. If, however, the objective is to identify the extent of shared understanding between two individuals with respect to a common domain of discourse, then any conclusions drawn from the MINUS or CORE approaches are dependent upon the assumption that the verbal labels given to the elements and constructs hold the same meaning to both individuals. In light of the work of Duck (1975) and McKnight, (1976) it appears that neither the approaches of MINUS nor CORE are particularly reliable for making comparisons between multiple grids to these ends. As such neither approach is reliable for modelling multiple expertise in expert systems development.
SOCIOGRIDS (Thomas et al., 1976) is an approach that goes some way in overcoming the difficulties outlined above. It was Kelly's (1955) original contention that a grid's elements and constructs should be elicited from the individual. The work of Duck (1975) and McKnight (1976) demonstrates that from a theoretical stand-point using identical offered elements and constructs is suspect. However, from a practical stand-point, to adequately compare multiple grids it is necessary that the elements and/or the constructs are identical. In general elements are more easily shared between a group of individuals than constructs (Thomas et al., 1976). This is especially true when the elements are physical objects or shared events, (as for example, business opportunities represented by tender enquiries) rather than role descriptions as was frequently the case in Kelly's work as a clinical psychologist.

SOCIOGRIDS is an approach that compares a set of grids elicited from a small group of individuals who share the same elements, but whose constructs have been elicited independently from each individual. Any two of these grids can therefore be combined into one grid by aligning the common elements. This combined grid is then analysed and a measure of the extent of similarity established. A matrix of similarity measures between pairs of individual grids is created, from which a sequence of sociometric diagrams termed socionets is produced defined by the rank ordering of the matrix of similarity measures. This sequence of socionets shows which individuals have a high extent of shared understanding and which individuals have a strongly individualistic viewpoint.

To summarise, provided that a common or shared set of elements can be identified then the SOCIOGRIDS approach is a reliable method for revealing the extent of shared understanding between two or more individuals, and as such provides a useful framework for modelling multiple expertise in expert systems development. As a consequence, the underlying principles of SOCIOGRIDS were adopted for use within the case study organisation. The next section discusses the development of an appropriate grid design for the domain of tender enquiry evaluation.
7.2 Repertory Grid Design for Tender Enquiry Evaluation

7.2.1 Identifying Sources of Expertise

As previously noted in sections 5.5.1 and 6.2.1, the domain of tender enquiry evaluation is characterised by multiple expertise: the multi-functional structure of the Tender Action Group (TAG) ensures that several managers with different business perspectives influence the ultimate recommendations of the committee. For this reason it was agreed with the case study organisation's senior management that ideally several managers should be consulted in the knowledge acquisition and model development stages of the project (see sections 4.3.3-4.3.5). The objective of such an approach was both to reduce functional and individual managerial bias and to encapsulate as broad business perspective as possible.

From initial discussions with the Proposals Manager it was concluded that a sole representative from the four supporting functions (Engineering, Manufacturing, Procurement and Sales & Commercial) together with the relevant Business Group Managers attended the TAG committee meetings (see section 5.5.1). This scenario suggested that the underlying principles of the SOCIOLGRIDS approach (see section 7.1.4) could benefit the data elicitation stage of the knowledge acquisition process. In effect this would have facilitated a multi-functional knowledge acquisition methodology since it seemed feasible to elicit repertory grids based on a common or identical set of elements, that is tender enquiries, from each of the four functional representatives and also the Business Group Managers.

A brief analysis of the minutes from several TAG meetings proved the prior conclusion to be ill-founded. The minutes revealed that not only were the four supporting functions represented at TAG meetings, but so to were two corporate functions, namely Marketing and Finance. More importantly the minutes revealed that between 6 and 13 managers may be present at any particular meeting and that there is considerable variation in the personnel present from one meeting to the next. From this brief analysis it was apparent that each function had 2 or 3 managers who shared responsibility for attending TAG committee meetings; and also that it was very rare for an enquiry to be discussed at more than two consecutive meetings. Taken together these observations suggested that the majority of the managers involved in the TAG only directly influenced a small number of the bid versus no bid and bid resourcing decisions having being present at perhaps only half the TAG meetings. Therefore, due to the difficulty in identifying a set of enquiries (or elements) that
would constitute a shared set of events or experiences in the lives of a set of functional and business managers, the prospect of developing a multi-functional knowledge acquisition methodology proved to be unfeasible. Thus, rather than develop a model based on consultations with all parties involved in the TAG an alternative approach was adopted.

In the alternative approach a model would be developed based only on consultations with those managers who were believed to hold the greatest insight into the tender enquiry evaluation process. The criteria adopted for identifying the most appropriate managers was their degree of involvement in or exposure to TAG decisions, an appropriate measure being the percentage of TAG meetings attended. The rationale underlying this criteria is that those managers who are most frequently present at the TAG will have gained a greater insight and understanding of the relevant factors affecting the bid versus no bid and bid resourcing decisions and how the factors are taken into consideration. Further analysis of the TAG minutes revealed that those managers with the greatest exposure to TAG decisions were the Proposals Manager (present at nearly all the TAG meetings), the Business Group Manager of the largest Business Group (both in terms of sales revenue and number of orders placed) and the Sales and Commercial Manager. As the Sales & Commercial Manager was frequently overseas on business then only the Proposals Manager and the Business Group Manager were used during the knowledge acquisition and model development stages of the study.

Therefore, to summarise 2 managers were used during the knowledge acquisition and model development stages of the project; and the principles underlying the SOCIOGIDS approach were adopted in order to elicit two repertory grids, one from each manager, based on a common set of tender enquiries. These grids were then analysed to compare and contrast the managers' views of the tender enquiry evaluation process. The next section discusses the design of these two grids. The analysis of the managers' grids is discussed in chapters 8, 9 and 10.

7.2.2 Repertory Grid-Design

Easterby-Smith (1981) discusses three aspects to grid design relating to a grid's elements, constructs and linking mechanism.
7.2.2(1) Elements

The selection or generation of the elements is critical to the effective application of repertory grid techniques. The elements may influence the nature of the elicited constructs (see section 7.2.2(2)) and thereby influence (and possibly bias) the results of any subsequent grid analysis, and therefore the investigator's understanding of the individual's psychological processes. In fact this argument applies irrespective of whether or not the elements are used to generate the constructs. For this reason a grid's elements should satisfy the following three requirements. Firstly the elements should be homogeneous. Individuals erect different construct systems for different aspects of their lives and as a result constructs relevant to one aspect of an individual's life need not be relevant to other aspects of their life. Homogeneity ensures that the elicited constructs are equally applicable to all elements in the grid. Secondly, the elements should provide representative coverage of the domain of discourse. Unfortunately this is impossible to ensure, since if all the characteristics of the domain were known a priori then the exercise of eliciting and analysing a grid would serve no beneficial purpose! Although, as a minimum requirement one should ensure that no obviously important elements are overlooked. Finally, the elements should be meaningful to all subjects or individuals who are to complete the grid. This is especially relevant to grid designs involving multiple grids such as in the SOCIOGRIDS approach.

7.2.2(2) Constructs

The classic approach used to generate constructs is by the use of triads (Shaw, 1987). A triad is any set of three elements. In this method the individual is repeatedly asked to consider different triads and invited to say in what way two elements of the triad are similar or alike, and in what way the third element of the triad is different from the other two. The objective of this procedure is to produce the two contrasting emergent and implicit poles for the elicited construct. The individual is then asked to assign all the elements of the grid to the newly elicited construct using the chosen linking mechanism (see section 7.2.2(3)). Clearly the selection of triads influences the nature of the constructs elicited and therefore ultimately the interpretation of any subsequent grid analysis. To ensure that the investigator does not influence the nature of the constructs elicited and therefore impose their own interpretation on the domain of discourse, then the selection of triads should
be made on a purely random basis. Furthermore, each element should be
given the same chance of appearing in triads to reduce the effect of any
element dominating the triads and hence the nature of the constructs elicited.
Therefore during the elicitation of the grid it is expedient if each element
appears in a roughly equal number of triads. To assist the individual in the
identification of constructs it is generally recommended that any pair of
successive triads share no more than one element in common.

7.2.2(3) LINKING MECHANISM

The dichotomy corollary asserts that constructs are bipolar and measured on a
dichotomous or binary scale of measurement. As noted previously several
researchers have relaxed this assumption and have measured constructs on
ordinal and interval scales of measurement. Bannister (1962) adopted an
ordinal scale of measurement by asking individuals to rank order the elements
relative to the emergent pole of the construct. Cooke & McDonald (1987)
report that individuals often have difficulty in discriminating between middle
ranking elements and that the method forces the individual to indicate
differences between elements when the individual feels that no substantial
difference exists. Shaw (1980) warns of further problems with the ranking
method; she provides an example where one would naturally expect the rank
ordering to be dependent upon the nature of the implicit pole. Because of
these problems the most commonly used linking mechanism is the interval
rating scale. In this method the individual is asked to assign each element an
integral rating on a r point scale (r being an odd integer usually 5 or 7). This
overcomes some of the problems of the rank order method, but the method
introduces associated problems of its own. The notion that the individual is
using equal intervals is an assumption that cannot be empirically verified
easily. Eden & Jones (1984) express worries about the vagueness of the mid-
point: Does the mid-point suggest indifference or uncertainty? That is, is the
construct relevant to the element or is the individual unsure about what rating
to assign the element?

The above principles have been noted and used to develop an appropriate grid design
for use in the domain of tender enquiry evaluation with the Proposals and Business

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8 Messick (1957) details statistical techniques to test the validity of the equal
interval assumption. However, these techniques are not practically feasible since
they require that the data be replicated many times.
Group Managers. In this context repertory grids are being used to investigate what factors influence the bid versus no bid and bid resourcing decisions made by the TAG. It has been shown that a grid's elements correspond to events or experiences in an individual's life, thus in this context elements correspond to tender enquiries that have been vetted by the TAG. Similarly the constructs correspond to those factors that the managers believe are important in the determination of the overall attractiveness of an enquiry, and the subsequent level of resources to allocate to the preparation of a tender proposal.

The first stage of the grid design was to derive a set of elements that were meaningful to both managers; that is, a common set of tender enquiries with which both managers had been involved. A summary of the 44 tender enquiries which had passed before the TAG during the 6 month period from 1st Jan. 1989 to 30th June 1989 was analysed to identify a suitable set of enquiries. This resulted in a set of 10 enquiries being picked from the 44 possible candidates so as to obtain representative coverage of the five final bid decision categories (Bid A, Bid B, Bid C, Referral, and No Bid) together with the various Business Groups. To improve the coverage of the problem domain, for each manager 2 extra enquiries were chosen to be included in his individual grid. Thus a grid would be elicited from each manager based on 12 enquiries with 10 enquiries common to each grid. The grids could then be analysed independently and in addition could be aligned by the 10 common enquiries to produce a combined grid and analysed as one grid as in the SOCIOGRIDs approach.

From a purely theoretical stand-point the validity of eliciting individual grids based on 12 elements and then removing the 2 uncommon elements to form the combined grid is questionable. Such a methodology runs the risk that the constructs generated in each manager's individual grid are influenced by the presence of the 2 rogue elements, and therefore that any subsequent analysis to determine a measure of the similarity between the grids is ill-founded because the grids were not constructed on an equitable basis. As one of the overall objectives was to develop as broad based perspective of the tender evaluation process as possible rather than solely construct a measure of the shared understanding between the two managers, then this theoretical consideration is largely irrelevant. In retrospect the difficulties encountered in

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9 Since all the enquiries have been drawn from one 6 month period it is assumed that they are homogeneous (see modelling assumption (ii) section 6.2(5)).

10 Easterby-Smith (1981, pp. 11) suggests that it should be possible to provide adequate coverage of the domain of discourse with around 12 elements.
eliciting the constructs indicate that the presence of the 2 rogue elements had little effect on the nature of the constructs elicited (see section 7.3).

For each manager a set of 12 prompt cards was produced. On each card several pieces of information were typed relating to the tender enquiry that the card represented. This information was to refresh the managers' minds concerning each enquiry. This information included an enquiry number, the relevant Business Group, the identity of the customer, a description of the customers' requirements, the tender due date and finally the bid decision category.

To use the triadic approach to elicit constructs for each manager a set of 30 random sets of 3 enquiries were produced. This would ensure that the researcher could not influence the nature of the constructs elicited through selective choice of triads for comparison. However, it should be noted that the researcher had already influenced the nature of the constructs elicited through his independent selection of the enquiries for the grids' elements. Again in retrospect this seems to have had little effect on the nature of the constructs elicited (see section 7.3). The two sets of random triads were then rearranged to ensure that no two successive triads in either set had more that one enquiry in common.

Honey (1979) uses repertory grid techniques to provide a pre-post course evaluation of a sales training course. Part of Honey's study looked at salesmen's perceptions of what differentiates effective from less effective salesmen. It was therefore expedient to identify how closely each of the salesmen's constructs related to sales effectiveness. To do this at the end of each elicitation session the salesmen were provided with the additional construct: most effective salesman - least effective salesman and asked to rate each element in their grid against this supplied construct. The scenario in Honey's 1979 study is not too dissimilar to the current researcher's interest into what factors influence the bid versus no bid and bid resourcing decisions. Therefore after the elicitation of constructs with triads the managers would be provided with the construct overall attractiveness of tender enquiry and asked to rate each of the 12 enquiries in their grid against this supplied construct.

Since it is believed that the managers classify tender enquiries along a number of dimensions and that enquiries do not necessarily show marked differences along some of the dimensions (see section 6.2(4)) then the characteristics of interval rating scales highlighted above suggest that such scales are more appropriate for the domain of tender enquiry evaluation than either a binary or ordinal scale. Managers would
therefore be asked to assign each of the 12 enquiries an integral rating in the range of 1 to 5 on each elicited construct.

7.3 Grid Elicitation - Experiences with the Managers

After the grids had been designed an independent meeting was then arranged with each manager. At the start of each meeting the manager was briefed on the nature and objectives of the project as a whole, and in particular on the format and objectives of the repertory grid exercise. Following this briefing, the manager was asked to study his 12 cards for a few minutes in order to familiarise himself with the enquiries with which the cards represented. Then, following the standard triad method, the manager was asked to think of those factors that were relevant to the bid versus no bid and bid resourcing decisions. He was then presented with one of the random triads and invited to say in what way two enquiries were alike, and in what way the third enquiry was different from the other two. This procedure elicited a construct and its respective emergent and implicit poles. For example, whilst considering one particular triad the Business Group Manager suggested that 2 of the enquiries were alike because low levels of technical risk were associated with the projects; whereas the third enquiry was different because there was a high level of technical risk. The manager was then asked to assign each of the 12 enquiries an integral rating in the range of 1 to 5 for that factor or construct. For example, the Business Group Manager would assign a rating of 1 to those enquiries where he thought there was a very low level of technical risk; and a rating of 5 to those enquiries where he thought there was a very high level of technical risk.

To improve the quality and relevance of the elicited constructs the technique of laddering (Hinkle, 1965; Easterby-Smith, 1981) was used in conjunction with the elicitation of constructs from triads to generate super-ordinate constructs from elicited constructs that appeared to have little general value. For example, the Proposals Manager commented that "these two enquiries were received from customer A, whereas this third enquiry came from customer B". The manager was then asked to describe why the identity of the customer was important in his assessment of the enquiries. The manager's response was that "... we are certain of customer A's ability to pay...". In this case the more relevant and super-ordinate construct was the customer's ability to finance the project rather than the customer's identity. The outlined process of showing the manager one of the random triads was repeated until he could not identify any further constructs or factors.
Both managers found great difficulty in identifying constructs from the random triads. Naturally one expects the elicitation of constructs to become progressively more difficult as more are elicited, since consideration of further triads only suggests construct duplication. However, both managers found difficulty in identifying constructs at the early stages of the elicitation session when relatively few constructs had previously been identified. To ease the elicitation of constructs variants to the traditional triad approach were employed. Prior to his elicitation session the Proposals Manager had drawn up a list of factors which he felt were relevant to the bid versus no bid and bid resourcing decisions. During the elicitation session when considering the random triads the manager was allowed to refer to his list of relevant factors for inspiration! In addition the manager was also asked to configure his own triads around a factor on his list, effectively working backwards from construct to relevant triad, rather than forwards from triad to relevant construct. The addition of these variants to the traditional approach appeared to relax the manager and eased the elicitation of constructs. Thus, prior to his elicitation session the second manager was asked to draw up a list of factors which he felt were relevant to bid versus no bid and bid resourcing decisions. The dependency upon the managers' factor lists in the elicitation of constructs suggested that neither the presence of the two rogue elements nor the fact that the enquiries had been selected independently of the managers by the researcher had any significant influence on the nature of the constructs elicited.

When no further constructs could be elicited the manager was provided with the supplied construct: overall attractiveness of the tender enquiry. The manager was then asked to both rank order and rate (using a 1,...,5 integral scale) the enquiries against this offered construct.
Table 7.4(i)  The Business Group Manager’s Constructs

<table>
<thead>
<tr>
<th>C1</th>
<th>design available - no design available</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>low level of technical risk - high level of technical risk</td>
</tr>
<tr>
<td>C3</td>
<td>high expected added value - low expected added value</td>
</tr>
<tr>
<td>C4</td>
<td>low level of financial risk - high level of financial risk</td>
</tr>
<tr>
<td>C5</td>
<td>low manufacturing investment required - high manufacturing investment required</td>
</tr>
<tr>
<td>C6</td>
<td>good chance of additional business - poor chance of additional business</td>
</tr>
<tr>
<td>C7</td>
<td>price likely to be competitive - price unlikely to be competitive</td>
</tr>
<tr>
<td>C8</td>
<td>manufacturing capacity available - no manufacturing capacity available</td>
</tr>
<tr>
<td>C9</td>
<td>work for a low loaded factory - work for a high loaded factory</td>
</tr>
<tr>
<td>C10</td>
<td>attractive build size - unattractive build size</td>
</tr>
<tr>
<td>C11</td>
<td>high level of competition - low level of competition</td>
</tr>
</tbody>
</table>

Table 7.4(ii)  The Proposals Manager’s Constructs

<table>
<thead>
<tr>
<th>C1</th>
<th>standard design - customer design</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2</td>
<td>small order size - large order size</td>
</tr>
<tr>
<td>C3</td>
<td>small chance further business - good chance of further business</td>
</tr>
<tr>
<td>C4</td>
<td>poor potential profits - good potential profits</td>
</tr>
<tr>
<td>C5</td>
<td>poor chance of project going ahead - good chance of project going ahead</td>
</tr>
<tr>
<td>C6</td>
<td>low involvement - high involvement</td>
</tr>
<tr>
<td>C7</td>
<td>low demands on bid resources - high demands on bid resources</td>
</tr>
<tr>
<td>C8</td>
<td>low demands on design and build resources - high demands on design and build resources</td>
</tr>
<tr>
<td>C9</td>
<td>low desire to be in market - high desire to be in market</td>
</tr>
<tr>
<td>C10</td>
<td>low competition - severe competition</td>
</tr>
<tr>
<td>C11</td>
<td>poor prospects of available finance - good prospects of available finance</td>
</tr>
<tr>
<td>C12</td>
<td>poor or non existent formal enquiry - fully documented formal enquiry</td>
</tr>
<tr>
<td>C13</td>
<td>no previous dealings with customer - well known customer</td>
</tr>
<tr>
<td>C14</td>
<td>low probability of success - high probability of success</td>
</tr>
<tr>
<td>C15</td>
<td>poor ability to meet delivery dates - good ability to meet delivery dates</td>
</tr>
</tbody>
</table>
**Figure 7.4(iv) The Proposal Manager's Repertory Grid**

### REPERTORY GRID DATA (PROPOSALS MANAGER)

<table>
<thead>
<tr>
<th></th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
<th>E5</th>
<th>E6</th>
<th>E7</th>
<th>E8</th>
<th>E9</th>
<th>E10</th>
<th>E11</th>
<th>E12</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1 standard design</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>C2 small order size</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>C3 sm. chance further bus.</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>C4 poor pot. profit.</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>C5 poor chance of go. ahead</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>C6 low involvement</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>C7 low dem. bid resources</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>C8 low dem. des/bui resource</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>C9 low des. to be in market</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>C10 low competition</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>C11 poor pros. avail. finance</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>C12 poor/non exist formal enq</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>C13 no prev. dealings cust</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>C14 low prob. of success</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>C15 poor abil. meet delivery</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>2</td>
</tr>
</tbody>
</table>

**Bid Decision Category**

| A | N | C | C | B | R | N | B | A | N | N | A |
**Figure 7.4(iii)  The Business Group Manager's Repertory Grid**

**REPERTORY GRID DATA (BUSINESS GROUP MANAGER)**

<table>
<thead>
<tr>
<th></th>
<th>E1</th>
<th>E2</th>
<th>E3</th>
<th>E4</th>
<th>E5</th>
<th>E6</th>
<th>E7</th>
<th>E8</th>
<th>E9</th>
<th>E10</th>
<th>E11</th>
<th>E12</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>design available</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>C2</td>
<td>low technical risk</td>
<td>1</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>C3</td>
<td>high added value</td>
<td>1</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>1</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>C4</td>
<td>low financial risk</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>C5</td>
<td>low manufact. investment</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>C6</td>
<td>good chance addn. business</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>C7</td>
<td>price likely competitive</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>C8</td>
<td>manufact. cap. available</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>C9</td>
<td>work for low load factory</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>C10</td>
<td>attractive build size</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>C11</td>
<td>high level of competition</td>
<td>5</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

*Bid Decision Category*  
A N C C B R N B A N B A
Duck (1975) used a verbal approach to measure similarity between two individuals' construct systems. Duck suggested that two constructs could be regarded as similar if they satisfied one of either two criteria. These criteria were literal similarity - satisfied if the individuals used precisely the same verbal labels; and conceptual similarity if the individuals used different verbal labels to convey the same idea.
Tables 7.4(i) and 7.4(ii) show the constructs elicited from the Business Group Manager and the Proposals Manager respectively. The two full grids obtained by the elicitation process outlined in the previous section are shown in figures 7.4(iii) and 7.4(iv). Figure 7.4(iii) shows the Business Group Manager's grid. Eleven constructs C1, ..., C11 were elicited from the consideration of the 12 tender enquiries E1, ..., E12. Figure 7.4(iv) shows the Proposal Manager's grid. His grid contains 15 constructs C1, ..., C15. The enquiries represented by E1, ..., E10 are the 10 enquiries common to both grids. Whereas, the enquiries represented by E11 and E12 are unique to their respective grids. The constructs have been arranged so that a rating of 1 corresponds to the verbal label provided at the left hand side of the grid and a rating of 5 to the verbal label provided at the right hand side of the grid. For example, the Business Group Manager assigned a rating of 1 to enquiry E1 on his design construct C1 design available - no design available. Thus indicating that an existing design would be available if the enquiry E1 were to be pursued.

Duck (1975) used a verbal approach to measure similarity between two individuals construct systems based on the ideas of literal and conceptual similarity (see section 7.1.4). By adopting this verbal approach it is possible to identify similarities between the two managers' construct systems. Based on the criteria of conceptual similarity there are 4 shared constructs in the two grids. These are the constructs related to design, order/build size, competition and further/additional business (see figure 7.4(v)).

Most researchers favour a direct comparison approach to measuring similarity between two individuals' construct systems (Thomas et al, 1976). Direct comparison approaches are discussed in detail in chapter 8, but for the time being note that both managers assigned a rating of 1 to their respective design constructs design available - no design available and standard design - customer design. This implies that both managers agree that an existing or standard design could be used if enquiry E1 were to be pursued. This provides some evidence that the managers are using their design constructs in the same way with respect to the enquiries in the grid. Although clearly before such an inference can be drawn it is necessary to make the same comparison across all the enquiries and not only E1.
7.5 **Summary**

The underlying theory and issues in the design of repertory grid techniques have been discussed with particular emphasis on the design of multiple grid design for modelling multiple expertise in expert system development.

A grid design appropriate for use in the domain of tender enquiry evaluation has been developed and used to elicit grids from the two managers who are thought to have the broadest perspective on the factors influencing the bid versus no bid and bid resourcing decisions made by the TAG.

The initial grids elicited from the two managers have been presented and briefly examined.
CHAPTER 8

KNOWLEDGE ACQUISITION STAGE 2 - INITIAL KNOWLEDGE ANALYSIS: GRID VALIDATION
8.0 INTRODUCTION

This chapter, the first of three, describes the initial methods used and the results obtained from the analysis of the managers' grids and is therefore concerned with the second stage of the knowledge acquisition process, as outlined by Kidd (1987, pp. 3). The overall objective of the grid analyses has been to try and identify the managers' underlying reasoning processes and to this extent the analyses have been successful in that a hierarchical inference network together with a set of rules or heuristics have been developed (see chapters 9 and 10). The initial analyses described in this chapter concentrate on establishing the validity of the managers' grids as instruments to investigate the bid versus no bid and bid resourcing decisions of the TAG. The chapter commences with a brief overview of the various methods of analysing repertory grids and based on this discussion an appropriate method for establishing the validity of the managers' grids has been selected. This method is then reviewed and the results obtained from the analyses presented.

8.1 THE ANALYSIS OF A REPERTORY GRID

The objective of analysing a repertory grid is to "identify the natural structure and pattern between the elements and the constructs" (Hart, 1986 pp. 138.). That is, grid analyses help the investigator understand and explain the individual's psychological processes by highlighting the existence of conceptual relationships between the grid's constructs, the elements and ultimately between the grid's constructs and its elements, thereby revealing how the individual uses the constructs to distinguish between the elements in the grid. This section commences with a discussion of the most commonly used methods for analysing a single grid. This is followed by a discussion of the developments of these methods for the analysis of multiple grid designs (see section 7.1.4).

Traditional methods of analysing a single grid are generally based on multivariate statistical methods (Slater, 1964 & 1969; Thomas et al., 1976; Shaw & Thomas, 1978); although more recently logical based approaches have been advocated (Shaw & Gaines, 1980). These two methods are similar in respect that they both base the inferred existence of conceptual relationships on the direct comparison of constructs
and elements (Thomas et al., 1976), rather than on a verbal based comparative approach, as advocated by Duck (1975). In these direct comparison approaches a grid's elements are compared against each other to see if they are being used in a similar way on all the constructs; and conversely the constructs are compared against each other to see if they are being used in a similar way on all the elements. Thus, pairs of elements, and correspondingly pairs of constructs, that have been construed similarly are regarded as being in some way conceptually related. The major difference between the two approaches is that multivariate statistical methods assume a spatial view of both elements and constructs; whereas in logical based approaches the assignment of an element to a construct (or for that matter the assignment of a construct to an element) is viewed as an assignment of a truth value to a logical predicate.

In multivariate statistical approaches a grid with p rows of constructs and n columns of elements is analysed by considering each element as a point in p-dimensional space and each construct as a point in n-dimensional space. From this perspective the most natural way of examining the individual's conceptual structure of the domain is to consider the distance between the elements in p-dimensional space and correspondingly the distance between the constructs in n-dimensional space. If two elements are a statistically small distance apart in p-dimensional space, then the elements are being used in a similar way on all the constructs; and it can therefore be inferred that this statistical relationship between the elements reflects a conceptual relationship that may or may not be true. Conversely, if two constructs are a statistically small distance apart in n-dimensional space, then this may reflect a conceptual relationship between the two constructs.

In logical based approaches equivalent construct (or element) comparisons can be made by comparing the truth values across all the elements (or constructs respectively) in the grid, thereby highlighting conceptual relationships between the constructs (or elements) in the form of logical implications. The most significant advantage of logical based analyses over distance based multivariate statistical

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1 The theoretical problems with Duck's (1975) verbal approach to the analysis of construct systems were discussed in sections 7.1.4 & 7.4.

2 Since conceptual relationships between the constructs are inferred from a statistical analysis of the n elements grid based techniques are necessarily inductive methods (see section 6.3). As a result grid based techniques can be compared to rule induction (see sections 6.3 & 7.1.2)
approaches is that asymmetric conceptual relationships can be identified (Shaw & Gaines, 1980).

The assumption underlying both approaches is that a similarity measure for a pair of concepts whether they be elements or constructs (that is, a measure of how similarly the concepts are being construed, as for example a multidimensional distance in the multivariate statistical approach) is representative of the distance between the concepts in memory. According to the distance metaphor of memory, concepts that are semantically or conceptually related are closer in memory than are concepts that are less related (Cooke & McDonald, 1987). Therefore, the underlying premise of both the statistical and logical based approaches is that by modelling the similarities between the constructs and the elements one is in effect modelling the relationships that define the individual's conceptual structure of the domain.

8.1.1 Multivariate Statistical Grid Analysis Methods

Kelly's (1955) original method of analysis was the $D^2$ non-metric method of factor analysis. The advantage of analysing grids using non-metric methods is that the linking mechanism used to assign elements to constructs is assumed to be measured on an ordinal scale rather than an interval scale of measurement. Thus, non-metric methods only consider the order in which elements are assigned to the constructs and not the numerical difference between the elements (Easterby-Smith, 1981 pp. 22.) and therefore overcome the empirical problems associated with validating the equal interval assumption (see section 7.2.2(3)). Since Kelly's original work other non-metric and metric methods of factor analysis have been used to analyse grids (see Cronbach, 1955).

According to Shaw (1980) around 70% of studies using grids make use of interval scales of measurement thereby facilitating the use similarity measures derived from distance based metrics. As a result, by far the most prevalent multivariate statistical methods used for analysing grids are principal component analysis (Slater, 1964; Slater, 1969) and cluster analysis (Thomas et al., 1976; Shaw & Thomas, 1978). Specially devised computer programs have been made available for analysing grids using these two methods. INGRID (see Easterby-Smith, 1981) and FOCUS (Shaw & Thomas, 1978) are two such programs based on principal component analysis and cluster analysis respectively.
The primary motivation underlying principal component analysis is that of data reduction (Munford & Bailey, 1989). Given a multidimensional data set comprising of \( n \) observations measured on \( p \) variates, then principal component analysis aims to produce a small number \( q \) (\( q < p \)) of uncorrelated or orthogonal dimensions \( z_1, \ldots, z_q \) say, known as the principle components, which are linear combinations of the original \( p \) variates and are such that they account for nearly all the variation in the original data. Principle component analysis can therefore be used to establish relationships between a grid's constructs and to combine the constructs into a smaller number of more fundamental constructs that account for nearly all of the variation in the grid's elements.

The objective of cluster analysis is to group the \( n \) observations into mutually exclusive and exhaustive so called clusters such that all the observations in a particular cluster bear a high degree of similarity to one another (see Everitt, 1973 pp. 1-8; Manly, 1986 pp. 100-113). Cluster analysis can therefore be used to group together those elements of a grid that the individual regards as being semantically or conceptually related; and similarly the technique can be used as an alternative to principal component analysis to group together constructs.

There is some debate as to which of the two techniques is the most appropriate for grid analyses (Rump, 1974; Slater, 1974). Although given that the objectives of the two techniques are different a simple comparison of their appropriateness cannot be made. It is therefore recommended that one should adopt the technique whose characteristics best match the objectives of the study. In general, it has been observed that principal component analysis can produce a visually explicit link between the grid's elements and constructs in the form of a cognitive map, and therefore provides

\[
\text{If } X_1, \ldots, X_p \text{ are the original } p \text{ variates then the objective of principal component analysis is to find } q \text{ (} q < p \text{) dimensions } Z_1, \ldots, Z_q \text{ of the form}
\]

\[
Z_i = a_{i1}X_1 + \ldots + a_{ip}X_p \text{ with } a_{i1}^2 + \ldots + a_{ip}^2 = 1
\]

such that

\[
a_{i1}a_{j1} + \ldots + a_{ip}a_{jp} = 0 \text{ for all } i \text{ and } j
\]

\[
\text{Var}(Z_1) \geq \text{Var}(Z_2) \geq \ldots \geq \text{Var}(Z_q)
\]

\[
\text{Var}(Z_1) + \ldots + \text{Var}(Z_q) \approx \text{Var}(X_1) + \ldots + \text{Var}(X_p)
\]

(See Manly, 1986 pp. 59-71 for further details.)

4 A cognitive map provides a graphical representation of a grid's elements and constructs relative to the principle components (Easterby-Smith, 1981 pp. 23).
a richer analysis than cluster analysis (Easterby-Smith, 1981 pp. 23.). However, the over zealous mathematical transformation of the grid data to derive the principle components may seem artificial to, and ultimately alienate, the individual from whom the grid was elicited. Furthermore, the results from principle component analysis become very difficult to illustrate and interpret if the number of significant principle components exceeds two, because in these circumstances the elements need to be represented visually on a cognitive map in three or more dimensions! Thus, if an individual’s cognitive processes are complex the results of principle component analysis become difficult to illustrate and interpret. Clearly these problems are compounded if the results are to be used to gather feedback from the individual from whom the grid was elicited, as is generally the situation in grid based studies. This was precisely the situation envisaged with both the Proposals and Business Group Managers in the case study under discussion.

8.1.2 LOGICAL BASED GRID ANALYSIS METHODS

The seminal work on logical based grid analyses is that of Shaw and Gaines (1980). In their paper "New Directions in the Analysis and Interactive Elicitation of Personal Construct Systems" they develop the theory of entailment analysis based on predicate calculus and fuzzy set theory (Zadeh, 1965). Entailment analysis provides a means of identifying the implicational (or logical) links between a grid’s constructs. The method produces a graph of entailments or logical implications with associated measures of strength of entailment of implication. The computer program ENTAIL was developed to derive entailments between a grid’s constructs.

8.1.3 METHODS FOR THE ANALYSIS OF MULTIPLE GRID DESIGNS

Both principal component analysis and cluster analysis are appropriate methods for analysing multiple grid designs (see section 7.1.4), and several computer programs have been devised to make comparisons between grids for a specific objective and multiple grid design. Both DELTA (see Easterby-Smith, 1981) based on principal components analysis and MINUS (Shaw 1980, Shaw 1981, Thomas et al. 1976) a derivative of FOCUS based on cluster analysis can be used to determine the

---

5 The significant principle components are the q (q << p) dimensions Z₁,...,Zₚ, that is those dimensions Zₖ such that Var(Zₖ) >> 0.

6 Smith (1986) argues that the more complex an individual’s cognitive or psychological processes are, then a greater number of principle components are required to account for nearly all the variation in the individual’s grid.
differences between two grids with identical elements and constructs. The similarity or commonality between two grids with identical elements and constructs can be identified using either SERIES (see Easterby-Smith, 1981), based on principal components analysis, or CORE (Shaw, 1980 & 1981) a further derivative of FOCUS based on cluster analysis. To extract the similarity from several grids with the same elements but different constructs then either PREFAN (see Easterby-Smith, 1981) based on principal components analysis or SOCIOGRIDS another derivative of FOCUS could be adopted.

8.1.4 Grid Centred Knowledge Acquisition Workbenches

In the USA in particular there has been a concerted effort to develop grid centred knowledge engineering workbenches. These are tools that interactively interview experts, elicit grids, analyse the grids, construct knowledge bases and ultimately produce skeletal systems. Both entailment analysis and cluster analysis have been embedded in the grid centred Expertise Transfer System (ETS) developed at Boeing (Boose, 1985; Boose et al, 1987; Boose, 1988).

The next section outlines the objectives of the analyses of the managers' grids (see figures 7.4(iii) and 7.4(iv)) and discusses the choice of an appropriate analysis method.
The overall objective of analysing the two managers' grids was to identify the hierarchical inference network that was assumed to exist in section 6.2(5). To achieve this overall goal it was necessary to answer the following questions.

8.2.1 How consistent are the two managers' views concerning the overall attractiveness of tender enquiries?

One of the principal motivations for using more than one manager throughout the knowledge acquisition and model development stages of the project (see sections 4.3.3-4.3.5) was to try to encapsulate as broad as business perspective as possible (see section 7.2.1). If, however, the managers' views concerning the enquiries' overall attractiveness were found to be inconsistent with each other, then it would seem natural to conclude that the two managers' approaches to tender enquiry evaluation were incompatible. Under such circumstances it would be difficult to reconcile the managers' differences and develop a model with a broad based business perspective.

8.2.2 Are the managers' grids valid?

The validity of the managers' grids as an instrument to investigate their decision processes and those of the TAG is dependent upon the grids' ability to discriminate or differentiate between attractive and unattractive tender enquiries, that is, enquiries awarded Bid A and No Bid decisions respectively at TAG. So can the data in the grids discriminate between such enquiries? If so, then how well do the discriminations made in the grids correspond to the managers' views?

8.2.3 What are the similarities between the managers' views?

Provided that the managers' views concerning the overall attractiveness of the tender enquiries are consistent, then what are the similarities and differences between the two managers' views at lower levels in the enquiry evaluation process? In particular, is it plausible to combine the managers' construct systems and therefore combine their respective views, thus broadening the business perspective being modelled?
8.2.4 **What do the grids tell us about how the managers evaluate tender enquiries?**

Provided that the grids are valid, then can they be used to identify those characteristics that the managers associate with attractive and unattractive enquiries respectively?

The remainder of this chapter concentrates on the first three of these analysis objectives. The fourth objective is discussed separately in chapters 9 and 10.

According to the distance metaphor of memory, concepts that are strongly semantically related are closer in memory than are concepts that are less strongly related. It seems natural to assume that the managers' will have organised their memories so that highly attractive enquiries are semantically related and so that very unattractive enquiries are semantically related. Based on this premise, the highly attractive enquiries are expected to be close together in memory and correspondingly the very unattractive enquiries are also expected to be close together in memory; and these two groups of attractive and unattractive enquiries are expected to be separated some distance apart. Furthermore, under this premise, scattered between these two groups will be medium attractiveness enquiries which may be weakly semantically related to both groups. According to this model of the managers' memories, the most appropriate analysis technique for establishing the grids' validity (section 8.2.2) is cluster analysis. Thus, if the grids were analysed using a clustering routine and the grids were valid, then one would expect the highly attractive enquiries to be clustered together, and correspondingly the very unattractive enquiries would be expected to be clustered together.

It is worth noting that a grid's elements could also be analysed using principal component analysis to establish its validity. With principal components analysis, if the grid is valid the analysis would be expected to reveal two or three principal components. The first two of these would correspond to the highly attractive and very unattractive enquiries respectively. The third principal component, if it was significant, would correspond to medium attractiveness enquiries.

The disadvantages of principal components analysis have already been discussed in section 8.1. Furthermore, since cluster analysis can also be used as an alternative to principle component analysis to group together constructs, it can be used to identify the similarities and differences between the two managers' views at lower levels of
the tender enquiry evaluation process (section 8.2.3). Consequently, to answer the questions raised in sections 8.2.2 and 8.2.3 respectively, the principles underlying FOCUS (Shaw & Thomas, 1978), a cluster analysis based grid analysis tool, were used to analyse the two managers' individual grids and the combined grid formed by aligning the 2 individual grids by the 10 common enquiries (see section 7.1.4 & 7.2.2). The FOCUS algorithm is described in the next section.

8.3 THE FOCUS ALGORITHM (SHAW & THOMAS, 1978)

The objective of the FOCUS algorithm is to reorder both the elements and the constructs of the original grid to create a second grid referred to as the focused grid. In the focused grid the rows of constructs and the columns of elements are rearranged in such a way so as to display the greatest similarity (or least variation) between any two adjacent rows or columns down and across the focused grid. The implication being that elements and constructs that are adjacent or close in the focused grid are conceptually related. The algorithm is based upon a two way agglomerative hierarchical clustering technique (see Everitt, 1974 pp. 24-34). In such clustering schemes each of the n observations is initially assigned to its own individual cluster. The n observations are then successively grouped together into larger clusters based on the level of similarity between the observations and the clusters, until eventually all the observations are grouped into one cluster.

In addition to the focused grid the FOCUS algorithm produces two dendograms (Everitt, 1974 pp 24; Manly, 1986 pp. 100-104), one showing the level of similarity between adjacent elements in the focused grid and the other showing the same for the constructs. FOCUS also produces two matrices of similarity measures showing the similarity between pairs of elements in one case and between pairs of constructs in the other. It is the simplicity of this output that many researchers regard as the major benefit of cluster analysis based methods over other multivariate statistical techniques, especially principal component analysis (see Shaw & Thomas, 1978; Shaw, 1980 & 1981; Eden & Jones, 1984; Hassard, 1987).

"The focused grid is clearly only a rearrangement of the raw responses (subjective ratings), and hence the mathematics is almost hidden. The subject (individual) is therefore not disturbed by 'mathematical magic' being performed behind his back, or factors (fundamental constructs or principal components) produced out of the hat." (Shaw, 1980 pp. 121.)
The FOCUS algorithm comprises of two sequential steps:

**Step 1** : Calculate the similarity matrices for the grid's elements and constructs respectively. These two matrices illustrate the level of similarity for each pair of elements and constructs respectively.

**Step 2** : Cluster the elements and then the constructs based on the respective similarity matrices to produce the rearranged element and construct orders for the focused grid. (The element and construct dendograms are also produced during this clustering step.)

The calculation of the similarity matrices requires the definition of an appropriate similarity measure to quantify the level of similarity between each pair of elements and constructs respectively. According to the distance metaphor of memory the similarity measure is a quantification of the extent of a conceptual relationship between any two elements or constructs.

There are several commonly used methods for measuring similarity between variates when the variates have been measured on either an interval or ratio scale (Everitt, 1974 pp. 9-22). The most commonly used similarity measure is the product moment correlation coefficient, but this has received severe criticism (Everitt, 1974 pp. 53). Since the coefficient is unity whenever two variate profiles are parallel, all that is required for perfect correlation and a similarity measure of 100% is that one variate is linearly related to a second variate. This raises the important question of whether or not multidimensional parallelism provides evidence of a conceptual relationship?

Consider a hypothetical scenario where managers assess tender enquiries against a fixed number of salient factors. If the managers are asked score enquiries as 5 against those factors on which the enquiry is highly attractive and 1 against those factors on which the enquiry is very unattractive; then, irrespective of the relative weights that the managers associate with the factors, an enquiry that scores 5 on all the factors must be regarded as highly attractive and conversely an enquiry that scores 1 on all the factors must be regarded as very unattractive. If in this example, the product moment correlation coefficient was used as a similarity measure then the two

---

7 The issues raised in this section are general issues relating to cluster analysis and are not specific to grid analyses or to the FOCUS algorithm. Therefore, rather than refer to similarity between pairs of element or constructs, then in line with standard statistical parlance the word variate is used.
enquiries scoring all 5's and 1's respectively would be perfectly correlated and therefore produce a 100% similarity measure. According to the distance metaphor of memory these two enquiries would be regarded as being conceptually related. As previously stated, however, it seems natural that the managers would organise enquiries in memory so that highly attractive enquiries are grouped together and so that very unattractive enquiries are grouped together, with these two groups separated some distance apart. Thus, in this scenario the product moment correlation coefficient results in a contradiction to the distance metaphor of memory!

It can be seen that in the domain of tender enquiry evaluation multidimensional parallelism does not necessarily provide sufficient evidence for conceptual relationships between enquiries. For this reason in the domain of tender enquiry evaluation the product moment correlation coefficient is an inadequate measure of similarity between enquiries; and as a result favour lies in the use of similarity measures based on simple transformations of distance measures or minkowski metrics. Two of the most commonly used minkowski metrics are the generalised euclidean distance metric and the city block or mean absolute difference (MAD) metric.

---

8 It shall be noted in chapter 9 that the product moment correlation coefficient does not contradict the distance metaphor of memory when applied to constructs. Although in general terms there is no difference between the nature of elements and constructs (see footnote 5 section 7.1.4), in the domain of tender enquiry evaluation their nature is markedly different because elements represent possible future projects and constructs the factors that are used to differentiate between the projects. Thus, it is possible that a similarity measure may be appropriate for the constructs, but not the elements.

9 Suppose there are n observations measured on p variates $X_1, \ldots, X_p$, then the generalised euclidean distance between observations $i$ and $j$, $D_{ij}$ say is defined by

$$D_{ij} = \left( \sum_{k=1}^{p} (X_{ik} - X_{jk})^2 \right)^{1/2}$$

(Manly, 1986 pp. 44.)

10 Suppose there are n observations measured on p variates $X_1, \ldots, X_p$, then the city block distance between observations $i$ and $j$, $D_{ij}$ say is defined by

$$D_{ij} = \sum_{k=1}^{p} |X_{ik} - X_{jk}|$$

(Everitt, 1974 pp. 18.)
There is considerable debate about how the euclidean metric is best incorporated within a clustering routine. The issues raised concern the general scaling of variates. If, for example, the variates are measured on different scales then the variate measured on the widest ranging scale will tend to dominate the calculation of the euclidean metric. Furthermore, even if all the variates are measured on the same scale, if one of the variates shows considerable more variability than any of the other variates then it will also tend to dominate the euclidean metric (Manly, 1986 pp. 45). It is therefore recommended that to ensure that all the variates have about the same influence on the euclidean metric, and therefore the same influence on the similarity measure, that a preliminary scaling is performed to normalise the variates to zero mean and unit variance. This can have a serious effect on diluting the differences between observations on variates which are the best discriminators. In contrast to this diluting approach Boose (1985) suggests that one may want to explicitly weight the difference between the ratings of two observations on a particular variate to reflect the relative importance of that variate. However, a priori this may not be feasible, as for example if one of the objectives of the analysis was to gain insight into the relative importance of each of the variates. This is the situation this study of the TAG’s decision processes, and was also the case in Honey’s 1979 study of salesmen’s effectiveness (see section 7.2).

Rather than use a similarity measure based upon either of the controversial product moment correlation coefficient or the generalised euclidean metric, the FOCUS algorithm adopts a similarity measure based on the city block metric. This has the advantage that the similarity measure for any pair of observations, whether they be elements or constructs, is the same irrespective of whether the observations are 2 units apart on one variate and identical on all other variates, or 1 unit apart on 2 variates and identical on all other variates (Hassard, 1987). The overall effect is that the influence of high variance variates is reduced without recourse to normalisation.

---

11 This scaling problem cannot arise in repertory grid analyses since all variates in a grid (that is, the constructs and elements respectively) are measured on the same standardized scale.

12 Consider 3 observations O₁, O₂ and O₃ measured on 2 variates X₁ and X₂ such that

\[
\begin{array}{ccc}
X₁ & O₁ & O₂ & O₃ \\
1 & 2 & 1 \\
3 & 4 & 1 \\
\end{array}
\]

Now Var(X₂) = 14/9 > Var(X₁) = 2/9

Let Dᵢⱼ = Distance between observation i and j measured using the euclidean metric.
Let $R_E(C_i)$ denote the rating for the $j$th element $E_j$ ($j = 1, \ldots, n$) on the $i$th construct $C_i$ ($i = 1, \ldots, p$) in a grid with $n$ elements and $p$ constructs. Each element $E_j$ can be viewed as a vector in $p$-dimensional space (section 8.1). Let $D_{jk}$ be the distance between element $E_j$ and $E_k$ in this $p$-space measured by the city block metric. Then $D_{jk}$ is given by

$$D_{jk} = \sum_{i=1}^{p} |R_{E_j}(C_i) - R_{E_k}(C_i)|$$

Suppose that each $R_{E_j}(C_i)$ ($i = 1, \ldots, p; j = 1, \ldots, n$) is an integer in the interval $[1, R]$ (as for example $[1, 5]$ as was the case with the two managers' grids, see figures 7.4(iii) and 7.4(iv)), then the maximum distance between any two elements (or enquiries), $D_{\text{max}}$ say, is given by

$$D_{\text{max}} = p(R - 1)$$

A measure of the similarity $S_{jk}$, expressed as a percentage, between the elements $E_j$ and $E_k$ based on the city block metric is therefore given by

$$S_{jk} = 100(1 - \frac{D_{jk}}{D_{\text{max}}})$$

Similarly, by viewing the constructs as points in $n$-dimensional space and letting $R_{C_x}(E_j)$ denote the rating for the $x$th construct on the $j$th element, then the similarity, $S_{xy}$ say, between two constructs $C_x$ and $C_y$ is given by

$$S_{xy} = 100(1 - \frac{D_{xy}}{D'_{\text{max}}})$$

Let $D'_{ij} = \text{Distance between observation } i \text{ and } j \text{ measured using the city block metric.}$

Then,

$$D_{12} = 1.414 \quad D_{13} = 2$$
$$D'_{12} = 2 \quad D'_{13} = 2$$

Thus, the city block metric has reduced the effect of the high variance variate $X_2$. 

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where

\[ D_{xy} = \sum_{j=1}^{n} |R_{Cx}(E_j) - R_{Cy}(E_j)| \]  
\[ D'_{\text{max}} = n(R - 1) \]

In the elicitation of a repertory grid the assignment of the emergent and implicit poles is arbitrary (section 7.2.2(2)). Two constructs \( C_x \) and \( C_y \) displaying 0% similarity as measured by eq 8.3 (iv) would display 100% similarity if one of the constructs, \( C_x \) say, had its emergent and implicit poles reversed. For example, consider the two constructs *tall-short* and *fight-heavy* in relation to people known to an individual. Then, based on the premise that in general taller people weigh more than shorter people, one would naturally expect these two constructs to display a low level of similarity. If however, the second construct had its poles reversed so the construct became *heavy-light*, then one would expect the constructs *tall-short* and *heavy-light* to display a high level of similarity. So, when measuring similarity between pairs of constructs it is also necessary to measure the similarity between the pair with one construct reversed.

The second stage of the FOCUS algorithm involves repeatedly joining the elements together into clusters at successively lower levels of similarity, so that eventually all the elements are part of a single cluster. The process is then repeated for the constructs. This requirement highlights a second problem with the use of agglomerative hierarchical clustering techniques because the different methods rely upon different ways of defining the similarity between an individual observation and a cluster of observations, or between two clusters of observations. Definitions of a cluster tend to be vague and circular. "The majority of techniques find clusters of a particular shape, but *a priori* there is usually no conceptual reason for believing that clusters in the data should be of any particular shape" (Everitt, 1974 pp. 60). The various methods include the single linkage or nearest neighbour method, the furthest neighbour or complete linkage method, centroid cluster analysis, median cluster analysis and the group average mean (see Everitt, 1974 pp. 25-34). The FOCUS algorithm relies upon the single linkage method for formulating clusters and joining clusters together. This approach along with the complete linkage method is by far the most computationally efficient and for small grids the process can be carried out by manually.

\[ \text{In the present context an observation could either be an element or a construct.} \]
Let $C_1$ and $C_2$ be two non-empty clusters\(^{14}\), then the single linkage method defines the similarity between these two clusters, $S_{C_1, C_2}$ say, as follows

$$S_{C_1, C_2} = \max \{ S_{ij} : i \in C_1 \& j \in C_2 \} \quad \text{eq. 8.3 (vii)}$$

Thus, according to the distance metaphor of memory the FOCUS algorithm being based on the single linkage joining algorithm is in general over ambitious in its identification of conceptual relationships between clusters because the relationships are based on the minimum distance between the clusters.

\(8.4\) GRID ANALYSES USING FOCUS

\(8.4.1\) MANAGER VERSUS MANAGER COMPARISON

Before analysing the managers' grids in detail using FOCUS it was expedient to derive a measure of the consistency between the managers with regard to their views of the overall attractiveness of tender enquiries (see section 8.2.1). Table 8.4.1 shows the respective rankings provided by the Proposals and Business Group Managers for the 10 tender enquiries which were common to both their grids.

---

\(^{14}\) The clusters $C_1$ and $C_2$ could be single observations. In which case eq. 8.3 (vii) reduces to a measure of similarity between two observations.
Table 8.4.1 Proposals and Business Group Managers' Overall Attractiveness Rankings for the 10 Enquiries Common to Both their Grids

<table>
<thead>
<tr>
<th>Tender Enquiry</th>
<th>Proposals Manager's Ranking</th>
<th>Business Group Manager's Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>E2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>E3</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>E4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>E5</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>E6</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>E7</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>E8</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>E9</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>E10</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

Rank Spearman Correlation Coefficient ($r_s$) between Proposals and Business Group Managers' Rankings

$r_s = 0.842^a$

$^a$ Significant at the 0.5% level

The rankings in table 8.4.1 are arranged so that high rankings ($>> 5$) are associated with highly attractive enquiries, that is, those enquiries that one would expect to be awarded Bid A decisions at TAG; conversely, low rankings ($<< 5$) are associated with very unattractive enquiries, that is, those enquiries that one would expect to be awarded No Bid decisions at TAG.

It is clear that a similar pattern exists between the managers' sets of rankings. In particular, both managers regard the business opportunities represented by enquiries E9 and E1 as the first and second most attractive business opportunities respectively; whilst at the same time they have low opinions of the business opportunities represented by enquiries E2, E10 and E3. The most marked differences between the managers' rankings occurs with the mid-attractiveness enquiries E4, E8, E6 and E7. Thus, it appears that there is a high level of agreement between the two managers with respect to the highly attractive and very unattractive enquiries; but, and as one would naturally expect, there is a more marked variation in the managers' overall
opinions of those enquiries which are difficult to evaluate because of the greater need to make trade-offs between the enquiries' attractive and unattractive traits.

The rank spearman correlation coefficient (Mendenhall et al. 1986 pp. 649) was used to measure the consistency of the managers' overall views. The rank correlation (0.842) between the two sets of attractiveness rankings was found to be statistically significant at the 0.5% level. This suggests that the managers' overall views of the enquiries' attractiveness and the business opportunities that they represent are consistent (see section 8.2.1). In itself this result does not prove that the managers arrived at their similar overall assessments using similar processes of reasoning, indeed a cursory glance at the two managers' construct systems (see figures 7.4(iii) and 7.4(iv)) shows that differences do exist. The result does, however, provide credence to the hypothesis that there may be common elements to the managers' reasoning processes, and therefore to the suggestion that it may be possible to combine the managers' construct systems to encapsulate a broad based business perspective (see section 8.2.3).

8.4.2 Analysis of the Individual Managers' Grids

8.4.2(1) Analysis of the Business Manager's Grid

To illustrate the FOCUS algorithm its application to the Business Group Manager's grid (the smallest of the two managers' grids with only 11 constructs) will be described. As previously noted in section 8.3, FOCUS employs a two way hierarchical clustering technique that firstly clusters the grid's elements together followed by the constructs to produce the focused grid with the property that any two adjacent columns of elements, or rows of constructs, display the greatest similarity across and down the grid respectively.
Figure 8.4.2(1)(i)  The Business Group Manager's Grid

<table>
<thead>
<tr>
<th>REPERTORY GRID DATA (BUSINESS GROUP MANAGER)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>C1</td>
</tr>
<tr>
<td>C2</td>
</tr>
<tr>
<td>C3</td>
</tr>
<tr>
<td>C4</td>
</tr>
<tr>
<td>C5</td>
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<td>C6</td>
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<td>C7</td>
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<td>C8</td>
</tr>
<tr>
<td>C9</td>
</tr>
<tr>
<td>C10</td>
</tr>
<tr>
<td>C11</td>
</tr>
</tbody>
</table>

Bid Decision Category
A   N   C   C   B   R   N   B   A   N   B   A
8.4.2(1) (a) Clustering the Enquiries (Elements)

Table 8.4.2(1)(ii) is the percentage similarity matrix showing the similarity measure, based on the city block metric, for each pair of enquiries in the Business Group Manager’s grid (figure 8.4.2(1)(i)).

Table 8.4.2(1)(ii) Percentage Similarity Matrix for the Business Group Manager’s Enquiries

<table>
<thead>
<tr>
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<th>E1</th>
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<td>E2</td>
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<td>E4</td>
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<td>E7</td>
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<td>E11</td>
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<td>E12</td>
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</table>

Inspection of the matrix reveals that the two enquiries displaying the highest similarity (at the 86% level) are E10 and E11. Therefore, according to the distance metaphor of memory it can be inferred that the Business Group Manager regards these two enquiries as being conceptually related. Enquiries E10 and E11 were awarded No Bid and Bid B decisions respectively by the TAG, so at first sight the inference of a conceptual relationship between E10 and E11 appears to invalidate the model of the managers’ memories as described in section 8.2 and the choice of FOCUS as an appropriate grid analysis tool. The Business Group Manager, however, rated both enquiries E10 and E11 as 1 on the offered construct Overall attractiveness of tender enquiry. So, his individual assessment of the two enquiries, as opposed to that of the consensus view of the TAG, was that both enquiries represented very unattractive business opportunities; and therefore according to the model of the managers’ memories one would expect the two enquiries to be conceptually related, as indeed FOCUS has revealed. The grid thus represents the personal views of the Business Group Manager rather than that of the TAG. As previously described in section 8.3 FOCUS then joins these two elements together to form the cluster {E10-
Clearly, since $E_{10}$ and $E_{11}$ are the most similar pair of enquiries they are taken to form adjacent columns in the focused grid.

FOCUS then searches the percentage similarity matrix to find the pair (or pairs) of enquiries displaying the second highest level of similarity. This occurs between the pairs $(E_1,E_{12})$ and $(E_8,E_{12})$ at the 84% similarity level. According to the single linkage joining method used by FOCUS (eq. 8.3(vii)) these three enquiries can then be joined into a single cluster $(E_1-E_{12}-E_8)$ at the 84% level. Since the objective of FOCUS is reorder the enquiries so that the rearrangement displays the greatest similarity between any two adjacent enquiries, then it is important that as enquiries are joined into clusters, and as clusters are fused together, that a linear ordering of the enquiries is maintained. Thus, since both pairs of enquiries $(E_1,E_{12})$ and $(E_{12},E_8)$ display 84% similarity it is expected that $E_{12}$ be adjacent to both $E_1$ and $E_8$ in the focused grid, and therefore $E_{12}$ must necessarily lie between $E_1$ and $E_8$. For this reason the linear re-ordering of the enquiries is maintained by referring to the newly formed cluster as $(E_1-E_{12}-E_8)$ rather than say, $(E_{12}-E_1-E_8)$.

Enquiries $E_1$ and $E_{12}$ were both awarded Bid A decisions by the TAG, whilst enquiry $E_8$ was awarded a Bid B decision. Correspondingly, the Business Group Manager rated $E_1$ and $E_{12}$ as 5, and $E_8$ as 4, on the offered construct overall attractiveness of tender enquiry. Thus, with regard to the enquiries $E_1$, $E_{12}$ and $E_8$ the Business Group Manager is in agreement with the recommendations made by the TAG. Moreover, FOCUS has clustered these attractive enquiries together suggesting that the Business Group Manager, and in this instance also the TAG, regard these enquiries as being conceptually related.

At this stage FOCUS has revealed two clusters: the first of these, cluster $(E_{10}-E_{11})$, corresponds to those enquiries that the Business Group Manager regards as very unattractive; whilst the second cluster $(E_1-E_{12}-E_8)$ corresponds to those enquiries that the Business Group Manager regards as highly attractive.

On its next search of the percentage similarity matrix FOCUS identifies the pairs of elements $(E_1,E_8)$, $(E_3,E_6)$, $(E_3,E_{10})$, $(E_3,E_{11})$, $(E_5,E_6)$ and $(E_5,E_8)$ sharing the 77% similarity level. Enquiries $E_1$ and $E_8$ are already joined with $E_{12}$ in the cluster $(E_1-E_{12}-E_8)$ at the 84% similarity level so this latest relationship can be ignored. Enquiries $E_3$ and $E_6$ can be joined to form the cluster $(E_3-E_6)$ at the 77% level. Then, according to eq. 8.3(vii) this newly formed cluster can be fused with the cluster $(E_{10}-E_{11})$. Enquiry $E_3$ displays equal similarity (77%) with both enquiries $E_{10}$ and
E11, so in principal it is possible to fuse the two clusters together to produce either the cluster \{E6-E3-E10-E11\}, or the cluster \{E6-E3-E11-E10\}. Since the linear order of enquiries in clusters is important, however, then because E6 displays higher similarity to E10 than to E11 (73% versus 59%) the linear order in the former of the two possible fused clusters is preferred. Therefore, the two clusters \{E3-E6\} and \{E10-E11\} are fused at the 77% level to form the cluster \{E6-E3-E10-E11\}. Then, since the pair (E5,E6) displays 77% similarity E5 can join the cluster \{E6-E3-E10-E11\} to form the cluster \{E5-E6-E3-E10-E11\}; and then following this, since the pair (E5,E8) displays 77% similarity the two clusters \{E5-E6-E3-E10-E11\} and \{E1-E12-E8\} can be fused together to form the cluster \{E1-E12-E8-E5-E6-E3-E10-E11\}.

By this stage in the proceedings FOCUS has fused together the two major clusters \{E1-E12-E8\} and \{E5-E6-E3-E10-E11\} representing the highly attractive enquiries and lesser attractive enquiries respectively. In light of the assumed model of the managers' memories, and also the opportunistic nature of the single linkage joining method, any further cluster formations are unlikely to reveal any meaningful conceptual relationships. All that now remains to be done is to find the lower levels of similarity at which the individualistic enquiries E2, E7, E9 and E4 join the cluster \{E1-E12-E8-E5-E6-E3-E10-E11\}.

On its next search of the percentage similarity matrix FOCUS identifies the pairs of enquiries (E1,E9), (E2,E3), (E2,E11) and (E4, E9) displaying 75% similarity. So, the enquiries E4 and E9 can be joined to form the cluster \{E4-E9\} at the 75% level. Then, this newly formed cluster can be fused with the cluster \{E1-E12-E8-E5-E6-E3-E10-E11\} to form the cluster \{E4-E9-E1-E12-E8-E5-E6-E3-E10-E11\} also at the 75% level; and also at this similarity level E2 can link with E11 to form the cluster \{E4-E9-E1-E12-E8-E5-E6-E3-E10-E11-E2\}.

The Business Group Manager rated enquiries E9 and E2 as 5 and 1 respectively on the offered construct overall attractiveness of tender enquiry. So, although the enquiries E9 and E2 can be regarded as individualistic, it is interesting to note that E9 displays greater similarity to the highly attractive cluster containing the enquiries E1, E12, and E8 (75%, 68% and 70% similarity respectively) than it does to the very unattractive cluster containing enquiries E10 and E11 (59% and 51% respectively). Conversely, E2 displays greater similarity to E10 and E11 (66% and 75% respectively) than to E1, E12 and E8 (39%, 50%, 61% respectively). Thus, although the highly attractive E9 and the very unattractive E2 are individualistic they still display greater similarity to the attractive and unattractive enquiries respectively.
At this juncture only E7 remains isolated from the main cluster \{E4-E9-E1-E12-E8-E5-E6-E3-E10-E11-E2\}. Enquiry E7 displays 68% similarity with E2; so at this level E7 joins the main cluster linking with E2. Thus the final reordering of the enquiries for the focused grid is given in the cluster \{E4-E9-E1-E12-E8-E5-E6-E3-E10-E11-E2\}.

8.4.2(1)(B) CLUSTERING THE CONSTRUCTS

Table 8.4.2(1)(iii) is the percentage similarity matrix showing the similarity measure, based on the city block metric, for each pair of constructs in the Business Group Manager’s grid.

<table>
<thead>
<tr>
<th></th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>C10</th>
<th>C11</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>-</td>
<td>65</td>
<td>67</td>
<td>65</td>
<td>63</td>
<td>79</td>
<td>67</td>
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<td>58</td>
<td>46</td>
</tr>
<tr>
<td>C2</td>
<td>44</td>
<td>-</td>
<td>73</td>
<td>79</td>
<td>77</td>
<td>65</td>
<td>85</td>
<td>79</td>
<td>46</td>
<td>60</td>
<td>60</td>
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<tr>
<td>C3</td>
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<td>-</td>
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<td>48</td>
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<tr>
<td>C5</td>
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<td>40</td>
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<td>48</td>
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<td>79</td>
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<td>C8</td>
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<td>38</td>
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<td>73</td>
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<tr>
<td>C9</td>
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<td>63</td>
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<td>-</td>
<td>77</td>
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</tr>
<tr>
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<td>27</td>
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<td>54</td>
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<tr>
<td>C11</td>
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<td>65</td>
<td>58</td>
<td>69</td>
<td>54</td>
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<td>65</td>
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<td>54</td>
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</tbody>
</table>

The procedure for clustering the constructs is similar to that described for clustering the elements (or enquiries) in the previous section 8.4.2(1)(A). The only difference being that when clustering constructs it is also necessary to consider the similarity between pairs of constructs with one construct reversed (section 8.3). For this reason the percentage similarity matrix for constructs contains entries below the leading diagonal. These entries represent the similarity for the construct pair (row, column) with the row reversed.

For the Business Group Manager’s grid the formation of the construct clusters and the reordering of the constructs for inclusion in the focused grid proceeds as follows:-
The pair of constructs displaying the highest similarity (94%) are C4 representing level of financial risk and C7 representing likely competitiveness of price. Thus, these two constructs are joined to form the cluster \{C4-C7\} at the 94% level. The construct pairs (C2,C7) and (C3,C8) both display 85% similarity. Thus, the constructs C3 representing added value and C8 representing availability of manufacturing capacity are joined to form the cluster \{C3-C8\} at the 85% level; also at the 85% level C2, representing level of technical risk, joins the cluster \{C4-C7\} to create the cluster \{C4-C7-C2\}. The constructs C7 and C8 display 81% similarity so it is possible to fuse the clusters \{C4-C7-C2\} and \{C8-C3\} together at this level. Now, C8 displays the same level of similarity with C2 as it does with C4 (79%). However, C3 displays greater similarity with C2 than it does with C4 (73% versus 65%) so the two clusters are fused together to create the cluster \{C4-C7-C2-C8-C3\} to ensure that C3 is closer to C2 than it is to C3 in the focused grid.

At the next highest level of similarity are the construct pairs (C1,C6), (C2,C4), (C2,C7), (C2,C8), (C4,C8), (C5,C7) and (C11',C6), each displaying 79% similarity. With the exception of the constructs C1, C6, C5 and the reversed construct C11', all the other constructs included in these seven construct pairs are already included in the cluster \{C4-C7-C2-C8-C3\}, so the relations in the pairs (C2,C4), (C2,C7), (C2,C8), (C4,C8) can be ignored. Therefore, at the 79% level the only pairs that require further consideration are (C1,C6), (C5,C7) and (C11',C6). Thus, the constructs C1 representing availability of design, C6 representing chances of additional business and C11' representing level of competition join together to form the cluster \{C1-C6-C11'\} at the 79% level: also at this level C5, representing level of manufacturing investment, can join the cluster \{C4-C7-C2-C8-C3\}. Enquiry C5 displays greater similarity with C4 (77%) than it does to either C3 or C8 (71% and 73% respectively), so C5 links with C4 to create the cluster \{C5-C4-C7-C2-C8-C3\} at the 79% level.

The constructs pairs (C2,C5), (C4,C5) and (C9,C10) display the next highest level of similarity (77%). The constructs C2, C4 and C5 are already clustered together in \{C5-C4-C7-C2-C8-C3\} so the relations in the pairs (C2,C5), (C4,C5) can be ignored. So at the 77% level the constructs C9, representing work for a low/high loaded factory, and C10, representing attractiveness of build size, join together to form the cluster \{C9-C10\}. At this juncture all eleven constructs have been accounted for and FOCUS has revealed three major clusters \{C9-C10\}, \{C5-C4-C7-C2-C8-C3\} and \{C1-C6-C11'\}. Finally, at the 73% similarity level these three clusters fuse together to form the cluster \{C9-C10-C5-C4-C7-C2-C8-C3-C1-C6-C11'\} showing the reordering of the constructs for the focused grid.
Figure 8.4.2(kiv) Dendrogram showing the Clustering of the 12 Enquiries in the Business Group Manager's Grid


**8.4.2(1)(C) DISCUSSION AND SIGNIFICANCE OF RESULTS**

Figure 8.4.2(1)(iv) shows the clustering (in the form of a dendogram) of the 12 enquiries in the Business Group Manager's grid produced by the FOCUS analysis. The analysis has revealed the presence of three major clusters. The first of these is the cluster \{E10-E11\} representing those enquiries that the Business Group Manager regards as very unattractive. The second cluster \{E1-E12-E8\} represents those enquiries that the manager regards as highly attractive\(^\text{15}\), and finally the third cluster \{E5-E6-E3\} represents medium attractiveness enquiries\(^\text{16}\).

The pattern that the three clusters \{E10-E11\}, \{E1-E12-E8\} and \{E5-E6-E3\} create in figure 8.4.2(1)(iv) closely reflects the assumed model of the managers' memories. This model proposed that the highly attractive enquiries would be close together in memory and also that the very unattractive enquiries would be close together in memory, but that these two groups would be separated by the medium attractiveness enquiries which would be weakly conceptually related to both groups (see section 8.2). This is precisely what the re-ordering of the enquiries with FOCUS has achieved, with the medium attractiveness cluster \{E5-E6-E3\} lying in between the highly attractive and very unattractive clusters \{E1-E12-E8\} and \{E10-E11\} respectively. Furthermore, the level of similarity between the medium attractiveness enquiries (77%) is less than the level of similarity between the enquiries in either of the highly attractive or very unattractive clusters (84% and 86% respectively). This supports the organisation's earlier comment that appropriate recommendations are easily reached on highly attractive and very unattractive enquiries because the managers' recognise the implications of a similar set of characteristics, but that medium attractiveness enquiries are the most difficult to evaluate because their characteristics are less similar, and as a result the managers have more difficulty in recognising the implications of these enquiries' characteristics (see section 5.5.1).

The relatively low level of similarity between the enquiries E2, E7, E9 and E4 and the other enquiries in the grid (see figure 8.4.2(1)(iv)) suggests that the manager views

\(^{15}\) The Business Group Manager rated the enquiries E1, E12 and E8 as 5, 5 and 4 respectively on the offered construct *overall attractiveness of tender enquiry*. Although the manager did not regard enquiry E8 as favourably as E1 and E2 it was the only enquiry of the 12 which he rated as 4, and can therefore still be regarded as highly attractive relative to the other enquiries.

\(^{16}\) From a purely theoretical stand-point this third cluster is not distinct from either of the clusters \{E1-E12-E8\} or \{E10-E11\} because all three clusters fuse together at the 77% similarity level (see figure 8.4.2(1)(iv)).
these enquiries as individualistic; this is especially true for enquiry E7. Both enquiries E2 and E7 were regarded as very unattractive. Therefore, although both E2 and E7 display greater similarity to the unattractive cluster {E10-E11} than to the attractive cluster {E1-E12-E8}, their individualistic nature suggests that the manager regards these enquiries as being very unattractive for *slightly* different reasons than for the enquiries E10 and E11. Similarly, although enquiry E9 was regarded as highly attractive, and displays greater similarity to the attractive cluster {E1-E12-E8} than to the unattractive cluster {E10-E11}, its individualistic nature suggests that the manager regards E9 as attractive for reasons different from the other highly attractive enquiries E1, E12 and E8.

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17 The Business Group Manager rated both E2 and E7 as 1 on the offered construct *overall attractiveness of tender enquiry.*

18 The Business Group Manager rated E9 as 5 on the offered construct *overall attractiveness of tender enquiry.*
Figure 8.4.2(1)(vi) The Business Group Manager's Focused Grid

<table>
<thead>
<tr>
<th>FOCUSED GRID DATA (BUSINESS GROUP MANAGER)</th>
<th>E7</th>
<th>E2</th>
<th>E11</th>
<th>E10</th>
<th>E3</th>
<th>E6</th>
<th>E5</th>
<th>E8</th>
<th>E12</th>
<th>E1</th>
<th>E9</th>
<th>E4</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5  low manufact. investment</td>
<td>5</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>2</td>
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<tr>
<td>C4  low financial risk</td>
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<tr>
<td>C7  price likely competitive</td>
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<td>1</td>
<td>3</td>
</tr>
<tr>
<td>C8  manufact. cap. available</td>
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</tr>
<tr>
<td>C3  high added value</td>
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<td>3</td>
<td>3</td>
<td>1</td>
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</tr>
<tr>
<td>C1  design available</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>5</td>
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<td>4</td>
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<td>C6  good chance addn. business</td>
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<td>2</td>
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<td>1</td>
<td>4</td>
</tr>
<tr>
<td>C11' low level of competition</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>4</td>
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<td>5</td>
<td>2</td>
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<td>C10 attractive build size</td>
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<td>5</td>
<td>4</td>
<td>5</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>C9  work for low load factory</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>4</td>
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Bid Decision Category

<table>
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<th>E11</th>
<th>E10</th>
<th>E3</th>
<th>E6</th>
<th>E5</th>
<th>E8</th>
<th>E12</th>
<th>E1</th>
<th>E9</th>
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<td>B</td>
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<td>A</td>
</tr>
</tbody>
</table>
Figure 8.4.2(1)(vi) shows the Business Group Manager's focused grid. As noted above FOCUS has separated the highly attractive and very unattractive enquiries. In the focused grid the enquiries have been rearranged so that those representing unattractive business opportunities (N - No Bid) are positioned at the left hand side of the grid. As previously noted (see section 8.4.2 (1) A) the Business Group Manager rated enquiry E11 as 1 on the offered construct overall attractiveness of tender enquiry, thus indicating that his individual view was that the enquiry represented a very unattractive business opportunity. So it can be seen that the focused grid represents the individual view of the Business Group Manager rather than the consensus view of the TAG. Those enquiries representing highly attractive business opportunities (A - Bid A) have been positioned at the right hand side of the grid. Medium attractiveness enquiries, that is those enquiries awarded intermediate Bid B and Bid C decisions, appear almost without exception in the middle of the focused grid. The rank spearman correlation coefficient (Mendenhall et al, 1986 pp. 649) was used to measure how well the discriminations made by the manager's constructs matched his views concerning the enquiries' overall attractiveness. The rank correlation (0.958) between the Business Group Manager's attractiveness rankings and the position of the enquiries relative to the left hand side of the focused grid was found to be statistically significant at the 0.5% level. This result implied that the discriminations between the enquiries made in the focused grid closely matched the manager's opinions concerning the relative overall attractiveness of the 12 enquiries. Consequently, at an overview level the manager's grid appeared to be valid (see section 8.2.2).

19 The rank correlation coefficient not only measures the effect of the manager's constructs, but also the effect of the FOCUS algorithm because a different analysis technique used with the same constructs may produce different results.
Figure 8.4.2(1)(v) shows the clustering (in the form of a dendogram) of the 11 constructs in the Business Group Manager's grid produced by the FOCUS analysis. The analysis has revealed the presence of three quite distinct clusters: \{C5-C4-C7-C2-C8-C3\}, \{C10-C9\} and \{C1-C6-C11'\).

The cluster \{C5-C4-C7-C2-C8-C3\} suggests that the constructs level of manufacturing investment, level of financial risk, likely competitiveness of price, level of technical risk, availability of manufacturing capacity and added value are conceptually related. In particular, this cluster suggests that the constructs level of financial risk, likely competitiveness of price, level of technical risk forming the sub-cluster \{C4-C7-C2\} are very closely related, as are the constructs availability of manufacturing capacity and added value which form the sub-cluster \{C8-C3\}. It appears that the relationship between the construct level of manufacturing investment and these two sub-clusters is relatively weak compared to the relationships between the constructs within the two sub-clusters.

The cluster \{C5-C4-C7-C2-C8-C3\} illustrates a very important issue. For, it indicates that the FOCUS algorithm is myopic in its identification of relationships between constructs\(^{20}\).

Firstly, the presence of C5, C4, C7, C2, C8 and C3 in this cluster suggests that these constructs are conceptually related. However, in the creation of the dendogram in figure 8.4.2(1)(v) FOCUS lost the source of the relationships within the cluster; that is, which pairs of constructs within the cluster display the strongest conceptual similarity. This is because although the dendogram in figure 8.4.2(1)(iv) reveals the source of the relationships in the 2 sub-clusters \{C4-C7-C2\} and \{C8-C3\}, the source information relevant to the fusing together of these 2 sub-clusters at the 81% level is lost. That is, from the dendogram it is not possible to identify which construct pair is responsible for the fusing together of the 2 sub-clusters \{C4-C7-C2\} and \{C8-C3\}.

Secondly, several relationships between pairs of constructs in the cluster \{C5-C4-C7-C2-C8-C3\} were overlooked. For example, when the cluster \{C5-C4-C7-C2-C8-C3\} was formed at the 79% level by C5 linking to C4, the construct pairs \{(C2,C4), (C2,C7), (C2,C8) and (C4,C8)\} also displayed 79% similarity, but these were ignored because the constructs C2, C4, C7 and C8 were already clustered together at the 81%

\(^{20}\) The same argument applies to the analysis of the enquiries (elements) provided in section 8.4.2(1) A. However, in the case of clustering the enquiries the myopic effect of FOCUS was irrelevant.
level (see section 8.4.2(1)(B)). Now, if in the development of the model of the managers' decision processes one is prepared to take notice of the construct pair (C4,C5) displaying 79% similarity, then to perform a consistent and complete analysis of the domain it seems expedient to consider all other construct pairs displaying 79% similarity or more!

So, FOCUS is myopic because it loses the source of the relationships between constructs within a cluster and overlooks some of the strongest construct relationships. This apparent weakness with FOCUS and the manner in which it was overcome is discussed in chapter 9.

The cluster \{C1-C6-C11\} suggests that the constructs availability of design, chances of additional business and level of competition are conceptually related. Similarly the cluster \{C9-C10\} suggests that the constructs attractiveness of build size and work for a low/high loaded factory are conceptually related. It can also be seen that these two smaller clusters are formed at lower levels of similarity than the major cluster \{C5-C4-C7-C2-C8-C3\}. This suggests that the statistical evidence for the existence of these clusters, and therefore for the conceptual relationships within these clusters, is weaker than the evidence supporting the existence of the major cluster. This observation raises attention to the issue that interpretation of the construct clusters' significance involves some degree of subjectivity of behalf of the researcher\(^{21}\).

Ultimately all the constructs are joined together into a single cluster, (in the case of the Business Group Manager's Grid this occurred at the 73% similarity level) the implication being that all the constructs are conceptually related. In the widest possible sense this is true because the manager considers all the constructs to be relevant to the bid versus no bid and bid resourcing decisions and therefore at this level they are all conceptually related! However, such a wide interpretation yields little insight into how the manager evaluates enquiries and thence arrives at his overall recommendations. The subjective element to the interpretation of the significance of the construct clusters is therefore deciding upon what level of similarity between two constructs is necessary for a conceptual relationship to be inferred.

\(^{21}\) The same argument applies to the analysis of the enquiries (elements) provided in section 8.4.2(1) A. However, in the case of clustering the enquiries the subjective interpretation was largely irrelevant.
The objective of clustering the constructs in FOCUS is in effect to emulate principle component analysis, that is, to identify a small number of top level dimensions that the managers use to evaluate enquiries. In the interpretation of the construct clustering provided above it was implicitly assumed that the minimum level of similarity required between two constructs for a conceptual relationship to be inferred was 77%. At the 77% level three distinct clusters of constructs emerged suggesting that the Business Group Manager uses three principal dimensions on which to evaluate enquiries. If however, the minimum level of similarity required for a conceptual relationship to be inferred was raised to 81% the emergent clusters would be very different. At the 81% level the constructs in the clusters \{C10-C9\} and \{C1-C6-C11'\} would become distinct and C5 would break away from the cluster \{C5-C4-C7-C2-C8-C3\}. Thus, at the 81% level there would appear to be seven top level dimensions! This issue is discussed further in chapter 9.

8.4.2(2) Analysis of the Proposals Manager's Grid

The FOCUS algorithm was also applied to the Proposals Manager's grid. The output produced from this analysis is included in Appendix B.

Figure 8.4.2(2)(iv) shows the clustering (in the form of a dendogram) of the 12 enquiries in the Proposals Manager's grid derived from the percentage similarity matrix in table 8.4.2(2)(ii). Whereas the analysis of the Business Group Manager's grid revealed three clusters representing highly attractive, medium attractiveness and very unattractive enquiries respectively (see section 8.4.2(1)(iv)), the analysis of the Proposals Manager's grid to identify corresponding clusters was far less successful. Indeed, the only strongly bonded or significant cluster is \{E2-E11\} formed at the 82% similarity level. Since the Proposals Manager rated both enquiries E2 and E11 as 1 on the offered construct overall attractiveness of tender enquiry, the cluster \{E2-E11\} can be interpreted as representing very unattractive enquiries. At the 78% level three further clusters are formed: \{E7-E10-E12\}, \{E5-E3\} and \{E9-E4\}. The Proposals Manager rated the enquiries E7, E10, E12, E5, E3, E9 and E4 as 3, 2, 4, 4, 3, 5 and 3 respectively on the offered construct overall attractiveness of tender enquiry, so it is difficult to provide any of these three clusters with a meaningful interpretation. At the 75% level the four existing clusters and the individual enquiries E8, E6 and E1 all fuse together into the single cluster \{E2-E11-E7-E10-E12-E8-E5-E3-E6-E1-E9-E4\}, which provides the linear re-ordering of the enquiries for the focused grid.
Figure 8.4.2(2)(vi) (see Appendix B) shows the Proposals Manager's focused grid. Although FOCUS failed to identify distinct clusters of highly attractive and very unattractive enquiries, it has in general still separated the attractive enquiries from the unattractive enquiries. As was the case with the Business Manager's focused grid the enquiries have been rearranged so that in general those representing unattractive business opportunities (N - No Bid) are positioned at the left hand side of the grid. Those enquiries representing highly attractive business opportunities (A - Bid A) have been positioned at the right hand side of the grid, whilst enquiries given intermediate Bid B and Bid C decisions appear in the middle of the focused grid. As was also the case for the Business Manager's grid, the rank spearman correlation coefficient was used to measure how well the discriminations made by the Proposal Manager's constructs matched his views concerning the enquiries' overall attractiveness. The rank correlation (0.615) between the Proposals Manager's attractiveness rankings and the position of the enquiries relative to the left hand side of the focused grid was found to be statistically significant at the 2.5% level. This result implied that the discriminations between the enquiries made in the focused grid closely matched the Proposal Manager's opinions concerning the relative overall attractiveness of the 12 enquiries. Consequently, at an overview level the manager's grid appeared to be valid (see section 8.2.2).

A similar result confirming the validity of the Business Group Manager's grid was also obtained (see section 8.4.2(1) C), therefore both managers' grids appeared to be valid. Furthermore, not only did the Business Manager's constructs separate the highly attractive and very unattractive enquiries in the focused grid (see figure 8.4.2(1)(vi)), but they also produced distinct clusters of attractive and unattractive enquiries (see figure 8.4.2(1)(iv)). This latter observation, taken together with the earlier observation that the two managers' views concerning the relative overall attractiveness of the enquiries were found to be consistent (see section 8.4.1), suggested that taken as a whole the Business Group Manager's constructs were better discriminators of attractive and unattractive enquiries than were the Proposals Manager's constructs.

Figure 8.4.2(2)(v) shows the clustering (in the form of a dendogram) of the 15 constructs in the Proposals Manager's grid derived from the percentage similarity matrix in table 8.4.2(2)(iii). The analysis revealed four major clusters: {C1-C8-C10-C7-C14}, {C6-C4-C9}, {C11-C5-C12} and {C15'-C2'-C3'-C13'}.

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22 From a purely theoretical stand-point the clusters {C11-C5-C12}, {C1-C8-C10-C7-C14} and {C15'-C2'-C3'-C13'} are not distinct. By treating the clusters as distinct one is in effect ignoring the relationships between the 3 clusters and as
The largest cluster (C1-C8-C10-C7-C14') suggests that the constructs *nature of design, demands on design & build resources, level of competition, demands on bid resources* and *probability of success* are conceptually related. In particular, this cluster suggests that the constructs *nature of design* and *demands on design & build resources* forming the sub-cluster [C1-C8] are very closely related, as are the constructs *demands on bid resources* and *probability of success*. The cluster (C6-C4-C9) suggests that the constructs *level of involvement, potential profitability and desire to be in a particular market* are conceptually related. The cluster (C11-C5-C12) suggests that the constructs *prospects of available finance, chances of the project going ahead* and the *nature of the formal enquiry* are conceptually related. Finally, the cluster (C15'-C2'-C3'-C13') suggests that the constructs *ability to meet delivery dates, order size, chances of further business and knowledge of the customer* are conceptually related.

### 8.4.3 Analysis of the Combined Grid

The combined grid formed by aligning the Proposals and Business Group Managers' grids by the 10 common enquiries E1,...,E10 is shown in figure 8.4.3(i) (see Appendix B). The grid comprises of 26 rows of constructs and 10 columns of enquiries or elements. In the combined grid the first 15 constructs C1,...,C15 correspond to the 15 constructs in the original Proposals Manager's grid and the next 11 constructs C16,...,C26 to the 11 constructs in the original Business Group Manager's grid. The output produced from the analysis the combined grid with FOCUS is included in Appendix B.

Figure 8.4.3(iv) shows the clustering (in the form of a dendogram) of the 10 enquiries in the combined grid derived from the percentage similarity matrix in table 8.4.3(ii). With some sympathetic interpretation it is possible to detect three clusters: {E10-E3-E6}, {E5-E8} and {E1-E9-E4}²³. By comparing the average of the two managers' ratings on the offered construct *overall attractiveness of tender enquiry* for each of the enquiries in these clusters it is possible to provide each cluster with a meaningful

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²³ From a purely theoretical standpoint the two clusters {E10-E3-E6} and {E5-E8} are not distinct because they fuse together at the 73% similarity level (see figure 8.4.3(iv)).
interpretation. The average of the two managers' ratings on the offered construct 
*overall attractiveness of tender enquiry* for the enquiries E10, E3, E6, E5, E8, E1, E9 
and E4 are 1.5, 2.5, 2, 3, 4.5, 5, 5 and 2.5 respectively. The cluster \{E10-E3-E6\} can 
be interpreted as representing low attractiveness enquiries and the cluster \{E5-E8\} as 
representing medium attractiveness enquiries. Finally, provided that the presence of 
E4 is overlooked, the cluster \{E1-E9-E4\} can be interpreted as representing highly 
attractive enquiries. The very unattractive enquiries E2 and E7, both rated as 1 on the 
offered construct *overall attractiveness of tender enquiry* by both managers, are the 
most individualistic enquiries in the grid.

So, the cluster pattern produced by the combined grid is stronger than the pattern 
obtained from the Proposals Manager's individual grid where no cluster pattern at all 
emerged (see figure 8.4.2(2)(iv)), but weaker than the pattern obtained from the 
Business Group Manager's grid where a distinctive pattern emerged (see figure 
8.4.2(1)(iv)). Therefore, the net effect of combining the two sets of manager's 
constructs is that the Proposals Manager's constructs dilute the discriminations made 
in the Business Group Manager's grid; put the other way round this shows that the 
Business Group Manager's constructs strengthen the discriminations made in the 
Proposal Manager's Grid.

Since the Business Group Manager's constructs are better discriminators of attractive 
and unattractive enquiries than the Proposals Manager's constructs, one could almost 
be forgiven for thinking that the latter manager's constructs could be excluded from 
any subsequent analysis in favour of the former manager's more powerful construct 
system. However, such a conclusion would be unwise and unjustified. Firstly, it was 
assumed that the managers' decision processes can be modelled using a hierarchical 
inference network (see section 6.2(5)), therefore each manager's individual constructs 
are believed to operate or have relevance at different conceptual levels. However, in 
FOCUS each construct is effectively assumed to operate at the same conceptual level, 
because each construct is implicitly assigned the same weight when determining the 
similarity between each pair of enquiries (see eqs. 8.3(i)-8.3(iii)). So, although in 
general the Proposals Manager's constructs appear to be relatively poor discriminators 
of an enquiry's overall attractiveness, they may yet prove to be good discriminators of 
mid-level concepts and could therefore be used as a basis for making inferences about 
mid-level concepts within a knowledge based expert system. Secondly, since FOCUS 
only measures the discriminating power of a construct system as a whole and not the 
power of any construct sub-systems (that is, a sub-set of the original construct set), 
the identification of an individually powerful discriminator can be masked by the
presence of several poor discriminators. Thus, it is possible that some of the Proposal Manager's constructs are high level concepts and may be super-ordinate to some of the Business Group Manager's constructs, but that their true conceptual level has been masked by the presence of several low level poor discriminating constructs in the Proposal Manager's grid.

Figure 8.4.3(vi) (see Appendix B) shows the focused combined grid. As was the case with the managers' individual grids the rearrangement of the enquiries in the focused combined grid resulted in the unattractive enquiries being repositioned at the left hand side of the grid and the highly attractive enquiries more towards the right hand side of the grid. Those enquiries given intermediate Bid B and Bid C decisions have been repositioned in the middle of the grid. Again the rank spearman correlation coefficient was used to measure how well the discriminations made by the combined set of constructs matched each manager's respective views concerning the enquiries' overall attractiveness. The rank correlation (0.952) between the Business Group Manager's attractiveness rankings and the position of the enquiries relative to the left hand side of the focused grid was found to be statistically significant at the 0.5% level; as was the rank correlation (0.770), statistically significant at the 0.5% level, between the Proposals Manager's attractiveness rankings and the relative grid positions.

The results in the previous paragraph implied that the discriminations produced by the combined set of constructs closely matched both managers' respective opinions concerning the relative overall attractiveness of the 10 enquiries in the combined grid. Thus, at an overview level the combined grid was proven to be valid with respect to both managers' individual overall opinions. Indeed this last result follows as a direct consequence of the fact that the two managers' views concerning the relative overall attractiveness of the enquiries were found to be consistent (see section 8.4.1) and that both managers' individual grids were proven to be valid (see sections 8.4.2(1) C & 8.4.2(2))\textsuperscript{24}. Thus, the two sets of managers' constructs were found to complement...
each other, rather than contradict each other, and thereby provided a broader insight into the TAG's decision processes than either of the managers' individual construct systems. For, if the two sets of constructs were contradictory, then one would have expected a random rearrangement of the enquiries in the focused combined grid, as each set of constructs cancelled out the discriminations made by the other. However, such a result could only have occurred if the two managers' views were inconsistent, but both their respective grids were valid; or if the managers' views were consistent, but at least one of their grids was not valid.

The results above suggested that there may have been common elements to the two managers' reasoning processes, which raised the possibility of formulating an acceptable model of the TAG's decision processes from combining the two managers' construct systems. This claim was further substantiated by the results obtained from the clustering of the constructs in the combined grid described below.

Figure 8.4.3(v) (see Appendix B) shows the clustering (in the form of a dendogram) of the 26 constructs in the combined grid derived from the percentage similarity matrix in table 8.4.3 B. The relevance of the construct clusters derived from the combined grid is not only that they highlight the existence of conceptual relationships between the managers' own constructs, and therefore validate the earlier interpretations of the construct clusters derived from the managers' individual grids; but that they also highlight conceptual relationships between the two managers' construct systems, and therefore draw attention to the similarities and differences between the two managers' views at lower conceptual levels in the enquiry evaluation process (see section 8.2.3).

Figure 8.4.3(v) shows that at the 83% level there are three major clusters which account for all but 6 of the 26 constructs in the combined grid. There is a significant small relative to $D_{\text{max}} = D^{(1)}_{\text{max}} + D^{(2)}_{\text{max}}$. Thus $E_i$ and $E_j$ are conceptually related relative to the construct system $C = C_1 \cup C_2$.

Conversely, suppose that $E_i$ is a highly attractive enquiry and that $E_j$ is a very unattractive enquiry (that is, $E_i$ and $E_j$ are not conceptually related). Since the managers' overall views are consistent and their respective grids are valid then $D^{(1)}_{ij}$ and $D^{(2)}_{ij}$ are large relative to $D^{(1)}_{\text{max}}$ and $D^{(2)}_{\text{max}}$. Thus the distance between $E_i$ and $E_j$ measured on the construct system $C = C_1 \cup C_2$ by the city block metric, $D_{ij} = D^{(1)}_{ij} + D^{(2)}_{ij}$ is large relative to $D_{\text{max}} = D^{(1)}_{\text{max}} + D^{(2)}_{\text{max}}$. Thus $E_i$ and $E_j$ are not conceptually related relative to the construct system $C = C_1 \cup C_2$.

Thus, the combined grid or construct system $C = C_1 \cup C_2$ is valid with respect to the two managers' respective overall opinions.
3% jump to the next highest similarity level, the 80% level, at which there are only two major clusters because two of the clusters at the 83% level have now fused together. Since in the construct clusters derived from the managers' individual grids there were at least three clusters present then it seems expedient in the interpretation of the construct clusters in the combined grid to assume that the minimum level of similarity required between two constructs for a conceptual relationships to be inferred is 83%. At the 83% level there are three major clusters: {C19-C22-C17-C14'-C7-C1-C8-C8-C10-C15'}, {C5-C3-C26-C12-C13-C21'} and {C23'-C18'-C9-C4-C6}; and 6 individual constructs C20, C25'C2', C16', C11, C24'.

The cluster {C19-C22-C17-C14'-C7-C1-C8-C8-C10-C15'} can be regarded as the result of fusing together the two sub-clusters {C19-C22-C17} and {C14'-C7-C1-C8-C8-C10} at the 85% level, and then joining the relatively weakly related construct C15' to the result of this fusion at the 83% level. Interpreting the cluster in this way enables the relationships between the constructs level of financial risk, likely competitiveness of price and level of technical risk drawn from the Business Group Manager's individual grid to be confirmed (see section 8.4.2(1) C). That is the nature of the relationships between these constructs remains stable subject to the removal of the two rogue enquiries from the manager's grid. A similar conclusion can be made for the relationships between the constructs probability of success, demands on bid resources, standard/customer design, demands on design & build resources and level of competition drawn from the Proposals Manager's individual grid (see section 8.4.2(2)). Moreover the analysis of the combined grid suggests that the two construct sub-clusters derived from the managers' individual grids are conceptually related, and furthermore that the construct ability to meet delivery date is weakly conceptually related to these two sub-clusters.

The cluster {C23'-C18'-C9-C4-C6} can be interpreted in a similar fashion to that just described for the cluster {C19-C22-C17-C14'-C7-C1-C8-C8-C10-C15'}. This cluster confirms the relationships between the constructs added value and availability of manufacturing capacity drawn from the Business Manager's grid (see section 8.4.2(1) C) and the relationships between the constructs desire to be in the market, potential profitability and level of involvement drawn from the Proposal Manager's Grid. However, whereas in the Business Manager's grid the constructs added value and availability of manufacturing capacity were regarded as being related to the constructs level of financial risk, likely competitiveness of price and level of technical risk, in the combined grid they are regarded as displaying greater conceptual
similarity to the Proposal Manager's constructs desire to be in the market, potential profitability and level of involvement.

The construct \{C5-C3-C26-C12-C13-C21\}' confirms the relationship between the constructs chances of additional business and level of competition drawn from the Business Group Manager's grid, and between the constructs chances of the project going ahead and nature of formal enquiry, and also between chances of further business and knowledge of the customer drawn from the Proposals Manager's grid. However, to replicate all the construct clusters derived from the managers' individual grids the minimum level of similarity between two constructs for a conceptual relationship to be inferred has to be successively reduced, and ultimately to the 75% level at which point all the 26 constructs belong to the same cluster! Thus several of the relationships identified in the managers' individual grids appear to be sensitive to the enquiries under consideration.

To summarise, each of the three major construct clusters derived from the combined grid was in effect formed from combining two of the major clusters, or sub-clusters thereof, derived from the managers' individual grids respectively. For example, the cluster \{C23'-C18'-C9-C4-C6\} derived from the combined grid resulted from the fusion of the sub-cluster \{C23'-C18'\} (formerly \{C8-C3\}, see section 8.4.2(1) C) and the cluster \{C9-C4-C6\} derived from the Business Group and Proposals Managers' individual grids respectively. This suggested that there was both considerable similarity between the top-level dimensions that the two managers use to evaluate enquiries and also between the two managers' views at lower conceptual levels of the enquiry evaluation process. This conclusion follows because the construct analysis of the combined grid is in essence the superimposition, that is the joining together, of the two managers' respective construct cluster patterns derived from their individual grids. Thus, if the managers' respective views were very different one would have expected the two sets of clusters to remain distinct because there would only be weak conceptual similarity between the managers' construct clusters. If however, the managers' respective views were very similar one would have expected the pairs of managers' individual construct clusters to join together because there would be strong conceptual similarities between the managers constructs; and this is precisely what happened in the analysis of the managers' combined grid. The combined construct cluster pattern derived from the combined grid suggests that the two sets of managers' top level dimensions are effectively aligned in space, that is that they are conceptually very similar. It was therefore concluded that there is considerable similarity between the two managers' views of the enquiry evaluation process (see section 8.2.3) and that
it may be possible to develop an acceptable model of the TAG decision processes by combining the two managers' construct systems, thus combining their respective views.

8.5 SUMMARY

The objectives and methods of analysing a repertory grid have been discussed, and FOCUS a grid analysis method based on cluster analysis was chosen as an appropriate method for establishing the validity of the managers' grids as instruments to investigate the bid versus no bid and bid resourcing decisions of the TAG.

The most significant results obtained from the initial analyses of the managers' individual grids and the combined grid using FOCUS are summarized below:

1. The Business Group and Proposals Managers' respective views concerning the enquiries' overall attractiveness and the business opportunities that they represent are consistent (see sections 8.2.1 & 8.4.1). That is, there is a high level of agreement between the managers regarding the relative overall attractiveness of the enquiries.

2. Both managers' individual grids are valid (see section 8.2.2). That is, both managers' respective construct systems can discriminate between attractive and unattractive enquiries and the discriminations made by their construct systems closely correspond to the managers' respective views concerning the enquiries' overall attractiveness (see sections 8.4.2(1)C & 8.4.2(2)).
3. Taken as a whole the Business Group Managers' construct system is a better discriminator of attractive and unattractive enquiries than the Proposals Manager's construct system. However, the Proposal Manager's constructs may prove to be good discriminators of mid-level concepts and could therefore be used as a basis for making inferences about mid-level concepts within a knowledge based expert system. Furthermore, because FOCUS only measures the discriminating power of a construct system as a whole it is possible that some of the Proposals Manager's constructs are high level concepts and may be super-ordinate to some of the Business Group Manager's constructs, but that their true conceptual levels are masked by the presence of several low level poor discriminating constructs in the Proposals Manager's grid.

4. The combined grid formed by aligning the Proposals and Business Group Manager's grid by the 10 common enquiries is also valid with respect to both managers. So, the discriminations made by the managers' combined construct systems closely correspond to both managers' respective views concerning the enquiries' overall attractiveness. This suggests the existence of several common elements to the two managers' decision processes.

5. Conceptual relationships between pairs of constructs in the managers' respective construct systems have been identified. This resulted in both managers' respective construct systems being structured into three (or four) construct clusters or groups. Thus, suggesting that both managers use three (or four) top-level dimensions on which to evaluate enquiries (see sections 8.4.2(1) C & 8.4.2(2)).

6. Analysis of the conceptual relationships between pairs of constructs in the combined grid suggests that there is both considerable similarity between the top-level dimensions that the two managers use to evaluate enquiries and also between the two managers' views at lower conceptual levels of the enquiry evaluation process. It was therefore concluded that there is considerable similarity between the two managers' views of the enquiry evaluation process and that it may be possible to develop a decision model of the TAG based on the managers' combined construct system, thereby combining their respective views and encompassing a broad based business perspective (see sections 8.2.3 & 8.4.3).
When forming the construct clusters to determine of the top-level dimensions of the domain FOCUS is myopic in its identification of conceptual relationships between constructs. This is because it both loses the source of the relationships between constructs within a cluster (that is, the information concerning which pairs of constructs within the cluster display the greatest conceptual reality) and overlooks some of the strongest construct relationships (see section 8.4.2(2) C). Consequently, the analyses of the managers’ grids using FOCUS were insufficient to reveal the underlying hierarchical inference network that was assumed to model the domain. To identify this network a second stage of analysis was performed. This is described in the next chapter.
CHAPTER 9

KNOWLEDGE ACQUISITION STAGE 2 (CONTINUED)-
DEVELOPMENT OF THE HIERARCHICAL INFERENCE NETWORK
9. **Knowledge Acquisition Stage 2 (Continued) - Development of the Hierarchical Inference Network**

9.0 **Introduction**

This second chapter describing the analysis of the managers' grids is concerned with the identification of the managers' overall conceptual structure of the domain of tender enquiry evaluation. The chapter commences by highlighting the limitations of FOCUS to these ends. Following this, a methodology based on correlation analysis is devised to assist in the identification of the domain's conceptual structure and the results from applying the methodology to the managers' individual grid and the combined grid respectively are presented. Finally, the managers' overall conceptual structure of the domain is presented in the form of a hierarchical inference network.

9.1 **The Limitations of FOCUS**

The analyses of the managers' individual grids and the combined grid using FOCUS proved successful in answering the first three analysis objectives outlined in sections 8.2.1-8.2.3. That is, the analyses established that the Business Group and Proposals Managers' respective overall views are consistent, that their individual grids are valid; and finally that there is sufficient similarity between the two managers' views at the lower conceptual levels of the enquiry evaluation process to justify developing a knowledge based model based on the managers' combined construct system. These analyses revealed however, little insight regarding the fourth analysis objective; that of identifying the processes that the managers' use to combine their constructs, and ultimately the characteristics that they associate with attractive and unattractive enquiries respectively.

This overall deficiency with the previous analyses can be traced back to the product of several characteristics of the FOCUS algorithm. It was assumed that the domain of tender enquiry evaluation can be modelled by a hierarchical inference network in which the relevant constructs operate or have relevance at different conceptual levels. As previously noted in section 8.4.3, however, in FOCUS all constructs are treated at the same conceptual level, thus disregarding the natural hierarchical structure of the domain. As a result the nature of any link between enquiries and constructs in the focused grid, that is a relationship highlighting the characteristics of attractive and
unattractive enquiries respectively, is masked by the presence of the high variability low level constructs which are relatively poor discriminators of an enquiry's overall attractiveness. Principle components analysis circumvents this problem because it first reduces the dimensionality of the domain by identifying the top level fundamental constructs or the principal components, and only then provides an explicit link between the elements and the fundamental constructs in a cognitive map, thus highlighting the characteristics of attractive and unattractive enquiries respectively.

In theory, if the identity of the hierarchical domain structure were known, the highest level constructs could be extracted and the enquiries focused again with FOCUS using only these constructs. This ought to increase the transparency of the link between the enquiries' overall attractiveness and the top level constructs and produce a comparative representation to the cognitive map derived from principle components analysis. In principle the process of construct extraction could be repeated at each level in the hierarchy and thereby provide insight into the nature of the relationships at each hierarchical level. Unfortunately, the previous analyses of the constructs in the managers' individual grids and the combined grid using FOCUS were unable to reveal the hierarchical structure of the tender enquiry evaluation domain. This deficiency arose because of FOCUS's myopic identification of conceptual relationships between the grids' constructs (see sections 8.4.2(1) B and 8.5).

The analogy with principle components analysis suggested that the first step in addressing the fourth analysis objective (see section 8.2.4) needed to be the identification of the overall hierarchical structure of the domain. This in turn required a method for identifying and explicitly displaying the existence of possible dependence-influence relationships both within and between the managers' construct systems. One method for identifying networks of conceptual relationships which could have been beneficial to the hierarchy's development is the general weighted network technique (GWN). An overview of GWN and a discussion of its relevance to the domain of tender enquiry evaluation is provided in the next section.
9.2 AN OVERVIEW OF GENERAL WEIGHTED NETWORKS (GWN) AND ITS RELEVANCE TO THE DOMAIN OF TENDER ENQUIRY EVALUATION

The general weighted network (GWN) (or proximity analysis) is a psychological scaling technique that can be used to generate networks of conceptual relationships from a symmetric matrix of distance measures for each pair of concepts in a domain. In general practice the matrix of distance measures is elicited directly from the expert, for example Gammack & Young (1985) repeatedly use each domain concept as a reference and then ask the expert to provide a distance estimate for all other domain concepts relative to the reference concept. However, as previously noted in section 6.3 and shown below, a repertory grid provides an appropriate indirect alternative for generating the matrix of distance measures; and as a consequence GWN can be used to generate networks of conceptual relationships from the managers' individual and combined grids.

To show how a repertory grid can be used as a basis for the GWN technique consider the analysis of one of the manager's grids using FOCUS. The sole requirement of GWN is a symmetric matrix of distance estimates representing the conceptual similarity between each pair of domain concepts. The first step in the FOCUS algorithm involves the generation of a percentage construct similarity matrix. Each entry in this matrix is a simple linear transformation of the city block distance metric (eq. 8.3(v)). Therefore, the percentage construct similarity matrix can undergo a simple linear transformation to produce a matrix of construct distance measures representing the conceptual similarity between each pair of constructs in the grid.

Furthermore, although at first sight the percentage construct similarity matrix appears to be asymmetric, because the similarity measure for entry (i,j) is not the same as that for entry (j,i), this is misleading. This apparent asymmetry arises not because the psychological distance between the construct pair (C_x,C_y) say is different from that between the pair (C_y,C_x), but because of the arbitrary assignment of the emergent and implicit construct poles. As previously noted a construct pair (C_x,C_y) displaying 0% similarity would display 100% if one of the constructs were to have its poles reversed. Thus, when construct reversal is taken into account by only considering the larger of the two similarity measures for entries (i,j) and (j,i) respectively, then the construct similarity matrix is in essence symmetric. Therefore, in theory, a network of construct relationships can be derived by applying GWN to a linear transformation

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1 For further details of GWN or proximity analysis see Olsen & Reuter, 1987; Cooke & McDonald, 1987; Gammack & Young, 1985; Gammack, 1987a & 1987b, Neale 1987 & 1988)
the percentage construct similarity matrix produced by FOCUS. That is, that it is possible to base GWN on a distance matrix derived from a repertory grid. For this reason it was expedient to investigate the relevance of GWN to identifying the hierarchical structure of the tender enquiry evaluation domain from the managers' individual and combined grids.

The underlying assumption of GWN is that "the psychological distances between any two concepts arises from the expert traversing a network of associations, a network in which there exists a single primary path between every pair of concepts, and for some pairs a secondary differently encoded path as well" (Olsen & Reuter, 1987 pp. 60). The implications of this assumption regarding the technique's suitability to the domain of tender enquiry evaluation are discussed later in this section.

The network, or graph, of associations is generated in two steps. The first step involves using the distance matrix to derive the so called minimal connected network (MCN). The MCN is obtained by the application of a single linkage agglomerative hierarchical clustering technique. The first step in GWN is therefore very similar to the second step in FOCUS, the only difference being that GWN retains the source or identity of the strongest conceptual relationships and these are explicitly shown in the MCN; whereas with FOCUS the source or identity of the strongest construct relationships is lost within the construct clusters and the construct re-ordering. In the second step additional links or relationships are added to the MCN to derive the so called minimal elaborated network (MEN). In this second step an additional link is added to the MCN between two domain concepts if the distance estimate for that pair of concepts in the expert's distance matrix is less than the minimum distance between the two concepts as measured along all existing paths between the two concepts (see Cooke & McDonald, 1987).

As with other psychological scaling techniques the analysis provided by GWN does not provide any information about the semantics of the conceptual relationships illustrated in the MCN and MEN (Cooke & McDonald, 1987). However, Olsen and Reuter (1987) argue that studies have shown that when experts are fed back their networks they can easily identify with the relationships using terms such as affects and is a, thus identifying the semantic hierarchical sub/super-ordinate nature of the relationships. Furthermore, they suggest in particular that the MCN and MEN should be examined for dominating concepts, that is those nodes that have a large number of connections to other nodes; and for members of cycles, that is those nodes that are fully linked into circles.
To summarise, GWN appears to overcome the two principle weaknesses of FOCUS. Firstly, GWN explicitly shows the relationships between the domain concepts rather than simply the concepts' membership to a particular cluster of concepts. Secondly, the generation of the MEN appears to ensure that all the strongest conceptual relationships are identified. Therefore, the elaborated relationships in the MEN connect together larger conceptual structures and thereby provide a much richer conceptual picture of the domain than that produced by FOCUS.

Closer inspection of the technique's underlying assumption, in particular its criterion for determining whether or not an additional link or relationship should be added to the MCN for inclusion in the MEN, reveals two conceptual anomalies. Firstly, the MEN may in some circumstances provide an inconsistent and incomplete representation of the relationships between the domain concepts because the MEN does not necessarily include all the strongest relationships in the domain. Secondly, some of the relationships present in the MEN may be based on very weak statistical evidence and are therefore such that their inclusion masks the domain's true conceptual structure.
Figure 9.2 MCN Produced by GWN for the 11 Constructs in the Business Group Manager's Grid

- C1 Level of Competition
- C6 Chances of Additional Business
- C1 Availability of Design
- C8 Availability of Manufacturing Capacity
- C10 Attractiveness of Build Size
- C11 Work For A Low/High Loaded Factory
- C2 Level of Technical Risk
- C3 Added Value
- C4 Level of Financial Risk
- C5 Level of Manufacturing Investment
- C7 Competitiveness of Price
To illustrate these two observations consider figure 9.2 which shows the MCN for the constructs in the Business Group Manager's grid. In this network the number alongside each link joining two constructs is the psychological distance between the constructs measured by the city block metric and is indicative of the strength of the statistical evidence supporting the link's or relationships existence. As the derivation of the MCN is almost equivalent to second stage of FOCUS it is not surprising that the MCN displays the three major clusters (I_{C5-C4-C7-C2-C8-C3}, I_{C10-C9} and I_{C1-C6-C11'}) produced by FOCUS (see fig 8.4.2(1)(v)). In the MCN these three clusters are joined together by the two weakest links in the network, (C8,C1) and (C8,C10).

Now consider the derivation of the MEN from the MCN: in particular consider whether additional links should be made for the construct pairs (C4,C2) and (C8,C11) respectively. The psychological distance estimate for (C4,C2) is 10, and the minimum distance along any path joining C4 and C2 is also 10 (10 = 7 + 3). Therefore according to the criterion for including additional links to the MEN there is no useful insight to be gained about the structure of the domain by including a link between C4 and C2. Thus, the possible existence of a relationship between C4 and C2 is rejected irrespective of the fact that there is stronger statistical evidence to support its existence than for the relationships (C1,C6), (C6,C11) and (C10,C9) which are already included in the MCN! Conversely, the psychological distance estimate for (C8,C11) is 21 and the minimum distance along any path between C8 and C11 is 34. Therefore according to the criterion for including additional links in the MEN an additional link would be made between C8 and C11. For the moment suppose that the constructs C8 and C11 were generated on a purely random basis. Under this hypothesis the psychological distance estimate between C8 and C11 would be a random variate assuming an integral value in the interval \([0,48]\] with an expected value or mean of 19.2. Furthermore, the variates probability distribution would be asymmetric; and because the probability of the variate assuming a value less than the mean (13/25) is greater than the probability of the variate assuming a value greater than the mean (12/25) the median would be less than the mean of 19.2. So, under the hypothesis of random generation the probability of observing a psychological distance of at most 21 for (C8,C11) would greater than 0.5. This implies that there is no statistical evidence for the existence of a conceptual relationship between C8 and C11, and that its inclusion in the MEN masks the overall domain structure.

\(^2\) Small psychological distances alongside links in the MCN in figure 9.2 indicate strong statistical evidence for the existence of a conceptual relationship between the two constructs joined by the link.
If GWN is applied to the Business Group Manager's grid a strong relationship (C2,C4) is apparently overlooked, whilst a relatively weak relationship (C11,C8) is included in the MEN. Now, if as the theory suggests, the networks derived from the Business Group Manager's grid were to be used to obtain feedback from the manager on the nature of the relationships revealed, then the question must be raised as to whether there is any sense in prompting the manager to comment on relationships with little or no statistical support, as for example the nature of the relationship between C8 and C11, whilst at the same time not prompting the expert to comment on the nature of some of the statistically strongest relationships, as for example the nature of the relationship between C4 and C2? For, if it is believed that a relationship between two constructs displaying x% similarity may provide useful insight into the domain's structure, and is therefore worthy of the manager's consideration, then is there any theoretical justification for rejecting consideration of any other relationship that displays at least x% similarity? Clearly, the advocates of GWN believe that such a theoretical justification exists, and in order to fully comprehend this it is necessary to expand upon the concept of a strong relationship.

In the derived networks a construct relationship can be locally strong, that is strong relative to the relationships within the cluster of constructs of which it is a part, or globally strong, that is strong relative to all construct relationships. Therefore, in theory, a construct relationship can be globally strong but locally weak; whereas a relationship that is locally strong is necessarily globally strong. GWN is primarily concerned with the identification of locally strong relationships and this is why the globally strong, but locally weak, relationship between C2 and C4 is excluded from the Business Group Manager's MEN. However, even if GWN's theoretical justification of the exclusion of a relationship between C2 and C4 is valid in the domain of tender enquiry evaluation, then the problem regarding the inclusion of the statistically invalid relationship between C1 and C8 remains unanswered.

The reason GWN is primarily concerned with the identification of locally strong relationships is because its objective is to exclude possibly transitive \(^3\) relationships from the MEN. This has a significant impact on the development of the hierarchical inference network in the domain of tender enquiry evaluation. In this domain the nature of the relationships that it is hoped will be revealed by GWN are relationships of influence and its mutual partner dependency, that is relationships of the form

\(^3\) A relationship \(R\) operating on a set \(S\) is said to be transitive if whenever \(aRb\) (that is \(a\) is related to \(b\) under \(R\) in \(S\)) and \(bRc\) (\(a, b, c \in S\)) then \(aRc\)
construct C_x influences construct C_y; and conversely, C_y is dependent upon C_x.

Obviously such influence-dependency relationships display the transitive property because if C_x influences C_y and C_y influences C_z, then C_x must necessarily influence C_z. The consideration of such transitive relationships masks the domain's structure and therefore raises the critical question of whether GWN, or indeed any other analysis technique, can identify those relationships whose existence stems from a purely transitive basis. That is, if the analysis reveals that C_x influences C_y and that C_y influences C_z, then it should be no surprise if there is evidence suggesting that C_x influences C_z; the important question is whether the evidence supporting a relationship between C_x and C_z is sufficiently strong to suggest that C_x influences C_z independently of C_y, so that knowledge regarding C_x imparts knowledge of C_z irrespective of any knowledge of C_y either imparted from C_x or otherwise? Such non-transitive relationships create cycles in the derived network which represent complex or multi-reasoned relationships. The network traversal assumption underlying GWN addresses this problem by suggesting that the relationship between C_x and C_z is purely transitive if the direct distance between C_x and C_z represented by the expert's distance estimate is greater than or equal to the distance between C_x and C_z via C_y.

To summarise, the combination of psychological distances (in the case of GWN the simple addition of distances along a path) to produce a measure with significant cognitive relevance is intuitively appealing. The analysis of the Business Group Manager's grid with GWN, however, has shown that this method can produce spurious conceptual relationships with little statistical validity, as for example the relationship between C8 and C11, thereby casting doubt about the suitability of GWN and distance based similarity measures in modelling the conceptual relationships both within and between the Business Group and Proposal Manager's construct systems. Moreover, since the GWN analysis provides no information about the semantics of the conceptual relationships highlighted in the MCN and MEN, then in theory successive links in any path may hold different semantic interpretations. Thus, to add the strength of such links together to produce a further measure of strength seems highly spurious, because in effect this involves adding together different quantities. In addition Olsen & Reuter's (1987) suggestion that the MEN should be examined for members of cycles is in effect implicitly saying that the identification and subsequent removal of any transitive relationships should be made during a post analysis discussion with the expert, rather than made explicitly by the analysis technique.
Together these arguments suggested that in the domain of tender enquiry evaluation a more consistent and complete inferential hierarchy would result from an analysis technique that derived networks or maps based on the concept of globally strong construct relationships rather than locally strong relationships, thus ensuring that all the strongest relationships were included in the map. Following the analysis, then as in the GWN methodology these maps could be examined by the respective managers for dominating concepts and members of cycles, the nature of the relationships so identified and any transitive relationships removed. To achieve these objectives an appropriate analysis method was developed and applied to the managers' individual grids and the combined grid to identify construct relationships within and between the managers' construct systems. This method is described in the following section.

9.3 Correlation Analyses and Conceptual Mappings

Given the limitations of FOCUS and GWN a method was developed during the research project to assist in the identification of the hierarchical structure of the tender enquiry evaluation domain based on correlation analysis. This new method retained one of the major facets of the GWN technique: it incorporated the idea that a visually inspectable representation of the construct relationships provides an appropriate medium through which to communicate the findings of the analysis to the managers, and thereby establish the validity of, and further insight into the nature of, the relationships revealed. The major difference between the method advocated and the GWN technique is the process by which the graphical representation of the construct relationships is derived, and in this respect there are two differences. These are as follows:-

(1) In the new method the existence of a relationship between two constructs is based on the product moment correlation coefficient. This is because in the domain of tender enquiry evaluation this is a more appropriate measure of conceptual similarity between constructs than is the city block metric. An explanation for this is given below.
In GWN the MCN and MEN are derived primarily from considering the locally strongest relationships. In the method advocated the network or graph of construct relationships is derived from the consideration of the globally strongest relationships. Thus, the only criterion for determining whether or not a particular relationship should be included in the graph is the relationship's statistical validity. Therefore all the strongest construct relationships are included in the graph which ensures that the analysis is both consistent and complete.

To summarise, the derived graph of construct relationships is in effect simply a visually inspectable representation of all the statistically significant construct correlations. Therefore, in theory, by lowering the level of significance required for a construct relationship to be inferred more elaborate conceptual structures can be investigated. Although inevitably this process reaches a stage when the relationships revealed are highly spurious. For this reason the relationships in the graphs were colour coded at three significance levels (at the 0.5%, 1.0% & 2.5% levels respectively) to indicate their statistical validity. The graphs derived by this process have been termed conceptual maps.

To understand why the product moment correlation coefficient was preferred to city block metric when analysing construct relationships within and between the managers' construct systems consider the hypothetical scenario outlined below.

Consider a small component of the hierarchy that governs the relationships between 3 constructs C_x, C_y and C_z which are such that C_x and C_y are independent and both influence C_z, and assume that C_z is influenced by no other constructs. This small component of the hierarchy can be illustrated as below in figure 9.3

**Figure 9.3**  The relationships between C_x, C_y and C_z

It is assumed that in their psychological decision processes the managers' infer knowledge of C_z by combining their knowledge of C_x and C_y by employing weights to reflect the relative importance of the constructs C_x and C_y on C_z. So, assume the
existence of a hypothetical set of n enquiries which is such that the ratings for the
construct C_y are predominantly some fixed value, R_{C_y} say. Then, the effect of C_y on
C_z is almost fixed for all n enquiries, and therefore any variation in C_z must be
assumed to arise from the variation in the construct C_x. The fixed effect of C_y means
that C_z will be predominantly scaled on a sub-interval of [1..5] rather than the whole
interval^4. This implies that the city block metric which is an identity measure
between two variates will undermeasure the conceptual similarity between C_x and C_z.
This problem is easily overcome if the product moment correlation coefficient is used
to measure the conceptual similarity between C_x and C_z because this measures the
extent of a linear relationship between C_x and C_z and is therefore independent of the
scales upon which C_x and C_z are measured.

The outlined method was applied to both the managers' individual grids to assist in
the identification of relationships within the managers' own construct systems (see
sections 9.4.1 and 9.4.2 respectively), and also to the combined grid to assist in the
identification of relationships between the managers' construct systems (see section
9.4.3).

Both manager's were shown their respective conceptual maps, and asked to comment
upon the relationships present. The map derived from the combined grid was
reviewed by both managers. The objectives of this exercise were fourfold:-

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^4 This would not be true if the relative weight of C_y in relation to C_x was
insignificant. However, in the argument the choice of fixing C_x or C_y is arbitrary
and therefore the relative roles of C_x and C_y can be reversed.
(1) To confirm the validity of the relationships suggested by the correlation analyses. This was necessary because the correlation analysis only provided statistical support for a relationships inclusion in the conceptual map and not any logical or rational support for its inclusion. Therefore, although all the relationships in the conceptual maps were statistically valid some may have been spurious and therefore conceptually invalid. The managers were therefore asked to confirm whether or not a conceptual relationship did in fact exist between two constructs linked in the conceptual maps. Those relationships which the managers regarded as invalid or spurious were removed from the maps and therefore from any subsequent analysis or investigation. (Transitive relationships could also be regarded as spurious and would therefore require investigation. However, during this step unless the manager explicitly stated that a conceptual relationship existed only because of a series of other relationships then the relationship was regarded as conceptually valid. The fourth point below was designed to deal explicitly with transitive relationships.)

(2) To indicate the direction of the valid relationships. That is, which construct is the influencing or sub-ordinate construct, and which construct is the dependent or super-ordinate construct. This would enable the constructs to be ultimately arranged into a hierarchical inference network (see section 9.5).

(3) To disclose further important relationships that were not indicated by the correlation analyses.

(4) To examine all constructs that were members of cycles and to identify those relationships within these cycles whose existence stemmed from a purely transitive nature. Those relationships which the managers regarded as transitive were removed from the maps and therefore from any subsequent analysis or investigation.

This process of asking the managers to examine the conceptual maps derived from their individual and combined grids resulted in the generation of directed validated conceptual maps which illustrate the lines of inference or reasoning within and between the two managers construct systems.
9.4 Correlation Analyses of the Managers' Individual and Combined Construct Systems

The results from the correlation analyses of the managers' individual and combined construct systems are described in the following three sub-sections.
Table 9.4.1(i) Correlation Matrix for the Business Group Manager's Constructs

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<tr>
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<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
<th>C7</th>
<th>C8</th>
<th>C9</th>
<th>C10</th>
<th>C11</th>
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</table>

a Significant at the 0.5% level
b Significant at the 1.0% level
c Significant at the 2.5% level
Table 9.4.1(i) shows the correlation matrix for the 11 constructs in the Business Group Manager's Grid. Those construct relationships which are believed to be statistically valid (at least to the 2.5% significance level) are annotated in bold typeface. For example, table 9.4.1(i) demonstrates that there is a strong positive correlation (0.951) between the constructs C₄ level of financial risk and C₇ likely competitiveness of price, thus suggesting that these constructs are conceptually related. Furthermore, this positive correlation indicates that the emergent pole of the construct C₄ level of financial risk is associated with the emergent pole of the construct C₇ likely competitiveness of price; and conversely that the implicit pole of the construct C₄ level of financial risk is associated with the implicit pole of the construct C₇ likely competitiveness of price. So this positive correlation not only suggests the existence of a relationship, but also that low levels of financial risk are associated with a competitive price, and conversely that high levels of financial risk are associated with an uncompetitive price. Together these observations provide further insight into the precise nature of the relationship between the constructs C₄ level of financial risk and C₇ likely competitiveness of price.

In general, for each statistically valid construct relationship it was possible to derive a verbal proposition⁵ which highlighted the nature of the relationship in more detail. These verbal propositions were presented to the manager when asked to examine the conceptual map in order to act as a catalyst in the identification of the conceptually valid relationships. They also helped the manager expand upon the nature and significance of those relationships which were conceptually valid.

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⁵ For example, the Business Group Manager was asked to consider the following propositions:

The map suggests that the constructs C₄ level of financial risk and C₇ likely competitiveness of the price are related.

Further the analysis suggests that, in general:

*low levels of financial risk are associated with a highly competitive price*

*high levels of financial risk are associated with a very uncompetitive price*

Could you comment on whether or not you agree with these findings, and why?
Figure 9.4.1(ii)  The Business Group Manager's Conceptual Map

- C1 Availability of Design
- C2 Level of Technical Risk
- C3 Added Value
- C4 Level of Financial Risk
- C5 Level of Manufacturing Investment
- C6 Chances of Additional Business
- C7 Competitiveness of Price
- C8 Availability of Manufacturing Capacity
- C9 Work For A Low/High Loaded Factory
- C10 Attractiveness of Build Size

Significant at the 0.5% level
Significant at the 1.0% level
Significant at the 2.5% level
Figure 9.4.1(ii) shows the Business Group Manager's conceptual map that was derived from the correlation matrix given in table 9.4.1. In essence the map is a reproduction of the three major construct clusters derived from the FOCUS analysis (see section 8.4.2(1)(v)). The sole difference between the two sets of results is that in the manager's conceptual map the construct $C_4$ availability of design is regarded as bearing greater conceptual similarity to the constructs $C_2$ level of technical risk and $C_5$ level of manufacturing investment than to the construct $C_6$ chances of additional business as was the case in the dendogram or construct re-ordering produced by FOCUS. The independence of the results from the method of analysis serves to validate the emergent conceptual structure of the domain. The presence of the three cycles in the map between the four constructs $C_8$ availability of manufacturing capacity, $C_7$ likely competitiveness of price, $C_4$ level of financial risk and $C_2$ level of technical risk indicates that these four constructs are very closely related. Thus, implying that either there are several purely transitive relationships displayed in the conceptual map, or that the nature of the relationships between these four constructs is complex.

The map was validated by the Business Group Manager following the four step procedure outlined in section 9.3. The resultant validated conceptual map showing the direction of the conceptually valid relationships is shown in figure 9.4.1(iii). Furthermore, in the validated map the convention used in both systems dynamics and structural modelling (Courtney & Paradice, 1987; Pidd, 1986 pp. 181-130) of annotating the directed arcs with '+s' and '-'s to illustrate the effect of the influencing construct on the dependent construct has been adopted.
Figure 9.4.1(iii) The Business Group Manager's Validated Conceptual Map

- C_1: Availability of Design
- C_2: Level of Technical Risk
- C_3: Added Value
- C_4: Level of Financial Risk
- C_5: Level of Manufacturing Investment
- C_6: Chances of Additional Business
- C_7: Competitiveness of Price
- C_8: Availability of Manufacturing Capacity
- C_9: Work For A Low/High Loaded Factory
- C_10: Attractiveness of Build Size
- C_11: Level of Competition

The diagram illustrates the relationships between these variables, with arrows indicating the direction of influence.
The validated map indicates that the construct $C_2$ level of technical risk is influenced by both constructs $C_1$ availability of design and $C_5$ level of manufacturing investment. Furthermore, these relationships suggest that as the availability of the design increases then the level of technical risk becomes lower, or stated alternatively that as the design element to a project increases then the level of technical risk becomes higher. Similarly, the requirement to make significant levels of manufacturing investment results in higher levels of technical risk. The manager found no difficulty in explaining the rationale behind these relationships. For, if the organisation had an appropriate design available, then at some time in the past they would also have manufactured that design (this is because of the organisation's focus on design and manufacture projects). Therefore, the organisation's "learning process" would be complete (and hopefully the expertise retained) and any manufacturing problems previously "ironed out"; as a consequence the technical risk would be perceived to be low. Conversely, if the organisation was required to produce a new design, then it would not have any of the above advantages of experience; as a result the technical risk would be perceived to be higher. In a similar vein the requirement to make significant levels of manufacturing investment suggests that changes to manufacturing processes, or ultimately the introduction of new manufacturing technologies, implies that manufacturing problems would again need to be "ironed out" and as a result the perceived level of technical risk will be higher.

In the validated map, relationships which are generally true but are not universally true are depicted by broken lines. One such example is the relationship between the constructs $C_1$ availability of design and $C_5$ level of manufacturing investment. For example, if an appropriate design is already available, then any manufacturing investment necessary to manufacture that design will have previously been taken because at some time in the past the design will have been manufactured. Therefore, existing designs are generally associated with low levels of manufacturing investment. However, if due to manufacturing capacity problems it was necessary to manufacture the product at a site other than where the original investment was made then some further investment may be necessary. Perhaps of more significance is this argument's converse. That is, that producing a new design does not automatically necessitate the requirement to make significant levels of manufacturing investment. This would be the case if the new design could be manufactured using existing in house manufacturing technology.

Constructs such as $C_1$ availability of design and $C_5$ level of manufacturing investment joined by partial relationships were treated as independent when modelling the TAG's
decision processes. Thus, no attempt was made to incorporate "rules" into the knowledge base for inferring \( C_5 \) level of manufacturing investment from the \( C_4 \) availability of design.

At the core of the manager's validated map are the four constructs \( C_7 \) likely competitiveness of price, \( C_2 \) level of technical risk, \( C_4 \) level of financial risk and \( C_8 \) availability of manufacturing capacity. A comparison of the relationships between these four constructs in the un-validated (figure 9.4.1(ii)) and validated maps reveals that only the relationship between the constructs \( C_2 \) level of technical risk and \( C_7 \) likely competitiveness of price has been removed. This relationship was removed not because it was deemed to be conceptually invalid, but because of its transitive nature. (It was believed that \( C_2 \) level of technical risk could only influence \( C_7 \) likely competitiveness of the price through its relationship with \( C_4 \) level of financial risk.) Thus, because of the presence of the two cycles within these four constructs then the nature of the relationships between them are complex. The map suggests that of these four constructs \( C_7 \) likely competitiveness of price is a dominating concept in respect that it is super-ordinate to the other three; and conversely that \( C_8 \) availability of manufacturing capacity is a dominating concept in respect that it is sub-ordinate to the other three. Furthermore, \( C_8 \) availability of manufacturing capacity can be seen to influence \( C_7 \) likely competitiveness of price in three different ways. Firstly, directly, secondly through its relationship with \( C_4 \) level of financial risk, and finally through its relationship with \( C_2 \) level of technical risk which in turn influences \( C_4 \) level of financial risk.

Looking at the map on the whole reveals that in addition to the constructs \( C_4 \) level of financial risk and \( C_8 \) availability of manufacturing capacity then the construct \( C_7 \) likely competitiveness of price is also influenced by the construct \( C_5 \) level of manufacturing investment. Furthermore, these relationships show that as the level of manufacturing investment required increases the competitiveness of the organisation's price will decrease. This is because there is a direct cost in changing manufacturing methods and buying in new technology which will need to be accounted for in the organisation's final tender price. (The organisation's accounting procedures were such that the cost of any manufacturing investment needed to be written off over the life of the project.) As the level of financial risk increases in a project then the organisation's competitiveness tends to decrease; this is because the organisation tries to reduce its financial exposure by increasing their tender price and therefore weakening their competitive posture. Low availability of manufacturing capacity will lead to a decrease in organisation's competitive position, as the company decides to increase its
tender price to cover the extra costs of overtime working or use of a third party, or alternatively to take on work at a premium price when the order book is full and the manufacturing overheads are already covered. Conversely when there is a high level of manufacturing capacity available the organisation's competitive position is improved as the decision is made to reduce their tender price to hopefully win the contract and therefore recover their large manufacturing overheads.

9.4.2 THE PROPOSAL MANAGER'S GRID

Table 9.4.2(i), figure 9.4.2(ii) and figure 9.4.2(iii) (see Appendix C) show the Proposals Manager's construct correlation matrix, conceptual map and validated conceptual map respectively. Inspection of the manager's validated map reveals several dominating constructs; these are $C_{14}$ probability of success, $C_5$ chances of project going ahead, $C_9$ desire to be in market and $C_3$ chances of further business.

The construct $C_{14}$ probability of success is influenced by the constructs $C_{10}$ level of competition and $C_1$ standard/customer design. Furthermore, these relationships suggest that as the level of competition against the organisation increases the manager's perception of their probability of success, that is of winning the contract, falls. Similarly, the requirement to produce a custom design reduces the manager's perception of their probability of winning, or alternatively the manager believes that the organisation's chances of winning the contract are enhanced by having an existing appropriate design.

The construct $C_5$ chances of project going ahead is influenced by the constructs $C_{11}$ prospects of available finance and $C_{12}$ nature of the formal inquiry. Furthermore, these relationships suggest that as the customer's prospects of securing or sanctioning finance for the project increases then so does the organisation's perception of the chances of the project coming to life. The nature of the formal inquiry is an indicator of how much investment the customer has already made in the project, as for example determining delivery dates, producing an accurate specification of requirements, and is also used by the manager as an indicator of the project coming to life. The more investment that the customer has made then the more likely the project is to go ahead.

The construct $C_9$ desire to be in market is influenced by the four constructs $C_{14}$ probability of success, $C_4$ potential profitability, $C_2$ size of order and $C_{13}$ knowledge of customer. Evidently the organisation's strong desire to be in a particular market is reflected by their ability to successfully win contracts in that market, and
simultaneously generate generous profits. Furthermore, it is one of the organisation's policies to pursue large order sizes since these are believed to reduce disruption in manufacturing operations facilitating better business planning and greater utilisation of manufacturing capacity; and therefore as the map suggests this reflects upon a strong desire to be in a particular market. Although there is a positive correlation between $C_{13}$ knowledge of customer and $C_9$ desire to be in market suggesting that increased knowledge of the customer would increase the organisation's desire to be in a particular market, in reality the manager suggested that increased knowledge of the customer could only enable the organisation to make an assessment of whether a particular market was desirable, and not necessarily that the desirability of the market was improved.

The construct $C_3$ chances of further business is influenced by the three constructs $C_5$ chances of project going ahead, $C_{14}$ probability of success and $C_{13}$ knowledge of the customer. These relationships suggest that as the chances of the project ever coming to life and probability of the organisation winning the contract increase then so does the manager's perception of the chances of obtaining further business from the customer. However, the manager commented that these relationships were only true if it were likely that the customer would have a future requirement. So in effect the influence of the constructs $C_5$ chances of project going ahead and $C_{14}$ probability of success on the construct chances of $C_3$ further business is dependent upon the construct $C_{13}$ knowledge of customer. Although there is a positive correlation between $C_{13}$ knowledge of customer and $C_3$ chances of further business suggesting that increased knowledge of the customer would increase the chances of further business, then again in reality the manager suggested that increased knowledge of the customer could only enable the organisation to make an assessment of the chances of further business, and not necessarily that the chances of further business were improved. Thus, in modelling the decision processes of the TAG $C_3$ chances of further business was treated as an independent construct.

The construct $C_4$ potential profitability is influenced by the constructs $C_2$ size of order and $C_6$ level of involvement. These relationships suggest that both increases in the size of the order and the level of organisational involvement in the project result in more generous profits.
9.4.3 The Combined Grid

Figure 9.4.3(i) and figure 9.4.3(ii) (see Appendix C) show the conceptual map, and validated conceptual map derived from the managers' combined grid respectively. It is important to note that the maps derived from the combined grid only indicate relationships between the two managers' construct systems and not any of the relationships within the managers' construct systems since these are already indicated in the managers' individual maps.

The combined conceptual map was validated by both managers, and whilst both managers agreed that all the relationships in the map held some conceptual significance, they felt that several of the relationships would be transitive if the relationships in their individual maps were also taken into account. For example, in the combined map the construct $C_{18}$ added value is related to both $C_{4}$ potential profitability and $C_{9}$ desire to be in market. However, the managers felt that the relationship between $C_{18}$ added value and $C_{9}$ desire to be in market was purely transitive when the relationship in the Proposals Manager's individual validated map between $C_{4}$ potential profitability and $C_{9}$ desire to be in market was also considered. Those relationships included in the combined map which have been omitted from the validated combined map were dropped not because they are conceptually invalid, but because they are transitive when considered alongside relationships in the managers' individual validated maps. This is a particularly significant feature of the validated combined map when one considers that the three validated maps were ultimately to be joined together to produce the overall hierarchical inference network (see section 9.5).

It is particularly interesting to examine the validated combined map for those construct pairs that satisfy Duck's (1975) verbal criteria for literal and conceptual similarity (see section 7.4). The map shows that the constructs $C_{2}$ size of order and $C_{25}$ attractiveness of build size are in effect synonymous (indicated by the bidirectional relationship between them); as are the constructs $C_{3}$ chances of further business and $C_{21}$ chances of additional business. Thus, a direct comparison of the conceptual similarity between these construct pairs using correlation analysis has validated the earlier hypotheses about their conceptually similar nature. However, the two pairs of constructs relating to design and competition respectively do not appear to be conceptually related in the validated map. Further inspection of the two design constructs revealed that their conceptual difference was a result of a difference of opinion on just one enquiry. It appeared that the Business Group Manager rated the enquiry as 1 (design available) whereas the Proposal manager rated the enquiry 5.
(customer design). A discussion with the managers revealed a subtle difference with the interpretation of the two constructs with respect to this one enquiry. The enquiry represented a project to manufacture a customer's own third party design (a particularly unusual occurrence for the organisation). As such, an existing design was indeed available so the Business Group Manager felt justified in rating the enquiry as 1, but the design was not one of the organisation's standard designs so the Proposals Manager felt justified in rating the enquiry as 5. When this anomaly was taken into account the constructs $C_{16}$ availability of design and $C_{1}$ standard/customer design appeared to be synonymous. However, it appears that the two managers' constructs relating to competition ($C_{10}$ and $C_{26}$ respectively) are conceptually unrelated, thus suggesting that the managers are either providing their respective constructs level of competition with a different meaning, or that they were in disagreement about the nature of the competition for the enquiries in the combined grid.

The validated map also illustrates that the Business Group Manager's design construct $C_{16}$ availability of design influences the construct $C_{14}$ probability of success; and furthermore, that as the design element to a project increases the organisation's perception of their probability of winning the contract decreases. This relationship therefore validates the previously derived relationship between the Proposal Manager's design construct $C_{1}$ standard/customer design and $C_{14}$ probability of success (see section 9.4.2). Similarly the relationship between the constructs $C_{1}$ standard/customer design and $C_{17}$ level of technical risk validates the previously derived relationship between the Business Group Manager's constructs $C_{16}$ availability of design and $C_{17}$ level of technical risk.
Table 9.5(i) A List of the 18 Constructs in the Overall Construct Hierarchy

**Base Constructs (11)**

- $C_1$ Standard of the Formal Enquiry
- $C_2$ Prospects of Available Finance
- $C_3$ Availability of Design
- $C_4$ Demands on Bid Resources
- $C_5$ Availability of Manufacturing Capacity
- $C_6$ Level of Manufacturing Investment
- $C_7$ Size of Order
- $C_8$ Expected Added Value
- $C_9$ Level of Involvement
- $C_{10}$ Chances of Further Business
- $C_{11}$ Level of Competition

**Higher Level Constructs 7 (6 Intermediate Results + 1 Overall Recommendation)**

- $C_{12}$ Chances of the Project Going Ahead
- $C_{13}$ Potential Profitability
- $C_{14}$ Level of Technical Risk
- $C_{15}$ Level of Financial Risk
- $C_{16}$ Competitiveness of Price
- $C_{17}$ Probability of Success

+ $C_{18}$ Overall Attractiveness of the Enquiry
Figure 9.5(ii) The Overall Construct Hierarchy

- $C_{18}$ Overall Attractiveness
  - Of Enquiry

- $C_{17}$ Probability of Success

- $C_{16}$ Competitiveness
  - Of Price

- $C_{15}$ Level of Financial Risk

- $C_{14}$ Level of Technical Risk

- $C_{13}$ Potential Profitability

- $C_{12}$ Chances of Project Going Ahead

- $C_{11}$ Level of Competition

- $C_{10}$ Chances of Further Business

- $C_9$ Level of Involvement

- $C_8$ Expected Added Value

- $C_7$ Size of Order

- $C_6$ Level of Manufacturing Investment

- $C_5$ Availability of Manufacturing Capacity

- $C_4$ Demands on Bid Resources

- $C_3$ Availability of Design

- $C_2$ Prospects of Available Finance

- $C_1$ Standard of the Formal Enquiry
9.5 THE OVERALL INFERENCE HIERARCHY

The construct relationships highlighted in the managers' individual validated conceptual maps together with those in the combined validated map were combined to produce the overall hierarchical conceptual structure of the tender enquiry evaluation domain. The overall process led to a reduction in the number of constructs considered relevant, and a list of the remaining constructs is given in table 9.5(i). The resulting inference hierarchy is shown in figure 9.5(ii). It consists of 11 base constructs together with 7 higher level constructs (including the offered construct overall attractiveness of tender enquiry) which the analyses suggested could be derived from the 11 base constructs.

9.6 SUMMARY

The analysis of the managers' grids using FOCUS (see chapter 8) proved insufficient in revealing the domain of tender enquiry evaluation's underlying hierarchical structure because of the technique's inability to highlight construct relationships both within and between the managers' grids. To overcome these problems a methodology based on both correlation analysis and the OWN technique (a method for deriving networks of conceptual relationships) was devised which allowed the conceptual structure of the domain to be identified and represented in the form of a hierarchical inference network. The derived network is shown in figure 9.5(ii).
CHAPTER 10

KNOWLEDGE ACQUISITION STAGE 3 - MODEL DEVELOPMENT
10. KNOWLEDGE ACQUISITION STAGE 3 - MODEL DEVELOPMENT

10.0 INTRODUCTION

This third chapter concerning the analysis of the managers' grids describes the methodology adopted to construct a model that described the managers' knowledge and is therefore concerned with the third stage of the knowledge acquisition process as outlined by Kidd (1987, pp. 3). The chapter commences with a discussion of the objectives of this stage of the knowledge acquisition process in the context of the case study organisation. This discussion is followed by a description of the methodology adopted. This methodology is illustrated by recourse to an example; and finally the resulting model is presented.

10.1 OVERALL OBJECTIVE - DETERMINING THE IMPORTANCE OF EACH CONSTRUCT

Figure 9.5(ii) shows the managers' overall conceptual structure of the domain of tender enquiry evaluation in the form of a hierarchical inference network. This network revealed the existence of relationships between constructs at different conceptual levels, but did not highlight the relative weights or importance that the managers associated with each of the constructs.

For example, the network revealed that the construct probability of success was influenced by the three constructs competitiveness of price, level of competition and availability/nature of design1. Furthermore, these relationships suggested that an increase in either the availability of an appropriate design, or the likely competitiveness of the organisation's price would raise the organisation's perception of winning the contract: whereas conversely, an increase in the level of competition that they faced would lower their perception of winning the contract. At this stage of the analysis, however, the information contained in the network did not illustrate the net change in, or sensitivity of, the organisation's perception of winning the contract given a unit increase in one of the three influencing constructs competitiveness of

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1 The construct availability/nature of design has been formed to represent the fact that both the Proposals Manager's design construct standard/customer design and the Business Group Manager's design construct availability of design were found to influence the construct probability of success (see sections 9.4.2, 9.4.3 and 9.5).
price, level of competition and availability/nature of design\textsuperscript{2}. Thus the network did not highlight the relative importance that the managers attributed to each of these three constructs in influencing their perception of the construct probability of success.

So, in general, although the network in figure 9.5(ii) revealed the presence of relationships between particular constructs at different conceptual levels it did not reveal the precise nature of these relationships, because it failed to highlight the relative importance or weight that the managers attributed to each construct in a particular set of relationships at a given level in the hierarchy. The methodology developed in this chapter addresses this issue and aims to reveal the managers' reasoning; that is, how the managers combine their assessments of constructs lower down in the hierarchy to arrive at their assessments for constructs higher up in the hierarchy. Thus, in the terminology of section 6.2(5) the overall objective of this stage of the analysis was to determine the relative weights that the managers associated with each of the network's directed arcs.

It was previously conjectured in section 9.1 that if the hierarchical structure of the domain was known, then at any given level in the hierarchy further insight into the nature of the relationship between a super-ordinate construct and its influencing subordinate constructs could be revealed by adopting a marginal focusing procedure\textsuperscript{3}. For each set of relationships at each level of the domain hierarchy this procedure would have involved: extracting the relevant super-ordinate and subordinate constructs, then focusing the enquiries using only these subordinate constructs; and finally comparing the pattern in the marginal focused grid\textsuperscript{4} to the ratings for the reordered enquiries on the super-ordinate construct.

Although the marginal focusing procedure would have elaborated upon the nature of the relationship between a super-ordinate construct and its influencing subordinates,

\textsuperscript{2} That is, if \( C_d \) is a dependent super-ordinate construct and \( C_i \) is an subordinate construct influencing \( C_d \), then the information presently contained in the network only reveals that as \( C_i \) increases then \( C_d \) increases (or decreases), and not the rate \( (\partial C_d/\partial C_i) \) at which \( C_d \) increases (or decreases) with respect to \( C_i \).

\textsuperscript{3} The marginal focusing procedure is identical to the standard FOCUS algorithm (see section 8.3) with the exception that only a sub-set of the grid's constructs are used to generate the percentage similarity matrix for the elements (enquiries).

\textsuperscript{4} The marginal focused grid is similar to the standard focused grid (see section 8.3) with the exception that it is derived from only a sub-set of the original construct system; and therefore, less emphasis is placed upon the re-ordering of the rows of constructs.
the procedure would not have enabled a complete and consistent set of rules to be derived from the marginal focused grids. These rules would need to express how the managers combined their assessments for sub-ordinate constructs to arrive at their assessments for super-ordinate constructs. The outlined procedure would be inadequate because for a relationship involving k sub-ordinate constructs only 10 of the $5^k$ possible combinations of construct ratings were included in the combined grid, and these 10 combinations would not necessarily provide a complete and consistent coverage of the $5^k$-state-space. For this reason the marginal focusing procedure was considered to be insufficient to reveal the managers' reasoning and was therefore not adopted for use during this stage of the analysis.

The problem noted above with ensuring that any derived "rules" provided a complete and consistent coverage of the domain, together with the unreliability of eliciting weights directly from the managers (section 6.3) suggested that an inductive approach to the generation of "rules" or weights was appropriate. Therefore, for each set of relationships at each level of the domain hierarchy given in figure 9.5(ii) an inductive approach was taken to generate a "general rule" or heuristic that related a super-ordinate construct to its influencing sub-ordinates. These "rules" were derived from the managers' assessments for the 10 enquiries in the combined grid.

The overall approach taken to induce a "general rule" or heuristic was similar to that adopted by Finlay & King (1989) in their development of an expert system for MBA admissions (see also King, 1989). Their approach involved modelling the expert's reasoning by using simple mathematical model forms to express the relationships between relevant domain concepts. Using mathematical models to model expert knowledge is not uncommon. For example, Courtney & Paradice (1987) used mathematical models and the theory of structural modelling to express expert knowledge in a knowledge based decision support system for managerial problem diagnosis. The hierarchical inference network shown in figure 9.5(ii) is similar to the structural model developed by Courtney & Paradice (1987) for managerial problem diagnosis in that both the network and structural model contain directed arcs that relate changes in one construct or variable to changes in a second construct or variable. Therefore, it was expedient to determine whether or not the theory of structural modelling was appropriate for modelling the managers' reasoning in the case study under discussion.

One of the underlying assumptions of the structural modelling approach to modelling expert knowledge as used by Courtney & Paradice (1987) is that the first partial
derivative of a super-ordinate construct with respect to any of its influencing subordinates is constant; and therefore that the underlying form of the relationship between the super-ordinate construct and its influencing subordinates is linear. Thus, the structural modelling approach can be regarded as a sub-set of the more general mathematical modelling approach as used by Finlay & King (1989). The assumption that all the first partial derivatives are constant implies that the sensitivity of a super-ordinate construct to a change in the assessment for any one of its influencing subordinates is independent of the assessments for the other influencing subordinates constructs, that is that the sub-ordinate constructs are orthogonal. However, unlike the elicitation of attributes in multi-attribute decision aiding which uses preference and utility independence checks to test that the attributes are independent or orthogonal (see Kidd & Prabhu, 1990), in the elicitation of the a repertory grid no check is made that the elicited constructs are orthogonal. Indeed if the laddering technique (Easterby-Smith, 1981) is used to generate either superordinate or sub-ordinate constructs, then several of the constructs in the elicited grid will be necessarily correlated. As such it was difficult to justify the assumption of the orthogonality of the so-called independent constructs C_j. For example, in the context of the case study under discussion, this assumption would imply that the sensitivity of the managers’ perception of winning a contract to changes in the level of competition is the same irrespective of whether or not the organisation have an appropriate design available, and therefore a proven design in service. It seemed plausible, however, that the managers may have shown less concern regarding the level of competition when they had an appropriate proven design available than in cases when a new design was necessary.

The assumption that all the first partial derivatives were constant was therefore considered too severe a restriction within the context of the domain of tender enquiry evaluation; and consequently the structural modelling approach was not adopted. Instead, rather than explicitly modelling the first partial derivatives (∂C_d/∂C_i), an

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5 Suppose that C_d is the super-ordinate construct, and C_i is any one of the sub-ordinate constructs that are known to influence C_d. Then in the theory of structural modelling the first partial derivative of C_d with respect to C_i, ∂C_d/∂C_i is assumed constant.

I.e. ∂C_d/∂C_i = K_i (a constant) ∀ i

This assumption implies that the underlying form of the relationship between the super-ordinate C_d and its influencing subordinates C_i is linear

I.e. C_d = Σ (∂C_d/∂C_i)C_i = Σ K_iC_i + K_0
approach was used that inductively modelled the underlying form of the relationship between a super-ordinate construct and its influencing sub-ordinates, more akin to the method adopted by Finlay & King (1989). The methodology developed is discussed in the following section.

10.2 Induction of a "General Rule" or Heuristic - Modelling Methodology

10.2.1 Two Simple Mathematical Models

Consider a set of relationships in the hierarchical inference network shown in figure 9.5(ii) between a super-ordinate dependent construct, $C_d$ say, and the sub-ordinate independent influencing constructs, $C_1,...,C_k$. This set of relationships is shown in the causation tree\(^6\) (Courtney & Paradice, 1987) given in figure 10.2.1 below.

![Causation Tree Showing the Relationship between $C_d$ and $C_1,...,C_k$](image)

Each enquiry $E_r$ ($r = 1,...,n$) in the combined grid was assigned an integral rating $R_{Er}(C_i)$ in the interval $[1,5]$ on each construct $C_i$ ($i = 1,...,k; i = d$). Furthermore, each construct $C_i$ was such that it had both an attractive pole and an unattractive pole. So that, if an enquiry $E_r$ was assigned a rating of 1 on the construct $C_i$ (i.e., $R_{Er}(C_i) = 1$), then this indicated the presence of either a highly attractive or very unattractive trait of the enquiry $E_r$. Conversely, if $E_r$ was assigned a rating of 5 on the construct $C_i$, then this indicated the presence of either a very unattractive or highly attractive trait of the enquiry $E_r$. Therefore, it was possible to subject all construct ratings $R_{Er}(C_d), R_{Er}(C_1),...,R_{Er}(C_k)$ ($r = 1,...,n$) to a simple transformation that ensured the attractive pole of any construct $C_i$ ($i = 1,...,k; i = d$) corresponded to a rating of 5, and the unattractive pole to a rating of 1, as shown in figure 10.2.1.

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\(^6\) A causation tree (Courtney & Paradice, 1987) shows a set of dependency-influence relationships, and is therefore similar to an influence map.
In theory at least, the relative importance or weight that the managers associated with each of the independent constructs $C_1, ..., C_k$ in relation to $C_d$ could have been identified using multiple linear regression. In which case the induced "general rule" or heuristic relating $C_d$ to $C_1, ..., C_k$ would have assumed a linear form. The first partial derivatives $\partial C_d / \partial C_i$ would have then been constant, so that multiple linear regression would have in effect emulated the structural modelling approach: an approach which was previously regarded as unduly restrictive in the present context (see section 10.1). Moreover, a multiple linear regression approach could have induced "general rules" or heuristics that were logically inconsistent. Such logical inconsistencies could have arisen in either of two ways:

Firstly, during the elicitation of the managers' grids the managers were restricted to assigning enquiries integral construct ratings in the interval $[1, 5]$. Since in multiple linear regression, however, there are no constraints on the regression coefficients ($\alpha_i$), then a resulting regression model could have produced a predicted assessment for an enquiry $E_r$ on the construct $C_d$, $R'_{E_r}(C_d)$, say, outside the interval $[1, 5]$ (i.e. $R'_{E_r}(C_d) \notin [1, 5]$). Thus, the induced "general rule" would have been inconsistent because its range was different from that used by the managers. This suggested using mathematical forms to model the managers' reasoning whose range was the interval $[1, 5]$.

Secondly and more importantly, the regression coefficients $\alpha_i$ in the induced "general rule" representing the relative weight that the managers attached to each of the independent constructs could have been negative. Since all the construct ratings $R_{E_r}(C_i)$ were transformed so that a high rating corresponded to an attractive trait and a low rating to an unattractive trait, then a negative regression coefficient $\alpha_i$ for any of the independent constructs $C_i$ would have implied that a high, and therefore attractive, rating on $C_i$ was detracting from the attractiveness of the dependent construct $C_d$!

Therefore, after the construct ratings were transformed it was important to ensure that all the induced weights were non-negative.

These two logical inconsistencies when modelling the managers' reasoning with the multiple linear regression approach were overcome by constraining the relative construct weights $\alpha_i$ to be normalised (see eqs. 10.2.1(i) and 10.2.1(ii)) and by restricting the assumed form of the "general rule" to be one of two simple linear regression models. These two model forms were the additive or linear model (equivalent to the structural modelling approach) corresponding to the weighted arithmetic mean of the independent construct ratings $R_{E_r}(C_i)$; and the multiplicative
or log-linear model corresponding to the weighted geometric mean. (See eqs. 10.2.1(iii) and 10.2.1(iv) respectively).

**Normalised Weights** $\alpha_i$

\[ \alpha_i \geq 0 \quad \text{eq. 10.2.1(i)} \]

\[ \sum_{i=1}^{k} \alpha_i = 1 \quad \text{eq. 10.2.1(ii)} \]

**Additive Model** (Linear Model - Weighted Arithmetic Mean)

\[ R_{E_{r}}(C_d) = \sum_{i=1}^{k} \alpha_i \times R_{E_{r}}(C_i) + \varepsilon \quad \text{eq. 10.2.1(iii)} \]

**Multiplicative Model** (Log-Linear Model - Weighted Geometric Mean)

\[ R_{E_{r}}(C_d) = \prod_{i=1}^{k} R_{E_{r}}(C_i)^{\alpha_i} + \varepsilon \quad \text{eq. 10.2.1(iv)} \]

Where,

- $R_{E_{r}}(C_d)$ = rating for enquiry $E_r$ on the dependent construct $C_d$
- $R_{E_{r}}(C_i)$ = rating for enquiry $E_r$ on the independent construct $C_i$
- $\alpha_i$ = relative weight or importance of $C_i$
- $k$ = number of independent constructs in the relationship
- $\varepsilon$ = the error term

### 10.2.2 Properties of Additive and Multiplicative Models

The proposed additive and multiplicative model forms given in eqs. 10.2.1(iii) and 10.2.1(iv) respectively display the following properties.

1. For all $R_{E_{r}}(C_i) \in [1,5]$ and normalised weights $\alpha_i$ (eqs. 10.2.1(i) and 10.2.1(ii)), then both additive and multiplicative models provide a predicted rating for an enquiry $E_r$ on a construct $C_d$, $R_{E_{r}}(C_d)$, in the interval $[1,5]$. Thus, the range of both the additive and multiplicative models is the same as that used by the managers.
(2) As all relative weights are non-negative \( \alpha_i \geq 0 \) (eq. 10.2.1(i)), then an increase in any one of the independent construct ratings \( R_{Ei}(C_i) \) results in an increase in the predicted rating for the dependent construct \( C_d \), \( R'_{Ei}(C_d) \); conversely, a decrease in any one of the independent construct ratings \( R_{Ei}(C_i) \) results in a decrease in the predicted rating for the dependent construct \( C_d \), \( R'_{Ei}(C_d) \). Thus, if the managers' perception of any of the independent traits becomes more attractive, then so does the perception of the related dependent trait: conversely, if the perception of any of the independent traits becomes less attractive, then so does the perception of the related dependent trait.

Together these properties (1) and (2) ensured that the induced "general rules" or heuristics were logically consistent.

(3) In both additive and multiplicative models the predicted rating for an enquiry \( E_i \) on a construct \( C_d \), \( R'_{Ei}(C_d) \), is such that \( R'_{Ei}(C_d) = 1 \) if and only if \( R_{Ei}(C_i) = 1 \) for all \( i = 1, \ldots, k \); and similarly \( R'_{Ei}(C_d) = 5 \) if and only if \( R_{Ei}(C_i) = 5 \) for all \( i = 1, \ldots, k \). Thus, in general both the additive and multiplicative models have a tendency to overestimate the attractiveness of those higher level constructs or traits that the managers regard as very unattractive, that is those constructs assigned a rating of 1 by the managers. This is because when \( k-1 \) of the independent constructs are such that \( R_{Ei}(C_i) = 1 \) (for all \( i = 1, \ldots, k-1 \)) and \( R_{Ei}(C_k) = 2 \) say, then \( R'_{Ei}(C_d) > 1 \) even though the manager may assert that \( R_{Ei}(C_d) = 1 \) since he regards the assessment for \( C_k \) as largely irrelevant in light of the assessments for \( C_i \) (i = 1, \ldots, k-1). Thus, the predicted rating \( R'_{Ei}(C_d) \) overestimates the trait's attractiveness \( R_{Ei}(C_d) \), that is \( R'_{Ei}(C_d) > R_{Ei}(C_d) \). Conversely both models have a tendency to underestimate the attractiveness of those higher level constructs or traits that the managers regard as highly attractive, that is those constructs assigned a rating of 5 by the managers. This selective bias was overcome by dividing the interval \([1,5]\) into 5 equal intervals, corresponding to predicted ratings of 1, 2, 3, 4 and 5 respectively, and then transforming the real scaled predicted rating \( R'_{Ei}(C_d) \) into the corresponding integral scaled predicted rating. This procedure also helped to stem the propagation of errors through the hierarchical network.
For all $R_{E_d}(C_i) \in [1,5]$ and for all normalised weights $\alpha_i$

$$\prod_{i=1}^{k} R_{E_d}(C_i)^{\alpha_i} \leq \sum_{i=1}^{k} \alpha_i \times R_{E_d}(C_i) \quad \text{eq. 10.2.2(v)}$$

Thus, the geometric mean of a set of construct ratings $R_{E_d}(C_i)$ ($i = 1,...,k$) is always less than or equal to the corresponding arithmetic mean. This suggests that, in general, the multiplicative model is more appropriate when the data suggests that a low rating for any one of the independent constructs $C_i$ gives rise to a low rating on the dependent construct $C_d$. Conversely, by reversing the polarity of all the constructs so that a low rating corresponds to an attractive trait and a high rating to an unattractive trait, then the multiplicative model is also more appropriate when an attractive trait on any one of the independent constructs $C_i$ gives rise to an attractive trait on the dependent construct $C_d$.

### 10.2.3 Determining the Appropriate Weights

For each set of relationships at each level of the hierarchical inference network shown in figure 9.5(ii), then the overall objective was to find the most appropriate mathematical form and determine the optimal weights $\alpha_i^*$ ($i = 1,...,k$) which maximised the percentage explained variance, $\%EV(C_d)$ (see eq. 10.2.3(i)), in the dependent construct $C_d$, subject to the optimal weights $\alpha_i^*$ being normalised (eqs. 10.2.2(i) and 10.2.2(ii)); and thereby provided the best explanation of the managers' reasoning. This approach corresponded to that of minimising the sum of the residual squares in multiple linear regression, except that in multiple linear regression the regression coefficients are not constrained.

The optimal weights $\alpha_i^*$ were found using a heuristic search procedure implemented in the spreadsheet package SuperCalc 4. This spreadsheet model allowed a step-wise approach to model development to be adopted (as akin to the multiple linear regression options available in several statistical packages). This allowed the determination of whether any of the independent constructs $C_i$ were redundant, that is whether a construct's inclusion in a model led to a decrease in the maximum explained variance. Furthermore, this approach allowed a construct's significance in explaining the variability in the dependent construct $C_d$ to be determined, the $F$-statistic being used as a rough guide for construct inclusion. The $F$-statistic was not a truly appropriate measure of significance because in light of the models' property (3) (see section 10.2.2) the residual errors were not normally distributed. The analysis
also determined the sensitivity of the optimum weights $\alpha^*_i$ and their effect on the results.

So, the overall objective was to determine both the most appropriate model form $f(.)$ and the optimal weights $\alpha^*_i (i = 1, ..., k)$ to maximise the explained variance $%EV(C_d)$ (see eq. 10.2.3(i)) in the dependent construct $C_d$.

Maximise

$$%EV(C_d) = 100 \times (1 - \text{RSS}(C_d)/\text{TSS}(C_d))$$

where,

- the residual sum of squares $\text{RSS}(C_d)$ in the dependent construct $(C_d)$ is given by

$$\text{RSS}(C_d) = \sum_{i=1}^{n} [R^{'E}(C_d)_i - R^E(C_d)_i]^2$$

(eq. 10.2.3(ii))

- the total sum of squares $\text{TSS}(C_d)$ in the dependent construct $(C_d)$ is given by

$$\text{TSS}(C_d) = \sum_{i=1}^{n} \{R^E(C_d)_i - R_{av}(C_d)\}^2$$

(eq. 10.2.3(iii))

- the average rating $R_{av}(C_d)$ for the dependent construct $(C_d)$ is given by

$$R_{av}(C_d) = \frac{\sum_{r=1}^{n} R^E(C_d)_r}{n}$$

(eq. 10.2.3(iv))

- and the predicted rating for enquiry $E_r, R^E(C_d)_r$ on the dependent construct $C_d$ is given by

$$R^{'E}(C_d)_r = f (R^E(C_d)_i; \alpha_i; i = 1, ..., k)$$

(eq. 10.2.3(v))

where $f(.)$ is either the additive model (eq. 10.2.1(iii)) operator or the multiplicative model operator (eq. 10.2.2(iv)).

The methodology outlined in this section was applied to each set of relationships at each level of the hierarchical inference network shown in figure 9.5(ii). This produced a set of induced "general rules" or heuristics that modelled or expressed the managers' reasoning. The full set of induced rules is provided in section 10.4. As a means of illustration the application of the methodology to one set of relationships in the network is described in the following section.
10.3 Modelling the Probability of Success - An Example of the "General Rule" Inducing Methodology

Figure 9.5(ii) suggested that the construct probability of success was influenced by the three constructs competitiveness of the price, level of competition and availability/nature of design. Expressed in the terminology of section 10.2.1 probability of success is the dependent construct $C_0$, and the constructs competitiveness of the price, level of competition and availability/nature of design are the independent constructs $C_i$. This set of relationships is shown in the causation tree given in figure 10.3(i) below.

![Causation Tree](image)

In the Proposal Manager's original grid (see figure 7.4(iv)) the left hand pole of the construct standard/customer design corresponding to a construct rating of 1 represented a standard design. Since the manager regarded a standard design as an attractive trait of an enquiry, then all the ratings for the construct standard/customer design were transformed so that a rating of 1 represented a customer design, an unattractive trait; and a rating of 5 represented a standard design, an attractive trait. Similar transformations were also made to the independent influencing constructs level of competition and availability of design and the dependent construct probability of success.

Following the procedure outlined in section 10.2.3, then the first stage of inducing a "general rule" expressing the relationship between the construct probability of success and the constructs competitiveness of price, level of competition and availability/nature of design was the determination of the relative importance of each of the independent influencing constructs, $C_3$, $C_{11}$ and $C_{16}$, in explaining the
variation in \textit{probability of success}. \(C_{17}\). Tables 10.3(ii) and 10.3(iii) below show the variation in \textit{probability of success} explained by the independent constructs in the additive model and the multiplicative model respectively\(^7\).

\textbf{Table 10.3(ii) \% Variation in \textit{Probability of Success} Explained in the Additive Model by the Individual Independent Constructs \(C_i\)}

\begin{center}
\begin{tabular}{|l|c|c|c|c|}
\hline
Independent Construct \((C_i)\) & \(\alpha^*_i\) & \(\alpha^*_i\) & \(\alpha^*_i\) & \(\alpha^*_i\) \\
\hline
\textit{Competitiveness of Price} & 0.77 & - & - & - \\
\textit{Level of Competition} & - & 0.85 & - & - \\
\textit{Standard/Customer Design} & - & - & 0.77 & - \\
\textit{Availability of Design} & - & - & - & 0.91 \\
\hline
\textbf{Additive Model} & & & & \\
\hline
Residual Variation & 5.33 & 6.52 & 8.88 & 10.4 \\
Explained Variation & 7.07 & 5.88 & 3.52 & 1.99 \\
Total Variation & 12.4 & 12.4 & 12.4 & 12.4 \\
% Explained Variation & 57.1\% & 47.4\% & 28.4\% & 16.0\% \\
F-Statistic & 11.94 & 8.12 & 3.57 & 1.72 \\
\hline
\end{tabular}
\end{center}

\textbf{Table 10.3(iii) \% Variation in \textit{Probability of Success} Explained in the Multiplicative Model by the Individual Independent Constructs \(C_i\)}

\begin{center}
\begin{tabular}{|l|c|c|c|c|}
\hline
Independent Construct \((C_i)\) & \(\alpha^*_i\) & \(\alpha^*_i\) & \(\alpha^*_i\) & \(\alpha^*_i\) \\
\hline
\textit{Competitiveness of Price} & 0.81 & - & - & - \\
\textit{Level of Competition} & - & 0.88 & - & - \\
\textit{Standard/Customer Design} & - & - & 0.8 & - \\
\textit{Availability of Design} & - & - & - & 0.9 \\
\hline
\textbf{Multiplicative Model} & & & & \\
\hline
Residual Variation & 4.77 & 6.89 & 7.57 & 9.66 \\
Explained Variation & 7.63 & 5.51 & 4.83 & 2.74 \\
Total Variation & 12.4 & 12.4 & 12.4 & 12.4 \\
% Explained Variation & 61.5\% & 44.4\% & 38.9\% & 22.1\% \\
F-Statistic & 14.34 & 7.20 & 5.74 & 2.55 \\
\hline
\end{tabular}
\end{center}

\(\text{Note that during this first stage of the analysis the relative weights } \alpha_i \text{ were constrained only to be non-negative (see eq. 10.2.1(i)), and not to sum to unity (see eq. 10.2.1(ii)).}\)
Tables 10.3(ii) and 10.3(iii) reveal that irrespective of which model form is adopted the construct most influential in explaining the variation in the probability of success is the competitiveness of price, explaining 57.1% of the variation in the additive model and 61.5% in the multiplicative model. Furthermore, the analysis indicated that the second most influential construct on the probability of success was the level of competition, explaining 47.4% of the variation in the additive model and 44.4% in the multiplicative model. Finally, of the two design constructs, then the Proposals Manager's construct standard/customer design was found to be the more influential, explaining 38.9% of the variation in the multiplicative model and 28.4% in the additive model. These figures compared with 22.1% and 16.0% respectively for the Business Group Manager's construct availability of design. Therefore, availability of design was dropped from subsequent analyses in favour of standard/customer design.

The variation in probability of success explained by each individual independent construct was greater in the multiplicative model than in the additive model; thus suggesting that the multiplicative model was a more appropriate model of how the managers formed their assessment of the probability of success from their assessments for the independent constructs. However, it seemed expedient to continue with the additive model through the second stage of the analysis which investigated the effect of adding one of the constructs level of competition and standard/customer design into the models alongside competitiveness of price. If at this juncture the performance of the multiplicative model was better than the additive model then the additive model would then be dropped from any subsequent analysis in favour of the multiplicative model.
Table 10.3(iv) % Variation in Probability of Success Explained in the 2-Construct (C_i) Additive Model

<table>
<thead>
<tr>
<th>Independent Construct (C_i)</th>
<th>$\alpha_i^*$</th>
<th>$\alpha_i^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitiveness of Price</td>
<td>0.44</td>
<td>0.46-0.5</td>
</tr>
<tr>
<td>Level of Competition</td>
<td>0.56</td>
<td>-</td>
</tr>
<tr>
<td>Standard/Customer Design</td>
<td>-</td>
<td>0.54-0.5</td>
</tr>
<tr>
<td>Additive Model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual Variation</td>
<td>4.16</td>
<td>5.25</td>
</tr>
<tr>
<td>Explained Variation</td>
<td>8.24</td>
<td>7.15</td>
</tr>
<tr>
<td>Total Variation</td>
<td>12.4</td>
<td>12.4</td>
</tr>
<tr>
<td>% Explained Variation</td>
<td>66.5%</td>
<td>57.7%</td>
</tr>
<tr>
<td>F-Statistic</td>
<td>17.83</td>
<td>12.26</td>
</tr>
</tbody>
</table>

Table 10.3(v) % Variation in Probability of Success Explained in the 2-Construct (C_i) Multiplicative Model

<table>
<thead>
<tr>
<th>Independent Construct (C_i)</th>
<th>$\alpha_i^*$</th>
<th>$\alpha_i^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitiveness of Price</td>
<td>0.45-0.46</td>
<td>0.56-0.54</td>
</tr>
<tr>
<td>Level of Competition</td>
<td>0.55-0.54</td>
<td>-</td>
</tr>
<tr>
<td>Standard/Customer Design</td>
<td>-</td>
<td>0.44-0.46</td>
</tr>
<tr>
<td>Multiplicative Model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Residual Variation</td>
<td>3.10</td>
<td>4.50</td>
</tr>
<tr>
<td>Explained Variation</td>
<td>9.30</td>
<td>7.90</td>
</tr>
<tr>
<td>Total Variation</td>
<td>12.4</td>
<td>12.4</td>
</tr>
<tr>
<td>% Explained Variation</td>
<td>75.0%</td>
<td>63.7%</td>
</tr>
<tr>
<td>F-Statistic</td>
<td>27.0</td>
<td>15.8</td>
</tr>
</tbody>
</table>

The results obtained from adding one of the constructs level of competition and standard/customer design into the additive and multiplicative models alongside competitiveness of price are shown in Tables 10.3(iv) and 10.3(v) respectively. From these tables it can be seen that the multiplicative model derived from adding level of competition into the model alongside competitiveness of price explains 75.0% of the variation in probability of success. Whereas, the corresponding additive model only accounts for 66.5% of the variation. Similarly, the multiplicative model derived from adding standard/customer design into the model alongside competitiveness of price explains 63.7% of the variation. Whereas, the corresponding additive model accounts
for only 57.7% of the variation. These results suggested that if any construct were to be added into either of the models alongside competitive of price then it should have been level of competition rather than standard/customer design. Furthermore, they also confirmed that the multiplicative model was a more appropriate model of the managers' reasoning than was the additive model. Thus suggesting that the managers' assessments for the constructs competitive of price and level of competition were not truly independent; and therefore that the managers' assessments of the organisation's likely competitive posture was relative to the level of competition that they faced. The additive model was therefore dropped from further consideration.

Since at this juncture in the analysis the weights were constrained to sum to unity, then any increase in the explained variation in probability of success was achieved without a decrease in the number of degrees of freedom. The number of degrees of freedom was 9 in both the multiplicative model containing only competitive of price and the model containing both competitive of price and level of competition. Therefore, the model incorporating both constructs competitive of price and level of competition was automatically a statistically better model than the model based on competitive of price alone.

<table>
<thead>
<tr>
<th>Independent Construct (C_i)</th>
<th>( \alpha^*_i )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitive of Price</td>
<td>0.39-0.40</td>
</tr>
<tr>
<td>Level of Competition</td>
<td>0.39-0.40</td>
</tr>
<tr>
<td>Standard/Customer Design</td>
<td>0.22-0.20</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Multiplicative Model</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Residual Variation</td>
<td>1.88</td>
</tr>
<tr>
<td>Explained Variation</td>
<td>10.5</td>
</tr>
<tr>
<td>Total Variation</td>
<td>12.4</td>
</tr>
<tr>
<td>% Explained Variation</td>
<td>84.9%</td>
</tr>
<tr>
<td>F-Statistic</td>
<td></td>
</tr>
</tbody>
</table>

The final stage of the analysis looked at the effect of introducing standard/customer design into the multiplicative model alongside competitive of price and level of competition. This resulting model accounted for 84.9% of the variation in probability of success (see Table 10.3(vi)). Introducing standard/customer design into the model, however, reduced the number of degrees of freedom to 8 and therefore the F-statistic.
was used as a rough guide\footnote{As previously noted in light of property 3. (section 10.2.2) the residual errors are not normally distributed, and therefore the F-statistic is not a theoretically valid measure of a construct's significance.} to determine the significance of introducing \textit{standard/customer design} into the model. The appropriate F-statistic was calculated to be $F_{1,8} = 5.11$, significant at the 0.1\% level. Therefore, \textit{standard/customer design} was introduced into the model alongside \textit{competitiveness of price} and \textit{level of competition}. The optimal weights $\alpha_i^*$ for the three independent constructs were as follows:-

$$
\begin{align*}
\alpha^*_{\text{competitiveness of price}} &= 0.39 - 0.40 \\
\alpha^*_{\text{level of competition}} &= 0.39 - 0.40 \\
\alpha^*_{\text{standard/customer design}} &= 0.22 - 0.20
\end{align*}
$$

Finally, the "general rule" or heuristic relating \textit{probability of success} to \textit{competitiveness of price}, \textit{level of competition} and \textit{standard/customer design} was given by the following formula.

$$
R_{ER}(\text{probability of success}) = R_{ER}(\text{competitiveness of price})^{0.39} \times R_{ER}(\text{level of competition})^{0.39} \times R_{ER}(\text{standard/customer design})^{0.22}
$$

\subsection*{10.4 The Induced Rules}

The full set of induced rules obtained derived from the methodology described in section 10.2 are provided below. It should be noted that the rules shown below do not strictly follow the results reported in the hierarchical inference network shown in figure 9.5(ii). This is because for some of the relationships the optimal induced weights $\alpha_i^*$ were found to be zero, that is a construct was found to be statistically insignificant in a particular relationship. As a result the actual rules derived follow a slightly less complex hierarchy than that depicted in figure 9.5(ii). The rules in part express the organisation's corporate policy towards tender enquiry evaluation and the bid versus no bid and bid resourcing decisions. As such the rules are proprietary and confidential; and therefore in the rules shown below the weights have been changed slightly to protect the confidentiality of the case study organisation.
\[ R_{Er}(\text{attractiveness of tender enquiry}) = 0.14 \times R_{Er}(\text{potential profitability}) + 0.14 \times R_{Er}(\text{level of financial risk}) + 0.14 \times R_{Er}(\text{availability of manufacturing capacity}) + 0.14 \times R_{Er}(\text{chances of further business}) + 0.30 \times R_{Er}(\text{probability of success}) + 0.14 \times R_{Er}(\text{chances of project going ahead}) \]

\[ R_{Er}(\text{potential profitability}) = \]
\[ R_{Er}(expected \ added \ value)^{0.38} \times R_{Er}(level \ of \ involvement)^{0.34} \times R_{Er}(size \ of \ order)^{0.28} \]

\[ R_{Er}(\text{level of financial risk}) = \]
\[ R_{Er}(level \ of \ technical \ risk)^{0.34} \times R_{Er}(availability \ of \ manufacturing \ capacity)^{0.4} \times R_{Er}(prospects \ of \ available \ finance)^{0.26} \]

\[ R_{Er}(\text{probability of success}) = \]
\[ R_{Er}(competitiveness \ of \ price)^{0.37} \times R_{Er}(level \ of \ competition)^{0.37} \times R_{Er}(availability \ of \ design)^{0.26} \]

\[ R_{Er}(\text{level of technical risk}) = \]
\[ 0.40 \times R_{Er}(availability \ of \ design) + 0.30 \times R_{Er}(availability \ of \ manufacturing \ capacity) + 0.17 \times R_{Er}(level \ of \ manufacturing \ investment) + 0.13 \times R_{Er}(demands \ on \ bid \ resources) \]

\[ R_{Er}(\text{competitiveness of price}) = \]
\[ R_{Er}(level \ of \ financial \ risk)^{0.45} \times R_{Er}(availability \ of \ manufacturing \ capacity)^{0.35} \times R_{Er}(level \ of \ manufacturing \ investment)^{0.20} \]

\[ R_{Er}(\text{chances of project going ahead}) = \]
\[ R_{Er}(nature \ of \ formal \ enquiry)^{0.42} \times R_{Er}(prospects \ of \ available \ finance)^{0.58} \]
10.5 System Development

The rules generated were encoded in the Leonardo 3 expert system shell (see section 4.4.) and a "tidy" user interface was developed. The resulting prototype system required management to make assessments relating to the enquiry under investigation for the 11 base constructs shown in table 9.5(i). The system then made inferences for the 7 higher level constructs also shown in figure 9.5(ii), including the six intermediate constructs and the ultimate bid versus no bid and bid resourcing decision. The resulting system was named TEES for Tender Enquiry Evaluation System.

10.6 Summary

For each set of relationships at each level of the hierarchical inference network shown in figure 9.5(ii) a "general rule" or heuristic that expressed that managers' reasoning (that is, expressing how the managers combine their assessments for sub-ordinate constructs to reach an assessment for a super-ordinate construct) was induced from the assessments provided in the combined grid (see figure 8.4.3(i), Appendix B). These induced "general rules" or heuristics were derived by fitting appropriate mathematical model forms to express the relationships between the relevant constructs.

Taken together the induced set of "general rules" provided a model of the managers' reasoning, expressing how the managers combined their assessments for the relevant constructs in order to evaluate enquiries to reach an overall bid versus no bid decision, and thereby allocate an appropriate level of resources for the preparation of a tender proposal.
CHAPTER 11

DEVELOPING A FORMAL VALIDATION FRAMEWORK FOR TEES
11. DEVELOPING A FORMAL VALIDATION FRAMEWORK FOR TEES

11.0 INTRODUCTION

Several characteristics of both the problem domain and the development approach described in the previous five chapters highlighted the importance of an extensive validation study. The purpose of this study was to establish the credibility of the tender enquiry evaluation system (TEES) with the TAG. (The results of the validation study are presented in chapter 12). This chapter therefore describes the development of a formal framework for the validation of TEES. The chapter commences with a brief discussion of the literature in relation to expert system validation which highlights the difference in emphasis between the validation of expert systems and more conventional systems. The key issues in the expert system validation are then outlined with particular emphasis on the issues relevant to the validation of TEES. Finally, from the relevant literature a formal validation framework for TEES, incorporating a formal validity measure and statistical test, is devised.

11.1 COMMENTS ON THE VALIDATION OF EXPERT SYSTEMS

O'Keefe et al (1987, pp. 81) in their paper reviewing approaches to expert system (ES) validation define validation as the process of “testing systems to ascertain whether they achieve acceptable performance levels”. Their validation theme of measuring an ES’s performance against an acceptable benchmark is also one shared by several other researchers, namely Yu et al (1979), Chandresakaren (1983) and O’Leary (1987).

Clearly, it is important that ES are adequately validated if they are to be used as a basis for making or supporting decisions. Invalid systems, or systems that have not been adequately validated, provide few organisational benefits because decisions made by, or based upon the recommendations of, such systems would be ill-founded. Dependency on such systems can result in costly, and at worst potentially dangerous consequences. This would be the case for example, with an ES used to select appropriate investment portfolios, or a “closed loop” ES monitoring a process control plant in the chemical industry.
The observations made above suggest that both the extent and formality of the validation procedures required to pronounce an ES valid are dependent upon how the system is to be put to use. The key lying in the degree of judgement that the user surrenders to the system (Sell, 1985 pp. 63). For so called consultant or advisory ES, that is ES which disseminate expertise to less skilled and qualified personnel, formal validation is of paramount importance because the naive user surrenders all their judgement to the system. An example of such a system is the EvEnt system developed by a French bank for corporate loan evaluation, as described by Rozenholc (1988). The objective of the EvEnt system was to disseminate the scarce and costly expertise of the corporate loan officers based at head office throughout the bank's national network. Whereas, for expert support systems (ESS), whose role is to support rather than replace decision making, the requirement to formalise the validation procedures is of less importance because the knowledgeable or expert user can choose to override or ignore the system when they spot spurious recommendations or results. This is precisely the scenario envisaged in the case study under discussion with the use of TEES by the TAG. ESS still require a pronouncement of validity according to some acceptable performance benchmark. For such systems, however, the validation effort is more concerned with establishing the credibility of the system with the user group (as for example with the members of the TAG in the case study under discussion), rather than with providing a formal test of validity (O'Keefe, 1989); although clearly, if properly devised, formal methods and tests are still appropriate.

A survey of the relevant literature¹ suggests that the debate concerning appropriate methods for validating ES (and ESS) has only just begun. O'Leary (1987) hypothesizes that if ES are like conventional systems then they ought to be able to be validated in the same way as conventional systems. He goes on to assert that ES display a number of technical, environmental, design and domain characteristics that distinguish ES from more conventional systems. O'Leary argues that ES process symbolic rather than numeric information; directly influence or make decisions whereas other systems simply support decision making (DSS), or have an indirect impact on decision making (MIS); are developed using a middle-out methodology rather than a top-down or bottom-up approach; and finally that ES frequently operate in domains where there is not always a unique correct solution. On the basis of this

comparison O'Leary (1987) concludes that conventional methods of validation are inappropriate for ES, and as a result a validation framework specific to ES is required.

As previously noted in chapter 3, the differences between ES and more conventional systems are primarily one of emphasis. A careful analysis of the comparison between expert and conventional systems on the four technical, environmental, design and domain characteristics suggests that O'Leary (1987) is overstating their differences. Firstly, although the representational form used by the two types of system is different, it is not clear how this affects their validation. O'Leary (1987) suggests that the transparency of an ES's knowledge base can be used within the validation framework; but in practice transparency of the domain knowledge is seldom achieved because developers are required to "bend" or "engineer" the knowledge to fit the representational formalism of the chosen development tool (Pollitzer & Jenkins, 1985; Cullen & Bryman, 1988; King, 1989). Secondly, as previously noted ES are not necessarily used in a decision making or influencing role, they can be developed for use as decision support tools in the form of ESS. This is the present situation with TEES the system developed for use by the TAG. It was also true of the ESS for analysing and interpreting an organisation's financial statement, as described by Kerschberg & Dickinson (1988). Thirdly, the benefits of prototyping are now widely recognised and the approach is becoming common place in conventional systems development, thus suggesting a move away from top-down or bottom-up approaches (Kelly, 1986; Willmott, 1986).

O'Leary's (1987) fourth point that ES operate in domains where there is not necessarily a unique correct solution is perhaps the most significant, although this is not a characteristic that is unique to ES. Finlay et al (1988) argue that DSS operate in semi and ill-structured domains where there is no correct answer. Rather than demonstrating the need for a specific validation framework for ES, they propose that the similarities between ESS and conventional DSS suggest that the concepts and methods used to validate the mathematical models of DSS are also appropriate for the validation of ESS. O'Keefe (1989) severely criticizes their conclusion arguing that there are subtle differences, concerning both what to validate against and what to validate, between ES and conventional DSS that need to be taken into account when validating ES. (These two issues are discussed further in section 11.2.1 and 11.2.2 respectively.) However, many of the concepts and approaches to validating ES

2 It could be argued that differences in the form of representation used by expert and conventional systems is simply a manifestation of their more fundamental differences concerning their domains' knowledge characteristics.
provided in an earlier paper by O'Keefe et al (1987) are taken from considering the
validation of computer simulation models which frequently involve mathematical
relations. This itself suggests that similarities can be drawn between the validation of
ESS and more conventional decision support computer models.

Some of the issues in the debate about the differences between the validation of ES
and conventional systems arise from a tendency to contrast the two types of system in
terms of their technical differences regarding representation and inference, rather than
in terms of their domain characteristics. A clearer picture of validation emerges if the
distinction between the socio-technical and functionalist perspectives, as described by
Whitely (1990), to ES development is made, and thus if the comparison is made
between systems that operate in formal domains and those which operate in non-
formal domains. As previously noted in chapter 6, formal domains are those where
knowledge is clearly defined and openly examinable. In such domains there is a
single view of truth and a unique correct solution exists, as for example with many
MIS type applications. Whereas, in non-formal domains knowledge is personally or
socially constructed and there may be many views of the truth. In such domains
knowledge is often unarticulated and is seldom, if ever, openly examinable. From this
perspective, it is necessary to distinguish between the concepts validation and
verification. Validation establishes a model's relations adequately reflect the real
world. Verification establishes whether a model's relations have been correctly
encoded (Gass, 1983).

Systems operating in formal domains are seldom formally validated. For such
systems formal validation is not emphasized because the relevant knowledge, that is
the model's relations, is clearly defined and open to public scrutiny. One common
approach deemed appropriate for the validation of such systems is that of the project
sponsor examining and discussing the formal systems specification with the systems
analyst. When the sponsor is satisfied with the specification it is signed off which is
in effect a seal of validation. Rather, for such systems the emphasis lies with formal
verification which occurs during systems testing stage. The objective of the systems
test is to check whether or not the system meets the specification and not whether the
specification reflects the real world. Although in practice the nature of the tests used
to verify systems do undoubtedly highlight discrepancies between the specification
and the real world! In contrast to this approach the emphasis with systems operating
in non formal domains is primarily with validation, that is checking that the model is
an adequate representation of reality. This is because there is far greater uncertainty
regarding the quality and relevance of the knowledge upon which the system is based.
In summary, O'Leary (1987) is correct in identifying differences between ES and conventional systems which influence the nature of their validation. It is suggested, however, that O'Leary (1987) overstates the significance of several of these differences and a clearer picture of validation emerges if the comparison is made not between ES and conventional systems, but between systems that operate in non-formal domains and those that operate formal domains. In recognition that both conventional DSS and ESS operate in non-formal, that is semi or ill-structured, domains Finlay et al. (1988) conclude that the methods for validating the mathematical models of DSS are appropriate for ESS. O'Keefe et al. (1987) and O'Keefe (1989) generally support this view but warn of subtle differences between DSS and ES which need to be taken into account when validating ES.

The next section discusses the key issues in the validation of ES. The discussion emphasizes the differences between the validation of ES and DSS, as noted by O'Keefe et al. (1987) and O'Keefe (1989) (see sections 11.2.1 & 11.2.2), and places particular importance on the issues relevant to the development of a validation framework for TEES.

11.2 Key Issues in Expert System Validation

This section summarizes the debate on three of the key issues in ES validation. These are:  
* What to validate against?,*  
* What to validate?,*  
* What to validate for?*. Each of these issues is discussed in the respective sub-sections below.

11.2.1 What to Validate Against?

An ES can be validated against known results or against human experts' level of performance (Sell, 1985 pp. 63; O'Keefe et al., 1987, O'Keefe 1989, Chandrasekaren, 1983).

Several problems exist with measuring an ES's performance against known results. Firstly, Chandrasakeran (1983, pp. 30) warns of the so called "super-human fallacy" surrounding ES, and argues that when a system's level of performance is measured against an absolute standard of "correctness" the system's level of performance or expertise may be underestimated. This is precisely what happened with the initial validation of MYCIN, a system developed for the diagnosis and treatment of
bactrema infections (see section 3.1). When MYCIN was validated against reality its performance or level of expertise was poor. Yet in subsequent studies when it was validated against both expert domain specialists and non-expert but knowledgeable medical practitioners, then its performance was found to be better than the specialists and much better than the non-specialists (Sell, 1985 pp. 63). The experiences of the MYCIN study suggest that it is unreasonable to measure the performance of an ES against known or correct results when its human counterparts, from whom its knowledge base was derived, cannot perform at levels close to known results (Sell, 1985, pp. 63; O'Keefe et al, 1987; O'Keefe, 1989).

Secondly, decisions made by experts may influence the results themselves (O'Keefe et al (1987), O'Keefe, 1989). O'Keefe (1989, pp. 510) cites the example: "suppose that a bank uses a performance prediction when deciding whether or not to support a company X financially. If an expert had decided a year ago that the financial position of company X would be poor in a year's time and thus implemented withdrawal of financial support, the present poor financial position of company X might be due in part to that previous expert decision". This observation is of particular relevance to the case study under discussion and the validation of TEES. For example, if the TAG decide to award an enquiry an intermediate Bid B or Bid C decision and subsequently fail to win the contract, then they may feel justified that their decision had been reasonable. However, their failure to win the contract could have been in part due to not allocating sufficient resources at the tender proposal stage. As a result their early bid versus no bid and bid resourcing decisions had in part influenced the final outcome. The overall effect of this phenomenon is that the system's level of performance measured during validation is not the same as it would be in "live" use!

Finally, there may not be a correct result to measure the performance of the ES against (Yu et al, 1979; Chandresekaren, 1983; O'Leary, 1987). Again this is relevant to the case study under discussion regarding the validation of TEES and is closely related to the previous problem concerning expert decisions influencing the resulting outcomes. For example, it is impossible for the TAG to reassess their previous decisions for those enquiries that were awarded a No Bid decision to see if they were in fact "correct" decisions and therefore for these enquiries no known results would be available.

So, not only is it unreasonable to measure the performance of an ES against known results when this is beyond the capabilities of human experts; but such comparisons may be infeasible because known results are not available, and mis-leading because
expert decisions can influence the results themselves. This suggests that in many situations it is more feasible and appropriate to measure an ES's performance against the performance of human experts.

Validating ES against human experts' performance is not itself without problems. Firstly, the MYCIN study demonstrates the fact that human experts are not always correct. Thus when developing the ES's knowledge base the inadequacies of the human expert(s) are also implicitly modelled. As a result the system will suffer from the same inadequacies as the human expert(s). Unfortunately, this undesirable characteristic has to be accepted unless one believes it is possible to develop ES with "super-human" capabilities, but as previously noted this is a foolish notion. So, when validating ES against human experts' level of performance it is imperative that the system is as given as much benefit of doubt as the human expert(s) (Chandresakaren, 1983). That is, the ES and the human expert(s) must be considered to be of equal status. As a result the emphasis of validation changes from one of trying to establish whether the ES is in agreement with the expert(s) to that of establishing whether the ES and the expert(s) are in agreement.

A further problem arises in selecting which experts to validate the ES against. An ES can be validated against those experts from whom the knowledge base was derived, so providing an intra-expert test; or against a different set of experts, so providing an inter-expert test (O'Leary, 1987 & 1988).

Using an intra-expert test can introduce elements of selective bias because the knowledge base is biased by the original choice of expert(s) used during knowledge acquisition. So, in non-formal domains, an ES pronounced valid by an intra-expert test could be regarded as inappropriate by a different user group. It has therefore been suggested that it is expedient to validate ES with an inter-expert test using a different set of experts, but drawn the same "school of thought" as the original experts (O'Leary, 1987). However, the principles of basic scientific experimental design dictate that results obtained from an inter-expert test can only be sensibly interpreted relative to a control set of results from an intra-expert test. The best approach therefore appears to be to conduct both types of test, as was the case in the validation of MYCIN (Yu et al, 1979) in which two groups of experts were used. The first group consisted of a group of experts from Stanford medical school who had been involved in MYCIN's development. Whilst the second group consisted of experts from another medical school. This approach enabled measurement of MYCIN's bias towards Stanford's view of the problem.
11.2.2 What to Validate?

It is possible to treat an ES as a black box and perform a *synoptic* validation checking that the system produces an acceptable result for each set of inputs (O'Leary, 1987; Finlay *et al.*, 1988). This only measures a system's total performance establishing that the system produces the *correct* result. It does not establish how or why the system produced the result it did! Alternatively, it is possible to open up the black box and perform an *analytical* validation (O'Leary, 1988; Finlay *et al.*, 1988). This form of validation checks each part of the system in detail: in particular it facilitates both the validation of the system's intermediate results and the structure of the system's reasoning (Yu *et al.*, 1979; Chandrasekaran, 1983; O'Keefe *et al.*, 1987; O'Keefe, 1989).

There is a clear consensus within the relevant literature⁴ that it is not sufficient to only validate an ES's final result or conclusion. In recognition that ES are supposed to emulate human experts both Yu *et al.* (1979) and Chandrasekaran (1983) argue that a complex reasoning program must be validated against the structure of its reasoning and its intermediate recommendations, and not solely against its final or overall recommendation. Furthermore, testing an ES's reasoning and intermediate results demonstrates how well the system could be extended to a larger domain. For example, the results from MYCIN were tested at three levels. These were firstly the significance of the bacterial infection, that is whether treatment was necessary; secondly the identity of bacterial organism; and finally treatment selection (Yu *et al.*, 1979).

11.2.3 What to Validate For?


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⁴ Consistency is also referred to as *reliability* by O'Leary (1987).

⁵ Accuracy is referred to as *soundness* by Sell (1985, pp. 69).
11.2.3(1) Consistency

Consistency is defined as the ability of an ES to "produce similar solutions to similar problems" (Sell, 1985, pp. 64). Thus consistency is synonymous with sensitivity. As such consistency cannot be tested for because of the difficulty in differentiating between inconsistency and appropriate system response when the inputs are subject to small perturbations (O'Leary, 1987, Finlay et al 1988). For this reason consistency is often rephrased as "the ability of a system to generate identical solutions given identical inputs" (O'Leary, 1987 pp. 478.). Under this redefinition it is possible to test for consistency; but any such test is then primarily concerned with verification rather than validation.

11.2.3(2) Completeness

Completeness demands that "everything which is true is derivable by the [expert system]" (Sell, 1985 pp. 67). Thus completeness is concerned with the amount of knowledge in the knowledge base or that there are no missing "rules" (O'Leary, 1987 & 1988). Completeness therefore guarantees total coverage of the domain and ensures that all acceptable inputs produce an outcome (Finlay et al, 1988).

11.2.3(3) Accuracy

Accuracy is the opposite to completeness and demands that "everything derivable is true" (Sell, 1985 pp. 69). Thus tests for accuracy establish whether the system reaches the correct conclusions intermediate and final, whether they be measured against human experts or known results. Accuracy is therefore a measure of systematic bias (Finlay et al, 1988).

11.2.3(4) Precision

Precision is regarded as an extension of accuracy (Sell, 1985 pp. 70). Whereas accuracy establishes whether the system reaches the correct conclusions, precision establishes that conclusion is presented within an acceptable error tolerance. Thus precision is a measure random variability or spread, referred to as random bias by Finlay et al (1988).
The issues raised in the above sub-sections have been noted and used to develop an appropriate formal validation framework for TEES. This framework is described in the following three sections 11.3-11.5.

11.3 A FORMAL FRAMEWORK FOR VALIDATING TEES

The tender enquiry evaluation system (TEES) was developed based on the combined expertise of the Proposals Manager and one of the Business Group Managers. Primarily these two managers were chosen because their management roles provided them with considerable exposure to the thinking of the TAG. However, their views represent only a sample of those of the TAG as a whole. Other managers on the TAG, especially those from different functional or business specialisms, may view enquiries differently. In this respect the domain of tender enquiry evaluation can be regarded as non-formal. Furthermore, TEES was developed from the managers' views regarding fourteen historic enquiries which passed before the TAG between January 1989 and June 1989. Although these enquiries were carefully selected to ensure representative coverage of the domain, that is all the business groups and the five bid decision categories, they only represented a sample of the characteristics of enquiries that may arise in the future. Together these characteristics of the development approach highlighted the importance of an extensive validation study.

The practical and theoretical problems with validating ES against known results discussed in section 11.2.1 suggested that it was more feasible and appropriate to measure the performance of TEES against human experts' level of performance. Furthermore, the implicit bias in the content of TEES's knowledge base suggested that it was important to measure not only how closely the system reflected the views of the two managers used in its development, but also the views of other members of the TAG especially those from different business and functional specialisms. Thus, both intra-expert and inter-expert validation tests were to be performed. These would enable TEES's consensual business perspective to be measured, and thereby assist in establishing the credibility of TEES with the TAG.

Furthermore, during the development of the knowledge base heuristics (see chapter 10) the construct weights $\alpha_i$ were chosen to optimise the performance of TEES with respect to the enquiries in the managers' combined grid. The optimal knowledge base construct weights $\alpha_i^*$ were thereby biased by the original enquiries and it was
therefore expedient to validate TEES's performance against a new set of enquiries as well as a new set of managers.

As TEES was to be used in a supporting role, then if the TAG was to have full confidence in its recommendations it was important that its reasoning as well as its final recommendations were validated. Therefore, TEES's intermediate conclusions as well as the final recommendations were to be validated, as this provided an indication as to the quality of its reasoning. The underlying structure of TEES's knowledge base (see table 9.5(i) and figure 9.5(ii)) suggested that all seven of the system's results should be tested. These corresponded to the six intermediate constructs $C_{12}$ chances of project going ahead, $C_{13}$ potential profitability, $C_{14}$ level of technical risk, $C_{15}$ level of financial risk, $C_{16}$ competitiveness of price and $C_{17}$ probability of success, together with TEES' overall recommendation for the construct $C_{18}$ overall attractiveness of enquiry. This approach followed the example provided by Yu et al (1979) in MYCIN's validation.

Due to the difficulty in differentiating between inconsistency and appropriate system response, as noted in section 11.2.3(I), the narrower definition of consistency as an aspect of verification was used throughout the validation of TEES. That is, TEES would be pronounced as consistent provided that it produced identical solutions given identical inputs. Furthermore, the nature of the mathematical relations underlying TEES's knowledge base implied that TEES was necessarily complete. This implied that in the context of validating TEES the issue of completeness also became an aspect of verification rather than validation. So, TEES would be both consistent and complete provided that the mathematical relations expressing the domain knowledge were properly encoded. TEES was verified by comparing its responses for the 10 enquiries included in the combined grid with the results obtained from the spreadsheet models used to induce the optimal knowledge base construct weights $\alpha_i$ discussed in

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6. Each rule in TEES's knowledge base is a mathematical function, $f$ say, such that $f: A \rightarrow A$ where $A = \{1,2,3,4,5\}$.

To prove the knowledge base is complete it is sufficient to prove that each rule is complete. Thus, let $f$ be any rule of the knowledge base relating a dependent construct $C_d$ say to its influencing constructs $C_1,...,C_k$, so that

$$R'_E(C_d) = f(R_E(C_t); \alpha_i: i = 1,...,k)$$

Then, $f$ is complete because for all $j \in A$,

$$j = f(R_E(C_1 = j); \alpha_1, ..., R_E(C_k = j); \alpha_k)$$

(see eqs. 10.2.1(i) and 10.2.1(ii))
chapter 10. The criteria of consistency and completeness as aspects of validation are therefore not discussed further in this chapter.

In the context of validating TEES a measure of accuracy or systematic bias reflects whether or not TEES consistently views enquiries, or particular traits of enquiries, in either an over-attractive or under-attractive light as compared to the managers. Provided that TEES is not systematically biased, a measure of precision reflects the closeness or extent of agreement between system and manager, and is therefore a measure of the similarity between the manager's and TEES's perspective of tender enquiry evaluation. So, in the context of validating TEES precision is a more stringent criterion of validity than accuracy. The statistic that was used to measure the extent of agreement between TEES and the managers is discussed in section 11.5.

In summary, the formal validation framework for TEES would include both intra-expert and inter-expert tests. These would enable TEES's consensual business perspective to be measured and assist in establishing the credibility of the system with the TAG. Furthermore, the framework would enable TEES's intermediate results as well as its final recommendation to be tested, so that the structure of the system's reasoning was validated. Finally, TEES's validity would be established, or tested, using a statistical measure and formal test that emphasised the system's precision as well as its accuracy.

The next section discusses the data requirements for the outlined framework.

11.4. DATA REQUIREMENTS FOR VALIDATING TEES

The most commonly used procedure for validating ES is the Turing Test (Blanning, 1984). The objective of the Turing Test is to compare an ES's results against known results or expert decisions to obtain measures of the accuracy and precision of the system. If these measures lie within an acceptable performance range, or satisfy formal statistical tests, the system can be pronounced valid.

To validate TEES using a Turing Test required the construction of a 3-dimensional validation database. This database needed to include ratings or assessments for the 18 constructs $C_1, \ldots, C_{18}$ (see table 9.5(i)) used by TEES assessed by several different managers across a new and representative set of enquiries.

There were two possible approaches to the construction of the validation database. The first approach involved collecting data on an ongoing basis by asking the
managers to record their assessments for enquiries whilst at TAG meetings. However, the high turnover of personnel from one TAG meeting to the next posed problems with ensuring that the managers considered the same enquiries and that the enquiries formed a representative set. Furthermore, because TAG meetings only took place once every fortnight the construction of a suitable validation set could have taken several months.

The second approach involved analysing the TAG minutes to identify an appropriate set of managers and a representative set of enquiries for inclusion in the validation study, and then collecting the relevant managerial assessments on a retrospective basis. Although this approach was itself not without problems, namely that the managers' assessments would suffer from the effects of post rationalisation (see section 12.3), it was considered to be more efficient than collecting data on an ongoing basis.

The minutes from the 11 TAG meetings held between July 1989 and December 1989 during which 38 enquiries passed before the TAG were analysed. From these minutes it was established at which TAG meetings enquiries were reviewed, at which TAG meetings any given manager was present; and therefore which managers were present whilst any given enquiry was reviewed. This process enabled the identification of a set of managers who were familiar with a common set of enquiries, such that the managers provided coverage of the different functional perspectives and the enquiries provided representative coverage of the domain.

The manager from each of the four functions Engineering, Finance, Manufacturing and Marketing who had the greatest exposure to the 38 enquiries was identified. These four managers together with the original Proposals and Business Group Managers provided a cross section of the views of the TAG and formed the set of managers used in the validation study.

From the 38 enquiries it was only possible to identify 12 enquiries which were familiar to all six managers, and these 12 enquiries were significantly biased towards two of the business groups. To provide a more representative coverage of the domain

7 The analysis of the minutes from the 11 TAG meetings held between July 1989 and December 1989 revealed that a representative from the Procurement function had been present at the TAG on only one occasion. It was therefore concluded that the Procurement function's influence on the bid versus no bid and bid resourcing decisions was insignificant; and consequently, it was not necessary to include a manager from the Procurement function in the validation study.
it was necessary to consider enquiries which were not familiar to all 6 managers. This resulted in a validation set of 17 enquiries of which only 11 enquiries were familiar to all six managers; although in theory each manager was familiar with at least 14 of the 17 enquiries.

A standard questionnaire was used with each of the six managers to collect their respective assessments on a five point semantic differential scale for the 18 constructs across the 17 enquiries. The managers' assessments were therefore recorded in 6 repertory grids with the same element and construct labels as in the MINUS and CORE approaches (see section 7.1.4). This approach was not without its problems because in practice several of the managers felt they were unqualified to provide expert assessments for some of the enquiries and constructs. The resulting validation database therefore contained several missing data values.

11.5 AN APPROPRIATE VALIDITY MEASURE FOR TEES

This section describes the selection of an appropriate statistical validity measure used to measure TEES's level of performance, that is the level of agreement between TEES and the six managers included in the validation study.

The validation database contained managerial assessments for the 11 input or base constructs $C_1, ..., C_{11}$, and the 7 higher level constructs. These later higher level constructs included the 6 intermediate results $C_{12}, ..., C_{17}$ and TEES's final recommendation for the construct overall attractiveness of enquiry $C_{18}$. These assessments were provided by $m$ ($m=6$) managers $M_1, ..., M_m$ across a new and representative set of $n$ ($n=17$) enquiries $E_1, ..., E_n$.

In this database let $R_{ErMj}(C_q)$ denote the integral expert assessment in the interval $[1,5]$ provided for enquiry $E_r$ by manager $M_j$ on the construct $C_q$ ($r = 1, ..., 17; j = 1, ..., 6; q = 1, ..., 18$). Then, for each manager $M_j$ and for each enquiry $E_r$, the first eleven of these assessments $R_{ErMj}(C_1), ..., R_{ErMj}(C_{11})$ form a set of inputs to TEES. This set can be represented by the single column vector $X_{ErMj}$, defined by

$$X_{ErMj} = [R_{ErMj}(C_1), ..., R_{ErMj}(C_{11})]^T$$

eq. 11.5 (i)

Similarly, the remaining seven assessments $R_{ErMj}(C_{12}), ..., R_{ErMj}(C_{18})$ correspond to the set of intermediate and final results from TEES. This set can be represented by the single column vector $Y_{ErMj}$, defined by
TEES can then be applied to the input vector $X_{ErMj}$ to provide the vector of intermediate and final system results $Y'_{ErMj}$. Using the vector operator $E$ to represent TEES's knowledge base, then $Y'_{ErMj}$ is defined by

$$Y'_{ErMj} = E(X_{ErMj})$$  

where,

$$Y'_{ErMj} = [R'_{ErMj}(C_{12}), ..., R'_{ErMj}(C_{18})]^T$$  

and,

$$R'_{ErMj}(C_t) = f_t(X_{ErMj})$$  

$t = 12, ..., 18$  

where, $f_t$ represents the sub-component of TEES's knowledge base that determines the response for the construct $C_t$, $R'_{ErMj}(C_t)$.

TEES can be regarded as valid in the eyes of manager $M_j$ if its response $Y'_{ErMj}$ and the manager's assessment $Y_{ErMj}$ are in agreement. Thus, by comparing the vectors $Y'_{ErMj}$ and $Y_{ErMj}$ both TEES's intermediate and final results can be compared with the manager's respective assessments; and therefore both the system's overall recommendation and the structure of its reasoning can be validated.

Both $R_{ErMj}(C_t)$ and $R'_{ErMj}(C_t)$ ($t = 12, ..., 18$) were measured on a five point semantic differential scale. The vector difference between $Y'_{ErMj}$ and $Y_{ErMj}$ was therefore an indication of the level of agreement between TEES and manager $M_j$. Consequently, a validity measure was sought that was based on the difference between $Y'_{ErMj}$ and $Y_{ErMj}$.

As previously noted in section 11.3, in establishing a validity measure for TEES it was important to identify a statistic that emphasised the precision of the system's recommendations rather than their accuracy. For example, for any manager $M_j$ ($j = 1, ..., 6$) and any construct $C_t$ ($t = 12, ..., 18$) the manager's assessments $R_{ErMj}(C_t)$ and TEES's responses $R'_{ErMj}(C_t)$ for the 17 enquiries formed a paired sample. Therefore, as both $R_{ErMj}(C_t)$ and $R'_{ErMj}(C_t)$ were measured on a five point semantic differential scale, the students $t$-test, as recommended by O'Keefe et al (1987), could have been used to measure the significance of the difference between a given manager's assessments and TEES's responses. Alternatively, to overcome the problems associated with correlated multiple responses (Harris, 1975 pp. 6), Hotelling's $T^2$ test, the generalised multivariate counterpart to the students $t$-test, could have been used to measure the significance of the vector difference between $Y'_{ErMj}$ and $Y_{ErMj}$. Both of
these statistics, however, would have tested the significance of the mean difference between the manager's assessments and TEES's responses. Therefore, although these statistical tests could have been used to demonstrate that the mean difference was not significantly different from zero, they would have failed to highlight the shape of the underlying distribution of the differences; and thus would not have highlighted the differences between the manager and TEES on any single enquiry. So, in theory, as a result of aggregation over a number of enquiries, TEES's recommendation could be pronounced as accurate but of low precision. Clearly, such a statement would bestow little confidence in the TAG to use TEES to evaluate any single given enquiry which was the purpose for which it was developed. Consequently, it was important to identify a validity measure that emphasised the precision of TEES's recommendations as well as their accuracy.

Furthermore, since the form of the distributions of the differences between the managers' assessments and TEES's responses were unknown, it was expedient if the validity measure made no assumptions about the distributions of these differences. Consequently, a non-parametric statistic was sought for a validity measure.

Norman & Naveed (1990) use the non-parametric \( \chi^2 \) goodness of fit test to validate an ES to control the operation of a cement kiln. In the context of ES validation, however, the \( \chi^2 \) statistic suffers from two major drawbacks. Firstly, the \( \chi^2 \) statistic based on a contingency table analysis is a measure of association rather than agreement (Light, 1971). In a square contingency table providing a cross classification \( A \times A \) of a set \( A \), a measure of association is a measure of a 1 to 1 or 1 to many functional correspondence \( f \) such that \( f:A \rightarrow A \): whereas a measure of agreement is a measure of the identity correspondence \( \text{Id} \), such that \( \text{Id}(a) = a \) for all \( a \in A \). As such agreement can be regarded as a specific form of association and in the context of ES validation is a more reliable measure of validity. For example, if TEES were to have been validated with the \( \chi^2 \) statistic, then in theory, TEES could have been pronounced as valid even if its recommendations were consistently diametrically opposed to the managers' assessments! Secondly, the \( \chi^2 \) statistic is best suited to measuring association between variates measured on nominal or ordinal scales. However, in the validation study the managers' assessments and TEES's responses were measured on a five point semantic differential scale which was assumed to be an

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8 The shape of the distribution of the differences between the manager's assessments and TEES's responses was unknown. Therefore, to apply either of these tests legitimately one would have to appeal to the central limit theorem in order to satisfy the tests' respective underlying normality assumptions.
interval scale of measurement. The differences between TEES's responses and the managers' assessments were therefore an indication of the level of agreement between system and manager. If the $\chi^2$ statistic were to have been used as a validity measure for TEES then no credit would have been given when TEES's responses and the managers' assessments were close.

Together the considerations outlined above led to a statistic used by psychologists to assess the level of agreement between individuals referred to as weighted kappa ($\kappa_w$) (Cohen, 1968) being adopted as the validity measure for TEES (see section 11.5.1). Weighted kappa $\kappa_w$ is a non-parametric statistic that would simultaneously measure both the precision and accuracy TEES's results and enable credit to be given when its responses and the managers' assessments were close.

In the validation study (see chapter 12) weighted kappa ($\kappa_w$) was used to measure the level of agreement between TEES and each of the six managers individually for each of the 7 higher level constructs $C_{12} \ldots C_{18}$ (see table 9.5(i)) under test. Similarly, $\kappa_w$ was used to measure the level of agreement between TEES and the consensus of management opinion (see section 12.3) for each of the 7 higher level constructs under test. It was also used to investigate the similarity between the views of the six managers.

11.5.1 WEIGHTED KAPPA: A VALIDITY MEASURE FOR TEES

Suppose that we have a paired sample of size $n$ in which two independent processes are used to classify each of $n$ entities into one of $m$ mutually exclusive categories $A_1 \ldots A_m$. Then these $n$ paired observations can be represented in a $m \times m$ contingency table (see figure 11.5.1)
Figure 11.5.1  Contingency Table Representing the \((n)\) Paired Observations from the Two Classification Processes (Process 1 & Process 2)

<table>
<thead>
<tr>
<th>Process 1</th>
<th>Process 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A_1)</td>
<td>(A_1)</td>
</tr>
<tr>
<td>(A_2)</td>
<td>(A_2)</td>
</tr>
<tr>
<td>(A_i)</td>
<td>(A_i)</td>
</tr>
<tr>
<td>(A_m)</td>
<td>(A_m)</td>
</tr>
<tr>
<td>(M_{i,1})</td>
<td>(M_{i,1})</td>
</tr>
</tbody>
</table>
|           |           | \[n\]

Where,

\[ F_{ij} = \text{Number of observations in the (i,j)th cell of the contingency table} \]
\[ M_i = \text{The marginal frequency of the } i\text{th row of the contingency table} \]
\[ M_i = \sum_{j=1}^{m} F_{ij} \]
\[ M_j = \text{The marginal frequency of the } j\text{th column of the contingency table} \]
\[ M_j = \sum_{i=1}^{m} F_{ij} \]

So that \[ \sum_{j=1}^{m} M_i = \sum_{i=1}^{m} M_j = n \]

In the case study, then the entities are the \(n\) \((n=17)\) enquiries, the first process is TEES and the second process any of the six managers included in the validation study. If \(m = 5\), then the \(m\) categories can be used to represent the 5 ratings \(\{1, 2, 3, 4, 5\}\) used by the managers and TEES. For example, \(A_1\) denotes a rating of 1 on a given construct \(C_t\). Then, each cell \((i,j)\) of the table denotes the event that TEES produces the recommendation \(i\) for an enquiry \(E_r\) on the given construct \(C_t\) whilst the manager provides a respective assessment \(j\). Any observation that lies on the leading diagonal of the table (that is, in the \(i\)th row and \(i\)th column) is such that there exists full or perfect agreement between TEES and the manager regarding a given enquiry \(E_r\) and the construct \(C_t\). Therefore, there would be contingency tables for each of the 7
higher level constructs C₁₂,...,C₁₈ under test and each of the six managers included in the validation study, thus creating 42 tables in all. Furthermore, there would be an additional 7 tables for 7 higher level constructs under test and the consensus of management opinion.

The original statistic proposed by Cohen (1960) was kappa κ, based on the total number of observations on the leading diagonal of the contingency table. This would measure the level of perfect agreement between the TEES and the manager over and above the expected level of agreement that could be accounted for by chance. Kappa (κ) is given by

\[
k = \frac{\text{Observed Level of Perfect Agreement} - \text{Expected Level of Perfect Agreement}}{\text{Maximum Level of Perfect Agreement} - \text{Expected Level of Perfect Agreement}}
\]

\[
k = \frac{\sum_{i=1}^{m} F_{ii} - \sum_{i=1}^{m} (M_iM_i)/n}{n - \sum_{i=1}^{m} (M_iM_i)/n}
\]

Equation 11.5.1(i)

In the calculation of κ, all those cells off the leading diagonal of the contingency table where there is some disagreement between TEES and the manager are treated equally. In several respects κ is similar to the \( \chi^2 \) statistic except that κ is a measure of agreement rather than association. Like \( \chi^2 \), if κ were to have been used as a validity measure for TEES then no credit would have been given when TEES's responses and the managers' assessments were close. Cohen's weighted kappa \( \kappa_w \) (Cohen, 1968) generalizes κ by assigning an a priori defined non-negative ratio scaled agreement weight \( W_{ij} \geq 0 \) to each of the \( m \times m \) cells of the table, thus recognizing that some of the cells off the leading diagonal are of greater or lesser significance.

In establishing the validity of TEES against the assessments of any one of the six managers included in the validation study, those observations in cells which are close to the leading diagonal support the hypothesis that TEES and the manager are in agreement. Whereas, those observations in cells a long way from the leading diagonal tend to oppose the same hypothesis of agreement because observations in such cells are the result of the manager and TEES system having diametrically opposed views. Therefore in the validation study, in the calculation of \( \kappa_w \) each cell was associated with a scaled agreement weight \( W_{ij} \). This weight \( W_{ij} \) signified the
perceived level of agreement between TEES’s recommendation i and the manager’s assessment j. A maximum weight $W_{\text{max}} (>0)$ was associated with all cells (i,i) on the leading diagonal of the table, that is those cells which denoted the event that TEES and the manager were in full agreement. Smaller weights $W_{ij}$ ($0 \leq W_{ij} \leq W_{\text{max}}$) were associated with all other cells (i,j) (i$\neq$j) depending upon the perceived level of agreement between TEES and the manager. This facilitated the concept of partial credit (Cohen, 1968) in the calculation of $\kappa_w$ when TEES’s recommendations and the manager’s assessments were close.

Weighted kappa $\kappa_w$ was therefore used as a measure of the level of scaled agreement between TEES and the manager over and above the level of scaled agreement that could be accounted for by chance. Weighted kappa $\kappa_w$ is given by.

$$\kappa_w = \frac{\text{Observed Level of} \ Scaled \ Agreement - \text{Expected Level of} \ Scaled \ Agreement}{\text{Maximum Level of} \ Scaled \ Agreement}$$

$$\kappa_w = \frac{\sum_{i=1}^{m} \sum_{j=1}^{m} W_{ij} - \sum_{i=1}^{m} \sum_{j=1}^{m} W_{ij}(M_i M_j / n)}{(W_{\text{max}} \times n) - \sum_{i=1}^{m} \sum_{j=1}^{m} W_{ij}(M_i M_j / n)}$$

Significance tests were conducted using $\kappa_w$ to test a research hypothesis suggesting that the level of scaled agreement between TEES and a manager was greater than that which can be accounted for by chance. The null and alternative hypotheses $H_0$ and $H_1$ respectively were expressed as follows.

$$H_0 : \kappa_{w(\text{pop})} = 0 \ (\text{TEES is invalid with respect to } C_i \text{ and manager } M_j)$$

$$H_1 : \kappa_{w(\text{pop})} > 0 \ (\text{TEES is valid with respect to } C_i \text{ and manager } M_j)$$

where $\kappa_{w(\text{pop})}$ is the level of scaled agreement for the underlying population between TEES and the manager with respect to construct $C_i$.

Studies have shown that $\kappa_w$ is asymptotically normal (Everitt, 1968; Fleiss et al., 1969). However, in the case study under discussion the validation sample was only of size 17, and because some managers felt uncomfortable about providing qualified assessments for some of the enquiries in some instances the sample was smaller. Thus, to conduct tests on the level of scaled agreement between a manager and TEES
it was necessary to determine the exact distribution of $\kappa_w$ under $H_0$. A proof establishing a formula for the exact distribution of $\kappa_w$ under $H_0$ is provided in Appendix D.

11.5.2 Choice of Scaled Agreement Weights $W_{ij}$

Equation 11.5.1(ii) reveals that the weights $W_{ij}$ are an integral part of how agreement between TEES and the managers is measured and defined in terms of $\kappa_w$. Consequently, the probability distribution of $\kappa_w$ is a function of the weights $W_{ij}$; and therefore the results of any significance tests on the level of agreement between TEES and a manager were dependent upon these weights. So, the weights became an implicit component of the validity hypothesis being tested and therefore some care needed be exercised in their selection.

As both TEES's responses and the managers' assessments were measured on a five point semantic differential scale, then the absolute difference between TEES's responses and the managers' assessments represented a measure of agreement between TEES and the managers. Therefore an intuitively appealing reference point for assigning weights $W_{ij}$ to the $5 \times 5$ cells of the TEES-manager contingency table was to base the weights $W_{ij}$ on the difference between the manager's assessment and TEES's response. This difference was a measure of the distance of the cell from the leading diagonal of the table, and hence a measure of the closeness of an observation within that cell to the concept of perfect agreement.

The implications of any set of weights $W_{ij}$ on the validation of TEES are far reaching and very difficult, if not impossible, to assess fully. For example, assume that the TAG were to act without question on TEES's recommendations and consider for any given enquiry TEES's recommendation and the TAG's assessment for the construct overall attractiveness of enquiry. Then should the same weight be associated with the cells (2,3) and (4,3) respectively? That is, does it make any difference to the organisation whether TEES suggests that they should commit more resources to the preparation of the bid proposal or less resources to its preparation given the TAG's own assessment of the situation? The answer to this question is most probably yes, but determining the relative weights $W_{2.3}$ and $W_{4.3}$ so that the TAG would show an indifference to the two recommendations of TEES is clearly a very difficult problem. Answering such questions was considered to be beyond the scope of this validation study, and it therefore proved impossible to devise a single justifiable set of scaled agreement weights $W_{ij}$ with which to validate TEES. Indeed, in theory, a separate set
of weights would be required for each of the six managers included in the validation study and for each of the 7 higher level constructs under test in order to reflect the manager's own preferences. For this reason it was decided to experiment with several sets of weights so that the sensitivity of the validation results to the chosen weights could be established. Before choosing the the weights $W_{ij}$ with which to validate TEES a set of four reasonable assumptions were proposed. These were as follows:

1. Equal Status of TEES and Manager
2. Symmetry of Weights about TEES-Manager Assessments
3. Independence of Weights from TEES-Manager Assessments
4. Weights $W_{ij}$ are described by non-increasing function of $|i - j|

To state these assumptions it is necessary to introduce the concept of an arbitrary rewards or risk function $h$. This function defines the rewards or risk to the organisation of acting upon TEES' recommendations when TEES provides a recommendation $j$ and the TAG's or manager's assessment is $c$.

11.5.2(1) EQUAL STATUS OF SYSTEM AND MANAGER

Firstly, as previously noted in section 11.2.1, since the TAG could not always be regarded as right in their bid versus no bid and bid resourcing decisions, it was imperative that TEES and the managers were assumed to be of equal status. That is, for all managerial assessments $R_{EiMj}(C_i)$ and for all system responses $R'_{EiMj}(C_i)$, the rewards or risk, $h$, associated with TEES producing a response $j$ given that the manager provided an assessment $c$ was assumed equal to the rewards or risk associated with the manager providing an assessment $j$ given that TEES produced the response $c$. The assumption of equal status implied that the weights $W_{ij}$ were symmetric, that is $W_{ij} = W_{ji}$. 

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11.5.2(2) **Symmetry of Weights about TEES-Manager Assessments**

Secondly, it was assumed that for all managerial assessments $R_{Ermj}(C_i)$ the rewards or risk, $h$, associated with TEES overestimating the managerial assessment, $c$, by an integral positive deviation, $x$, was equal to the rewards or risk associated with TEES underestimating the assessment $c$ by the same deviation $x$. This assumption implied that the weights $W_{ij}$ were such that $W_{j+x,j} = W_{j-x,j}$.

Similarly, because of the equal status assumption the weights $W_{ij}$ were such that $W_{i,i+x} = W_{i,i-x}$.

11.5.2(3) **Independence of Weights from the TEES/Manager Assessments**

Thirdly, it was assumed that for all managerial assessments $R_{Ermj}(C_i)$ the rewards or risk, $h$, associated with the TEES overestimating, and in light of assumption 11.5.2(2) above underestimating, the managerial assessment, $c$, by an integral non-negative deviation, $x$, was independent of the managerial assessment $c$. Together with the assumption of equal status this implied that the weights $W_{ij}$ were only a function of the difference between the manager's assessment and TEES's response. That is, $W_{ij} = W(|i-j|)$.

11.5.2(4) **$W$ is a Non-Increasing Function of $|i-j|$**

Finally, as $|i-j|$ increases, that is as the level of disagreement between the manager and TEES increases, it was important that the weight for the cell $(i,j)$, $W_{ij}$, should be non-increasing.

In light of the above four assumptions the simplest way of assigning the weights $W_{ij}$ was to set them in accordance with the absolute difference between the manager's assessment and TEES's response. This difference was a measure of disagreement rather than the agreement between the manager and TEES; and therefore this difference was subtracted from the maximum possible level of disagreement to obtain an appropriately scaled agreement weight. Thus, a simple and intuitive way of defining the weights $W_{ij}$ was by defining $W_{ij}$ by

$$W_{ij} = 4 - |i-j|$$
These weights displayed the following two properties:– Firstly, a non-zero weight was associated with cells where there is a wide variation of opinion between the manager and TEES, as for example with the cell (2,5), \( W_{2,5} = 1 \). This suggested that it may be reasonable to associate a zero weighting with those cells which represented a considerable difference of opinion between the manager and TEES. Secondly, the perceived level of agreement associated with a cell \((i,j)\) decays as a linear function of the distance of the cell from the leading diagonal. Since the weights were ratio scaled then the perceived level of agreement associated with cells on the leading diagonal was only twice as high as that for cells displaced from the leading diagonal by a distance of 2 units. This suggested that it may be expedient to define an use sets of weights that displayed exponential rather than linear decay.

Thus, to overcome these possible anomalies, and also to investigate the sensitivity of the validation results with respect to the definition of agreement, four sets of weights \( W_{ij} \) were used in the validation study. These four sets of weights were defined as follows:

\[
W^{(1)}_{ij} = 4 - |i - j| \quad \text{eq. 11.5.2(i)}
\]

\[
W^{(2)}_{ij} =
\begin{align*}
1 & \quad \text{if } |i - j| = 0 \\
0 & \quad \text{if } |i - j| > 0
\end{align*}
\quad \text{eq 11.5.2(ii)}
\]

\[
W^{(3)}_{ij} =
\begin{align*}
2 & \quad \text{if } |i - j| = 0 \\
1 & \quad \text{if } |i - j| = 1 \\
0 & \quad \text{if } |i - j| > 1
\end{align*}
\quad \text{eq. 11.5.3(iii)}
\]

\[
W^{(4)}_{ij} =
\begin{align*}
4 & \quad \text{if } |i - j| = 0 \\
2 & \quad \text{if } |i - j| = 1 \\
1 & \quad \text{if } |i - j| = 2 \\
0 & \quad \text{if } |i - j| > 2
\end{align*}
\quad \text{eq. 11.5.2(iv)}
\]

These four sets of weights were used in the calculation of \( \kappa_w \) to measure the level of agreement between TEES and each of the six managers individually for each of the 7 higher level constructs \( C_{12}, \ldots, C_{18} \) (see table 9.5(i)) under test. Similarly, they were used to measure the level of agreement between TEES and the consensus of management opinion (see section 12.3) for each of the 7 higher level constructs under test; and were also used to investigate the similarity between the views of the six managers (see chapter 12).
11.6 EXPLAINING THE DIFFERENCES BETWEEN TEES AND THE MANAGERS

As previously noted in section 11.3, in the context of validating TEES precision is a more stringent criterion of validity than accuracy. Consequently, weighted kappa $\kappa_w$ was chosen as an appropriate validity measure because it would emphasise the precision of TEES's results or recommendations as well as their accuracy. So that, when using $\kappa_w$ the null hypothesis of chance agreement would be rejected at a given significance level if and only if TEES's results were both accurate and precise.

Unfortunately, when there are differences or discrepancies between TEES recommendations and a manager's assessments (that is, when the observed levels of agreement are such that the null hypothesis of chance agreement cannot be rejected) $\kappa_w$ does not provide sufficient information as to the underlying cause of the result. This is because $\kappa_w$ provides no indication of whether the result was due the imprecision of TEES's results, the inaccuracy of TEES's results, or a combination of both. As such weighted kappa $\kappa_w$ was sufficient to test for system validity, but by itself was not sufficient to explain the differences between TEES and manager when there were low levels of observed agreement.

In order to explain any differences between TEES's and the managers' views it was necessary to investigate the differences between TEES's results and the managers' assessments with a statistic that solely measured the accuracy of the results. This was because in theory, using $\kappa_w$ the null hypothesis of chance agreement could be rejected solely because the results were inaccurate, that is systematically biased, rather than because they were of low precision. In theory, it would be possible for the managers to compensate for a system that was known to be systematically biased; and therefore if this systematic bias were to be removed there may be a high levels of agreement between TEES and the managers.

Both TEES's results and the managers' assessments were measured on a five point, relative rather than absolute, semantic differential scale. So, when validating TEES it was more important to concentrate on the variation in the managers' assessments and the system's results from one enquiry to the next, rather than purely on their equality. For example, by investigating the level of systematic bias a given manager may have appeared to be either consistently optimistic or pessimistic in relation to a particular facet of tender enquiry evaluation. However, in assessing how well TEES reflected the managers' views it was more meaningful to concentrate solely on the variability of the managers' assessments and the system's results from one enquiry to the next.
The relationship between systematic bias and level of agreement with respect to the validity of TEES is illustrated in table 11.6 below.

<table>
<thead>
<tr>
<th>Systematic Bias</th>
<th>Level of Agreement</th>
<th>TEES a good representation of managers' views</th>
<th>TEES a poor representation of managers' views</th>
<th>Can removal of bias improve agreement?</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>Yes</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td></td>
</tr>
</tbody>
</table>

Table 11.6 shows that when there is no systematic bias and a high level of agreement, as measured by \( \kappa \), between TEES's results and a manager's assessments on a given construct, then TEES is a good, that is valid, representation of the manager's perspective regarding that aspect of tender enquiry evaluation. Whereas, when there is no systematic bias, but a low level of agreement then TEES is a very poor, that is invalid, representation of the manager's perspective. This is because TEES is failing to sufficiently account for the variation in the manager's assessments from one enquiry to the next.

When there is both systematic bias and a high level of agreement then it is important to determine the practical significance, that is the size, of the observed bias. However, if the observed bias were of any practical significance it would be impossible to have a high level of agreement! Therefore, it can again be concluded that TEES provides a valid representation of the manager's perspective regarding that aspect of tender enquiry evaluation under consideration.

Finally, when there is systematic bias and a low level of agreement it is important to determine whether the observed low level of agreement is accounted for predominantly by the bias or the imprecision between the two sets of results. If the observed level of agreement can be significantly increased by taking into account the
bias, and simultaneously there is some evidence to suggest that the manager is either consistently optimistic or pessimistic, then again it can be concluded that TEES provides a reasonable representation of the manager's perspective. If however, the removal of the bias leads to no significant increase in the observed level of agreement then it must be concluded that TEES is a poor representation of the manager's perspective.

Using the notation outlined in section 11.4 the level of systematic bias between TEES and any of the six managers M_j for any given construct, C_t, can be determined by analysing the differences D_{ErMj}(C_t) between the manager's assessments R_{ErMj}(C_t) and the TEES's recommendations R'_{ErMj}(C_t) for the 17 enquiries (r=1,...,17) included in the validation set. In particular a statistic was required to test whether the arithmetic mean of these differences D_{ErMj}(C_t)_{av} was statistically significant from zero. Ideally a non-parametric test should have been more appropriate to test for systematic bias. However, because the distribution of the differences D_{ErMj}(C_t) was discrete rather than continuous, and also because of the possibility of large number of zero differences or tied ranks, then the students t test was used rather than either the sign test or the Wilcoxon sign rank test. Appeal was therefore made to the central limit theorem so that for any manager M_j (j=1,...,6) and for each construct C_t (t=12,...,18) the distribution of the mean of the differences D_{ErMj}(C_t) could be assumed to be approximately normally distributed. In theory with a validation sample of size 17, this seemed as reasonable assumption. However, because in some instances a manager felt unqualified to give assessments for particular enquiries, then the effective sample size was much smaller. This was particularly true for the Engineering and Marketing managers whom only responded to 11 and 5 of the enquiries respectively. Thus in the case of the marketing manager in particular the results from the significance tests using the students t test needed careful interpretation.

Furthermore, since the distribution of the mean of the differences D_{ErMj}(C_t) of the differences was discrete rather then continuous it was necessary to take into account of the appropriate continuity correction factor in calculating the appropriate test statistic.

Given a sample of size n. Then, since each difference D_{ErMj}(C_t) ε [-4,4], the mean of the differences D_{ErMj}(C_t)_{av} ε [-4, -2/n, -1/n, 0, 1/n, 2/n, 4]. Therefore, the probability that the observed mean of the differences, D_{ErMj}(C_t)_{av}, is greater than some value x_0, P(D_{ErMj}(C_t)_{av} > x_0) say, is given by
A similar relationship can be derived for $P(D_{ErMj}(C_t)_{av} < x_0)$. Thus, when $D_{ErMj}(C_t)_{av} > 0$ the test statistic, $t$, that was compared with the critical values from the appropriate students’ $t$ distribution with $n-1$ degrees of freedom was given by:

$$t = \frac{(D_{ErMj}(C_t)_{av} + 1/2n)/(\sigma/\sqrt{n})}{\text{eq. 11.6(i)}}$$

Similarly, when $D_{ErMj}(C_t)_{av} < 0$ the test statistic, $t$, that was compared with the critical values from the appropriate students’ $t$ distribution with $n-1$ degrees of freedom was given by:

$$t = \frac{(D_{ErMj}(C_t)_{av} - 1/2n)/(\sigma/\sqrt{n})}{\text{eq. 11.6(ii)}}$$

The continuity corrected $t$ statistic was used to measure the level of systematic bias between TEES and each of the six managers individually (section 12.3), and also that between TEES and the consensus of management opinion (section 12.4), for each of the 7 higher level constructs $C_{12},...,C_{18}$ (see table 9.5(i)) under test. It was also used to measure the level of systematic bias between the views of the six managers (section 12.2)

### 11.7 Summary

The difference in emphasis between the validation of ES and that of more conventional systems has been outlined and the key issues in ES validation, namely *What to validate against?*, *What to validate?*, and *What to validate for?*, have been briefly discussed. From this discussion a formal validation framework for TEES has been devised which incorporates a quantitative measure of validity together with a formal statistical test.

In recognition that the domain of tender enquiry evaluation is non-formal and is characterised by multiple expertise, then the devised validation framework is based around both intra-expert and inter-expert tests. This approach would involve the use of six managers who together would provide a cross section of the different business and functional perspectives. Furthermore, this approach would enable TEES’s
consensual business perspective to be measured and assist in establishing the credibility of TEES with the TAG.

Furthermore, the validation framework has been devised such that TEES's intermediate results as well as its ultimate bid versus no bid recommendation could be tested. This approach would ensure that the structure of the system's reasoning could be validated. This was seen as especially important because TEES was designed to support the TAG rather than to replace it.

The weighted kappa ($\kappa_w$) statistic, used by psychologists to assess the level of agreement between individuals, has been adopted as a suitable validity measure for TEES. This is a non-parametric statistic that emphasises both the precision and accuracy of TEES's results and enables partial credit to be given when TEES's responses and the managers' assessments are close. Weighted kappa ($\kappa_w$) would be used to measure the level of agreement between TEES and each of the six managers individually for each result under test. Similarly, $\kappa_w$ would be used to measure the level of agreement between TEES and the consensus of management opinion; and would also be used to investigate the similarity between the views of the six managers.

The results from the validation study are presented in the next chapter.
CHAPTER 12

THE VALIDATION STUDY
12. **The Validation Study**

12.0 **Introduction**

This chapter presents the results obtained from the validation of TEES using the framework devised in chapter 11. The chapter commences with an overview of the validation study. This serves to outline the objectives of the validation study, and explain how the framework devised in chapter 11 was used in practice. Following this, the results from three separate analyses are presented. These are, the analysis of the level of agreement between the six managers included in the validation study, the analysis of the level of agreement between TEES and each of the six managers individually, and the analysis of the level of agreement between TEES and the consensus of management opinion. In addition, the results from an informal study are also presented. Finally, the significance of both sets of results is summarised.

12.1 **Overview of the Validation Study**

This section provides an overview of the validation study. In particular, it outlines the overall objective of the study and explains how this objective was operationalised within the validation framework devised in chapter 11.

The overall objective of the study was to test the overall hypothesis of model validity. Thus, the objective of the study was to establish that TEES provided an appropriate, that is valid, representation of the organisation's consensual business perspective with respect to its bid versus no bid and bid resourcing decisions. Since TEES was developed to be used in a supporting role, it was important to validate the structure of the system's reasoning as well as its overall bid versus no bid and bid resourcing recommendations. Therefore, the overall hypothesis of model validity was operationalised such that the objective of the study was to establish that both TEES's reasoning, as measured by its intermediate conclusions or results, and its final recommendations are consistent with those reached by the TAG.

Thus, the overall hypothesis of model validity $H_0$ can be stated as follows:-

$$H_0: \text{TEES is valid if and only if both its intermediate results } (C_{12}, ..., C_{17}) \text{ and its final recommendation } (C_{18}) \text{ are consistent with those reached by the TAG.}$$
To investigate the truth or otherwise of $H_0$, two separate analyses were performed:

The first of these analyses, described in section 12.3, involved establishing statistical measures of TEES's performance using both inter-expert and intra-expert tests. In total four inter-expert tests were performed, one test for each of the Finance, Manufacturing, Engineering and Marketing managers respectively. The purpose of these tests was to determine how the perspective embedded within TEES differed from that of those managers from business and functional specialisms who were not consulted in its development. Put alternatively, these inter-expert tests were used to determine whether the perspective embedded within TEES was unduly biased by the choice of managers used in its development, namely the Proposals and Business Group managers. The intra-expert tests were used as control. They were used to determine how well TEES represents the views of the managers included in its development on the new enquiries in the validation set. As such these intra-expert tests were used to determine whether the knowledge base heuristics within TEES were significantly biased by the enquiries and/or the time period during which the enquiries used in its development were sampled.

Together these inter-expert and intra-expert tests gave informative insights into the truth or otherwise of $H_0$, and therefore to the validity of TEES. However, in order to strengthen the study a second analysis was performed. Given the consensual basis for the TAG's decisions, then in the second analysis the six managers' expert assessments were used to produce a single set of expert assessments that represented the consensus of management opinion, that is the consensual view of the TAG, on the 17 enquiries in the validation set. The results from TEES were then compared against this consensus view to establish whether TEES provided an appropriate representation of the consensus of management opinion.

Together these two analyses provided three operational sub-hypotheses, $H_{01}$, $H_{02}$ and $H_{03}$ given below, with which to establish the truth or otherwise of $H_0$.

$H_{01}$: (Intra-Expert Test) The knowledge base heuristics within TEES are stable. That is, are TEES's intermediate results ($C_{12},...,C_{17}$) and its final recommendation ($C_{18}$) are consistent with those reached by the Proposals and Business Group managers used in its development?
H_{02}: (Inter-Expert Test) The perspective embedded within TEES is not unduly biased by the choice of managers, namely the Proposals and Business Group managers, used in its development. That is, TEES's intermediate results (C_{12},...,C_{17}) and its final recommendation (C_{18}) are consistent with those reached by the four managers, namely the Finance, Manufacturing, Engineering and Engineering managers, not used in its development.

H_{03}: (Consensus Test) TEES's intermediate results (C_{12},...,C_{17}) and its final recommendation (C_{18}) are consistent with those of the consensus of management opinion.

In order to test these sub-hypotheses H_{01}, H_{02} and H_{03} it was necessary to measure and test the level of agreement, using weighted kappa (\kappa_w), between TEES and each of the six managers included in the validation study, and also that between TEES and the consensus of management opinion, for each of the seven higher level constructs (C_{12},...,C_{18}) for which TEES offers a recommendation. The statistical significance of the levels of agreement in each instance was obtained by comparing the observed levels of agreement with the critical values obtained from the appropriate distribution of weighted kappa under the null hypothesis of chance agreement. The appropriate distribution is that of \kappa_w given both TEES's and the managers' marginal distributions for the given construct under consideration and the matrix of scaled agreement weights W_{ij}. The statistical significance of the observed levels of agreement indicated the extent to which TEES's recommendations and any manager's assessments (or TEES's recommendations and the assessments for consensus of management opinion) differed from that which could be accounted for by chance happening. As such the statistical significance of the observed levels of agreement were therefore a reliable indication of how well TEES reflected any manager's perspective (or the perspective of the consensus of management opinion) on any given construct.

However, as previously noted in section 11.6 weighted kappa is sufficient to test for system validity, but by itself is not sufficient to explain the differences between TEES's recommendations and a manager's assessments (or the assessments for the consensus of management opinion) when there are very low, that is statistically insignificant, observed levels of agreement. Therefore, in order to effectively test the sub-hypotheses H_{01}, H_{02} and H_{03} it was also necessary to measure and test the level of systematic bias, using the continuity corrected student's t statistic, between TEES and each of the six managers included in the validation study, and also that between
TEES and the *consensus of management opinion*, for each of the seven higher level constructs \((C_{12},...,C_{18})\) for which TEES offers a recommendation.

The analyses performed to establish the truth or otherwise of sub-hypotheses \(H_{01}\), \(H_{02}\) and \(H_{03}\) are described in section 12.3 and 12.4. In the next section 12.2 a preliminary analysis is described which investigated the similarities and differences between the different business and functional perspectives of the managers included in the validation study.

### 12.2 Analysis of the Level of Agreement between the Six Managers Included in the Validation Study

As previously noted in section 12.1 the overall objective of the validation study was to establish that TEES provided an appropriate, that is valid, representation of the organisation's consensual business perspective with respect to the bid versus no bid decision and the resourcing of tender proposals. Two separate analyses were performed to investigate the overall hypothesis of model validity \(H_0\) and these are described in detail in sections 12.3 and 12.4. However, to achieve these successfully it was expedient to investigate the similarities between the different business and functional perspectives of the managers included in the validation study. Such an analysis had two major benefits. Firstly, it assisted in the interpretation of the results derived from the validation of TEES against the individual managers (section 12.3), and also that of TEES against the *consensus of management opinion* (section 12.4). For example, if there was evidence of systematic bias between TEES and a given manager on a particular construct, then the analysis helped to determine whether or not there was any reasonable justification for adjusting the manager's assessments. Secondly, the analysis helped with the identification of the *consensus of management opinion*.

#### 12.2.1 Method

To determine the similarities between the different business and functional perspectives an analysis of the level of agreement between the six managers was performed. This analysis was performed by considering each of the 18 constructs shown in table 9.5(i) in turn. Furthermore, for each construct \(C_t (t = 1,...,18)\) a pairwise comparison was made for each possible pairing of two managers from six \((M_q,M_r)\) \((q=1,...,6; r=q+1,...,6)\). Thus, in theory, if each of the six managers had
provided expert assessments for all 18 constructs, then for each construct 15 pairwise comparisons would have been made. Although in practice because some managers felt unable to provide qualified assessments on some of the constructs, then for some constructs fewer than 15 pairwise comparisons were made. Such pairwise comparisons were performed for both the level of agreement, as measured by weighted kappa $\kappa_w$ using the 4 sets of scaled agreement weights $W^{(k)}_{ij}$ ($k=1,...,4$) given in section 11.5.2, and the level of systematic bias, as measured by the continuity corrected $t$ value discussed in section 11.6. This procedure produced 18 sets (one set for each construct) of 5 tables. For each construct, 4 tables measured the pairwise levels of agreement between the six managers using the 4 different sets of scaled agreement weights $W^{(k)}_{ij}$, whilst the fifth table measured the pairwise levels of systematic bias between the six managers.

To analyse the similarity between the managers' views or opinions it was necessary to determine the statistical significance of the observed levels of agreement between each pair of managers $(M_q, M_r)$ on each construct $C_t$ ($t=1,...,18$). This required the derivation of the critical values from the appropriate distributions of weighted kappa $\kappa_w$ under the null hypothesis of chance agreement. From the definition of weighted kappa $\kappa_w$ given in eq. 11.5.1(ii) it can be seen that its distribution is dependent upon not only the scaled agreement weights $W^{(k)}_{ij}$, but also the empirically observed managers' marginal distributions. Thus, in theory, for each of the 18 constructs $C_t$ and for each of the 4 sets of weights $W^{(k)}_{ij}$ it was necessary to derive the critical values from 15 (one for each pair of managers $(M_q, M_r)$) distributions of weighted kappa $\kappa_w$. So, in theory, it was necessary to derive the critical values from $(18 \times 4 \times 15) = 1080$ distributions. In practice, however, in order to reduce the amount of computational effort required, it was assumed that on any given construct $C_t$ under the null hypothesis of chance agreement each of the six managers' assessments on any enquiry $E_r$ was a random sample from the same fixed marginal distribution. This assumption reduced the number of critical values to be derived by a factor of 15. For each construct $C_t$ ($t=1,...,18$) the single managers' marginal distribution used to determine the distribution of $\kappa_w$ under each set of weights $W^{(k)}_{ij}$ ($k=1,...,4$) was formed by combining all six managers' assessments for the given construct $C_t$ over all 17 enquiries in the validation set. Then, for each construct $C_t$ and each set of weights $W^{(k)}_{ij}$ the critical values were obtained from the exact distribution of weighted kappa $\kappa_w$ (see Appendix D).

The purpose of using 4 sets of scaled agreement weights $W^{(k)}_{ij}$ was to investigate the effect of different definitions of $\kappa_w$, and therefore different definitions of agreement.
on the observed levels of agreement between the six managers. Consequently, before attempting to interpret the observed levels of agreement in detail it was expedient to analyse the sensitivity of the results to the definition of $\kappa_w$ and agreement, as defined by the 4 sets of weights $W^{(k)}_{ij}$. To do this effectively required the derivation of a measure of the total significance of the observed levels of agreement for each set of weights $W^{(k)}_{ij}$ $(k=1,\ldots,4)$. This measure would need to be aggregated over both managers and constructs. Since the marginal distributions for each construct $C_t$ $(t=1,\ldots,18)$ were different, but for any given construct under the above assumption were the same for all six managers, then it made more sense to initially derive an aggregated measure over each of the 15 possible pairs $(M_p,M_q)$ of managers for each construct $C_t$ rather than a measure for each pair of managers $(M_p,M_q)$ aggregated over all 18 constructs. Furthermore, because some managers felt unable to provide qualified assessments on some enquiries and some constructs, then the sample size ($n$) was not constant for each pair of managers $(M_p,M_q)$, nor for each construct $C_t$. As a result for each $W^{(k)}_{ij}$ it would have been misleading to simply add together the values for the total level of scaled agreement, $T$, a simple linear transform of $\kappa_w$ (see Appendix D), across all pairs of managers, or indeed across all the constructs. Therefore, to overcome such problems and to take into account the statistical significance of each of the observed levels of agreement, a significance score $S_{MqMrCt}$ was associated with each observed level of agreement between each pair of managers $(M_p,M_q)$ on each construct $C_t$. These significance scores $S_{MrMqCt}$ were such that: $S_{MrMqCt}=5$ if the observed level of agreement between the managers $M_p$ and $M_q$ on the construct $C_t$ was significant at the 1% level; $S_{MrMqCt}=4$ if the level of agreement was significant at the 2.5% level; $S_{MrMqCt}=3$ if the level of agreement was significant at the 5% level; $S_{MrMqCt}=2$ if the level of agreement was significant at the 10% level; $S_{MrMqCt}=1$ if the level of agreement was significant at the 20% level; and finally $S_{MrMqCt}=0$ if the level of agreement was only significant at a level below 20%. Then, for each construct $C_t$ $(t=1,\ldots,18)$ and for each set of weights $W^{(k)}_{ij}$ $(k=1,\ldots,4)$ a total significance score $S_{Ct}$ was formed by summing the $S_{MrMqCt}$ over each pair of managers $(M_p,M_q)$. Then, for each construct $C_t$ the four total significance scores $S_{Ct}$ for each set of weights $W^{(k)}_{ij}$ were rank ordered to produce a set of significance ranks for each set of weights $W^{(k)}_{ij}$ on each construct $C_t$. Finally, for each set of weights $W^{(k)}_{ij}$ the significance ranks were summed over all 18 constructs. This procedure provided a ranked measure of the total significance of the observed levels of agreement for each of the 4 sets of weights $W^{(k)}_{ij}$.
The results from the construct by construct pair-wise analysis of the six managers' assessments for the 17 enquiries included in the validation set are discussed in the following section.

12.2.2 Results

The ranked measures for the total significance of the observed levels of agreement for the 4 sets of weights $W^{(1)}_{ij}$, $W^{(2)}_{ij}$, $W^{(3)}_{ij}$, $W^{(4)}_{ij}$ defined in section 11.5.2 were 58, 19.5, 45 and 57.5 respectively. Thus, the lowest levels of agreement were observed by defining $\kappa_w$ in terms of $W^{(2)}_{ij}$. This result was to be expected because the set of weights $W^{(2)}_{ij}$ gave no partial credit when the managers' assessments were close and focussed entirely on the equality of the manager's assessments rather than on the similarity in the variation of the managers' assessments from one enquiry to the next.

The highest levels of agreement were observed by defining $\kappa_w$ in terms of $W^{(1)}_{ij}$ and $W^{(4)}_{ij}$ respectively; and indeed the respective summed ranks of 58 and 57.5 suggested that the observed levels of agreement were insensitive to these two sets of weights.

The weights $W^{(4)}_{ij}$ were exponentially scaled rather than linearly scaled. Furthermore, the observed levels of agreement for $\kappa_w$ defined in terms of $W^{(4)}_{ij}$ lay between those observed for $\kappa_w$ defined in terms of $W^{(3)}_{ij}$ and $W^{(1)}_{ij}$ respectively, and were therefore neither unduly optimistic nor pessimistic. For these reasons the set of weights $W^{(4)}_{ij}$ were used to interpret the observed levels of agreement between the six managers in detail.

The results have been systematically analysed in order to identify the overall level of agreement between the six managers on each of the 18 constructs; and furthermore the effect of any systematic bias between the managers has been investigated. The conclusions from this analysis are summarised on a construct by construct basis in table 12.2.2.

1 The results from the analysis of the levels of agreement and levels of systematic bias between the six managers' assessments are shown in tables 12.2.2(A)(i)-12.2.2(A)(xviii) and 12.2.2(B)(i)-12.2.2(B)(xviii) respectively (see Appendix E). Tables 12.2.2(A)(i)-12.2.2(A)(xviii) show the observed levels of agreement for the 18 constructs between each pair of managers $(M_r,M_q)$ ($r=1,...,6; q=r+1,...,6$) as measured by $T$, the total level of scaled agreement, a simple linear transform of weighted kappa $\kappa_w$ defined in terms of the scaled agreement weights $W^{(4)}_{ij}$. Whereas, tables 12.2.2(B)(i)-12.2.2(B)(xviii) show the observed levels of systematic bias for the 18 constructs between each pair of managers $(M_r,M_q)$ ($r=1,...,6; q=r+1,...,6$) as measured by $t$, the continuity corrected students t statistic. In all tables statistically significant results are shown in bold typeface and annotated with a subscript $a, b, c, d,$ or $e$ which indicate the levels at which the results are statistically significant.
Table 12.2.2  Comments on the Similarities between the Different Business and Functional Specialisms

<table>
<thead>
<tr>
<th>Construct</th>
<th>Comments</th>
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<tr>
<td>$C_{18}$ Overall Attractiveness of Enquiry</td>
<td>Overall there is a very high level of agreement between all six managers. This is especially so between five of the managers namely, the Finance, Proposals, Manufacturing, Business and Engineering managers. The engineering manager consistently views enquiries less enthusiastically than the other managers and especially in comparison to the Business and Marketing managers. The Marketing manager consistently views enquiries as being more attractive than the other managers, and this is especially so in comparison to the technical functions Engineering and Manufacturing. Furthermore, the Marketing Managers view is the most dissenting view. Very pronounced level of agreement between the Proposals and Business Group managers.</td>
</tr>
<tr>
<td>$C_{17}$ Probability of Success</td>
<td>Overall there is a very high level of agreement between all six managers. This is especially so between five of the managers namely, the Finance, Proposals, Manufacturing, Business and Engineering managers. The Finance manager consistently views the probability of success as being more attractive than all other managers with the exception of the Marketing manager. However, the high levels of agreement between the Finance managers and the other managers suggests that this bias is of no practical significance. The Marketing manager consistently views the probability of success as being more attractive than all other managers with the exception of the Finance Manager. Furthermore, the Marketing managers view is different from that of the other managers and therefore represents a dissenting view. Very pronounced level of agreement between the Proposals and Business Group managers.</td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td>Engineering manager felt unable to provide qualified assessments on this construct. Overall there is a very high level of agreement between all five remaining managers. This is especially so between three of the managers namely the Proposals, Manufacturing, Business managers. The Finance manager consistently views the competitiveness of the price as being more attractive than all other managers with the exception of the Marketing manager. This may explain why there are only general levels of observed agreement between the Finance manager and the Proposals, Manufacturing and Business managers. The Marketing manager's view is markedly different from that of the other managers and therefore represents a dissenting view. Very pronounced level of agreement between the Proposals and Business Group managers.</td>
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<td>C₁₅  Level of Financial Risk</td>
<td>Engineering manager felt unable to provide qualified assessments on this construct. Overall there is a general level of agreement between all five remaining managers, but this is not as pronounced as for constructs C₁₈, C₁₇ and C₁₆. Very high levels of agreement between the Finance, Business and Marketing managers, as is also the case between the Proposals and Manufacturing managers. There is neither any significant agreement or bias between the Proposals and Business Group managers. This suggests that these managers views with respect to the level of financial risk are different.</td>
</tr>
<tr>
<td>C₁₄  Level of Technical Risk</td>
<td>Overall there is a general level of agreement between all six managers, but this is not as pronounced as for constructs C₁₈, C₁₇ and C₁₆. Very high levels of agreement between the Finance, Engineering and Marketing managers, as is also the case between the Proposals, Manufacturing and Business managers. Very pronounced level of agreement between the Proposals and Business Group managers.</td>
</tr>
<tr>
<td>C₁₃  Potential Profitability</td>
<td>Engineering manager felt unable to provide qualified assessments on this construct. Generally a very high level of agreement between the Finance, Proposals and Manufacturing managers. The Business Group manager consistently views the potential profitability as being less attractive than all the other managers. If this apparent bias is taken into account then there is a significant improvement in the level of agreement between the Business Group manager and the Proposals and Manufacturing managers, and a marginal improvement in the level of agreement between the Business Group manager and the Finance manager. The Marketing manager consistently views the potential profitability as being more attractive than all the other managers. However, in this case no significant improvement in level of agreement between the Marketing manager and the other managers can obtained by taking into account the Marketing managers apparent optimism. This suggests that the Marketing managers view represents a dissenting view. When the Business Group managers apparent pessimism is taken into account there is a very high level of agreement between himself and the Proposals manager.</td>
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Table 12.2.2 Comments on the Similarities between the Different Business and Functional Specialisms

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<th>Construct</th>
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<tr>
<td>C_{12} Chances of Project Going Ahead</td>
<td>Overall a very high level of agreement between five of the managers, namely the Finance, Proposals, Manufacturing, Business and Engineering Managers. The Marketing manager consistently views the chances of the project going ahead as being more attractive than the other managers especially the Finance and Manufacturing managers. No significant improvement in the levels of agreement between the Marketing manager and the other managers can be obtained by taking into account the apparent bias. This suggests that the Marketing managers view represents a dissenting view. Very pronounced level of agreement between the Proposals and Business Group managers.</td>
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<tr>
<td>C_{11} Level of Competition</td>
<td>Generally a very low level of agreement between all six managers. Sole exception is between the Proposals and Business Group managers where there is a very pronounced level of agreement.</td>
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<tr>
<td>C_{10} Chances of Further Business</td>
<td>Overall there is a very high level of agreement between all six managers. This is especially so between four of the managers namely, the Proposals, Manufacturing, Business and Engineering Managers. The Finance manager consistently views the chances of further business as being more attractive than all the other managers with the exception of the Marketing manager. However, the high or general levels of agreement between the Finance manager and the other managers suggests that this bias is of no practical significance. The Marketing manager also consistently views the chances of further business as being more attractive than all the other managers including the Finance manager. Even if the Marketing managers apparent optimism is taken in account, then with the exception of the Proposals manager there is no significant improvement in the level of agreement between the Marketing manager and any of the remaining four managers. This suggests that the Marketing managers view represents a dissenting view. Very pronounced level of agreement between the Proposals and Business Group managers.</td>
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Table 12.2.1 Comments on the Similarities between the Different Business and Functional Specialisms

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<td>C9  Level of Involvement</td>
<td>Generally a very low level of agreement between all six managers. Generally the marketing manager views the level of involvement as being more attractive than the other managers. However, the removal of this apparent bias does not significantly improve the level of agreement between the Marketing manager and any of the other managers. Similarly, the Business Group manager views the level of involvement as being more attractive than the other managers. However, in this case the removal of the apparent bias leads to a significant improvement in the level of agreement between the Business Group and the Proposals Managers. This suggests that these two managers are in agreement with regard to the variation in the level of involvement from one enquiry to the next.</td>
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<td>C3  Added Value</td>
<td>Both the Engineering and the Marketing managers felt unable to provide qualified assessments on this construct. Very low levels of agreement between the remaining four managers. Considerable variation in opinion between managers.</td>
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<tr>
<td>C7  Size of Order</td>
<td>Engineering manager felt unable to provide qualified assessments on this construct. Overall a very high level of agreement between four of the managers, namely the Finance, Proposals, Manufacturing and Business managers. The Marketing manager consistently views the size of the order as being more attractive in comparison to the Finance, Proposals and Manufacturing managers. Removal of this apparent bias gives rise to significant improvements in the level of agreement between the Marketing manager and the Finance, Proposals and Manufacturing Managers. So, if the Marketing managers' optimism is taken into account there is in general a very high level of agreement between the five managers who provided assessments. Very pronounced level of agreement between the Proposals and Business Group managers.</td>
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<tr>
<td>C6  Level of Manufacturing Investment</td>
<td>The Marketing manager felt unable to provide qualified assessments on this construct. Generally a low level of agreement between the remaining five managers except for between the Proposals and Business Group managers, and the Proposals and Engineering Manager. Very pronounced level of agreement between the Proposals and Business Group managers.</td>
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<tr>
<td>C₅ Availability of Manufacturing Capacity</td>
<td>Generally a very low level of agreement between all six managers. Sole exception is between the Manufacturing and Business Group managers where there is a very pronounced level of agreement. The Marketing manager consistently views the availability of manufacturing capacity as being more attractive than the other managers.</td>
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<tr>
<td>C₄ Demands on Bid Resources</td>
<td>Generally a very low level of agreement between all six managers. The Finance manager consistently view the demands on bid resources as being less attractive than the other managers.</td>
</tr>
<tr>
<td>C₃ Availability of Design</td>
<td>Results suggest that there is a general level of agreement between all six managers with a very pronounced level of agreement between the Proposals and Business Group managers.</td>
</tr>
<tr>
<td>C₂ Prospects of Available Finance</td>
<td>Engineering manager felt unable to provide qualified assessments on this construct. Overall there is a very high level of agreement between all five remaining managers. This is especially so between three of the managers, namely the Proposals, Business and Marketing managers. There is some evidence to suggest that the Finance manager consistently views the prospects of available finance as being less attractive than the other managers. Very pronounced level of agreement between the Proposals and Business Group managers.</td>
</tr>
<tr>
<td>C₁ Standard of Formal Enquiry</td>
<td>A general but not very strong level of agreement exists between five of the managers, namely the Finance, Proposals, Manufacturing, Business and Engineering Managers. The Marketing manager views the standard of the formal enquiry as being consistently more attractive than the other managers. Removal of this apparent bias gives rise to significant increase in the level of agreement between the Marketing manager and the Manufacturing, Business and Engineering managers. Thus, if the marketing managers apparent optimism is taken into account, there is general, but not strong level of agreement between all six managers.</td>
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In this section only the general pattern of agreement that emerged between the six managers is discussed. The general conclusions detailed below were sufficient to assist in the identification of the consensus of management opinion and provide possible explanation for any observed differences between TEES's recommendations and the managers' (or the consensus of management opinion's) assessments.

It can be seen from table 12.2.2 that in general there is a high level of agreement between all the managers for the seven higher level constructs C_{12},...,C_{18}. Therefore, on those constructs which are in the middle and at the top of the overall construct hierarchy given in figure 9.5(ii) and which are believed to be the most influential, or central, to the bid versus no bid and bid resourcing decisions there is generally a very high level of agreement between all the managers. This is especially true for the constructs C_{18} overall attractiveness of enquiry, C_{17} probability of success, C_{16} competitiveness of price, and C_{12} chances of project going ahead.

There is less agreement, or more variation of opinion, between the managers on the constructs C_{15} level of financial risk and C_{14} level of technical risk respectively, but it is still reasonable to conclude that there is a general level agreement between the managers in relation to these two constructs.

For construct C_{13}, potential profitability, the results revealed a very high level of agreement between the Finance, Proposals and Manufacturing managers. Furthermore, the analysis indicated that the Business Group manager consistently regarded the enquiries' potential profitability less optimistically than these three managers. Adjusting for this bias revealed a high level of agreement between all four managers. So the Business Group manager is in agreement with the Finance, Manufacturing and Proposals manager in relation to the variation in the enquiries' potential profitability, if not the level of profitability. This suggests that, apart from being generally less optimistic about enquiries' potential profitability, the Business Group manager's cognitive processes for assessing enquiries' potential profitability are similar to those of the Finance, Proposals and Manufacturing managers. Similar analyses suggested that the Marketing manager was consistently more optimistic about enquiries' potential profitability than the other managers; but in his case no significant agreement could be identified by adjusting for the observed bias. This suggests that the Marketing manager's cognitive processes for assessing enquiries' potential profitability are different from those of the other managers. Indeed, this conclusion was supported by comments made by the Marketing manager during interviews. The Marketing manager stated that historic projects indicated that the
most profitable projects resulted from small orders and that the organisation had a history of making losses on larger orders. This view was in contrast to all the other managers who were of the opinion that large orders were the most profitable.

In general there is considerably less agreement between the six managers on the 11 lower level or base constructs which are believed to influence the 7 higher level constructs mentioned above. Therefore, on those constructs at the bottom of the overall construct hierarchy given in figure 9.5(ii) there is generally a low level of agreement, or a wide variation of opinion, between all six managers.

In particular there is a wide variation of opinion between the managers on six constructs C_{11} level of competition, C_{9} level of involvement, C_{8} expected added value, C_{6} level of manufacturing investment, C_{5} availability of manufacturing capacity, and C_{4} demands on bidding resources. It is important to note, however, that for the three constructs C_{11} level of competition, C_{9} level of involvement and C_{6} level of manufacturing investment there are very high levels of agreement between the two managers whose views were sought to develop TEES, namely the Proposals and Business Group managers.

There is a general level of agreement between the managers for two constructs C_{3} availability of design and C_{1} standard of the formal enquiry. Furthermore, for construct C_{3} availability of design there is again very high levels of agreement between the Proposals and Business Group Managers whose views were sought to develop TEES.

Finally, with respect to three constructs C_{10} chances of further business, C_{7} size of the order and C_{2} prospects of available finance there is generally a very high level of agreement between all the managers. Furthermore, in all three cases there are very pronounced levels of agreement between the Proposals and Business Group managers whose views were sought to develop TEES. There is evidence to suggest, however, that the Marketing manager consistently views the chances of the project leading to further business as being more attractive than all the other managers. When the Marketing manager's apparent optimism is taken into account, and with the exception of the Proposals manager, there is no significant level of agreement between the Marketing manager and any of the four remaining managers. This suggests that in relation to C_{10} chances of further business, the Marketing manager's views can be regarded as representing a dissenting view. Similarly, for C_{7} size of the order, there is again evidence to suggest that the Marketing manager consistently views the size of
the order as being more attractive (that is, larger) than the other managers. Although in this case, removal of the apparent bias gives rise to significant improvements in the level of agreement between the Marketing manager and the other managers. This suggests that apart from being generally more optimistic of an enquiry's order size, the Marketing manager's cognitive processes for assessing an enquiry's order size are similar to those of the other managers.

There is evidence to suggest that in general the Business Group and the Marketing managers view enquiries in a more attractive light than the other managers; and this is especially true for the Marketing manager. What is not clear from the results is that the Marketing manager interviewed was an International Marketing manager. In fact the Marketing manager only responded to overseas enquiries, so this may be a reflection of the Marketing manager's over enthusiasm towards overseas enquiries, or it may reflect the other managers' reluctance towards pursuing overseas business based on past experience. Even if the Marketing manager's apparent optimism, however, is taken into account, his views are predominantly different from the views of the other managers. In this respect the Marketing manager's view can be regarded as the dissenting view.

Similarly, there is some evidence to suggest that in general those managers from what may be regarded as technical functions namely Manufacturing and Engineering take a more pessimistic stance than the other managers. Although its overall effect is not as significant as it is for the Marketing manager's apparent optimism and neither the Manufacturing nor the Engineering manager could be said to hold a dissenting view. Such differences are most notable between the Engineering and Marketing managers, where even for those constructs where there is generally a very high level of agreement between all the managers, as for example the constructs relating to overall attractiveness of the enquiry and the probability of winning the contract, there is no statistically significant agreement between the Marketing and Engineering managers' views.

With the exception of only 4 constructs $C_{15}$ level of financial risk, $C_8$ expected added value, $C_5$ availability of manufacturing capacity and $C_4$ demands on bid resources there is very high levels of agreement between the Proposals and Business Group Managers. This suggests that there is a considerable shared level of understanding between the two managers whose views were sought to develop TEES.
So, in summary the analysis of the similarities between the six managers' views or opinions reveals that in general there is a high level of agreement between all the managers on the higher level constructs which are believed to be the most influential in the bid versus no bid and bid resourcing decisions; whereas for the lower level constructs which are believed to influence the higher level constructs there are considerably lower levels of agreement, or wider variation of opinion, between the managers' views. Furthermore, the analysis reveals that there is a considerable level of shared understanding between the Proposals and Business Group managers whose views were sought to develop TEES. Finally, the analysis reveals that the Marketing manager holds a strongly dissenting view.

12.3 Validation of TEES against each of the six managers

In this section the methods and results of the intra-expert and inter-expert tests involving the validation of TEES against each of the six managers are described. The purpose of these intra-expert and inter-expert tests was to provide insights into the truth or otherwise of sub-hypotheses $H_{01}$ and $H_{02}$ respectively.

12.3.1 Method

For each manager $M_q$ ($q=1,...,6$) and for each enquiry $E_r$ ($r=1,...,17$) the manager's assessments for the 11 base constructs, represented by the column vector $X_{E_rM_q}$ (see eq.11.5(i)), were entered into TEES. The system's intermediate results and the final recommendation, represented by $Y_{E_rM_q}$ (see eq. 11.5(iii)), were compared to the manager's assessments for the 7 higher level constructs represented by $Y_{E_rM_q}$ (see eq. 11.5(ii)). Both levels of agreement, measured by weighted kappa $\kappa_w$ using the 4 sets of scaled agreement weights $W(k)_{ij}$ ($k=1,...,4$), and levels of systematic bias, measured by the continuity corrected $t$ value, between the manager $M_q$ and TEES were calculated for each of the 7 higher level constructs $C_t$ ($t=12,...,18$) from the components of the vector differences $Y_{E_rM_q} - Y'_{E_rM_q}$ ($r=1,...,17$).

To validate TEES against any of the managers $M_q$ ($q=1,...,6$) it was necessary to determine the statistical significance of the observed levels of agreement between TEES and the given manager $M_q$ on each of the 7 higher level constructs $C_t$ ($t=12,...,18$). This required the derivation of the critical values from the appropriate distributions of weighted kappa $\kappa_w$ under the null hypothesis of chance agreement. From the definition of weighted kappa $\kappa_w$ given in eq 11.5.1(ii) it can be seen that its
distribution is dependent upon both the empirically observed manager's and system's marginal distributions. Thus, in theory, for each of the 7 higher level constructs $C_t$ and for each of the 4 sets of weights $W^{(k)}_{ij}$ it was necessary to derive the critical values from 6 (one for each pairing of manager and TEES) distributions of weighted kappa $\kappa_w$. However, as previously noted in section 12.2 in order to reduce the amount of computational effort required it was assumed that on any given construct $C_t \ (t=1,\ldots,18)$ under the null hypothesis of chance agreement each of the six managers' assessments on any enquiry was a random sample from the same fixed marginal distribution. Furthermore, due to the deterministic nature of TEES's knowledge base, the system's marginal distributions for each of the 7 higher level constructs could be theoretically derived from the managers' marginal distributions for the 11 base constructs. Therefore, in order to again reduce the amount of computational effort required, this time by a factor of 6, then rather than use the empirically observed manager's and system's marginal distributions, the managers' combined marginal distributions and the system's theoretically derived marginal distributions for each of the 7 higher levels constructs were used to derive the necessary critical values for weighted kappa $\kappa_w$ under each of the 4 set of weights $W^{(k)}_{ij}$.

As was the case with the analysis of the level of agreement between the six managers it was expedient to analyse the sensitivity of the observed levels of agreement between TEES and the managers to the definition of $\kappa_w$ and agreement, as defined by the four sets of weights $W^{(k)}_{ij}$. As before a significance score $S_{MqCt}$ was associated with each observed level of agreement between TEES and each manager $M_q \ (q=1,\ldots,6)$ for each of the 7 higher level constructs $C_t \ (t=12,\ldots,18)$. Then, for each set of weights $W^{(k)}_{ij} \ (k=1,\ldots,4)$ and for each construct $C_t \ (t=12,\ldots,18)$ a total significance score was formed by summing over all six managers $M_q \ (q=1,\ldots,6)$. Then, for each of the 7 higher levels constructs the total significance scores for the 4 sets of weights were rank ordered, to produce a set of significance ranks for each set of weights.

The results from the analysis of the levels of agreement and the levels of systematic bias between TEES and each of the six managers $M_q \ (q=1,\ldots,6)$ are shown in tables 12.3.1(A)(i)-12.3.1(A)(vi) and tables 12.3.1(B)(i)-12.3.1(B)(vi) respectively (see Appendix E). Tables 12.3.1(A)(i)-12.3.1(A)(vi) show the observed levels of agreement between TEES and each manager $M_q \ (q=1,\ldots,6)$ for each of the 7 higher level constructs $C_t \ (t=12,\ldots,18)$ as measured by $T$, the total level of scaled agreement a simple linear transform of weighted kappa $\kappa_w$ for each of the 4 sets of scaled agreement weights $W^{(k)}_{ij} \ (k=1,\ldots,4)$. Whereas, tables 12.3.1(B)(i)-12.3.1(B)(vi) show the observed levels of systematic bias between TEES and each manager $M_q \ (q=1,\ldots,6)$ for each of the 7 higher level constructs $C_t \ (t=12,\ldots,18)$, as measured by $t$ the continuity corrected students $t$ statistic. In all tables statistically significant results are shown in bold typeface and annotated with a subscript a, b, c, d, or e which indicate the levels at which the results are statistically significant.
\( W^{(k)}_{ij} \) \((k=1,\ldots,4)\) on each of the 7 higher level constructs \( C_t \) \((t=12,\ldots,18)\). Finally as before, for each set of weights \( W^{(k)}_{ij} \) the significance ranks were summed over all 7 higher level constructs. This procedure provided a ranked measure of the \textit{total significance of the observed levels of agreement} for each of the 4 sets of weights \( W^{(k)}_{ij} \).

The results from the validation of TEES versus each of the six managers are discussed in the following section.

\subsection*{12.3.2 RESULTS}

The summed ranks for the 4 sets of weights \( W^{(1)}_{ij}, W^{(2)}_{ij}, W^{(3)}_{ij}, \) and \( W^{(4)}_{ij} \) defined in section 11.5.2 were 23.5, 7, 21, and 18.5 respectively. As before the lowest levels of agreement were observed by defining \( K_w \) in terms of \( W^{(2)}_{ij} \). In this case, however, the observed levels of agreement were relatively insensitive to the remaining three sets of weights. Consequently, the set of weights \( W^{(4)}_{ij} \) were again chosen to interpret the levels of agreement between TEES and the six managers. (The weights \( W^{(4)}_{ij} \) were also chosen to interpret the results from the validation of TEES against the \textit{consensus of management opinion} (section 12.4).)
Table 12.3.2  Total Level of Scaled Agreement (T) between The Six Managers, The Consensus of Management Opinion, And TEES

<table>
<thead>
<tr>
<th>Construct</th>
<th>Function</th>
<th>Finance Manager</th>
<th>Proposals Manager*</th>
<th>Manufacturing Manager</th>
<th>Business Group Manager</th>
<th>Engineering Manager</th>
<th>Marketing Manager</th>
<th>Consensus of Management Opinion*</th>
</tr>
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<tr>
<td></td>
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<td>(n) T</td>
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<tr>
<td>C₁₂ Chances of the Project Going Ahead</td>
<td>(17) 53&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(17) 47&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(17) 48&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(11) 32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(12) 36&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(5) 15&lt;sup&gt;d&lt;/sup&gt;</td>
<td>(17) 54&lt;sup&gt;a&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>C₁₃ Potential Profitability</td>
<td>(17) 49&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(17) 46&lt;sup&gt;c&lt;/sup&gt;</td>
<td>(17) 49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(11) 23</td>
<td>n/a</td>
<td>(5) 8</td>
<td>(17) 44&lt;sup&gt;e&lt;/sup&gt;</td>
<td></td>
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<tr>
<td>C₁₄ Level of Technical Risk</td>
<td>(17) 50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(17) 43&lt;sup&gt;d&lt;/sup&gt;</td>
<td>(17) 56&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(9) 25&lt;sup&gt;d&lt;/sup&gt;</td>
<td>(11) 32&lt;sup&gt;b&lt;/sup&gt;</td>
<td>(5) 11</td>
<td>(17) 51&lt;sup&gt;a&lt;/sup&gt;</td>
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<tr>
<td>C₁₅ Level of Financial Risk</td>
<td>(17) 50&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(17) 43&lt;sup&gt;e&lt;/sup&gt;</td>
<td>(17) 43&lt;sup&gt;e&lt;/sup&gt;</td>
<td>(9) 19</td>
<td>(9) [38&lt;sup&gt;a&lt;/sup&gt;]</td>
<td>n/a</td>
<td>(5) 7</td>
<td>(17) 50&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>C₁₆ Competitiveness of Price</td>
<td>(17) 42&lt;sup&gt;d&lt;/sup&gt;</td>
<td>(17) 33</td>
<td>(17) 42&lt;sup&gt;d&lt;/sup&gt;</td>
<td>(11) 28&lt;sup&gt;d&lt;/sup&gt;</td>
<td>n/a</td>
<td>(5) 9</td>
<td>(17) 46&lt;sup&gt;b&lt;/sup&gt;</td>
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<tr>
<td>C₁₇ Probability of Success</td>
<td>(17) 53&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(17) 43&lt;sup&gt;c&lt;/sup&gt;</td>
<td>(17) 39&lt;sup&gt;e&lt;/sup&gt;</td>
<td>(17) [45&lt;sup&gt;b&lt;/sup&gt;]</td>
<td>(13) 37&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(12) 31&lt;sup&gt;c&lt;/sup&gt;</td>
<td>(5) 14&lt;sup&gt;d&lt;/sup&gt;</td>
<td>(17) 55&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>C₁₈ Attractiveness of Tender Enquiry</td>
<td>(17) 49&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(17) 32</td>
<td>(17) 40&lt;sup&gt;e&lt;/sup&gt;</td>
<td>(12) 38&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(12) 31&lt;sup&gt;d&lt;/sup&gt;</td>
<td>(5) 13&lt;sup&gt;e&lt;/sup&gt;</td>
<td>(17) 54&lt;sup&gt;a&lt;/sup&gt;</td>
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* Manager Used Throughout the Knowledge Acquisition and Model Development Stages
+ Consensus of Management Opinion as Defined by the Categorised Mean of the Managers' Individual Assessments
(n) = Sample Size
T = Total Level of Scaled Agreement
[ ] = Total Level of Scaled Agreement Corrected for Systematic Bias
<sup>a</sup> Significant at the 1% Level
<sup>b</sup> Significant at the 2.5% Level
<sup>c</sup> Significant at the 5% Level
<sup>d</sup> Significant at the 10% Level
The results from the validation of TEES against each of the six managers are summarised in table 12.3.2. This shows both the observed levels of agreement between TEES and each of the six managers $M_q$ ($q=1,\ldots,6$) for each of the 7 higher level constructs $C_t$ ($t=12,\ldots,18$), as measured by $T$, the total level of scaled agreement a simple linear transform of weighted kappa $\kappa_w$, defined in terms of the scaled agreement weights $W(n,i,j)$. Figures in square parentheses (\{1\}) show the observed levels of agreement after correction for systematic bias (see section 11.6). All statistically significant results are shown in bold typeface and annotated with a subscript $a$, $b$, $c$, $d$, or $e$ which indicate the levels at which the results are significant. (Table 12.3.2 also shows the results from the validation of TEES against the consensus of management opinion (see section 12.4).)

In table 12.3.2 the results from the four inter-expert tests, investigating sub-hypothesis $H_{q2}$, are those for the Finance, Manufacturing, Engineering and Marketing managers respectively.

The very low observed levels of agreement between TEES and the Marketing manager suggest that the perspective of the bid versus no bid and bid resourcing decisions embedded within TEES is markedly different from that held by the Marketing manager. This result was not to be unexpected because as previously noted in section 12.2.2 the pair-wise analysis of the managers' individual assessments revealed that the Marketing manager held a strongly dissenting view. These differences could be partly a reflection of the Marketing manager's possible over-enthusiasm towards pursuing overseas business. However, with the sole exception of construct $C_{17}$ probability of success the level of agreement between TEES and the Marketing manager could not be improved by adjusting for any systematic bias. This suggests that a more reasonable thesis is that the knowledge base heuristics within TEES are an inappropriate representation, or model, of the Marketing manager's cognitive processes. As such it is unlikely that the bid versus no bid and bid resourcing recommendations produced by TEES would be considered credible by the Marketing manager.

The results from the remaining three inter-expert tests are considerably more positive. The results in table 12.3.2 reveal that with the exception of the construct $C_{16}$ competitiveness of price (where, as described below, there is a generally low level of agreement between TEES and all five managers who provided expert assessments) there are very high, that is strongly statistical significant, levels of agreement between TEES and the Finance manager on the five remaining intermediate results $C_{12}, C_{13}, C_{14}, C_{15}, C_{16}$. 

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C_{14}, C_{15}, C_{17} and also on the final recommendation C_{18}. These results suggest that TEES provides an appropriate model of the Finance manager's perspective, and therefore it is most likely that the bid versus no bid and bid resourcing recommendations produced by TEES would be considered credible by the Finance manager.

Furthermore, the results from the two remaining inter-expert tests suggest that (if the systematic bias between TEES and the Manufacturing manager on the constructs C_{16} *comparitiveness of price* and C_{17} *probability with success* is taken into account) with the exception of the final bid versus no bid recommendation C_{18} *overall attractiveness of enquiry*, where there are only general levels of observed agreement, there are in general very high levels of agreement between TEES and the Manufacturing and Engineering managers on the remaining constructs representing TEES's intermediate results. This suggests that TEES provides an appropriate model of the Manufacturing and Engineering Manager's reasoning; but, however, the general rather than very high observed levels of agreement between TEES and these managers on the construct C_{18} *overall attractiveness of enquiry* suggest that these managers may ultimately assess an enquiry's overall attractiveness in a manner slightly different from that of TEES.

Thus, the results from the four inter-expert tests, investigating sub-hypothesis H_{02}, suggest that with small minor differences the Finance, Manufacturing and Engineering managers' perspectives of the bid versus no bid and bid resourcing decisions are very similar to that embedded within TEES. If the Marketing manager's dissenting view is ignored, it can be concluded that the perspective embedded within TEES was not unduly biased by the choice of managers used in its development.

TEES was based on the combined expertise of the Proposals and Business Group managers and the results from the two intra-expert tests, investigating sub-hypothesis H_{01}, are also shown in table 12.3.2. The pair-wise analysis of these managers' individual assessments revealed that there is an exceptionally high level of agreement between the two managers whose views were sought to develop TEES (see section 12.2.2 table 12.2.2). However, the results in table 12.3.2 suggest that TEES is possibly a poorer representation of these managers' views with respect to the 17 enquiries included in the validation study, than it is for the Finance, Manufacturing and Engineering managers. It should be stressed, however, that without the use of sophisticated multivariate analysis of variance type statistics it is impossible to say that these results are in a statistical sense any poorer than the corresponding results.
for the Finance, Manufacturing and Engineering managers! Although from a qualitative comparison is does seem apparent that the levels of agreement between TEES and the Proposals Manager in particular are considerably lower than the corresponding results for TEES and the other managers, excluding of course the Marketing manager.

These results suggest that the Proposals and Business Group managers’ views may have changed over time. There was a 12 month period from which the enquiries used to develop and validate TEES were sampled. Moreover, the 14 enquiries used to develop TEES were sampled from the first six month period; whereas, the 17 enquiries used to validate TEES were sampled from the second six month period. So, one possible explanation is that the managers feel there has been, or should be, a change in the organisation’s bid versus no bid and bid resourcing policy due to changes in its business environment. One such influence for example could be indications of the start of a national recession. If this is the case it is important to address how TEES could be continually updated to reflect changes in the organisation’s policy. This important issue is discussed in chapter 13 Discussion and Conclusions. An alternative, but related, explanation could be that the observed differences are not so much the result of a change in policy, but are a result of some relevant super-ordinate constructs, as for example the nature of the international/national economy, having been excluded from TEES. For example, the nature of the international/national economy may have been fairly stable over the six month period during which the 14 enquiries used in TEES’s development were sampled. If this was the case then the elicitation of constructs through the use of triads would not have necessarily detected the relevance of this construct because there was no marked differences between any of the 14 enquiries with respect to the nature of the international/national economy. As such it is possible that the TEES was biased by the enquiries and/or the period during which the enquiries used in its development were sampled.

As noted above, the results from both the inter-expert and intra-expert tests shown in figure 12.3.2 reveal that there is a consistently low level of agreement between TEES and the managers on the intermediate construct C16 competitiveness of price. A possible explanation for this can be derived from figure 9.5(ii). For any enquiry the organisation’s position regarding their price competitiveness is relative to the competition that they face. Figure 9.5(ii) illustrates that the construct C16 competitiveness of price is influenced by the three constructs C15 level of financial risk, C6 level of manufacturing investment and C5 availability of manufacturing
capacity, but not by the construct $C_{11}$ level of the competition. Thus, the knowledge base heuristics are measuring the organisation's attempt to recover manufacturing overheads by reducing prices when spare capacity is available, and cover investment costs or higher levels of risk by increasing their price. Moreover, in reality their price competitiveness is a managerial decision variable, but TEES treats it as a wholly dependent variable. The organisation can improve their competitive position by increasing their financial exposure and conversely reduce their financial exposure by increasing their prices. Thus, the knowledge base is not calculating a true measure of the organisation's competitive posture, but rather a measure of the organisation's desire to discount or load their price.

It is important to stress that the managers involved with the TAG contribute selective expertise to the bid versus no bid and bid resourcing decisions, and therefore they cannot be regarded as experts in all facets of tender enquiry evaluation. On several constructs some managers are more qualified than others to provide expert assessments, and correspondingly some managers' assessments are more credible than others. This observation raises a very important issue. This concerns whose views should be incorporated into a system, and whose views should a system be compared against, in non-formal domains characterised by selective multiple sources of expertise. For example, if the technically orientated functions Engineering and Manufacturing ultimately have very little influence over the commercial decision as to whether or not to bid, then can any real significance be attached to the results indicating that there is only a general level of agreement between these managers and TEES on the construct $C_{18}$ overall attractiveness of enquiry? The results in Table 12.3.2, however, reveal that for those constructs which are thought to be of the greatest importance in establishing the credibility of the system in the eyes of one particular functional manager (with the exception of the Marketing manager) there is generally a high level of agreement between TEES and the managers. For example, since there are few rewards in expending effort and resources chasing projects that are unlikely to happen, or projects that are most likely to be awarded to other suppliers, then it is believed that all functions hold a mutually common interest in both the constructs $C_{12}$ chances of the project going ahead and $C_{16}$ the probability of success. For all of the managers a high level of agreement can be observed between TEES's recommendations and the managers' individual assessments for these two constructs. Furthermore, confidence in TEES's recommendations concerning the construct $C_{14}$ level of technical risk are probably most important to the non-commercial functions Engineering and Manufacturing. The results indicate high levels of agreement between TEES and these two functional managers.
To summarise, the inter-expert tests suggest that TEES was not unduly biased by the choice of managers used in its development, and that the perspectives of the Finance, Manufacturing and Engineering managers are very similar to that embedded within TEES. However, there is clearly some variation of opinion between the managers from different business and functional specialisms and this suggests that it is unlikely that it would be possible to develop a perfect system which adequately reflected the individual views of all parties involved in the TAG. Furthermore, the presence of selective multiple expertise suggests that this goal may itself be misguided. These observations, together with the consensual basis for the TAG's decisions, suggest that a more informative validation approach may be to validate TEES against single view which was representative of the consensus view of the TAG. This is described in the next section.
12.4 VALIDATION OF TEES AGAINST THE CONSENSUS OF MANAGEMENT OPINION

In this section the methods and results obtained from validating TEES against the so-called consensus of management opinion are described. This analysis was performed to establish the truth or otherwise of sub-hypothesis $H_{03}$.

12.4.1 METHOD

In order to determine how well TEES reflected the organisation's consensual business perspective of the bid versus no bid and bid resourcing decisions, it was necessary to construct a set of assessments $R_{E_{r}M_{Cons}}(C_{t})$ for each enquiry $E_{r}$ ($r=1,...,17$) and each construct $C_{t}$ ($t=1,...,18$) that reflected the consensus view of the TAG. As with the managers' individual assessments, for each enquiry $E_{r}$ ($r=1,...,17$) the assessments representing the consensus of management opinion for the 11 base constructs, as represented by $X_{E_{r}M_{Cons}}$, were entered into TEES and the system's intermediate results and final recommendation $Y'_{E_{r}M_{Cons}}$ were compared with the assessments representing the consensus of management opinion $Y_{E_{r}M_{Cons}}$. As above both levels of agreement and systematic bias were calculated for each of the 7 higher level constructs $C_{t}$ ($t=12,...,18$) from the components of the vector differences $Y_{E_{r}M_{Cons}} - Y'_{E_{r}M_{Cons}}$ ($r=1,...,17$).

The purpose of the set of assessments $R_{E_{r}M_{Cons}}(C_{t})$ ($r=1,...,17; t=1,...,18$) was to reflect the consensus view of the TAG on the 18 constructs used by TEES and the 17 enquiries included in the validation set. Unfortunately, the real world process used by the TAG to reach their consensus view was unknown and therefore it was necessary to devise a theoretical definition for the concept of the consensus of management opinion. For example, the TAG's consensus view could be reached by adopting the view most supported by the managers present, that is the modal view. Alternatively, it is possible that the TAG reach their consensus by forming some aggregated view approximating the mean or median of the managers' individual views, or by some process emulating minimax or maximin decision criteria, that is accepting the most pessimistic or optimistic of the individual managers' views respectively. Furthermore, because of the selective nature of the managers' expertise (see section 6.2.1) it is likely that in a given area of tender enquiry evaluation some managers may have more influence in steering the consensus view than others. Addressing such issues was considered to be beyond the scope of this validation study; and therefore the consensus of management opinion for any given enquiry $E_{r}$ ($r=1,...,17$) and any given construct $C_{t}$ ($t=1,...,18$), $R_{E_{r}M_{Cons}}(C_{t})$, was defined simply as the arithmetic mean of
the managers' individual assessments $R_{\text{ErMq}}(C_t)$ ($q=1,\ldots,6$). In order to calculate the level of agreement between TEES and the consensus of management opinion it was necessary for each assessment $R_{\text{ErMCons}}(C_t)$ to be integral scaled rather than real scaled. Therefore, the interval $[1,5]$ was divided into 5 equal intervals, corresponding to the integral assessments 1, 2, 3, 4 and 5 respectively, and the real scaled managers' mean assessment $R_{\text{ErMCons}}(C_t)$ was transformed into the corresponding integral scaled assessment.

Again, to validate TEES against the consensus of management opinion it was necessary to determine the statistical significance of the observed levels of agreement between TEES and the consensus of management opinion on each of the higher 7 higher level constructs $C_t$ ($t=12,\ldots,18$). This again required the derivation of the critical values from the appropriate distributions of weighted kappa $\kappa_w$ under the null hypothesis of chance agreement. In this case, however, the appropriate distributions of weighted kappa $\kappa_w$ for each of the 7 higher levels constructs were defined by the construct's respective marginal distribution for the consensus of management opinion and the system's theoretically derived marginal distribution for the consensus of management opinion. Therefore, it was necessary to consider how the marginal distributions for the consensus of management opinion for each construct $C_t$ ($t=1,\ldots,18$) could be obtained from either the managers' individual marginal distributions, or the managers' combined marginal distribution, for the construct $C_t$.

The purpose of using six managers in the validation study was to obtain six independent views of the 17 enquiries in the validation set. These views were assumed to represent the perspectives of the different business and functional specialisms. Under the premise that the managers' assessments represented six independent views, then it could be assumed that on any enquiry $E_r$ ($r=1,\ldots,17$) and any construct $C_t$ ($t=1,\ldots,18$) the managers' individual assessments $R_{\text{ErMq}}(C_t)$ ($q=1,\ldots,6$) were statistically independent. Since the interviews with the managers were conducted independently, then no manager had knowledge of any other manager's assessments. Therefore, under the premise of independence any observed correlation, or similarity, between the managers' assessments $R_{\text{ErMq}}(C_t)$ ($q=1,\ldots,6$) on any given enquiry $E_r$ and any given construct $C_t$ was due to the fact that the managers were assessing the same business opportunity and shared similar views as regards its attractiveness, or unattractiveness respectively.

Under the premise of independence, to determine the appropriate distribution of weighted kappa $\kappa_w$ under the null hypothesis of chance agreement, then in theory for
each construct $C_t$ (t=1,...,18) the marginal distribution of the *consensus of management opinion* (as defined by the categorised mean of the managers' individual assessments) could be obtained analytically by recognising that the mean assessment, that is the consensus view, is a linear function of six independent identically distributed random assessments $R_{E_{Mrq}}(C_t)$ (q=1,...,6). Following this, due to the deterministic nature of TEES's knowledge base, then as before the system's marginal distributions for each of the 7 higher level constructs could be theoretically derived from the marginal distributions for the 11 base constructs for the *consensus of management opinion*.

Unfortunately, the results from the analysis of the level of agreement between the six managers discussed in section 12.2.2 cast severe doubt as to the validity of the premise concerning the statistical independence of the managers' assessments. Of particular concern were the very high levels of observed agreement between the six managers on the 7 higher level constructs, which are believed to be most influential, or central, to the bid versus no bid and bid resourcing decisions, and the much lower levels of observed agreement on the majority (8 out of 11) of the 11 base constructs, which are believed to influence the higher level constructs.

Suppose for the moment that the six managers' assessments are statistically independent. Then, the results obtained in section 12.2.2 suggest that the managers, using their different assessments (that is, using their differing views) for the majority of the 11 base constructs reach *very similar* conclusions for the 7 higher level constructs. This suggests that the managers are using different cognitive processes to arrive at *very similar* conclusions. This is possible, and it must be remembered that one the objectives of using the six managers was to ascertain how their perspectives of tender enquiry evaluation differed. However, the generally very high levels of agreement between all six managers on the 7 higher level constructs suggests that this thesis is improbable.

Perhaps a more reasonable thesis is that because of the *political process* by which the consensus view is reached then the managers' assessments are *not truly* independent views. Thus, although no manager was influenced directly by any of the other managers assessments, then because their assessments were elicited retrospectively, after the TAG had decided upon appropriate action, they were in fact influenced by the consensus view that had already been reached at by the TAG. This thesis would explain the very high levels of observed agreement on the majority of the 7 higher level constructs (as for example $C_{18}$ *overall attractiveness of enquiry*, $C_{17}$ *probability*...
of success, C12 chances of project going ahead) and also that observed on several of the 11 base constructs (as for example C2 prospects of available finance, C6 size of order, C10 prospects of further business). Under this premise, it appears that the managers were constrained to provide assessments that conformed to their peer group consensus, and therefore on several constructs the validation data base may not reflect the full variation in the managers' opinions or views. More importantly, this thesis suggests that on any given enquiry E_r (r=1,...,17), then on certain constructs C_t the managers' assessments R_{ErM_q}(C_t) are not statistically independent.

Thus, in determining the appropriate distributions of weighted kappa \( \kappa_w \) with which to validate TEES against the consensus of management opinion it was necessary to choose between two competing and conflicting hypotheses. These were firstly, that the managers' assessments represented six independent views (that is, on any enquiry \( E_r \) (r=1,...,17) and any construct \( C_t \) (t=1,...,18) the managers' assessments \( R_{ErM_q}(C_t) \) (q=1,...,6) were statistically independent); and secondly, that the managers' views were not truly independent because in some instances they were influenced by the consensus view that had previously been reached at by the TAG (that is, the managers' assessments \( R_{ErM_q}(C_t) \) (q=1,...,6) were not necessarily statistically independent).

Clearly it was impossible to evaluate the truth of one of these hypotheses over the other. However, in validating TEES against the consensus of management opinion all that was really necessary was to ascertain the sensitivity of the critical values of weighted kappa \( \kappa_w \) to the two conflicting hypotheses. Therefore, a study was performed to determine the extent to which the critical values changed under the two hypotheses. For each of the 7 higher level constructs \( C_t \) (t=12,...,18) and for each of the 4 sets of scaled agreement weights \( W^{(k)}_{ij} \) (k=1,...,4) the relevant critical values were obtained using two different methods to reflect the two conflicting hypotheses.

In method 1 it was assumed that on any enquiry \( E_r \) (r=1,...,17) and any construct \( C_t \) (t=1,...,18) the managers' assessments \( R_{ErM_q}(C_t) \) (q=1,...,6) were statistically independent. Then, for each construct \( C_t \) (t=1,...,18) the marginal distribution of the consensus of management opinion was obtained analytically from the recognition that the consensus view was a transformed linear function of six independent identically distributed random assessments \( R_{ErM_q}(C_t) \) (q=1,...,6).

In method 2 it was assumed that on any enquiry \( E_r \) (r=1,...,17) and any construct \( C_t \) (t=1,...,18) the managers' assessments \( R_{ErM_q}(C_t) \) (q=1,...,6) were perfectly correlated.
Then, for each construct $C_t (t=1,...,18)$ the marginal distribution of the *consensus of management opinion* was taken to be the same as the managers' combined marginal distribution for the same construct $C_t$.

Clearly, the true critical values for validating TEES against the *consensus of management opinion* lay between those obtained by methods 1 and 2 respectively. As expected, due to the reduction in the variances of the marginal distributions used in method 1, the critical values obtained from method 1 were higher than those obtained by method 2. Moreover, it was found that the differences between the critical values obtained by the two methods were sufficient to affect the statistical significance of the observed levels of agreement between TEES and the *consensus of management opinion*.

It is important to note, however, that if it is assumed that the managers' assessments are statistically independent, and therefore that any observed correlation, or similarity, between their assessments is because they are assessing the same business opportunities and share the same views, then the marginal distribution for the *consensus of management opinion* for the construct $C_t$ is best approximated by the combined managers' marginal distribution for $C_t$, rather than by the distribution of the categorised mean of six independently identically distributed assessments. This apparent anomaly arises because in theory the marginal distribution for the *consensus of management opinion* for a construct $C_t$ should first be aggregated over the six managers and then over the 17 enquiries. However, because for each manager $M_q (q=1,...,6)$ and each enquiry $E_r (r=1,...,17)$ and each construct $C_t (t=1,...,18)$ the managers' probability distribution for his assessments $R_{ErMq}(C_t)$ was unknown it was necessary to aggregate over enquiries before managers.

Therefore, irrespective of whether or not the managers' assessments are statistically independent, when there are high levels of agreement between the six managers on a given construct $C_t$ the marginal distribution for the *consensus of management opinion* is best approximated by the combined managers' marginal distribution for the same construct $C_t$. This suggests that the true critical values with which to validate TEES against the *consensus of management opinion* are nearer to those values obtained by method 2 rather than those obtained by method 1. Thus when validating TEES against the *consensus of management opinion* the true critical values were taken to be the values midway between those values obtained by methods 1 and 2 respectively.
Under this assumption the statistical significance of the observed levels of agreement can be regarded as being conservative. The results from the validation of TEES versus the consensus of management opinion are discussed in the following section.

12.4.2 Results

The results from the validation of TEES versus the consensus of management opinion, investigating sub-hypothesis H13, are again summarised in table 12.3.2. Table 12.3.2 reveals that with the exception of TEES's intermediate result relating to the construct C13 potential profitability there are very high (that is, strongly significant) levels of agreement between TEES and the consensus of management opinion on all five remaining intermediate results (C12, C14, C15, C16 and C17) and the final recommendation (C18).

The results reveal that for the intermediate construct C13 potential profitability there is only a general (that is, weakly significant) level of agreement between TEES and the consensus of management opinion. A possible explanation for this poor result is given below.

The Marketing manager's views in relation to construct C13 potential profitability were known to differ from the other managers (see section 12.2.2 & table 12.2.2). Furthermore, he only responded to 5 of the 17 enquiries and could therefore not significantly influence the results. As such his views can be effectively ignored.

3 The results from the analysis of the levels of agreement and the levels of systematic bias between TEES and the consensus of management opinion are shown in tables 12.4.1(i) and tables 12.4.1(ii) respectively (see Appendix E). Table 12.4.1(i) shows the observed levels of agreement between TEES and the consensus of management opinion for each of the 7 higher level constructs Ct (t=12, ..., 18) as measured by T, the total level of scaled agreement a simple linear transform of weighted kappa \( \kappa_w \), for each of the 4 sets of scaled agreement weights W(k)ij (k=1, ..., 4). Whereas, table 12.4.1(ii) shows the observed levels of systematic bias between TEES and the consensus of management opinion for each of the 7 higher level constructs Ct (t=12, ..., 18) as measured by t the continuity corrected students t statistic. In both tables statistically significant results are shown in bold typeface and annotated with a subscript a, b, c, d, or e which indicate the levels at which the results are statistically significant. In particular these results show that the level of agreement is insensitive to the definition of \( \kappa_w \).
The results given in section 12.2.2 and tables 12.2.2 revealed very high levels of agreement between the Finance, Proposals, Manufacturing and Business Group managers in relation to the construct $C_{13}$ potential profitability. Furthermore, excluding the Business Group manager, the results from the inter-expert and intra-expert tests discussed in section 12.3.2 revealed very high levels of agreement between TEES and the Finance, Proposals, and the Manufacturing managers in relation to the construct $C_{13}$ potential profitability.

Therefore, given that the Marketing managers' views can be ignored and that there are high levels of agreement between TEES and the Finance, Proposals, and the Manufacturing managers on the construct $C_{13}$ potential profitability, then the general level of agreement between TEES and the consensus of management opinion on the construct $C_{13}$ potential profitability at first seems surprising. The anomaly, however, between these two sets of results can again be derived from figure 9.5(ii). The construct $C_{13}$ potential profitability is influenced by three constructs $C_{8}$ expected added value, $C_{9}$ level of involvement and $C_{9}$ size of order. Furthermore, the results in section 12.2.2 and table 12.2.2 revealed that there were very low levels of management consensus on the base constructs $C_{8}$ expected added value and $C_{9}$ level of involvement. These two constructs were, however, found to have a significant influence on the construct $C_{13}$ potential profitability within TEES (see section 10.4); and therefore the very low observed levels of management consensus had the effect of neutralising their influence on construct $C_{13}$ potential profitability in the validation study.

Thus, the relatively poor level of agreement between TEES and the consensus of management opinion on construct $C_{13}$ potential profitability is not so much due to TEES being a poor representation of the management consensus, but more a result of the poor consensus between the managers on two of the sub-ordinate constructs which are believed to influence $C_{13}$ potential profitability.

Therefore, the results in table 12.3.2 suggest that both the structure of TEES's reasoning (as measured by the levels of agreement between TEES and the consensus of management opinion on the six intermediate results represented by the constructs $C_{12}$,..., $C_{17}$) and the final bid versus no bid and bid resourcing recommendation (as measured by the level of agreement between TEES and the consensus of management opinion on the construct $C_{18}$) are in agreement with the TAG's consensus view (as measured by the categorised mean of the managers individual assessments). As such TEES provides an appropriate representation of the business perspective of the
Furthermore, it is believed that a manager's assessments for the 11 base constructs will influence the manager's higher level and overall assessments for any enquiry; and therefore, as a starting point for enquiry evaluation the TAG should aim to reach a consensus of opinion with regard to these 11 base constructs. The results from the study suggest that if such a consensus could be reached the intermediate results and final recommendation produced by TEES could be used as a catalyst for further discussion.

So, in summary the results from the two separate validation studies suggest that TEES's intermediate results ($C_{12},...,C_{17}$) and its final recommendation are consistent with those of the consensus of management opinion (sub-hypothesis $H_{03}$), and that the business perspective embedded within TEES has not been unduly biased by the choice of managers used in its development (sub-hypothesis $H_{03}$). However, there is some weak evidence to suggest that the perspective embedded within TEES may have been slightly biased by either the enquiries and/or the time period during which the enquiries used in its development were sampled, or that some managers feel there should be a change in the organisations bid versus no bid and bid resourcing policy (sub-hypothesis $H_{01}$). Therefore, it is reasonable to conclude that TEES's intermediate results ($C_{12},...,C_{17}$) and its final recommendation are consistent with those reached at by the TAG (overall hypothesis of model validity $H_0$). As such TEES provides an appropriate representation of the TAG’s consensual business perspective regarding the bid versus no bid and bid resourcing decisions.

12.5 Results from the Informal Validation

In addition to the formal validation procedures outlined in the previous sections, TEES was also validated using less formal methods. On two separate occasions throughout the project prototypes of the system were demonstrated to three members of the organisation's senior management including the Proposals manager.

During the first of these demonstrations the managers were allowed to experiment with the system and compare their own opinions against the system's recommendations on some of their past and current enquiries. In particular the managers were keen to use the system to review some of their past bid versus no bid and bid resourcing decisions on enquiries that were included in the repertory grids, and which were therefore central to the system's development. This enabled the managers to monitor the effect of new developments and information which had
become available during the bid proposals preparations and bid appraisal stages on the system's recommendations.

In general, the managers concluded that the system's revised recommendations were in line with their own assessments of the current situations. The managers, however, did not always find this encouraging since in some instances the system only served to confirm their own worse fears that a project which had looked like a good prospect some months ago was now beginning to look much more like a less attractive business proposition. On more recent enquiries the managers again concluded that for the majority of enquiries the system's recommendations were in line with their own assessments. For those enquiries where differences between the managers' assessments and the system's recommendations were discovered, then in retrospect the managers felt that the system had been more consistent and objective in the enquiries' evaluations than they themselves had been. This was especially true for those enquiries which the managers regarded as representing very unattractive business opportunities, as for example with small projects for customers in third world nations. The overall opinion of the managers was that with some minor modifications to the user interface the prototype system would be a useful decision support tool for use by the TAG.

The managers' recommendations were implemented such that by the time of the second demonstration the basic user interface of the first system prototype had been refined to include a simple but meaningful reporting module which summarised and explained the system's recommendations, together with a sensitivity analysis and a colour graphics facility which enabled management to assess the effect of changes in their assessments of any of the 11 base constructs. These were all facilities that the managers had asked to be incorporated into the system after the demonstration of the first prototype.

Again as in the first demonstration the managers were allowed to experiment with the system. This time, however, the presence of the reporting module enabled the managers to interrogate the system's reasoning. The managers' comments during the demonstration, especially those from the most senior manager present the Sales & Commercial manager who had originally agreed to the organisation's collaboration, provided some informal feedback as to both the system's validity and its benefits to the organisation.
The Sales & Commercial manager's comments drew attention to several interesting points. The manager was impressed by the level of sophistication of the system’s reasoning and expressed surprise at the level of sophistication in the rational underlying the organisation's decision making. Furthermore, all the managers present believed that both the development and validation stages, and the system itself, assisted in clarifying the organisation's knowledge of the relationships between the key factors underlying their bidding decisions. This had helped the organisation to clarify what was it current bid versus no bid and bid resourcing policy. This process highlighted several weaknesses in their own expertise over which the Sales & Commercial manager expressed some concern. Firstly, the manager felt unease at the system's recommendations in relation to an enquiry's potential profitability; and although he could not find any obvious fault with the system's reasoning, he felt that this was an area in which the both the managers' and the system's expertise was insufficient and one which management should consider further. These comments concur with the findings from the formal validation study discussed in section 12.4.2. Secondly, and perhaps more importantly, although he sympathised with the system for reflecting and clarifying what was the organisation's current policy, then once its policy was explicit he caste severe doubts as to whether this was a policy the organisation should be adopting. This last observation raises important questions concerning whose expertise should be incorporated within the system, and whether a system should represent a purely descriptive model of the domain or should it also contain a normative element. These issues are discussed further in chapter 13 Discussion and Conclusions.

So, to summarise, the managers believed that TEES provided a simple but useful decision support tool for use by the TAG. In particular the sensitivity analysis and colour graphics facilities were regarded as useful components, and one of the major perceived benefits of TEES was its ability to monitor the consistency and sensitivity of their bid versus no bid and bid resourcing decisions. This was believed to be beneficial in investigating the sensitivity of the system’s recommendations to elements of uncertainty surrounding the information at hand, and also in determining the relative importance of minor differences of opinion amongst the individual members of the TAG. The researcher's intervention helped the organisation to clarify the its bidding expertise in a changing business environment. In particular, it highlighted the organisation's current bid versus no bid and bid resourcing policy and has forced the organisation to reconsider what its ideal policy should be. Furthermore, the study drew attention to some dissenting views amongst the organisation's senior management and also highlighted possible weaknesses within its own expertise.
12.6 Summary

The formal validation framework devised in chapter 11 has been used successfully to investigate the validity or otherwise of TEES. Furthermore, the results from this formal study have been complemented with the results from an informal validation study which tested senior management's reactions to TEES.

In the formal study the overall hypothesis of model validity $H_0$ has been tested via three operational sub-hypotheses $H_{01}$ (intra-expert test), $H_{02}$ (inter-expert test) and $H_{03}$ (consensus test); and two major studies have been performed to establish the truth or otherwise of these three sub-hypotheses. (A preliminary study investigating the similarities between the perspectives of the different business and functional specialisms has also been performed.)

The results from the formal validation studies suggest that TEES's reasoning and its final recommendations are consistent with those of the consensus of management opinion (sub-hypothesis $H_{03}$) and that the business perspective embedded within TEES has not been unduly biased by the choice of managers used in its development (sub-hypothesis $H_{02}$). Together these results enable it to be concluded that both TEES's reasoning and its final recommendations are consistent with those reached at by the TAG (overall hypothesis of model validity $H_0$). As such it has been concluded that TEES is valid, and therefore provides an appropriate representation of the TAG's consensual business perspective regarding the bid versus no bid and bid resourcing decisions.

The results from the informal study suggest that senior management are highly receptive towards the use of TEES by the TAG. They were convinced that TEES was both more consistent and objective in its evaluation of enquiries than themselves, and that if a consensus could be reached on the 11 base constructs then the recommendations produced by TEES could be used as a catalyst for further discussion within the TAG. Furthermore, the ability to perform sensitivity type analyses within TEES was seen as a major benefit enabling the significance of uncertainty and dissent to be determined. In these respects the organisation felt that TEES represented a simple but useful decision support tool for use by the TAG.

The researcher's intervention was regarded as great success by the most senior of the organisation's management. It has helped the organisation to clarify its bidding expertise in a changing business environment. In particular, it has highlighted the
organisation's current bid versus no bid and bid resourcing policy and has forced the organisation to reconsider what its ideal policy should be. Furthermore, the study has drawn attention to some dissenting views amongst the organisation's senior management and also highlighted possible weaknesses within its own expertise which management deserved urgent consideration.

The formal validation study did, however, provide some weak evidence to suggest that some managers feel there has been, or should be, a change in the organisation's bid versus no bid and bid resourcing policy (sub-hypothesis $H_{01}$). If this is so, then how TEES can be continually updated to reflect the organisation's evolving policy becomes a very important issue in TEES's overall validity.
PART C

DISCUSSION AND CONCLUSIONS
CHAPTER 13

SUMMARY, DISCUSSION AND CONCLUSIONS
SUMMARY, DISCUSSION AND CONCLUSIONS

13.0 INTRODUCTION

This chapter briefly summarises the material presented in previous chapters of the thesis and then discusses in further detail some of the results and findings reported throughout the research. In particular, the methods used to develop and validate TEES are evaluated, as are the results obtained from the validation study. From these observations some tentative conclusions are drawn concerning the appropriateness of ES and ESS in competitive bidding, and non-formal managerial domains in general. Finally, some thoughts on possible directions in which future research in this area might be pursued are offered.

13.1 OVERVIEW OF THE RESEARCH

The foundations of the research arise from comprehensive reviews of the literature on competitive bidding and intelligent knowledge based expert systems reported in chapters 2 and 3 respectively.

The review in chapter 2 showed that the focus of previous bidding studies has been to provide managerial support in the determination of the optimum bid price in closed bidding situations where the contract is awarded to the lowest priced bidder. Several quantitative modelling approaches have been proposed for this problem: these include the decision and game theoretic approaches, and also the probabilistic strategy approach. Unfortunately, research has shown that there are well established theoretical and practical problems with the decision and game theoretic approaches, and that even the more flexible probabilistic strategy approach has its limitations. As a result of these limitations to date there is no universally agreed approach to optimal bid pricing.

Furthermore, it has been shown that managers responsible for preparing bids have good reason to be sceptical about these previous models. One just criticism is that they all emphasise the quantitative issues in bidding and play down the significance of many of the qualitative aspects. Yet, in many bidding situations qualitative non-price features are prevalent and the final bid price may not be a contractor's major
competitive weapon. In such cases it was suggested that the emphasis for a contractor may change from optimal bid pricing towards optimal resourcing of bids.

Thus, it is important to realise that bid pricing is only one of a series of interrelated decisions, and that in many bidding situations the bid versus no bid and bid resourcing decisions are equally important. The review in chapter 2 showed that these two related decisions have received scant attention within the relevant literature, but are areas in which the research suggests there is significant scope to provide management decision support. It was possible to conclude, therefore, that radically different approaches for improving bidding performance were worthy of investigation.

The review in chapter 3 showed that expert systems are a relatively new area of computing technology to have evolved from research into artificial intelligence. In essence an expert system (ES) is a computer program that aims to capture the expertise and emulate the performance of one or more human experts in a problem domain. This expertise consists of knowledge and judgement, as for example loosely associated facts and rules, often learnt from experience rather than theory. This expertise is frequently formulated in the form of simple heuristics, or rules of thumb, and is predominantly qualitative in nature rather than quantitative.

In chapter 4 it was suggested that in practice managers responsible for preparing competitive bids have gained considerable expertise and intuition, and can be relied upon for their good judgement to make rational and reasonable decisions. The managers' expertise is believed to have both quantitative and qualitative aspects. Customers, contracts and competitors are effectively diagnosed and various experiential rules of thumb are used to arrive at an appropriate decision. Furthermore, experience suggests that bidding is an area in which relevant expertise or knowledge is frequently dispersed or shared between several managers. It was therefore concluded that the modelling capabilities of ES closely match the type of reasoning carried out by managers preparing bids, and that ES may be appropriate for improving bidding performance. Based on this premise this thesis has sought to explore the possible roles and benefits that ES can provide in this area.

In particular, it was suggested that ES have several characteristics that may lend assistance to improved bidding performance. Firstly, ES emphasise qualitative rather than quantitative knowledge. Secondly, as bidding is an area where relevant expertise or knowledge is generally dispersed amongst several managers, then ES provide a means of consolidating these multiple sources of expertise within a single knowledge
The second part of the thesis, part B, described in depth, a case study concerning the development of an expert support system (ESS), referred to as TEES, for tender enquiry evaluation. TEES was developed for use by the senior management of a large electro-mechanical engineering company to assist in their bid versus no bid and bid resourcing decisions. A brief, but critical review, of this study is provided in the next section. In particular the review evaluates the methods used to develop and validate TEES, and also the results obtained from the validation study.

13.2 REVIEW AND EVALUATION OF CASE STUDY

Contact was initially established with the case study organisation to explore the possibility of a collaborative project using ES technology in competitive bidding. Senior managers in the organisation were convinced of the possible benefits that ES could provide and were enthusiastic about collaborating on a project to develop an ESS to assist in their bid versus no bid and bid resourcing decisions. The managers saw two major benefits resulting from collaboration: Firstly, they believed that the single consolidated knowledge base embedded within an ESS would enable future bid versus no bid and bid resourcing decisions to be made in a more systematic, objective and equitable fashion. Secondly, the managers were keen to review their criteria for deciding which enquiries to pursue and believed that collaboration would enable them to clarify their understanding of their current bid versus no bid and bid resourcing policy.

Each year the case study organisation receives about 80 tender enquiries inviting it to compete for the offered business via a competitive bid. All enquiries received are vetted by the Tender Action Group (TAG). This is a committee of senior managers...
representing the interests of the organisation's business group managers and the
functions who support their activities. The role of the TAG is to discuss the
implications of pursuing a particular enquiry; and ultimately to recommend
appropriate action regarding the bid versus no bid and bid resourcing decisions. Each
enquiry is awarded one of five bid decision categories which indicate the level of
resources to be allocated to the preparation of a tender proposal.

In the next three sub-sections the methods used to develop and validate TEES
together with the results from the validation study are critically evaluated.

13.2.1 DISCUSSION AND EVALUATION OF METHODS USED TO DEVELOP TEES

Knowledge acquisition (KA), the process at the centre of ES development, is
traditionally regarded as the critical bottleneck in ES development, and to improve
the efficiency and the effectiveness of the process numerous techniques have been
borrowed from the field of cognitive psychology. In recognition that experts use
different types of knowledge and store their knowledge in many different
representational forms, and that different KA techniques access different types and
forms of knowledge, then when developing an appropriate KA strategy it is important
to match the properties of the KA techniques to the underlying characteristics of the
domain. At present, however, there is very little empirical evidence indicating which
KA techniques are most appropriate for which domains; and therefore, it is expedient
if the KA techniques and methods of analysis used in the development of TEES are
critically evaluated.

It was noted that the structure of the TAG is such that several managers from different
business and functional specialisms influence the committee's recommendations, and
in this respect the bid versus no bid and bidding resourcing decisions were seen as co-
ordinative type decisions requiring the social interaction of several managers with
different vested interests. Thus the domain was regarded as non-formal, and therefore
to reduce both functional and individual managerial bias and to encapsulate as broad a
business perspective as possible two managers were used throughout the development
of TEES. Consequently, a KA strategy was required that enabled the different
perspectives of the two managers to be contrasted and combined. Furthermore, early
discussions with senior management led to the conclusion that the problem was one of
classification, with enquiries being effectively assessed along a number of dimensions
and then classified into one of the five bid decision categories.
The organisation's senior management were highly educated, in the main having obtained engineering degrees and then gaining charted status. They displayed a high intellect and were all considerably articulate, but nonetheless, the managers had difficulty in verbalising their knowledge when probed about how enquiries were evaluated. 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 experience and was therefore deeply compiled. This suggested that indirect KA techniques were more appropriate than more commonly used direct interviewing methods. With this mind repertory grid analysis was chosen primarily because of its overall flexibility, but also because it enables comparisons to be made between different perspectives both systematically and objectively.

It has been noted throughout this thesis that repertory grid based analyses are inductive based techniques. Thus, like rule induction itself, they can only identify patterns or relationships that are evident in the training set, that is the set of grid elements. Domain concepts (that is, constructs) and relationships revealed during the grid's elicitation and subsequent analysis can therefore be sensitive to the elements included in the grid. For this reason it has been noted that it is important to ensure that the training set (set of elements) provides representative coverage of the domain, although in general \textit{a priori} the characteristics of the domain are unknown.

Furthermore, large grids are both difficult and time consuming to elicit, and therefore in grid based studies the diversity of problem situations represented in the grid is often severely limited by the relatively small number of elements used. Owing to the small number of elements (and correspondingly the small number of constructs) the conceptual relationships derived from direct comparison based analysis methods can often be spurious and therefore need to be validated by the \textit{experts} from whom the grids were elicited, as was the case in the development of TEES. Unfortunately, even though in the case study great care was taken to develop an appropriate grid design, the results from the validation study (see section 12.3.2 and 13.2.3) show that TEES's perspective may have been biased by the enquiries used in its development.

Furthermore, the same results suggest that TEES's perspective may have been influenced by the manager's post rationalising their true assessments in light of the recommendations already reached by the TAG. These theoretical and empirical observations highlight potential weaknesses with the use of repertory grid analysis and inductive approaches in general. It is important to emphasise, however, that several other direct interviewing techniques such as protocol analysis and the critical incident technique are also essentially inductive. Even in open unstructured interviews it is dangerous to assume implicitly that an \textit{expert}'s statement or protocol
possesses general scope of application because it is well known that experts tend to forget exceptions to the rule. Furthermore, in favour of inductive techniques is that the elements used in the training set are at least made explicit. So, although the nature of inductive techniques suggests that they have several weaknesses, the same weaknesses are often implicit within many other direct, and more commonly used, interviewing techniques.

In the development of TEES a repertory grid was elicited from each of the two managers based on a representative set of 14 historic enquiries. This produced what was believed to be a comprehensive set of 26 constructs that were relevant to the bid versus no bid and bid resourcing decisions. The grids also provided a cross reference between the enquiries and the constructs used to discriminate between them. These grids were subsequently analysed independently and together using several direct comparison analysis based methods in order to gain informative insights into the managers', and consequently the TAG's, reasoning.

The majority of grid analysis methods make use of multivariate statistical techniques with cluster analysis and principle components being among the most commonly used. During the development of TEES the managers' grids were first analysed using FOCUS, a method based on a two way agglomerative clustering algorithm. The analyses using FOCUS established the validity of the managers' grids. That is, that they were capable of discriminating between highly attractive and very unattractive enquiries respectively, and that the discriminations produced closely matched the managers' respective views regarding the enquiries' overall attractiveness. Furthermore, the analyses established that there was considerable similarity between the managers' views. This suggested that it may be possible to produce an acceptable model of the TAG's reasoning based on the managers' combined construct system.

The results from the validation study (section 12.2.2 and section 13.2.3) again confirmed that there was considerable level of shared understanding between the managers used in TEES's development. The same results, however, indicated that there was much more variation in the views of the managers involved in the TAG as a whole. So, in retrospect the success of using repertory grid based techniques in TEES's development can be partly attributed to the high degree of consensus between the managers used during the knowledge acquisition and model development stages of its development. If two managers had been used whose views were less similar, then the grid analyses would have identified the conflict between the two managers, but would not, by themselves at least, have indicated how the conflict could have
been resolved. Consequently, it would have been impossible to justify combining the managers' construct systems in order to provide a broad based business perspective. These observations suggest that repertory grid based techniques are better suited to domains where there is a high degree of consensus and it is necessary to combine similar views to form a broader perspective, as for example in combining related areas of selective expertise, than they are for resolving conflict in domains where there is a low level of consensus.

Although the analyses of the managers' grid using FOCUS established their validity, they failed to highlight the managers' underlying conceptual structure. To achieve this objective a simple, but informative, method of analysis based on correlation analysis was devised. So, again the managers' grids were analysed independently and together this time using correlation analysis. The purpose of these analyses was to identify relationships between the 26 constructs and an additional construct overall attractiveness of enquiry. As was noted this led to a reduction in the number of constructs considered relevant, and to the development of conceptual maps which showed the hierarchical nature of the relationships between the key constructs used by the managers. These maps were validated by the managers and the remaining 17 constructs together with the construct overall attractiveness of enquiry were organised into a construct hierarchy. This hierarchy consisted of 11 base constructs together with 7 higher level constructs (including the construct overall attractiveness of enquiry) which the analyses suggested could be derived from the 11 base constructs (see table 9.5(i) and figure 9.5(ii)). Even this analysis, however, did not reveal the managers' reasoning because the precise nature of the relationships between domain concepts remained undefined. A further method of analysis was therefore devised to induce general rules or heuristics expressing the managers' reasoning using simple mathematical models. These heuristics were derived by determining the relative importance or weights of the constructs using statistical techniques on the data in the grids.

From the experiences with developing TEES several strengths of repertory grid based ES development methodologies have been identified. Firstly, the case study suggests that it is possible to use repertory grid based techniques successfully to elicit expert opinions in non-formal managerial domains characterised by unarticulated experiential based models which are not open to introspection. Secondly, repertory grid based techniques appear well suited to domains where there is a high degree of consensus and it is necessary to combine similar views from multiple sources to form a broader perspective. Finally, with the assistance of sophisticated mathematical and
Statistical techniques repertory grid based techniques can be used to develop qualitative descriptive models. Thus, quantitative techniques can be useful for expressing essentially qualitative relationships when experts find it difficult to articulate their knowledge.

The experiences in developing TEES, however, have also suggested that repertory grid based techniques have several weaknesses. Firstly, the models ultimately derived from grid based analyses can be biased by the small number of possibly unrepresentative elements in the grids, and in many cases could be influenced by the post-rationalisation of the experts' assessments. Secondly, if it is intended to use grid based methods to combine and/or contrast knowledge from multiple sources then in order to use robust and reliable direct comparison analysis methods it is necessary to use highly restrictive grid designs. Thirdly, the standard direct comparison methods of analysis provide only limited insights into experts' conceptual structures. In particular they are especially weak at highlighting the precise nature of experts' reasoning; and therefore it may be necessary to either adapt standard, or devise new, techniques for these ends in the domain under consideration. Finally, and perhaps most importantly, although grid based methods can identify conflict between experts, they are relatively poor at resolving conflict in domains where there is a low level of consensus.

This last conclusion raises the question of whose expertise should be modelled in domains where there is a low level of consensus amongst the relevant experts? An alternative perspective is to question how conflict be best resolved in order to obtain a consensus view amongst the relevant experts? One possible approach could be to use the iterative polling method Delphi with the relevant experts with the aim of producing a single consensual grid for subsequent analysis.

13.2.2 Discussion and evaluation of methods used to validate TEES

As previously noted TEES was developed based on the combined expertise of two managers. These managers' views, however, represented only a sample of those of the TAG as a whole and other managers, especially those from different functional or business specialisms, may view enquiries differently. Furthermore, TEES was developed from the two managers' views on fourteen historic enquiries. Although these enquiries were carefully selected to ensure representative coverage of the domain they only represented a sample of the characteristics of enquiries that may arise in the future. Together these observations highlighted the importance of an
extensive validation study, the objective of which was to establish the credibility of TEES with the TAG. Therefore, a framework was devised to establish whether or not TEES provides a valid representation of the TAG's bid versus no bid and bid resourcing decisions.

The framework involved establishing measures of TEES's performance using a combination of inter-expert and intra-expert tests. The inter-expert tests were used to establish how well TEES's perspective corresponded to that of those managers from business and functional specialisms who were not consulted in its development. In this respect these tests were used to determine whether TEES's perspective was unduly biased by the choice of managers used in its development. The intra-expert tests were used as a control to establish how well TEES's perspective corresponded to that of those managers who were used in its development. In this respect these tests were used to determine whether TEES's perspective was biased by the 14 enquiries, and/or the time period during which the enquiries used in its development were sampled. Together these tests enabled TEES's consensual business perspective to be measured, and thereby assisted in establishing the credibility of TEES with the TAG.

To perform the inter-expert and intra-expert tests six managers (including the two managers used in its development) were used. Together these managers provided a cross section of the various functional and business interests represented on the TAG. The aim, at least in theory, therefore was to obtain six independent views on a new and representative set of enquiries. These views were then assumed to be representative of each function's or business group's respective interests. In the validation study (see section 12.2.3) these six views were then compared against each other to identify the similarities and differences between the different business and functional perspectives. Moreover, each manager's view was compared against that expressed by TEES to determine how well TEES's perspective corresponded to that of each manager, and therefore that of each function or business group.

To perform these inter-expert and intra-expert tests a three dimensional database was constructed. This consisted of each manager's assessments on the 18 constructs $C_1 \ldots C_{18}$ used by TEES across a new and representative set of 17 enquiries. In effect this approach involved eliciting six repertory grids (one from each of the six managers) with identical element and construct labels as in the MINUS and CORE approaches. Unfortunately, it has been noted that there are well established weaknesses with these two approaches. The theoretical validity of the data base, therefore, rested on the assumption that for the managers literal similarity was a
reliable indication of conceptual similarity. That is, that each of the 18 constructs held the same meaning to each manager, and therefore that the observed differences on any construct were differences of opinion rather than differences in interpretation.

Furthermore, the results from the validation study have drawn attention to a further potential weakness with the overall validation approach (see section 13.2.3). The results suggested that the managers’ views may not have been truly independent. If this was the case, then there would be doubts as to the true validity of the inter-expert and intra-expert tests. To overcome this potential weakness, however, a second study was performed which compared TEES against a single consensus view. In theory, this approach itself required the identification of the real world process by which the TAG reaches its consensus based decisions. In practice, however, the consensus view was approximated by the average of the six managers assessments, although a more sophisticated and time consuming method such as the iterative polling method Delphi may have produced a more appropriate approximation.

TEES was designed as an ESS to assist the managers involved in the TAG with their bidding decisions, and therefore it was important to test the structure of TEES’s reasoning as well as its final bid versus no bid and bid resourcing decisions. In practice this was operationalised by measuring and testing TEES’s performance on the six intermediate level constructs (C12,...,C17) as well as the final bid versus no bid and bid resourcing recommendation C18. It was therefore assumed that TEES’s performance on these six constructs were reliable indicators as to the quality of the structure of its reasoning.

In establishing an ideal validity or performance measure for TEES it was important to identify a statistic that satisfied several criteria. Firstly, the statistic needed to emphasise both the precision and the accuracy of TEES’s results. Secondly, since the managers could not always be regarded as right in their assessments and decisions, it was important to identify a statistic that gave partial credit when TEES’s recommendations and the manager’s assessments were close. Thirdly, because the form of the distributions of the differences between the managers’ assessments and TEES’s responses were unknown, it was expedient if a non-parametric statistic was used. Fourthly, from a purely theoretical perspective, to interpret the results from the inter-expert and intra-expert tests required the use of an ANOVA type test. Such a test would have enabled it to be established whether or not TEES’s performance against any one manager was statistically any worse or better than it was against that of any other manager. Finally, in establishing the quality of TEES’s reasoning, then
owing to the hierarchical nature of the heuristics underlying TEES's knowledge base, some, but not all, of the system's intermediate results were correlated. Thus, to overcome the problems associated with correlated multiple responses multivariate statistics were more appropriate than repeated use of a univariate statistic on each higher level construct. In practice, however, it was not possible to meet all these criteria, and therefore a relatively simple non-parametric statistic known as weighted kappa $\kappa_w$ was used.

In the context of validating TEES weighted kappa $\kappa_w$ displayed several strengths. Firstly, like $\chi^2$, $\kappa_w$ is a non-parametric statistic. Secondly, unlike other contingency table based "goodness of fit tests" using $\chi^2$, the exact distribution of $\kappa_w$ was obtained and therefore exact significance tests could be performed. This meant that the paired observations in the contingency table did not need to meet any restrictive assumptions before the tests could be considered valid. Thirdly, unlike $\chi^2$, $\kappa_w$ is a measure of agreement rather than association, and furthermore enabled partial credit to be given when TEES's recommendations and a manager's assessments were close. Fourthly, like $\chi^2$, $\kappa_w$ is a relative rather than absolute measure and therefore took account of the influence of the distributions of the managers' assessments (and the dependent distributions of TEES's recommendations) on the expected observed level of agreement. Finally, $\kappa_w$ emphasised both the precision and accuracy of TEES's results.

In the context of validating TEES weighted kappa $\kappa_w$, however, also displayed several weaknesses. Firstly, owing to the qualitative nature of the managers' assessments and TEES's responses it was impossible to define a single justifiable measure of performance based on level of agreement using $\kappa_w$. It was therefore necessary to experiment with several sets of sensibly chosen scaled agreement weights so that the sensitivity of the results to the chosen weights, and therefore also to the precise definition of agreement and performance, could be established. Fortunately, this revealed that the observed levels of agreement were relatively insensitive to the weights chosen, and therefore to the precise definition of agreement and performance. If this had not been the case, then much more effort would have been required to elicit appropriate weights from the managers. Secondly, although weighted kappa $\kappa_w$ was sufficient to test for system validity, by itself it was not sufficient to explain the differences between TEES and a manager when there were low levels of observed agreement. This weakness was readily overcome, however, by using $\kappa_w$ in conjunction with a modified students t test. Thirdly, and perhaps most importantly, the tests using $\kappa_w$ only established that the observed levels of agreement
were better than those which could be reasonably expected due to chance happening. So, although the tests were a reliable indication of how well TEES corresponded to any manager's perspective, they did not measure the precise degree of correspondence between the two perspectives. Finally, it was not possible to generalise $\kappa_w$ into a multivariate statistic, nor incorporate it within an ANOVA type test. However, given the observed apparent non-independence of the six managers' views and the related questionable theoretical validity of the inter-expert and intra-expert tests, the latter of these weaknesses is largely irrelevant.

In summary the experiences with TEES have drawn attention to several difficulties in the validation of ES and ESS in non-formal managerial domains. First and foremost, the presence of multiple expertise suggests that inter-expert and intra-expert tests are appropriate. However, in domains where expertise is largely unarticulated and undocumented, as for example in bidding domains and management in general, there may be very little data available with which to validate the system. As with TEES, in these circumstances the construction of an appropriate data base may itself become a principle component of the validation process. The experiences with TEES, however, have demonstrated that the construction of such a data base gives rise to several problems. For, experience suggests that the experts' views may have been post-rationalised. This phenomenon could very easily occur in circumstances where the consequences of the experts' original decisions were already known at the time the data base was constructed. Thus, not only is it likely that suitable data is unavailable, it is also likely that subsequent attempts to obtain such data may be unreliable. When this is the case it has been shown that the experts' views are unlikely to be independent and therefore the inter-expert and intra-expert tests are of dubious value. It is proposed that in such circumstances an alternative approach to that of performing inter-expert and intra-expert tests is to validate the system using a single test against a consensus view. Even if this approach is followed, however, identifying the consensus view may be problematic!

Secondly, it was noted that for ESS it is important to validate the structure of its reasoning and intermediate results as well as its final recommendations. An ESS's intermediate and final recommendations will be correlated which suggests that formal multivariate statistical methods are appropriate. Furthermore, if inter-expert and intra-expert are appropriate, then ideally ANOVA type tests are also required. Together these observations suggest that very sophisticated statistical techniques are required to formally validate ES and ESS. However, the experiences with TEES suggest that in non-formal managerial domains, then owing to the qualitative nature
of the system's results and recommendations appropriate formal statistical measures of performance, or validity, are difficult to define. So, although in non-formal managerial domains formal statistical methods are appropriate they are very difficult to derive and use.

13.2.3 SUMMARY AND EVALUATION OF RESULTS FROM VALIDATION STUDY

This section briefly summarises and evaluates the most significant results obtained from both the formal and informal validation of TEES.

The overall objective of the study was to establish that TEES provided an appropriate, that is valid, representation of the organisation's consensual business perspective with respect to its bid versus no bid and bid resourcing decisions. This objective was operationalised into single hypothesis \(H_0\) given below.

\[ H_0: \text{TEES is valid if and only if both its intermediate results } (C_{12}, \ldots, C_{17}) \text{ and its final recommendation } (C_{18}) \text{ are consistent with those reached by the TAG.} \]

To investigate the truth or otherwise of \(H_0\) three further operational sub-hypotheses were formed. These were as follows.

\[ H_{01}: \text{(Intra-Expert Test) TEES's intermediate results } (C_{12}, \ldots, C_{17}) \text{ and its final recommendation } (C_{18}) \text{ are consistent with those reached by the managers used in its development?} \]

\[ H_{02}: \text{(Inter-Expert Test) TEES's intermediate results } (C_{12}, \ldots, C_{17}) \text{ and its final recommendation } (C_{18}) \text{ are consistent with those reached by the managers not used in its development?} \]

\[ H_{03}: \text{(Consensus Test) TEES's intermediate results } (C_{12}, \ldots, C_{17}) \text{ and its final recommendation } (C_{18}) \text{ are consistent with those of the managers' consensus view, namely the consensus of management opinion?} \]

Thus, TEES would be considered as valid if sub-hypotheses \(H_{01}, H_{02}\) and \(H_{03}\) could be established as being true. To investigate the truth or otherwise of these three sub-hypotheses two major studies were performed.
As previously noted, the first of these studies involved establishing statistical measures of TEES's performance using both intra-expert and inter-expert tests, and thereby tested the truth or otherwise of sub-hypotheses $H_{01}$ and $H_{02}$ respectively. In this first study, for each manager $M_q$ ($q=1, \ldots, 6$) and for each enquiry $E_r$ ($r=1, \ldots, 17$) the manager's assessments for the 11 base constructs were entered into TEES. TEES's intermediate results and its final recommendation were then compared to the manager's assessments for the 7 higher level constructs $C_{12}, \ldots, C_{18}$ and measures of performance were determined using weighted kappa $\kappa_w$. (For further details refer back to section 12.3.1.)

In the second study, the managers' individual assessments were used to derive a single set of assessments that represented the consensus view, referred to as the consensus of management opinion, on the 18 constructs and 17 enquiries. As in the first study, for each enquiry $E_r$ ($r=1, \ldots, 17$) the assessments for the consensus of management opinion on the 11 base constructs were entered into TEES. TEES's intermediate results and its final recommendation were then compared to the assessments for the consensus of management opinion on the 7 higher level constructs $C_{12}, \ldots, C_{18}$ and measures of performance were again determined using weighted kappa $\kappa_w$. This second study therefore tested the truth or otherwise of sub-hypotheses $H_{03}$. (For further details refer back to section 12.4.1.)

Before performing either of these studies, however, a preliminary study was performed that investigated the similarities and differences between the different business and functional perspectives of the managers included in the validation study. This study was performed by considering each of the 18 constructs $C_1, \ldots, C_{18}$ in turn. Then, for each construct $C_t$ ($t=1, \ldots, 18$) a pair-wise comparison was made for each possible pairing of two managers from six ($M_q, M_r$) ($q=1, \ldots, 6; r=q+1, \ldots, 6$). For each pair-wise comparison weighted kappa was again used to measure the similarity between the managers' perspectives on a given construct. (For further details refer back to section 12.2.1.) Furthermore, an informal validation study was also performed, and on two separate occasions prototypes of TEES were demonstrated to the organisation's senior management. During these demonstrations the managers were allowed to experiment with TEES and compare their own opinions against its recommendations on some of their past and current enquiries. The managers' comments during the demonstrations provided some informal feedback as to both TEES's validity and its benefits to the organisation. (For further details refer back to section 12.5.)
The preliminary study (investigating the similarities and differences between the different business and functional perspectives of the managers) revealed that, in general, there was a high level of agreement between the managers on the 7 higher level constructs which are believed to be the most influential in the bid versus no bid and bid resourcing decisions. Whereas on the 11 base constructs, which are believed to influence the higher level constructs, there was a considerably wider variation of opinion between the managers. Furthermore, the study revealed that the Marketing manager was not only more optimistic than the other managers, but that the variation in his assessments from one enquiry to the next was also different. From these observations it was concluded that the Marketing manager held a strongly dissenting view, a conclusion supported by the manager's own comments. Finally, it was revealed that there were very high levels of agreement between the Proposals and Business Group Managers. This last observation confirmed that there is a considerable level of shared understanding between the two managers whose views were sought to develop TEES, a conclusion previously drawn following the analysis of the managers' original grids with FOCUS.

Thus, it can be concluded that there is much more variation in the views of the managers involved in the TAG as a whole than there is between the two managers who were used in TEES' development. This suggests that the success of using repertory grid techniques in TEES' development may have been partly attributable to the choice of managers used. Moreover, this observation highlights the difficulties or possible infeasibility of developing a perfect system which adequately reflects the individual views of all parties involved. It therefore stresses the importance of the inter-expert tests to determine whether TEES was unduly biased by the choice of managers used in its development.

As previously noted the purpose of using six managers in the validation study was to obtain six independent views, representing the perspectives of the different business and functional perspectives, of the 17 enquiries in the validation set. The sharp contrast, however, between the levels of agreement amongst the managers on the 7 higher level constructs and the 11 base constructs respectively has a significant effect on how the results from the validation studies should be interpreted and the relative importance, or validity, of the sub-hypotheses $H_{01}, H_{02}$ and $H_{03}$. Two competing hypotheses have been proposed to explain this observed phenomenon.

The first hypothesis asserted that the six managers' views were indeed independent and that any observed correlation between their assessments was due to the fact that
they were assessing the same business opportunity and shared similar views as regards its attractiveness, or unattractiveness respectively. If this hypothesis was true, then the managers were using different cognitive processes to reach very similar conclusions. In establishing the validity of TEES, therefore, it was important to determine the extent to which the managers' cognitive processes differed. This validated the use of the inter-expert and intra-expert tests, and the importance of establishing the truth or otherwise of sub-hypotheses H_{02} and H_{01}.

The alternative, and perhaps more reasonable, hypothesis was that the managers' views were not truly independent. This was because the managers' assessments had been influenced by the consensus view already reached by the TAG, that is the managers' assessments had been post rationalised. If this hypothesis was true, then the validation data base would not reflect the full variation in the managers' opinions. Consequently, the inter-expert and intra-expert tests would only approximate the correspondence between a manager's cognitive processes and the perspective embedded within TEES. Thus, given the consensual nature of the TAG's decisions a more reliable method of validation would be to compare TEES against a single consensus view. Correspondingly, more emphasis should be associated with the results from the second validation study establishing the truth or otherwise of sub-hypothesis H_{03}. Furthermore, if this alternative hypothesis was true, then it suggests that TEES's perspective, which was induced from the original managers' grids, may have been influenced by the managers post rationalising their true assessments in light of the recommendations already reached at by the TAG.

Four inter-expert tests (investigating the truth or otherwise of sub-hypothesis H_{03}) were performed to measure the correspondence between TEES's perspective and those of the Finance, Manufacturing, Engineering and Marketing managers respectively. (The results from these tests are summarised in table 12.3.2). The results revealed very low levels of agreement between TEES and the Marketing manager; whereas generally, there were very high levels of agreement between TEES and the Finance, Manufacturing and Engineering managers respectively. It was therefore concluded that the perspective of the bid versus no bid and bid resourcing decisions embedded within TEES is markedly different from that held by the Marketing manager. Whereas, with small differences, the Finance, Manufacturing and Engineering managers' perspectives of the bid versus no bid and bid resourcing decisions are similar to that of TEES. By ignoring the Marketing manager's previously established dissenting view, it was concluded that the perspective
embedded within TEES was not unduly biased by the choice of managers used in its development.

Two intra-expert tests (investigating the truth or otherwise of sub-hypothesis $H_{01}$) were performed to measure the correspondence between TEES's perspective and those of the Proposals and Business Group managers respectively. (The results from these tests are summarised in table 12.3.2). Surprisingly perhaps, the results revealed that TEES is possibly a poorer representation of these managers' views than it is for the Finance, Manufacturing and Engineering managers. The results indicated an apparent change in these managers' views, and two possible explanations for this phenomenon were subsequently proposed.

The first explanation suggested that the managers feel there has been, or should be a change in the organisation's bid versus no bid and bid resourcing policy due to changes in its business environment. If this is true, then it is important to investigate ways of continually updating TEES to reflect changes in the organisation's policy.

Changing the construct weights $\alpha_j$ of the knowledge base heuristics would enable TEES's perspective to be altered; and therefore, in theory at least, this approach could be used to reflect changes in the organisation's policy. In practice, however, this approach would be difficult to implement and could also be potentially dangerous. To implement this approach would require the TAG to reinterpret changes in its policy in terms of the construct weights $\alpha_j$. Unaided by the knowledge engineer, however, it would be difficult for the TAG to evaluate and fully assess the implications of changes in the construct weights $\alpha_j$ on their bidding policy. Furthermore, if the changes in the TAG's policy were unarticulated and only operated at a subconscious level this approach would be almost impossible to implement. Moreover, allowing the TAG to alter the content of TEES's knowledge base raises potential dangers. The managers could very easily neglect to ensure that the construct weights $\alpha_j$ were normalised (although clearly checks could be made for this), and therefore over time TEES could become logically invalid.

An alternative approach to that of allowing the TAG to manually fine tune TEES would be to create a self-learning facility which enabled TEES to update itself in light of changes in the organisation's business environment. One possible approach for implementation would be to develop a learning program that induced new rules from a dynamic data base that was extended every time TEES was used to assist in an enquiry's evaluation. Over time the data base would therefore consist of the TAG's
assessment of all the enquiries which it vetted. The enquiries in the database could be weighted using an exponential weighting scheme to indicate the enquiries' recency and therefore their influence of the organisation's current policy. For this approach to be successful, however, TEES must be told when it is wrong, that is when its recommendations are out of line with those reached by the TAG. So, in this scenario every time the TAG were in disagreement with TEES, the TAG must not only override TEES's recommendations, but must also inform TEES of its optimal recommendations from which to learn from. Neither of these alternative are ideal, and therefore there are considerable difficulties to be overcome in maintaining the long term validity of TEES.

The second explanation was that the observed phenomenon was not so much the result of a change in policy, but the result of some of the highest level factors that influence the organisation's bidding decisions being excluded from TEES. If this was true, then it suggested that TEES had been biased by the enquiries and/or the period during which the enquiries used in its development were sampled. As previously noted this highlights a potential weakness with repertory grid based methods because the models derived can be biased by the small number of possibly unrepresentative elements in the grid.

It is, however, not only the non-independence of the managers' views that raises doubts as to the true validity of the inter-expert and intra-expert tests. Previously, it was stressed that the managers involved with the TAG contribute selective expertise to the bid versus no bid and bid resourcing decisions. Thus, on several constructs some managers were believed to be more qualified than others to provide expert assessments, and correspondingly some managers' assessments were believed to be more credible than others. This raises the question of whose views should TEES be ideally compared against? As previously noted, in turn this questions the relative importance of each of the inter-expert and intra-expert tests and also the statistical significance of the observed levels of agreement on each of the 7 higher level constructs in each test.

So, in summary, if it is assumed that the managers' assessments were not post-rationalised and therefore represented six independent views, then in theory the inter-expert and intra-expert tests are valid, but there are several problems with the relative significance of the results arising from the presence of selective expertise. If these problems are ignored the inter-expert tests suggest that TEES was not unduly biased by the choice of managers used in its development, and that the perspectives of the
Finance, Manufacturing and Engineering managers are similar to that of TEES. The intra-expert tests, however, highlight some potential problems with TEES's long term validity.

If, however, it is assumed that the managers' assessments were in fact influenced by the decisions that had already been reached by the TAG and were therefore not truly independent, then the inter-expert and intra-expert tests only approximate the correspondence between TEES's perspective and that of the managers. Under this premise it is more meaningful to validate TEES against single view which was representative of the consensus view of the TAG. This gives rise to the second validation study which determined the correspondence between TEES's perspective and that of the consensus of management opinion. Furthermore, given the consensual nature of the TAG's decisions this approach, and sub-hypothesis \( H_{03} \), is valid irrespective of whether the managers' assessments are independent or not.

A single test (investigating sub-hypothesis \( H_{03} \)) was therefore performed to measure the correspondence between TEES's perspective and that of the consensus of management opinion. (The results from this test are again given in table 12.3.2.) The high levels of agreement observed between TEES and the consensus of management opinion suggested that both the structure of TEES's reasoning and the final bid versus no bid and bid resourcing recommendation are consistent with the TAG's consensus view.

During the informal validation study the managers concluded that TEES's recommendations were in line with their own assessments. In those few cases where differences between the managers and TEES were observed, however, the managers felt that TEES had been more objective than they themselves had been. Furthermore, the managers believed that the researcher's intervention had helped the organisation to clarify its bidding expertise in a changing business environment. It highlighted the organisation's current bid versus no bid and bid resourcing policy and forced the organisation to reconsider what its ideal policy should be. The study also drew attention to some dissenting views amongst the organisation's senior management and also highlighted possible weaknesses within its own expertise which management deserved urgent consideration.

To summarise, it is concluded that TEES's reasoning and its final recommendations are consistent with those of the consensus of management opinion (sub-hypothesis \( H_{03} \)) and that the business perspective embedded within TEES has not been unduly
biased by the choice of managers used in its development (sub-hypothesis H_{02}).
These conclusions suggest that both TEES's reasoning and its final recommendations are consistent with those reached at by the TAG (overall hypothesis of model validity H_0). That is, TEES is valid and provides an appropriate representation of the TAG's consensual business perspective regarding the bid versus no bid and bid resourcing decisions.

Some weak evidence has been found, however, to suggest that some managers feel there has been, or should be, a change in the organisation's bid versus no bid and bid resourcing policy (sub-hypothesis H_{01}). If this is so, then there are potential problems with continually updating TEES to reflect the organisation's evolving policy.

The managers believed that TEES provided a simple but useful decision support tool for use by the TAG. They were convinced that TEES was both more consistent and objective than themselves. Furthermore, the ability to perform sensitivity type analyses within TEES was seen as a major benefit enabling the significance of uncertainty and dissent to be determined.

13.3 General Conclusions

A comprehensive review of the competitive bidding literature has revealed several weaknesses with previous bidding models. In particular, previous models fail to take into account the qualitative features prevalent in many bidding situations, and furthermore focus on optimal bid pricing whereas in many bidding situations the optimal resourcing of bids is of equal significance. It is suggested, therefore, that radically new approaches for improving bidding performance are required; and that the characteristics of expert systems (ES) suggest that they provide scope for further progress in this area.

An in depth case study concerning the development of an expert support system (ESS) to assist the senior management of a large electro-mechanical engineering company was undertaken. From this study it is possible to draw some tentative conclusions concerning the appropriateness of expert systems in competitive bidding and non-formal managerial domains in general. Before outlining these conclusions, however, it is expedient to highlight several limitations of the research study. Originally, it was proposed to carry out several small case studies; however, the time involved together with the difficulties in obtaining and maintaining a sufficient level
of collaboration in this highly commercially sensitive area suggested that this approach was infeasible. Consequently, the most significant limitation of the research is that it involves just one case study, and therefore any conclusions drawn should only be regarded as general observations from what experience suggests is a fairly typical bidding situation. Secondly, the success of the study was influenced considerably by the enthusiasm and commitment of the organisation's senior management and the excellent personal relationships developed. The level of collaboration maintained, therefore, has had a significant influence on the conclusions drawn. With these limitations in mind the general observations drawn from the case study are detailed below.

Several findings drawn throughout the study lead to the conclusion that both TEES's development and the researcher's intervention were overall a great success. First and foremost, the extensive support and co-operation from the organisation's senior management suggest that they are highly receptive towards introducing computer based support tools to assist them with their bidding decisions. In particular, the managers' comments and positive reactions towards TEES during its informal validation suggest that it has been possible to develop a simple, but appropriate, decision support tool incorporating knowledge based principles to assist the TAG in its bid versus no bid and bid resourcing decisions. Secondly, the results from TEES's formal validation suggest that its perspective has not been biased by the managers used in its development and that it provides a valid, or appropriate, representation of the TAG's consensual business perspective.

The study has also drawn attention to several reasons underlying TEES's success. Perhaps most importantly, it is because TEES represents the expertise of the managers at a conceptually high, and qualitative level. Its role is thus not to replace the managers, indeed TEES does not remove the need for senior management to make qualitative expert assessments on key issues, rather it is to focus the TAG's discussion towards an acceptable consensus view. TEES also provides several important and valued benefits to the organisation. TEES standardises the organisation's approach to the bid versus no bid and bid resourcing decisions by consolidating multiple sources of unarticulated expertise within a single knowledge base. This improves both the consistency and the objectivity of its bidding decisions by ensuring that decisions are reached systematically and that enquiries are evaluated equitably. Furthermore, the ability to perform sensitivity type analyses within TEES enables management to assess the significance of uncertainty and dissent to be determined. Finally, the researcher's intervention was itself beneficial to the organisation because it assisted
senior management in clarifying both their expertise and their current bid versus no bid and bid resourcing policy. In particular, it focussed attention on the key issues and their inter-relationships influencing their bidding decisions, drawn attention to some strongly dissenting views amongst the organisation's senior management and highlighted areas of weakness within their own understanding of the enquiry evaluation process.

TEES is not, however, without it weaknesses, and several findings point to potential difficulties with its ultimate acceptance and use by the TAG. Firstly, the results from the formal validation study highlight the possibility of an apparent change in the organisation's bid versus no bid and bid resourcing policy; and two alternative explanations for this phenomenon have been proposed. The first is that some managers feel there has been, or should be, a change in the organisation's policy. If this is the case, then there are several problems associated with continually updating TEES to reflect a dynamic policy. The alternative explanation is that some of the highest level factors which influence the organisation's bidding decisions have been excluded from TEES. If this is the case, then TEES's perspective is not sufficiently general because it has been unduly influenced by the time period during which the enquiries used in its development were sampled. In either case the observed phenomenon highlights problems in TEES's overall long term validity. Secondly, during TEES's informal validation the managers' began to question the rationale underlying their current bidding policy. In particular, the most senior manager expressed some doubts as to whether their current policy, as described by TEES, was the policy that the organisation should be adopting. This last observation points to the conclusion that the managers were themselves unconvinced of the adequacy their own policies. If this is truly the case, then a purely descriptive model such as TEES may not be ultimately acceptable, and a non-native model expressing the organisation's ideal bidding policy is required.

It has been noted that the generic model of the competitive bidding process includes a preliminary assessment of the customer's enquiry documents which leads ultimately to a contractor's bid versus no bid decision. Furthermore, in general, different contracts differ in their relative attractiveness to any given contractor, and therefore different levels of bidding resources or bidding effort are appropriate for different contracts. In this respect the case study organisation's approach to tender enquiry evaluation (and the related decisions as whether or not to bid and the level of resources to allocate to preparation of the bid proposal) is representative of a fairly typical bidding situation. This is especially true of those situations where the cost of
bidding is high due to a significant amount of design work creating a large front end cost.

So, given the successful experiences with TEES, it can be concluded that expert systems are appropriate for modelling competitive bidding situations, at least in modelling decisions concerning whether or not to bid and the level of resources to allocate to preparation of the bid proposal. The experiences with TEES suggest that beneficial expert systems need not be large nor complicated, and as previously noted TEES represents the managers' expertise at a conceptually high, and qualitative level. It does not remove the need for senior management to make qualitative expert assessments on key issues, and indeed given the operational importance of a contractor's bidding decisions this could be a pre-requisite for any such system's acceptance. If this is the case, then it appears that systems which support bidding managers in their decisions are more appropriate than systems whose role is to direct the responsibility for bidding decisions towards less experienced personnel. Furthermore, the experiences with TEES indicate that the principle benefits deriving from the use of ESS in competitive bidding are the clarification and consolidation of multiple sources of unarticulated experiential 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 bidding decisions. A closely related benefit is the ability to use an ESS to perform sensitivity type analyses to evaluate the consequences of a variety of scenarios. This is particularly beneficial in bidding situations where the ultimate decision is the result of social interaction between several managers and where it is therefore necessary to reach a consensus decision. In such situations ESS are beneficial in determining the significance of minor differences of opinion between the managers, and thereby focussing the attention of the group onto the key issues where a consensus is required.

The case study organisation's situation is representative of a fairly typical bidding situation. In particular, like many bidding situations the domain of tender enquiry evaluation is characterised by selective multiple expertise and unarticulated experiential, rather than theory, based models. As the development and validation methodologies devised in previous chapters of this thesis were strongly influenced by these characteristics, then given the success of these methodologies in the development and validation of TEES they may also be appropriate, with some adaptations, for developing ESS in similar bidding situations. For example, this thesis has analysed bidding situations from the bidders' eye view and has investigated the contractor's evaluation of the customers' tender enquiries or invitations to tender.
Customers, however, also need to evaluate, or appraise, the suppliers' bid proposals and their problem shares several characteristics with that of a contractor evaluating customers' enquiries. ESS could therefore 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 business for competitive tender. Moreover, this conclusion also suggests that ESS and the methodologies devised in this thesis may be appropriate in other non-formal managerial domains which are characterised by selective multiple expertise and which contain classification, diagnosis, or evaluation type problems. Furthermore, the research study suggests that mathematical modelling 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 time taken to develop and validate TEES, however, highlight that there are several problems to be overcome if commercially viable ESS are to be developed for use in competitive bidding and other non-formal managerial domains.

First and foremost, the experiences with TEES raises the important question of what are the most appropriate methods with which to develop qualitative descriptive models of expertise in non-formal managerial domains such as competitive bidding? Such domains are characterised by selective multiple expertise and unarticulated experiential based models, and therefore there is a need to elicit indirectly and then combine and contrast several experts' or managers' knowledge. From the successful experiences with TEES it can be concluded that repertory grid based methods are one such method. The study has, however, also highlighted several shortcomings with such methods. In particular, it has 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 very beneficial. Furthermore, the study has shown that standard grid based analysis techniques provide limited insight into an expert's conceptual structure of a domain, and that it may be necessary to complement these techniques with sophisticated mathematical modelling and statistical techniques. In light of these limitations it is expedient to determine which other techniques are also appropriate.

Secondly, the experiences with TEES have highlighted several problems with the validation of ES and ESS in non-formal managerial domains. In particular, the presence of multiple expertise raises the question of who a system should be validated
against? The study suggests that inter-expert and intra-expert tests can be used to detect any bias in a system's perspective. However, if replicative validity is used as the criteria, then such tests may be of dubious value because of the unreliability of the validation data due to experts post-rationalising their respective views. An alternative to using inter-expert and intra-expert tests is to validate the system against a single consensus view. If this approach is followed, however, then it is important to identify or approximate the real world process by which the consensus view is reached. Furthermore, if the system's results consist of essentially qualitative recommendations and these are being compared with an expert's subjectively based qualitative assessments then there are difficulties in defining an appropriate performance metric.

Thirdly, the study has highlighted that in dynamic domains there can be problems in maintaining the long term validity of such systems. Finally, the research suggests that in some situations ESS 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 a normative element, these systems may be ultimately unacceptable to managers.

In summary, this research study has established that it is possible to develop simple, but appropriate, expert support systems (ESS) to assist bidding managers with their bidding decisions. However, owing to the nature of competitive bidding domains several important issues need to be addressed before such systems can be regarded as commercially viable.

13.4 Future Work

The research presented in this thesis has been both exploratory and experimental in its nature. It has raised several important questions and these indicate possible directions in which future work in this area could be pursued.

The difficulty in obtaining a sufficient level of collaboration in the highly commercial sensitive area of competitive bidding together with the time taken to successfully develop and validate EES meant that only one case study could be pursued in any depth. This case study focussed on developing an ESS for use during the early stages of a contractor's bidding process, namely to assist in the bid versus no bid and bid resourcing decisions. However, the majority of previous bidding studies have
focussed on the final stages of a contractor's bidding process, namely final bid pricing. This is an area which is especially important within the construction and civil engineering industries where traditionally there is lower design content and the bid price is often a contractor's sole competitive weapon. Thus, one possible direction for future work would be to establish whether it is also possible to develop appropriate ESS to assist bidding managers in their pricing decisions.

One potential weakness with the use of ES and ESS in competitive bidding is that traditionally such systems are based on purely descriptive models. For, if bidding managers feel there are inadequacies within their own bidding expertise then systems which aim to replicate or emulate the same inadequacies may not find acceptance. If this is the case, then it is expedient to investigate whether it is possible to enhance or complement an ES or ESS's descriptive knowledge base with a normative component. One possible direction in which this could be pursued is to investigate the possibilities of using an ES's descriptive knowledge base as an experimental tool, as akin to the probabilistic strategy approach to bid pricing. The parameters within an the knowledge base could be manipulated and the resulting performance of the contractor evaluated. These experiments could be used to find improvements in the contractor's bidding policy, and thus change a descriptive model towards a normative type model expressing the contractor's ideal policy.

The research has highlighted the need to determine what methods are appropriate for developing ES (and ESS) in non-formal managerial domains. The MS/OR community has developed several formal tools to investigate the structure of non-formal, semi-structured managerial domains, although these have not been used explicitly within the context of ES development. These include the theory of multi-attribute decision aiding and the analytical hierarchy process. Furthermore, the Delphi method is a technique which can be used to develop a consensus within a group and which could therefore be used to produce a single consensual repertory grid for subsequent analysis. As such it would be expedient to review and compare these methods and investigate how they could be adapted for use specific to ES development.
APPENDIX A
PROPOSAL FOR COLLABORATIVE RESEARCH IN THE USE OF EXPERT SYSTEMS IN COMPETITIVE TENDERING

SUMMARY

Background

Past studies aimed at providing decision support in the management of competitive tenders based on statistical models, have had little practical success.

With the advent of Expert Systems a new, better and more practical approach is available.

Objectives

The overall objective is to develop and measure the benefits of Expert Systems in the management of competitive tenders

This process will include the following stages:

* Problem Definition and Refinement
  * Four possible areas of application have been identified:
    1. Determining an appropriate price and package
    2. Whether or not to bid
    3. Decisions concerning the most appropriate design
    4. The amount of tendering effort
* Knowledge Elicitation
* Programming and Testing
* System Evaluation (Measure the benefits)
Benefits

Expert Systems are:

* Consistent
* Comprehensive
* Complete

Together these benefits will ensure that tendering opportunities are evaluated in a systematic and equitable manner.

In addition expert systems offer the capability of being used as experimental management tools for evaluating different tendering strategies.

Through collaboration the organisation would have access to the researchers' expertise, together with full use of the system(s) developed.

Level of Commitment

The collaborative project will take place over a 6 to 9 month period.

All programming will be undertaken by the researchers, but the collaborating organisation will need to become actively involved in several areas of the research:

* Problem Definition
  - General Familiarisation (3 x 2 hrs)
  - Specific Problem Identification (2 x 2 hrs)
* System Development
  - Knowledge Elicitation (6 x 2 hrs)
  - System Testing (2 x 2 hrs)
* System Evaluation (1 hr per week over a 3 month period)

Confidentiality

The researchers guarantee that the strictest confidentiality will be maintained.

Researchers

Dr. M. King MA. Dip Ad Math. D.Phil.
Mr. G. J. Phythian BSc. MSc.(Dist).
PROPOSAL FOR COLLABORATIVE RESEARCH IN THE USE OF EXPERT SYSTEMS IN COMPETITIVE TENDERING

By
Dr. M. King &
Mr. G. J. Phythian.

Dept. of Management Studies,
University of Technology,
Loughborough.
PROPOSAL FOR COLLABORATIVE RESEARCH IN THE USE OF EXPERT SYSTEMS IN COMPETITIVE TENDERING

Background

For those organisations who obtain their business through competitive tendering the implementation of a successful tendering strategy is of paramount importance. This is reflected by the substantial amount of published work aimed at improving an organisation's final pricing decision. This work has relied upon the use of statistical models, but has had limited success. The major failings of the statistical modelling approaches can be seen as:

1. Not taking into account the qualitative features prevalent in many tendering situations
2. Not recognizing that in real life situations decisions need to be made with limited and inaccurate information.

Expert systems offer a new approach to modelling tendering situations. An expert system aims to capture human expertise. This expertise consists of knowledge, judgement and experience, and is more often qualitative in nature rather than quantitative. Expert systems can also reason with a combination of incomplete and uncertain information. These modelling capabilities closely match the type of reasoning carried out by managers preparing tenders. Given the importance of competitive tendering to an organisation's survival and prosperity it is worth investigating the possible benefits of expert systems in tendering situations.

Objectives

The overall objective of the proposed research is to develop and measure the benefits of expert systems in the management of competitive tenders.

Four areas within the tendering process where expert systems could be of value have been identified. These are as follows:

1. Determining an appropriate price and package
2. Whether or not to bid
3. Decisions concerning the most appropriate design
4. The amount of tendering effort

It is suggested that the first area is where the payoff from gains in improved performance will be greatest. In addition by adopting an expert systems approach to modelling the pricing decision, a comparison with the previous statistical modelling approaches can be achieved.

Past studies have suggested that an important factor in the successful development of expert systems is the full support and cooperation of both management and domain experts. Recognizing this, it is suggested that the most fruitful approach to collaboration would be if
the collaborating organisation became actively involved in identifying those stages within the tendering process where expert systems would be most beneficial. Thus the four areas of possible application outlined above can be viewed as a starting point for negotiation in identifying a suitable application to tackle.

Benefits

Expert systems are an important development in management decision support / making tools. Through their use both the effectiveness of experts and non experts alike can be improved.

In many successful expert system applications the objective has been to disseminate or share scarce and valuable expertise. This has allowed non experts to tap into the expert's knowledge, resulting in a redistribution of responsibilities to less qualified personnel, and an increase in their own capabilities.

Some successful systems outperformed the experts. Such behaviour does not suggest that expert systems are either more intelligent or knowledgeable than their human counterparts, but that they are reliably systematic, and under certain circumstances can be more objective than human experts. As a result, the experts were led to question their own reasoning. Frequently, the experts were willing to alter their own judgments, recognizing that they had ignored relevant material, misinterpreted or miscalculated results, etc. This argument suggests that expert systems can be used by experts themselves to support their own decision making. The benefits from using expert systems as decision support tools are that human fallibility and bias are minimised. These benefits are derived from an expert system's consistent, comprehensive and complete nature.

1. Consistency

Given the same (or similar) set of inputs then the same (or similar) set of outcomes or results is obtained.

2. Comprehensiveness

All of the available relevant information is taken into account in tackling the problem at hand.

3. Completeness

All information which is relevant to tackling the problem at hand is sought.
It is suggested that it is a decision support type expert system which will provide the greatest benefits to the management of competitive tenders. Such systems through their consistent, comprehensive and complete nature will allow the evaluation of different tendering opportunities to be made in a reliably systematic and equitable manner.

An additional possible benefit in the use of expert systems, but as yet largely unresearched, is their use as experimental management tools, as akin to simulation techniques. The researchers envisage the possibility of changing or adding new parameters to the knowledge base of an expert system, and then investigating the effect in a safe simulated environment.

**Level of Commitment**

It is envisaged that collaboration would need to take place over a 6 to 9 month period. During this time the collaborating organisation would need to become actively involved in several areas of the research. The collaborative process can be described in three stages.

1. **Problem Definition**

The first stage of collaboration would involve finding and adequately defining a suitable application area within the tendering process. Before this could be achieved the researchers would need to be familiarised with a general overview of the organisations tendering effort. This can be achieved through some general discussions with key personnel within the tendering function. From such discussions the researchers would hope to learn about the individual and collective responsibilities of the tender function personnel, and about the organisations approach to the various stages of the tender process (i.e. whether to bid, design elements, costing, pricing and tender submission).

Following this familiarisation, the next step would be to identify an area within the tendering process where the use of expert systems would be beneficial. Several factors that should be taken into account when choosing an appropriate application are listed below.

* Experts do indeed exist
* The application is supported by management
* The expert(s) is / are willing to cooperate
* The application has high value to the organisation
2. System Development

This stage takes on an iterative process, cycling through the sub-stages of knowledge elicitation, programming, and testing, until an acceptable system is produced. The nature of these three sub-stages are outlined below.

**Knowledge Elicitation**

Relevant knowledge must be elicited from the experts and other sources, in order that it can incorporated within the expert system. Sources of knowledge which may be available are

* Documentation (ie Company Procedures etc.)
* Experts
  - Open Ended Interviews
  - Semi-structured interviews
  - Interviews based around case studies
  - Live observation
* Previously documented tenders

It is envisaged that knowledge concerning the following areas would be incorporated within a system.

* Organisational objectives
* Current position
* Market trends
* The nature of the contract
* The nature of the competition
* The nature of the customer

**Programming**

The elicited knowledge would be analysed and then programmed into the knowledge base of an expert system shell. One of either the shells Leonardo or Xi-Plus would be used. The researchers have been periodically working with one or other of these shells for over a year, and are knowledgeable about their relative advantages and capabilities. The researchers are experienced programmers with extensive experience in Pascal and C. During this programming stage of the research no collaborative effort is required.
System Testing

The aim of this stage is to ensure that the systems results and reasoning are consistent with those derived and used by the experts themselves. During this stage the collaborating organisation would be involved in the following ways.

* Providing suitable test data
* Commenting on the system's reasoning and results
* Discussing errors, changes and possible improvements to the system with the researcher

3. System Evaluation

During this stage the researchers aim to measure the benefits of the developed system. The researchers would hope to carry out a parallel trial study lasting about 3 months. During this period the system's outputs would be compared with those decisions made by the personnel within the tendering function. This would involve the researchers visiting the collaborating organisation on a regular basis, perhaps once a week, in order to run the cases through the system, and collect and collate the relevant data.

Confidentiality

It is recognized that competitive tendering is a particularly commercially sensitive area in which to seek collaboration. The researchers can guarantee that the confidentiality would be maintained. In particular the researchers would guarantee the following.

* The collaborating organisation's identity would be withheld from any oral or written form of communication
* The nature of the industry would be protected
* The precise nature of the collaboration would be protected
* All data, information and results would be protected
* Any work which is to be published from the research would be heavily disguised and submitted to the collaborating organisation for approval.

Researchers

Dr. M. King MA. Dip Ad Math, D.Phil.
Mr. G. J. Phythian BSc, MSc.(Dist).
Appendix B contains the output from the analysis of the Business Group Manager's, the Proposals Manager's and the Managers' combined grids respectively using FOCUS.

Figure 8.4.2(1)(i) The Business Group Manager's Grid 356
Table 8.4.2(1)(ii) Percentage Similarity Matrix for the 12 Enquiries in the Business Group Manager's Grid 357
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Figure 8.4.3(vi) The Managers' Combined Focused Grid 371
![Figure 8.4.2(1)(i) The Business Group Manager's Grid](image)

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<th>E1</th>
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<th>E4</th>
<th>E5</th>
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<th>E10</th>
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<td>3</td>
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**Bid Decision Category**

| A N C C B R N B A N B A |
Table 8.4.2(1)(ii) \textbf{Percentage Similarity Matrix for the 12 Enquiries in the Business Group Manager's Grid}

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Figure 8.4.2(1)(iv)  Dendogram showing the Clustering of the 12 Enquiries in the Business Group Manager's Grid
Figure 8.4.2(2)(v)  Dendogram showing the Clustering of the 11 Constructs in the Business Group Manager's Grid
Figure 8.4.2(1)(vi) The Business Group Manager’s Focused Grid

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Bid Decision Category

N N B N C R B B A A A A C
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**Bid Decision Category**

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Figure 8.4.2(2)(iv) Dendogram showing the Clustering of the 12 Enquiries in the Proposals Manager's Grid
Figure 8.4.2(2)(v) Dendogram showing the Clustering of the 15 Constructs in the Proposals Manager's Grid
Figure 8.4.2(2)(vi) The Proposals Manager's Focused Grid

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**FOCUSED GRID (PROPOSALS MANAGER)**
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Table 8.4.3(ii)  
Percentage Similarity\(^1\) Matrix for the 10 Enquiries in the Managers' Combined Grid

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\(^1\) Similarity between Enquiries being Measured Across All 26 Constructs in the Managers' Combined Grid
Table 8.4.3(iii) Percentage Similarity Matrix for the 26 Constructs in the Managers' Combined Grid
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I

C2

c3

c,

cS

C6

c7

C8

C9

clO

Cll

C12

C13

Cl'

C15

C16

c17

C18

C19

C20

c2l

C22

C23

C24

c25

C26

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Figure 8.4.3(iv) Dendogram showing the Clustering of the 10 Enquiries in the Managers' Combined Grid
Figure 8.4.3(v) Dendrogram showing the Clustering of the 26 Constructs in the Managers' Combined Grid
### Figure 8.4.3(vi) The Managers' Combined Focused Grid

#### Focused Repertory Grid Data (Proposals & Business Group Manager)

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<th>E7</th>
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<tr>
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APPENDIX C
Appendix C contains the results from the analysis of the Business Group Manager's, the Proposals Manager's and the Combined Managers' Grids using correlation analysis respectively.

Table 9.4.1(i) Correlation Matrix for the Business Group Manager's Constructs 374

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Table 9.4.1(i)  Correlation Matrix for the Business Group Manager's Constructs

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<sup>a</sup> Significant at the 0.5% level
<sup>b</sup> Significant at the 1.0% level
<sup>c</sup> Significant at the 2.5% level
Figure 9.4.1(ii)  The Business Group Manager's Conceptual Map

C9 Work For A Low/High Loaded Factory

C10 Attractiveness of Build Size

C8 Availability of Manufacturing Capacity

C7 Competitiveness of Price

C6 Chances of Additional Business

C11 Level of Competition

C2 Level of Technical Risk

C5 Level of Manufacturing Investment

C1 Availability of Design

C4 Level of Financial Risk

C3 Added Value

C6 Significant at the 0.5% level
b  Significant at the 1.0% level
c  Significant at the 2.5% level
Figure 9.4.1(iii) The Business Group Manager's Validated Conceptual Map

C9 Work For A Low/High Loaded Factory

C10 Attractiveness of Build Size

C4 Level of Financial Risk

C7 Competitiveness of Price

C8 Availability of Manufacturing Capacity

C3 Added Value

C6 Chances of Additional Business

C11 Level of Competition

C2 Level of Technical Risk

C5 Level of Manufacturing Investment

C1 Availability of Design

C12 Level of Manufacturing Investment

C13 Level of Manufacturing Investment
Table 9.4.2(i) Correlation Matrix for the Proposal Manager's Constructs

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a Significant at the 0.5% level
b Significant at the 1.0% level
c Significant at the 2.5% level
Figure 9.4.2(ii) The Proposals Manager's Conceptual Map

- $C_7$ Demands on Bid Resources
- $C_8$ Demands on Design & Build Resources
- $C_1$ Standard/Customer Design
- $C_9$ Desire to be in Market
- $C_{13}$ Knowledge of Customer
- $C_5$ Chances of Project Going Ahead
- $C_{11}$ Prospects of Available Finance
- $C_{10}$ Level of Competition
- $C_{14}$ Probability of Success
- $C_{12}$ Nature of Formal Enquiry
- $C_2$ Size of Order
- $C_4$ Potential Profitability
- $C_6$ Level of Involvement
- $C_{15}$ Ability to Meet Delivery Targets

Significance levels:
- Significant at 0.5% level
- Significant at 1.0% level
- Significant at 2.5% level
Figure 9.4.2(iii) The Proposals Manager's Validated Conceptual Map

- $C_{14}$ Probability of Success
  - $C_7$ Demands on Bid Resources
  - $C_1$ Standard/Customer Design
  - $C_8$ Demands on Design & Build Resources

- $C_3$ Chances of Further Business
  - $C_{13}$ Knowledge of Customer
  - $C_9$ Desire to be in Market
  - $C_2$ Size of Order
  - $C_4$ Potential Profitability

- $C_5$ Chances of Project Going Ahead
  - $C_{11}$ Prospects of Available Finance

- $C_{10}$ Level of Competition
  - $C_{14}$ Probability of Success

- $C_6$ Level of Involvement
  - $C_{15}$ Ability to Meet Delivery Targets
Figure 9.4.3(i) The Conceptual Map Derived From the Managers' Combined Grid

- \( C_2 \) Size of Order
- \( C_3 \) Chances of Project Going Ahead
- \( C_4 \) Nature of Formal Enquiry
- \( C_5 \) Chances of Further Business
- \( C_6 \) Chances of Additional Business
- \( C_7 \) Nature of Formal Enquiry
- \( C_8 \) Added Value
- \( C_9 \) Level of Competition
- \( C_{10} \) Level of Competition
- \( C_{11} \) Level of Competition
- \( C_{12} \) Level of Competition
- \( C_{13} \) Level of Competition
- \( C_{14} \) Level of Competition
- \( C_{15} \) Level of Competition
- \( C_{16} \) Level of Competition
- \( C_{17} \) Level of Competition
- \( C_{18} \) Level of Competition
- \( C_{19} \) Level of Competition
- \( C_{20} \) Level of Competition
- \( C_{21} \) Level of Competition
- \( C_{22} \) Level of Competition
- \( C_{23} \) Level of Competition
- \( C_{24} \) Level of Competition
- \( C_{25} \) Level of Competition
- \( C_{26} \) Level of Competition

- \( a \) Significant at 0.5% level
- \( b \) Significant at 1.0% level
- \( c \) Significant at 2.5% level
Figure 9.4.3(ii) The Validated Conceptual Map Derived From the Managers' Combined Grid
Table 9.5(i)  A List of the 18 Constructs in the Overall Construct Hierarchy

**Base Constructs (11)**

- $C_1$ Standard of the Formal Enquiry
- $C_2$ Prospects of Available Finance
- $C_3$ Availability of Design
- $C_4$ Demands on Bid Resources
- $C_5$ Availability of Manufacturing Capacity
- $C_6$ Level of Manufacturing Investment
- $C_7$ Size of Order
- $C_8$ Expected Added Value
- $C_9$ Level of Involvement
- $C_{10}$ Chances of Further Business
- $C_{11}$ Level of Competition

**Higher Level Constructs 7 (6 Intermediate Results + 1 Overall Recommendation)**

- $C_{12}$ Chances of the Project Going Ahead
- $C_{13}$ Potential Profitability
- $C_{14}$ Level of Technical Risk
- $C_{15}$ Level of Financial Risk
- $C_{16}$ Competitiveness of Price
- $C_{17}$ Probability of Success
  -
- $C_{18}$ Overall Attractiveness of the Enquiry
Figure 9.5(ii) The Overall Construct Hierarchy
APPENDIX D
The Exact Distribution of Weighted Kappa $\kappa_w$

Cohen's (1968) weighted kappa ($\kappa_w$) is defined by

$$\kappa_w = \frac{\sum \sum W_{ij} F_{ij} - \sum \sum W_{ij}(M_i M_j / n)}{(W_{\text{max}}^2 - 1) - \sum \sum W_{ij}(M_i M_j / n)}$$

eq. 11.5.1(ii)

$n$ = Sample Size

$m$ = Number of Categories

$F_{ij}$ = Frequency of pair $(i,j)$: System's recommendation $= i$ & Manager's recommendation $= j$

$W_{ij}$ = Scaled Agreement Weight for cell $(i,j)$

$W_{\text{max}}$ = Maximum Scaled Agreement Weight ($W_{\text{max}} \geq W_{ij}$)

$M_i = \sum_{j=1}^{m} F_{ij}$

$M_j = \sum_{i=1}^{m} F_{ij}$

Inspection of eq. 11.5.1(ii) reveals that given any matrix of scaled agreement weights $W_{ij}$ and marginal frequency distributions $M_i$ and $M_j$ respectively, the stochastic nature of $\kappa_w$ under the null hypothesis of chance agreement $H_0$ is dependent solely upon the stochastic nature of the total level of scaled agreement $T$, a simple linear transform of $\kappa_w$, given by

$$T = \sum_{i=1}^{m} \sum_{j=1}^{m} W_{ij} F_{ij}$$

So, to determine the probability distribution of $\kappa_w$ under $H_0$ it is sufficient to determine the probability distribution of $T$ under $H_0$ given the same matrix of weights $W_{ij}$ and marginal distributions $M_i$ and $M_j$ respectively.

To determine the probability distribution of $T$ under $H_0$ assume that each weight $W_{ij}$ is an integral value. Then define $W_{\text{max}} + 1$ probabilities $p(w) (w = 0, 1, ..., W_{\text{max}})$ as the probability that any single observation lies in a cell in the table with corresponding weight $W_{ij} = w$.

Each $p(w)$ can be obtained by summing over all $m \times m$ cells the cell probabilities of all cells which contain a $W_{ij} = w$. Thus $p(w)$ is given by

$$p(w) = \sum \sum (M_i M_j / n^2) \delta_{ij} \quad w = 0, 1, ..., W_{\text{max}}$$
where,
\[ \delta_{ij} = 1 \text{ if } W_{ij} = w \]
\[ \delta_{ij} = 0 \text{ if } W_{ij} \neq w \]

The total level of scaled agreement, \( T \), can thus be expressed as
\[
T = \sum_{w=0}^{W_{\text{max}}} w \times F_w
\]
where,
\[
F_w = \sum_{i=1}^{m} \sum_{j=1}^{m} F_{ij} \delta_{ij}
\]
and
\[
\delta_{ij} = 1 \text{ if } W_{ij} = w \\
\delta_{ij} = 0 \text{ if } W_{ij} \neq w
\]

Given a sample size of \( n \), let \( P_n(T = k) \) denote the probability that the statistic \( T \) assumes the value \( k \) (\( 0 \leq k \leq n \times W_{\text{max}} \)). Therefore, when \( 0 \leq k \leq W_{\text{max}} \), the probability that \( T \) assumes the value \( k \), \( P_n(T = k) \) is given by
\[
P_n(T = k) = \sum_{A} (n! / n_0!n_1! \ldots n_k!) p(k)^{n_k} \ldots p(0)^{n_0} \delta_{n_0} \ldots \delta_{n_k}
\]

where,
\[ A = \{ \text{positive integers : } n_0 + n_1 + \ldots + n_k = n \} \]
\[
\delta_{n_0} \ldots \delta_{n_k} = 1 \text{ if } (0 \times n_0) + (1 \times n_1) + \ldots + (k \times n_k) = k \\
\delta_{n_0} \ldots \delta_{n_k} = 0 \text{ if } (0 \times n_0) + (1 \times n_1) + \ldots + (k \times n_k) \neq k
\]

When \( W_{\text{max}} < k \leq W_{\text{max}} \times n \), then \( P_n(T = k) \) can be defined recursively by
\[
P_n(T = k) = \sum_{w=0}^{W_{\text{max}}} p(w) P_{n-1}(T = k - w)
\]

Finally, when \( k > W_{\text{max}} \times n \) then \( P_n(T = k) = 0 \).

A program was written using Turbo Pascal v3.0 to calculate the probability distribution of \( T \) under \( H_0 \) for given marginal frequency distributions \( M_i \) and \( M_j \) and a given matrix of scaled agreement weights \( W_{ij} \). The program was validated informally using simulation.
APPENDIX E
Appendix E contains the tabulated results from the formal validation study described in chapter 12.

Tables 12.2.2(A)(i)-12.2.2(A)(xviii) Show the Pair-Wise Total Level of Scaled Agreement, T between the Six Managers included in the Validation Study for each of the 18 Constructs.

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Table 12.2.2(A)(ii)  \( C_2 \) Prospects of Available Finance  391
Table 12.2.2(A)(iii)  \( C_3 \) Availability of Design  392
Table 12.2.2(A)(iv)  \( C_4 \) Demands on Bid Resources  392
Table 12.2.2(A)(v)  \( C_5 \) Availability of Manufacturing Capacity  392
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Table 12.2.2(A)(vii)  \( C_7 \) Size of the Order  393
Table 12.2.2(A)(viii)  \( C_8 \) Expected Added Value  393
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Table 12.2.2(A)(x)  \( C_{10} \) Chances of Further Business  393
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Table 12.2.2(A)(xii)  \( C_{12} \) Chances of the Project Going Ahead  394
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Table 12.2.2(A)(xiv)  \( C_{14} \) Level of Technical Risk  394
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Table 12.2.2(A)(xviii)  \( C_{18} \) Overall Attractiveness of Tender Enquiry  395

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Table 12.2.2(B)(ii)  \( C_2 \) Prospects of Available Finance  397
Table 12.2.2(B)(iii)  \( C_3 \) Availability of Design  398
Table 12.2.2(B)(iv)  \( C_4 \) Demands on Bid Resources  398
Table 12.2.2(B)(v)  \( C_5 \) Availability of Manufacturing Capacity  399
Table 12.2.2(B)(vi)  \( C_6 \) Level of Manufacturing Investment  399
Table 12.2.2(B)(vii)  \( C_7 \) Size of the Order  400
Table 12.2.2(B)(viii)  \( C_8 \) Expected Added Value  400
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<td>12.2.2(B)(xi)</td>
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Tables 12.3.1(A)(i)-12.3.1(A)(i) Show the Levels of Scaled Agreement, $T$, between TEES and each of the Six Managers included in the Validation Study for each of the 7 Higher Level Constructs.

<table>
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<tr>
<td>12.3.1(A)(ii)</td>
<td>Level of Scaled Agreement Between TEES and the Proposals Manager</td>
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<td>12.3.1(A)(iii)</td>
<td>Level of Scaled Agreement Between TEES and the Manufacturing Manager</td>
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<td>12.3.1(A)(iv)</td>
<td>Level of Scaled Agreement Between TEES and the Business Group Manager</td>
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</tr>
<tr>
<td>12.3.1(A)(v)</td>
<td>Level of Scaled Agreement Between TEES and the Engineering Manager</td>
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<tr>
<td>12.3.1(A)(vi)</td>
<td>Level of Scaled Agreement Between TEES and the Marketing Manager</td>
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Tables 12.3.1(B)(i)-12.3.1(B)(i) Show the Levels of Systematic Bias between TEES and each of the Six Managers included in the Validation Study for each of the 7 Higher Level Constructs.

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<td>Table 12.3.1(B)(v)</td>
<td>Level of Systematic Bias Between TEES and the Engineering Manager</td>
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<td>Table 12.3.1(B)(vi)</td>
<td>Level of Systematic Bias Between TEES and the Marketing Manager</td>
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</table>
The 18 tables, 12.2.2(A)(i)-12.2.2(A)(xviii), below show the pair-wise total level of scaled agreement, $T$, between the six managers included in the validation study for each of the 18 constructs $C_1, ..., C_{18}$. In each case $T$ has been calculated using the set of scaled agreement weights $W^{(d)}_{ij}$ defined in section 11.5.2.

In the following tables the following notation has been adopted.

- $M_1$ = Finance Manager
- $M_2$ = Proposals Manager
- $M_3$ = Manufacturing Manager
- $M_4$ = Business Group Manager
- $M_5$ = Engineering Manager
- $M_6$ = Marketing Manager

$T$ = Total Level of Scaled Agreement between the managers $M_r$ and $M_q$ on the Construct $C_t$

($n$) = Sample Size

$^a$ Significant at the 1% level
$^b$ Significant at the 2.5% level
$^c$ Significant at the 5% level
$^d$ Significant at the 10% level
$^e$ Significant at the 20% level

**Table 12.2.2(A)(i) $C_1$ Nature of Formal Enquiry**

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<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
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<td>44$^b$ (17)</td>
<td>19$^d$ (7)</td>
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<td>41$^d$ (17)</td>
<td>19$^d$ (7)</td>
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<td>7 (5)</td>
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<td>27$^d$ (11)</td>
<td>9 (5)</td>
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<td>8 (3)</td>
</tr>
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**Table 12.2.2(A)(ii) $C_2$ Prospects of Available Finance**

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<th>M4</th>
<th>M5</th>
<th>M6</th>
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</thead>
<tbody>
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<td>M1</td>
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<td>43$^d$ (17)</td>
<td>34 (15)</td>
<td>0 (0)</td>
<td>10 (5)</td>
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<tr>
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<td>46$^d$ (15)</td>
<td>0 (0)</td>
<td>18$^d$ (5)</td>
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Table 12.2.2(A)(ix)  \( C_9 \) Level of Involvement

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Table 12.2.2(A)(x)  \( C_{10} \) Chances of Further Business

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393
### Table 12.2.2(A)(xi)  \( C_{11} \) Level of Competition

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### Table 12.2.2(A)(xvii) Probability of Success

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### Table 12.2.2(A)(xviii) Overall Attractiveness of Tender Enquiry

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395
The 18 tables, 12.2.2(B)(i)-12.2.2(B)(xviii), below show the pair-wise level of systematic bias, t, between the six managers included in the validation study for each of the 18 constructs C1,...,C18.

In the following tables the following notation has been adopted.

M1 = Finance Manager
M2 = Proposals Manager
M3 = Manufacturing Manager
M4 = Business Group Manager
M5 = Engineering Manager
M6 = Marketing Manager

(n) = Sample Size
|DMqMt(Ct)av| = Mean of the differences between the managers Mt and Mq on the Construct Ct

t = Level of Systematic Bias between the managers Mt and Mq on the Construct Ct, as measured by the continuity corrected Students' t statistic

\[ t = \frac{\text{DMqMt}(C_t)_{av} + 1/2n}{\sigma/\sqrt{n}} \text{ if } \text{DMqMt}(C_t)_{av} > 0 \]
\[ t = \frac{\text{DMqMt}(C_t)_{av} + 1/2n}{\sigma/\sqrt{n}} \text{ if } \text{DMqMt}(C_t)_{av} < 0 \]

\[ \sigma/\sqrt{n} \] = Standard Error of the Mean

a Significant at the 1% level
b Significant at the 2.5% level
c Significant at the 5% level
d Significant at the 10% level
e Significant at the 20% level
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**Nature of Formal Enquiry**

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**Prospects of Available Finance**

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Table 12.2.2(B)(iii)  
C₃ Availability of Design

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| M2 | -1.799c(17) | -0.807 (14) | -0.490 (11) | 1.543d(5) |
|    | [-0.529]  | [-0.286]  | [-0.182]  | [0.800]  |
|    | [0.311]  | [0.398]  | [0.464]  | [0.583]  |

| M3 | 0.837 (14) | 1.737d(11) | 1.837d(5) |
|    | [0.286]  | [0.545]  | [0.800]  |
|    | [0.384]  | [0.340]  | [0.490]  |

| M4 | 1.045e(10) | 0.000 (4) |
|    | [0.300]  | [0.000]  |
|    | [0.335]  | [0.408]  |

| M5 | -1.828d(4) |
|    | [-0.750]  |
|    | [0.479]  |

| M6 |        |
|    |        |
|    |        |

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Table 12.2.2(B)(iv)  
C₄ Demands on Bid Resources

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| M2 | 0.790 (17) | 0.712 (12) | -0.540 (12) | 1.837d(5) |
|    | [0.176]  | [0.333]  | [-0.167]  | [0.800]  |
|    | [0.261]  | [0.527]  | [0.386]  | [0.490]  |

| M3 | 0.349 (12) | -1.465d(12) | 1.500e(5) |
|    | [0.083]  | [-0.417]  | [0.200]  |
|    | [0.358]  | [0.313]  | [0.200]  |

| M4 | -1.625d(10) | 0.000 (3) |
|    | [-0.600]  | [0.000]  |
|    | [0.400]  | [0.577]  |

| M5 | -1.500e(4) |
|    | [-0.250]  |
|    | [0.250]  |

| M6 |        |
|    |        |
|    |        |

398
Table 12.2.2(B)(v)  
**C₅ Availability of Manufacturing Capacity**

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Table 12.2.2(B)(vi)  
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**C9 Level of Involvement**

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**C10 Chances of Further Business**

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Table 12.2.2(B)(xii)  \( C_{12} \) Chances of the Project Going Ahead

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### C16. Competitiveness of Price

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<td>M5</td>
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</table>

**Table 12.2.2(B)(xviii) C18 Overall Attractiveness of Tender Enquiry**

<table>
<thead>
<tr>
<th></th>
<th>M1</th>
<th>M2</th>
<th>M3</th>
<th>M4</th>
<th>M5</th>
<th>M6</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1</td>
<td>-</td>
<td>0.783(17)</td>
<td>1.945c(17)</td>
<td>-0.770(12)</td>
<td>2.002c(12)</td>
<td>-1.543d(5)</td>
</tr>
<tr>
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<td>[0.235]</td>
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<td>[-0.800]</td>
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<td>-</td>
<td>[0.338]</td>
<td>[0.166]</td>
<td>[0.271]</td>
<td>[0.229]</td>
<td>[0.583]</td>
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<tr>
<td>M2</td>
<td>-</td>
<td>0.334(17)</td>
<td>0.648(12)</td>
<td>1.709d(12)</td>
<td>-0.802(5)</td>
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<td>[0.083]</td>
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<td></td>
<td>-</td>
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<td>[0.193]</td>
<td>[0.414]</td>
<td>[0.374]</td>
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<td>M3</td>
<td>-</td>
<td></td>
<td>-2.002c(12)</td>
<td>0.957e(12)</td>
<td>-2.405c(5)</td>
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<td>[-0.800]</td>
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<td>M4</td>
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<td>2.603b(10)</td>
<td>-1.500e(4)</td>
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<td>[0.800]</td>
<td>[-0.250]</td>
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<td>-</td>
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<td>[0.250]</td>
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</tr>
<tr>
<td>M5</td>
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<td></td>
<td>-2.517c(4)</td>
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<td>-</td>
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<td>[0.645]</td>
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<td>M6</td>
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</tbody>
</table>
The 12 tables, 12.3.1(A)(i)-12.3.1(A)(vi) and 12.3.1(B)(i)-12.3.1(B)(vi), below show the level of scaled agreement, T, and the level of systematic bias, t, respectively between TEES and each of the six managers included in the validation study for the 7 higher level constructs C_{12},...,C_{18} under test.

In the following tables the following notation has been adopted.

\[
\begin{align*}
T & = \text{Total Level of Scaled Agreement} \\
\sigma & = \text{Standard Deviation of Differences } R_{ErMq(C_t)} - R_{ErMq(C_t)} \\
n & = \text{Sample Size} \\
\sigma/\sqrt{n} & = \text{Standard Error of the Mean} \\
t & = \text{Continuity corrected Students' } t \text{ statistic, so that} \\
& = (D_{ErMq(C_t)} + 1/2n)/(\sigma/\sqrt{n}) \text{ if } D_{ErMq(C_t)} > 0 \\
& = (D_{ErMq(C_t)} + 1/2n)/(\sigma/\sqrt{n}) \text{ if } D_{ErMq(C_t)} < 0 \\
\end{align*}
\]

\text{a} \text{ Significant at the 1\% Level} \\
\text{b} \text{ Significant at the 2.5\% Level} \\
\text{c} \text{ Significant at the 5\% Level} \\
\text{d} \text{ Significant at the 10\% Level} \\
\text{e} \text{ Significant at the 20\% Level}
Table 12.3.1(A)(i)  Level of Scaled Agreement Between TEES and the Finance Manager

<table>
<thead>
<tr>
<th>Scaled Agreement Weights $W^{(k)}_{ij}$</th>
<th>$W^{(1)}_{ij}$</th>
<th>$W^{(2)}_{ij}$</th>
<th>$W^{(3)}_{ij}$</th>
<th>$W^{(4)}_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{12}$ Chances of the Project Going Ahead</td>
<td>17</td>
<td>$T = 60^a$</td>
<td>$10^a$</td>
<td>$26^a$</td>
</tr>
<tr>
<td>$C_{13}$ Potential Profitability</td>
<td>17</td>
<td>$57^b$</td>
<td>$9^b$</td>
<td>$23^b$</td>
</tr>
<tr>
<td>$C_{14}$ Level of Technical Risk</td>
<td>17</td>
<td>$58^a$</td>
<td>$9^b$</td>
<td>$24^a$</td>
</tr>
<tr>
<td>$C_{15}$ Level of Financial Risk</td>
<td>17</td>
<td>$58^a$</td>
<td>$9^b$</td>
<td>$24^a$</td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td>17</td>
<td>$53^d$</td>
<td>$6^d$</td>
<td>$19^e$</td>
</tr>
<tr>
<td>$C_{17}$ Probability of Success</td>
<td>17</td>
<td>$60^a$</td>
<td>$10^a$</td>
<td>$26^a$</td>
</tr>
<tr>
<td>$C_{18}$ Attractiveness of Tender Enquiry</td>
<td>17</td>
<td>$57^a$</td>
<td>$9^a$</td>
<td>$24^a$</td>
</tr>
</tbody>
</table>

Table 12.3.1(B)(i)  Level of Systematic Bias Between TEES and the Finance Manager

<table>
<thead>
<tr>
<th></th>
<th>$(n)$</th>
<th>$D_{E_M}C_{ij}$</th>
<th>$\sigma$</th>
<th>$\sigma/N$</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{12}$ Chances of the Project Going Ahead</td>
<td>17</td>
<td>0.353</td>
<td>0.702</td>
<td>0.170</td>
<td>$2.246^b$</td>
</tr>
<tr>
<td>$C_{13}$ Potential Profitability</td>
<td>17</td>
<td>0.059</td>
<td>1.029</td>
<td>0.250</td>
<td>0.354</td>
</tr>
<tr>
<td>$C_{14}$ Level of Technical Risk</td>
<td>17</td>
<td>0.000</td>
<td>0.935</td>
<td>0.227</td>
<td>0.000</td>
</tr>
<tr>
<td>$C_{15}$ Level of Financial Risk</td>
<td>17</td>
<td>-0.118</td>
<td>0.928</td>
<td>0.225</td>
<td>-0.654</td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td>17</td>
<td>0.176</td>
<td>1.185</td>
<td>0.287</td>
<td>0.716</td>
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<tr>
<td>$C_{17}$ Probability of Success</td>
<td>17</td>
<td>0.353</td>
<td>0.702</td>
<td>0.170</td>
<td>$2.246^b$</td>
</tr>
<tr>
<td>$C_{18}$ Attractiveness of Tender Enquiry</td>
<td>17</td>
<td>0.294</td>
<td>1.047</td>
<td>0.254</td>
<td>$1.274^e$</td>
</tr>
</tbody>
</table>
Table 12.3.1(A)(ii) Level of Scaled Agreement Between TEES and the Proposals Manager

<table>
<thead>
<tr>
<th>Scaled Agreement Weights $W^{(k)}_{ij}$</th>
<th>(n)</th>
<th>$W^{(1)}_{ij}$</th>
<th>$W^{(2)}_{ij}$</th>
<th>$W^{(3)}_{ij}$</th>
<th>$W^{(4)}_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{12}$ Chances of the Project Going Ahead</td>
<td>17</td>
<td>$T = 57^a$</td>
<td>$7^d$</td>
<td>$23^a$</td>
<td>$47^a$</td>
</tr>
<tr>
<td>$C_{13}$ Potential Profitability</td>
<td>17</td>
<td>$56^b$</td>
<td>$7^e$</td>
<td>$23^b$</td>
<td>$46^c$</td>
</tr>
<tr>
<td>$C_{14}$ Level of Technical Risk</td>
<td>17</td>
<td>$55^c$</td>
<td>5</td>
<td>$21^c$</td>
<td>$43^d$</td>
</tr>
<tr>
<td>$C_{15}$ Level of Financial Risk</td>
<td>17</td>
<td>$53^e$</td>
<td>$7^e$</td>
<td>$21^d$</td>
<td>$43^e$</td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td>17</td>
<td>48</td>
<td>2</td>
<td>15</td>
<td>33</td>
</tr>
<tr>
<td>$C_{17}$ Probability of Success</td>
<td>17</td>
<td>$52^d$</td>
<td>$8^b$</td>
<td>$20^e$</td>
<td>$43^e$</td>
</tr>
<tr>
<td>$C_{18}$ Attractiveness of Tender Enquiry</td>
<td>17</td>
<td>47</td>
<td>2</td>
<td>14</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 12.3.1(B)(ii) Level of Systematic Bias Between TEES and the Proposals Manager

<table>
<thead>
<tr>
<th>(n)</th>
<th>$D_{EmQ}(C^*)$</th>
<th>$\sigma$</th>
<th>$\sigma/n$</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{12}$ Chances of the Project Going Ahead</td>
<td>17</td>
<td>-0.294</td>
<td>0.849</td>
<td>0.206</td>
</tr>
<tr>
<td>$C_{13}$ Potential Profitability</td>
<td>17</td>
<td>-0.353</td>
<td>0.996</td>
<td>0.242</td>
</tr>
<tr>
<td>$C_{14}$ Level of Technical Risk</td>
<td>17</td>
<td>0.176</td>
<td>0.951</td>
<td>0.231</td>
</tr>
<tr>
<td>$C_{15}$ Level of Financial Risk</td>
<td>17</td>
<td>-0.412</td>
<td>1.278</td>
<td>0.310</td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td>17</td>
<td>-0.118</td>
<td>1.409</td>
<td>0.342</td>
</tr>
<tr>
<td>$C_{17}$ Probability of Success</td>
<td>17</td>
<td>0.118</td>
<td>1.453</td>
<td>0.352</td>
</tr>
<tr>
<td>$C_{18}$ Attractiveness of Tender Enquiry</td>
<td>17</td>
<td>0.294</td>
<td>1.448</td>
<td>0.351</td>
</tr>
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</table>
Table 12.3.1(iii)  
Level of Scaled Agreement Between TEES and the Manufacturing Manager

<table>
<thead>
<tr>
<th>Scaled Agreement Weights $W^{(k)}_{ij}$</th>
<th>(n)</th>
<th>$W^{(1)}_{ij}$</th>
<th>$W^{(2)}_{ij}$</th>
<th>$W^{(3)}_{ij}$</th>
<th>$W^{(4)}_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C_{12} Chances of the Project Going Ahead</strong></td>
<td>17</td>
<td>-0.118</td>
<td>0.781</td>
<td>0.189</td>
<td>-0.776</td>
</tr>
<tr>
<td><strong>C_{13} Potential Profitability</strong></td>
<td>17</td>
<td>-0.118</td>
<td>0.857</td>
<td>0.208</td>
<td>-0.707</td>
</tr>
<tr>
<td><strong>C_{14} Level of Technical Risk</strong></td>
<td>17</td>
<td>-0.235</td>
<td>0.562</td>
<td>0.136</td>
<td>-1.941^c</td>
</tr>
<tr>
<td><strong>C_{15} Level of Financial Risk</strong></td>
<td>17</td>
<td>-0.412</td>
<td>0.870</td>
<td>0.211</td>
<td>-2.090^c</td>
</tr>
<tr>
<td><strong>C_{16} Competitiveness of Price</strong></td>
<td>17</td>
<td>-0.824</td>
<td>0.636</td>
<td>0.154</td>
<td>-5.530^a</td>
</tr>
<tr>
<td><strong>C_{17} Probability of Success</strong></td>
<td>17</td>
<td>-0.588</td>
<td>1.004</td>
<td>0.243</td>
<td>-2.537^b</td>
</tr>
<tr>
<td><strong>C_{18} Attractiveness of Tender Enquiry</strong></td>
<td>17</td>
<td>-0.294</td>
<td>1.047</td>
<td>0.254</td>
<td>-1.274^e</td>
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</tbody>
</table>

Table 12.3.1(B)(iii)  
Level of Systematic Bias Between TEES and the Manufacturing Manager

<table>
<thead>
<tr>
<th>(n)</th>
<th>$D_{ErM}(C_i)$, $\sigma$</th>
<th>$\sigma/\sqrt{n}$</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>C_{12} Chances of the Project Going Ahead</strong></td>
<td>17</td>
<td>-0.118</td>
<td>0.781</td>
</tr>
<tr>
<td><strong>C_{13} Potential Profitability</strong></td>
<td>17</td>
<td>-0.118</td>
<td>0.857</td>
</tr>
<tr>
<td><strong>C_{14} Level of Technical Risk</strong></td>
<td>17</td>
<td>-0.235</td>
<td>0.562</td>
</tr>
<tr>
<td><strong>C_{15} Level of Financial Risk</strong></td>
<td>17</td>
<td>-0.412</td>
<td>0.870</td>
</tr>
<tr>
<td><strong>C_{16} Competitiveness of Price</strong></td>
<td>17</td>
<td>-0.824</td>
<td>0.636</td>
</tr>
<tr>
<td><strong>C_{17} Probability of Success</strong></td>
<td>17</td>
<td>-0.588</td>
<td>1.004</td>
</tr>
<tr>
<td><strong>C_{18} Attractiveness of Tender Enquiry</strong></td>
<td>17</td>
<td>-0.294</td>
<td>1.047</td>
</tr>
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</table>
### Table 12.3.(A)(iv) Level of Scaled Agreement Between TEES and the Business Group Manager

<table>
<thead>
<tr>
<th>Scaled Agreement Weights $W_{k}^{(l)}$</th>
<th>$n$</th>
<th>$W_{1}^{(l)}_{ij}$</th>
<th>$W_{2}^{(l)}_{ij}$</th>
<th>$W_{3}^{(l)}_{ij}$</th>
<th>$W_{4}^{(l)}_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{12}$ Chances of the Project Going Ahead</td>
<td>11</td>
<td>37$^{b}$</td>
<td>6$^{b}$</td>
<td>16$^{a}$</td>
<td>32$^{b}$</td>
</tr>
<tr>
<td>$C_{13}$ Potential Profitability</td>
<td>11</td>
<td>29</td>
<td>4</td>
<td>10</td>
<td>23</td>
</tr>
<tr>
<td>$C_{14}$ Level of Technical Risk</td>
<td>9</td>
<td>30$^{d}$</td>
<td>4$^{e}$</td>
<td>12$^{d}$</td>
<td>25$^{d}$</td>
</tr>
<tr>
<td>$C_{15}$ Level of Financial Risk</td>
<td>9</td>
<td>27</td>
<td>1</td>
<td>9</td>
<td>19</td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td>11</td>
<td>35$^{d}$</td>
<td>4</td>
<td>13$^{e}$</td>
<td>28$^{d}$</td>
</tr>
<tr>
<td>$C_{17}$ Probability of Success</td>
<td>13</td>
<td>44$^{a}$</td>
<td>6$^{c}$</td>
<td>18$^{a}$</td>
<td>37$^{a}$</td>
</tr>
<tr>
<td>$C_{18}$ Attractiveness of Tender Enquiry</td>
<td>12</td>
<td>43$^{a}$</td>
<td>7$^{a}$</td>
<td>19$^{a}$</td>
<td>38$^{a}$</td>
</tr>
</tbody>
</table>

### Table 12.3.(B)(iv) Level of Systematic Bias Between TEES and the Business Group Manager

<table>
<thead>
<tr>
<th>$n$</th>
<th>$D_{E,M_{q}}(C_{l})_{o}$</th>
<th>$\sigma$</th>
<th>$\sigma/\mu$</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{12}$ Chances of the Project Going Ahead</td>
<td>11</td>
<td>-0.273</td>
<td>1.104</td>
<td>0.333</td>
</tr>
<tr>
<td>$C_{13}$ Potential Profitability</td>
<td>11</td>
<td>-1.364</td>
<td>1.362</td>
<td>0.411</td>
</tr>
<tr>
<td>$C_{14}$ Level of Technical Risk</td>
<td>9</td>
<td>0.000</td>
<td>1.000</td>
<td>0.333</td>
</tr>
<tr>
<td>$C_{15}$ Level of Financial Risk</td>
<td>9</td>
<td>-1.000</td>
<td>0.500</td>
<td>0.167</td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td>11</td>
<td>-0.455</td>
<td>1.036</td>
<td>0.312</td>
</tr>
<tr>
<td>$C_{17}$ Probability of Success</td>
<td>13</td>
<td>0.154</td>
<td>0.899</td>
<td>0.249</td>
</tr>
<tr>
<td>$C_{18}$ Attractiveness of Tender Enquiry</td>
<td>12</td>
<td>0.250</td>
<td>0.622</td>
<td>0.179</td>
</tr>
</tbody>
</table>
### Table 12.3.(A)(v)  Level of Scaled Agreement Between TEES and the Engineering Manager

<table>
<thead>
<tr>
<th>Scaled Agreement Weights $W^{(k)}_{ij}$</th>
<th>(n)</th>
<th>$W^{(1)}_{ij}$</th>
<th>$W^{(2)}_{ij}$</th>
<th>$W^{(3)}_{ij}$</th>
<th>$W^{(4)}_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{12}$ Chances of the Project Going Ahead</td>
<td>12</td>
<td>$T = 41^a$</td>
<td>7$^a$</td>
<td>17$^a$</td>
<td>36$^a$</td>
</tr>
<tr>
<td>$C_{13}$ Potential Profitability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{14}$ Level of Technical Risk</td>
<td>11</td>
<td>38$^a$</td>
<td>5$^a$</td>
<td>16$^b$</td>
<td>32$^b$</td>
</tr>
<tr>
<td>$C_{15}$ Level of Financial Risk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{17}$ Probability of Success</td>
<td>12</td>
<td>39$^b$</td>
<td>4$^b$</td>
<td>15$^c$</td>
<td>31$^c$</td>
</tr>
<tr>
<td>$C_{18}$ Attractiveness of Tender Enquiry</td>
<td>12</td>
<td>39$^c$</td>
<td>4$^c$</td>
<td>15$^d$</td>
<td>31$^d$</td>
</tr>
</tbody>
</table>

### Table 12.3.(B)(v)  Level of Systematic Bias Between TEES and the Engineering Manager

<table>
<thead>
<tr>
<th></th>
<th>(n)</th>
<th>$D_{E-M}(C_i)$</th>
<th>$\sigma$</th>
<th>$\sigma/N$</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{12}$ Chances of the Project Going Ahead</td>
<td>12</td>
<td>0.417</td>
<td>0.900</td>
<td>0.260</td>
<td>1.763$^d$</td>
</tr>
<tr>
<td>$C_{13}$ Potential Profitability</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{14}$ Level of Technical Risk</td>
<td>11</td>
<td>0.182</td>
<td>0.751</td>
<td>0.226</td>
<td>1.004$^e$</td>
</tr>
<tr>
<td>$C_{15}$ Level of Financial Risk</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$C_{17}$ Probability of Success</td>
<td>12</td>
<td>0.250</td>
<td>0.965</td>
<td>0.279</td>
<td>1.047$^e$</td>
</tr>
<tr>
<td>$C_{18}$ Attractiveness of Tender Enquiry</td>
<td>12</td>
<td>0.083</td>
<td>0.996</td>
<td>0.288</td>
<td>0.435</td>
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</tbody>
</table>
Table 12.3.1(A)(vi)  Level of Scaled Agreement Between TEES and the Marketing Manager

<table>
<thead>
<tr>
<th>Scaled Agreement Weights $W^{(k)}_{ij}$</th>
<th>(n)</th>
<th>$W^{(1)}_{ij}$</th>
<th>$W^{(2)}_{ij}$</th>
<th>$W^{(3)}_{ij}$</th>
<th>$W^{(4)}_{ij}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{12}$ Chances of the Project Going Ahead</td>
<td>5</td>
<td>T = 17$^d$</td>
<td>3$^d$</td>
<td>7$^e$</td>
<td>13$^d$</td>
</tr>
<tr>
<td>$C_{13}$ Potential Profitability</td>
<td>5</td>
<td>13</td>
<td>0</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>$C_{14}$ Level of Technical Risk</td>
<td>5</td>
<td>15</td>
<td>1</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>$C_{15}$ Level of Financial Risk</td>
<td>5</td>
<td>12</td>
<td>0</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td>5</td>
<td>14</td>
<td>0</td>
<td>4</td>
<td>9</td>
</tr>
<tr>
<td>$C_{17}$ Probability of Success</td>
<td>5</td>
<td>17$^d$</td>
<td>2</td>
<td>7$^d$</td>
<td>14$^d$</td>
</tr>
<tr>
<td>$C_{18}$ Attractiveness of Tender Enquiry</td>
<td>5</td>
<td>16</td>
<td>2</td>
<td>6</td>
<td>13$^e$</td>
</tr>
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</table>

Table 12.3.1(B)(vi)  Level of Systematic Bias Between TEES and the Marketing Manager

<table>
<thead>
<tr>
<th>(n)</th>
<th>$D_{E-Md}(C_i)$</th>
<th>$\sigma$</th>
<th>$\sigma/n$</th>
<th>Std. Err</th>
<th>t</th>
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<tr>
<td>$C_{12}$ Chances of the Project Going Ahead</td>
<td>5</td>
<td>0.200</td>
<td>1.095</td>
<td>0.490</td>
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<td>$C_{13}$ Potential Profitability</td>
<td>5</td>
<td>-1.000</td>
<td>1.225</td>
<td>0.548</td>
<td>-2.008$^d$</td>
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<tr>
<td>$C_{14}$ Level of Technical Risk</td>
<td>5</td>
<td>-0.600</td>
<td>1.140</td>
<td>0.510</td>
<td>-1.372$^e$</td>
</tr>
<tr>
<td>$C_{15}$ Level of Financial Risk</td>
<td>5</td>
<td>-1.200</td>
<td>1.483</td>
<td>0.663</td>
<td>-1.960$^d$</td>
</tr>
<tr>
<td>$C_{16}$ Competitiveness of Price</td>
<td>5</td>
<td>-0.400</td>
<td>1.342</td>
<td>0.600</td>
<td>-0.833</td>
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<tr>
<td>$C_{17}$ Probability of Success</td>
<td>5</td>
<td>0.600</td>
<td>0.548</td>
<td>0.245</td>
<td>2.858$^b$</td>
</tr>
<tr>
<td>$C_{18}$ Attractiveness of Tender Enquiry</td>
<td>5</td>
<td>0.400</td>
<td>1.140</td>
<td>0.510</td>
<td>0.981</td>
</tr>
</tbody>
</table>


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PERSONAL CONSULTANT PLUS, Texas Instruments, 12501 Research Boulevard MS2244, PO Box 2909, Austin, Texas 78769, USA.


XI-PLUS RELEASE 3, Expertech Ltd., Expertech House, 172 Bath Road, Slough, Berkshire, SL1 3XE, England.


