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A FRAMEWORK FOR MANAGING GLOBAL RISK FACTORS AFFECTING CONSTRUCTION COST PERFORMANCE

By

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A Doctoral Thesis submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of Loughbrough University

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Abstract

Poor cost performance of construction projects has been a major concern for both contractors and clients. The effective management of risk is thus critical to the success of any construction project and the importance of risk management has grown as projects have become more complex and competition has increased. Contractors have traditionally used financial mark-ups to cover the risk associated with construction projects but as competition increases and margins have become tighter they can no longer rely on this strategy and must improve their ability to manage risk. Furthermore, the construction industry has witnessed significant changes particularly in procurement methods with clients allocating greater risks to contractors.

Evidence shows that there is a gap between existing risk management techniques and tools, mainly built on normative statistical decision theory, and their practical application by construction contractors. The main reason behind the lack of use is that risk decision making within construction organisations is heavily based upon experience, intuition and judgement and not on mathematical models.

This thesis presents a model for managing global risk factors affecting construction cost performance of construction projects. The model has been developed using behavioural decision approach, fuzzy logic technology, and Artificial Intelligence technology. The methodology adopted to conduct the research involved a thorough literature survey on risk management, informal and formal discussions with construction practitioners to assess the extent of the problem, a questionnaire survey to evaluate the importance of global risk factors and, finally, repertory grid interviews aimed at eliciting relevant knowledge.

There are several approaches to categorising risks permeating construction projects. This research groups risks into three main categories, namely organisation-specific, global and Acts of God. It focuses on global risk factors because they are ill-defined, less understood by contractors and difficult to model, assess and manage although they have huge impact on cost performance. Generally, contractors, especially in developing countries, have insufficient experience and knowledge to manage them effectively. The research identified the following groups of global risk factors as having significant impact on cost performance: estimator related, project related, fraudulent practices related, competition related, construction related, economy related and political related factors.

The model was tested for validity through a panel of validators (experts) and cross-sectional cases studies, and the general conclusion was that it could provide valuable assistance in the management of global risk factors since it is effective, efficient, flexible and user-friendly. The findings stress the need to depart from traditional approaches and to explore new directions in order to equip contractors with effective risk management tools.

Key words: Cost performance; fuzzy logic; decision support system; global risk factors; knowledge, uncertainty

CERTIFICATE OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in the acknowledgements and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a higher degree.

..... (Signed)

.....(Date)

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Chapter One

Introduction

1.1 Introduction to the subject

The pace of change in the construction industry has imposed additional demands on construction project management. Risk management is a vital project management planning and control tool for reducing uncertainty and improving decision-making. Risk can not be avoided but must be recognised, assessed and managed.

The research reported upon in this thesis focuses upon global risk factors affecting construction cost performance in Mozambique. The research formulates a decision framework for modelling, assessing and managing global risk factors affecting cost performance from contractor's perspective and at a project level. The study is concerned with financial risk rather than hazard. It is argued that if contractors are equipped with an effective decision support system they can improve the quality of their decisions with regard the most significant global risk factors affecting cost performance.

Construction risk factors can broadly be grouped into: organisation specific, global and Acts of God. This classification is important for any risk management decision-making process since managers must examine both internal and external environments of their organisations and projects in order to evaluate the factors that pose serious challenges to success. Obviously, these three broad groups of risks can be broken down to achieve a more detailed classification, whenever necessary. Construction organisation's efficiency and effectiveness largely depends on how managers scan the external project environment, identify the critical factors and adapt their organisations accordingly.

Organisation specific or internal risks include factors related to an organisation's resources such as labour skills and availability, materials delivery and quality, equipment availability and management efficiency, (Schuette and Liska 1994). These risks are considered under contractors' control, and, in principle, contractors are solely responsible

for managing them. On the other hand, environmental or global risk factors are those risks that transcend organisational's boundaries. They are related to the external environment within which organisations operate, namely the operating or immediate and general or outer environments. Unlike the former, these risk factors are not directly present in cost estimates yet they may have significant financial impact (Schuette and Liska, 1994).

Acts of God represent risks with extremely low probability of occurrence, yet they are often unacceptable due to their huge negative impacts on projects. This category of risk includes events such as heavy floods, landslide, earthquake, hurricanes etc. These risks fall in the category of force majeure under the terms of contract. They are excusable but non-compensatable risks.

1.1.1 Cost performance

Poor cost performance of construction projects has been a major concern for both contractors and clients. Despite the large number of reported cases of poor performance, it seems that construction projects have increasingly experienced significant cost overruns on all sorts of projects ranging from the simplest to more complex projects such as nuclear plants, environmental restoration, transportation systems, and oil and gas platforms, (Al-Bahar, 1990 and Perry and Hayes, 1985). As a result, many construction organisations have faced successive financial burdens, which often have led to insolvency, bankruptcy and, eventually, failure.

1.1.2 Developing and developed countries

Although the issue of poor cost performance is a commonplace in the construction industry all over the world, it is particularly acute in developing countries where many management and structural problems permeate construction industry (Wells, 1986; Offori, 1993; and Jaselskis, 1998). The main problems confronting developing countries include management skills, shortage of skilled labour, low productivity, shortage of

supplies, and lack of equipment. The construction industry in Mozambique, for example, is incipient, deeply fragmented geographically unbalanced. Developing countries in this study refers to low and middle income countries, whereas developed countries refers to high income countries (World Bank, 1999a). Developed countries, for example, the UK have reached such an economic development that helped to overcome most of these problems and the construction industry has a significant contribution in the economy in terms of production output. Cox and Townsend, (1998) mentioned prevailing problems in the UK construction industry as poor quality, inefficient construction methods, inadequate investment, adversarial culture and fragmentation. However, the extent of these problems and their impact on the whole performance of the industry is not significant as compared to developing countries. The construction industry in developed countries have generally strong technical, material, human and financial capabilities.

1.1.3 Construction project risk

The commonest reason for such poor cost performance has been the failure to manage risks properly. Evidence shows that the rate of failures in the construction industry has been higher when compared with other sectors. Therefore, contractors' need for improved management styles is now more crucial than ever before. Furthermore, the process of globalisation creates additional difficulties because competition has become tougher. Globalisation here is taken to mean an increase in cross-border relations (internationalisation) and open-border relations (liberalisation) with regard to construction activities

Contractors have to produce realistic estimates, be competitive enough and still make profits so as to remain in business. Then, awareness of risks and their effective management should be an integral part of project management.

Several techniques and tools that aid risk management are available today, but very few construction practitioners make use of them (Lewis, 1996; and Shen and Cheung, 1996). These techniques are generally considered too theoretical, complex and of little use.

1.2 Research Background

Risk management has increasingly been recognised as an important part of project management in all spheres of business undertakings, (Royer, 2000). Some fields have well-established risk management practices, whereas others have not fully appreciated its potential. For instance, insurance, banking, financial markets, airspace, oil exploration, chemical industry, health care, nuclear plants, power plants are at the forefront in the effective and systematic implementation of risk management. With few exceptions, construction industry is one of the sectors where the pace of change has been very slow, (Flanagan and Norman, 1993; and Raftery, 1994). Uher and Toakley, (1997) regarded this lack of appreciation as a cultural gap.

There is a general agreement among construction practitioners that an improvement in the management of risks is necessary in order to increase the rate of success of construction projects. Berkeley (1991), Tah (1993) Raftery (1994) and Smith (1999) have all pointed out that construction projects have had a poor reputation for excessive time and cost overruns.

Construction projects all too often overrun initial cost estimates by large amounts even with carefully constructed cost estimates completed to a very detailed level by very experienced estimators, (Hullet, 1996). Morris and Hough (1989) examined the records of some 4000 different types of projects funded by the World Bank between 1974 and 1988 and concluded that 63 per cent of projects had experienced significant cost overruns. Recent examples of projects that experienced large cost overruns include the Channel Tunnel, Thames Barrier, Barbican Arts Centre, British Library and Sydney Opera House.

Chalabi and Camp (1984) conducted a detailed study of large projects in some developing countries in South America and concluded that cost and time overruns were commonplace. This situation is extensive to most developing countries in Africa and Asia because they share common characteristics with regard construction industry. Kaming et al (1997) studied factors influencing time and cost performance on high rise

building projects in Indonesia and concluded that time and cost overruns were very frequent. Many other studies with similar results were conducted in various countries (Okpala and Aniekwu, 1988; Elinwa and Buba, 1993; Mansfield et al., 1994 and Assaf et al., 1995).

The cost performance of a construction project is usually measured as the difference between the initial contract amount and the actual cost on completion, (Minato and Ashley, 1998; and Mckim et al., 2000). The cost on completion includes all changes made during the course of the project.

Several factors have been identified as the major causes of poor cost performance, namely: the difference between the lowest bid amount and the design cost estimate; level of competition; size and type of the project (de Neufville, 1977; Rowland, 1981; Rosemond, 1984).

Further, research by (Jahren and Ashe, 1990; Elinwa and Buba, 1993; Abubacar, 1992; Mansfield 1994; Giritli, 1996; and Kaming et el. 1997) found similar variables as the most influencing factors of project cost overruns. Risk factors associated with political instability, fluctuations in currency, corruption, interest rates and material availability were considered the main causes of additional costs in privatised infrastructure projects in developing countries, (Rosenbaun, 1997).

Kangari and Lucas (1997) mentioned that all Government funded projects in developing countries were political in nature. Political risk, in turn, lead, invariably, to bribery and corruption. Abdelkhalek (1997) studied the influence of politician owners in the private construction industry sector in Egypt and concluded that political factors highly influenced construction projects objectives.

Factors affecting cost performance of construction projects seem to be well appreciated in the literature. There are, nevertheless, some issues that need to be addressed thoroughly in order to improve risk management.

First, a general conclusion drawn for most studies was that, among other factors, poor cost performance of construction projects was largely affected by the difference between the lowest bid amount and the estimated tender value. The estimated tender value is the cost estimate provided to the client during the bidding process to enable the appreciation of probable cost involved in the project. Linear analytical models have been developed to formalise the relationship between cost overruns and their causes, as well as to propose corrective measures. Subsequent efforts have been placed on the refinement of such analytical models in order to reduce the difference, (Giritli, 1996). Yet such difference is significant in explaining the gap, it should be stressed that project cost and time overruns depend largely on the way uncertainties associated with unforeseen and foreseen events are identified, anticipated and accommodated, as discussed by (Perry and Hayes, 1985).

Secondly, despite some agreement on the above-mentioned factors, there is little evidence of an in-depth investigation of these factors including the underlying root causes. The occurrence of any given risk event is only dictated by the occurrence or not of the underlying causes. Therefore, the underlying root causes, their magnitude and relationships need to be uncovered so as to manage them properly. Furthermore, the analytical models developed so far have had very little application. Thus, they need further improvement.

Thirdly, there is a common limitation of the previous studies since they only considered the immediate and easily quantifiable variables, as recognised by (Jahren and Ashe, 1990; Giritli 1996; and Akinci and Fisher, 1998). Jahren and Ashe, for example, stated that considering additional factors, other than those mentioned in their study, would lead to the lack of soundness, because they were difficult to quantify. The main reason for supreme use of quantitative approaches is that risk management has been perceived as a quantitative discipline built upon prescriptive decision model of decision making.

Apart from other categories of risks, global risk factors seem to create serious constraints for contractors, particularly in developing countries and contractors are generally unfamiliar with them, (Akinci and Fisher 1998).

It should be stressed that although some sources of uncertainties are very difficulty to assess, analyse and to communicate, reliance on arbitrary assumptions may be misleading and controversial. Furthermore, overlooking or ignoring risks does not make them go away, (Hullet, 1996; Raftery, 1994; and Kikuchi and Pursula, 1999). All potentially serious risks should be considered for management. Many risks are often impossible to control, but they have to be taken, monitored and accommodated.

Due to the current shortcomings, alternative approaches to the traditional techniques based on statistical decision analysis have been advanced to help in management of risks. Kangari and Boyer (1989) investigated the feasibility of using fuzzy expert systems in risk management. Diekman et al., (1996) proposed a combination of Monte Carlo simulation for internal risks and influence diagrams for external risks. Sigurdsen (1996) developed a methodology called "objective cost risk analysis". Wirba et al. (1996) argued that there was a need to develop new techniques and tools to manage construction risks since they are becoming much complex. They performed a case study involving management of internal risks in a building project to evaluate the applicability of Fuzzy Set Theory. Yeo (1990) suggested a rule-based expert system for the classification of risk.

Uher and Toakley (1997) pointed out the need for addressing risk management in design, tendering, construction and commissioning phases of construction projects. Wang et al., (1999) suggested the introduction of innovative and effective risk management techniques for some types of risks such as political and financial.

This review indicates that there is an open debate on risk management and that there is a room for further improvements.

Major benefits in the process of estimating, tendering and contract strategy would be achieved if contractors had a better understanding of the main contributors to poor cost performance as well as appropriate techniques to analyse and manage them. In addition, they would be much more proactive in managing all significant and potential factors ahead of time, instead of considering the most easily quantifiable factors only as outlined by (ICE, 1998).

1.3 Justification

The literature search laid down the foundation for the research. The preceding discussions based on the theory, literature, practice and research on risk management and related disciplines have revealed three crucial issues:

- firstly, there is a need to address the important problem of risk management, particularly risk factors affecting cost performance as an intrinsic part of project management. Construction organisations and projects operate within an environment and not in a vacuum and as such they are inevitably influenced and constantly interacting with their environment. Moreover, the importance of risk management has grown as projects have become more complex and competition has increased;
- secondly, the existing techniques and tools have not been effective for handling risk in general and global risk factors affecting cost performance in particular; and
- thirdly, although all risks are important, global risk factors seem to pose more challenges to project success since they are poorly structured, the information related to them is retrieved from a variety of sources, the environment is increasingly dynamic and complex and contractors are less familiar with them.

The analysis and management of risks associated with the main decision-making problems in areas such as pre-project planning, resource planning, procurement, contract strategy, cost estimating and control, construction, operation and maintenance is of great importance because the associated financial and social impacts could be disastrous. Thus, the rationale for conducting the research on this topic are summarised as follows:

- risk management has increasingly had an important role in project management both from theoretical and practical grounds;
- construction industry has had a poor reputation for failing to meet project objectives particularly budgets. Time and cost overruns are widespread and have continually caused significant financial losses to both contractors and clients;

- past studies did not give much importance to the significance of global risk factors, probably due to the difficulties concerning their modelling and assessment. There are, though, evidences that global risk factors are determinant in the successful completion of construction projects, particularly in developing countries;
- there is little evidence in the literature that an in-depth work has been undertaken to integrate and investigate the nature and the impact of the different global risk factors influencing contractor's cost performance at the project level;
- although the conceptualisation of the external environment is available, its formal measurement has received little attention by researchers due to the complexity of the environments;
- contractors in developing countries have to bear the majority of construction risks. Typical problems of developing countries such as lack of skilled people, unfair contracting practices, shortage of material and equipment pose them serious risks than those born by clients;
- construction contractors in developing countries suffer from an unfavourable operating environment with complex procedures and regulations, delays in payments, unsuitable contract documents and low and fluctuating overall levels of construction activity;
- risk analysis and management has relied solely on quantitative techniques with the inherent degree of subjectivity. There are evidences showing that many contractors use experience and subjective methods in risk analysis and management;
- decision-making under uncertainty makes extensive use of empirical knowledge, which in most cases is not numerical but expressed in natural language;
- there is a need to explore new directions for risk analysis and management so as to enhance contractor's cost performance; and
- the use of fuzzy logic in the analysis and management of global risk factors can improve the decision-maker's interaction with the decision process at every project level. Fuzzy logic is a complement to rather than a substitute for statistical decision approach.

1.4 Aim and objectives

The previous sections provided a general overview on the importance of contractors managing the factors affecting construction costs. In particular, if contractors could systematically identify, assess and communicate the main risk factors, improvement may be achieved on the quality of both cost estimates and the costs throughout the construction process. The overall aim of this research is to evaluate and develop an effective decision framework for a systematic modelling, analysis and management of global risk factors that significantly influence contractors' cost performance at the project level.

To achieve the above mentioned aim it was necessary to thoroughly review the existing literature, research findings and to investigate current practices employed by contractors; review literature on methodologies of decision making under uncertainty; evaluate how risks have been allocated in contracts and the adequacy of the available contract strategies; identify and assess the main global risk factors that impact construction projects costs; examine the potential application of knowledge-based systems and decision support systems in risk management decision making; development of a knowledge based decision support system for a better management of global risk factors based on fuzzy logic approach; and verify and validate the decision system with the participation of construction professionals.

1.5 Research methodology

The research methodology adopted comprises the review of literature, discussion with construction contractors, questionnaire survey, repertory grid interviews, and case studies. The research methodology flow-chart details is depicted in Figure 1.1. The discussion of the methodology is presented in Chapter Two.

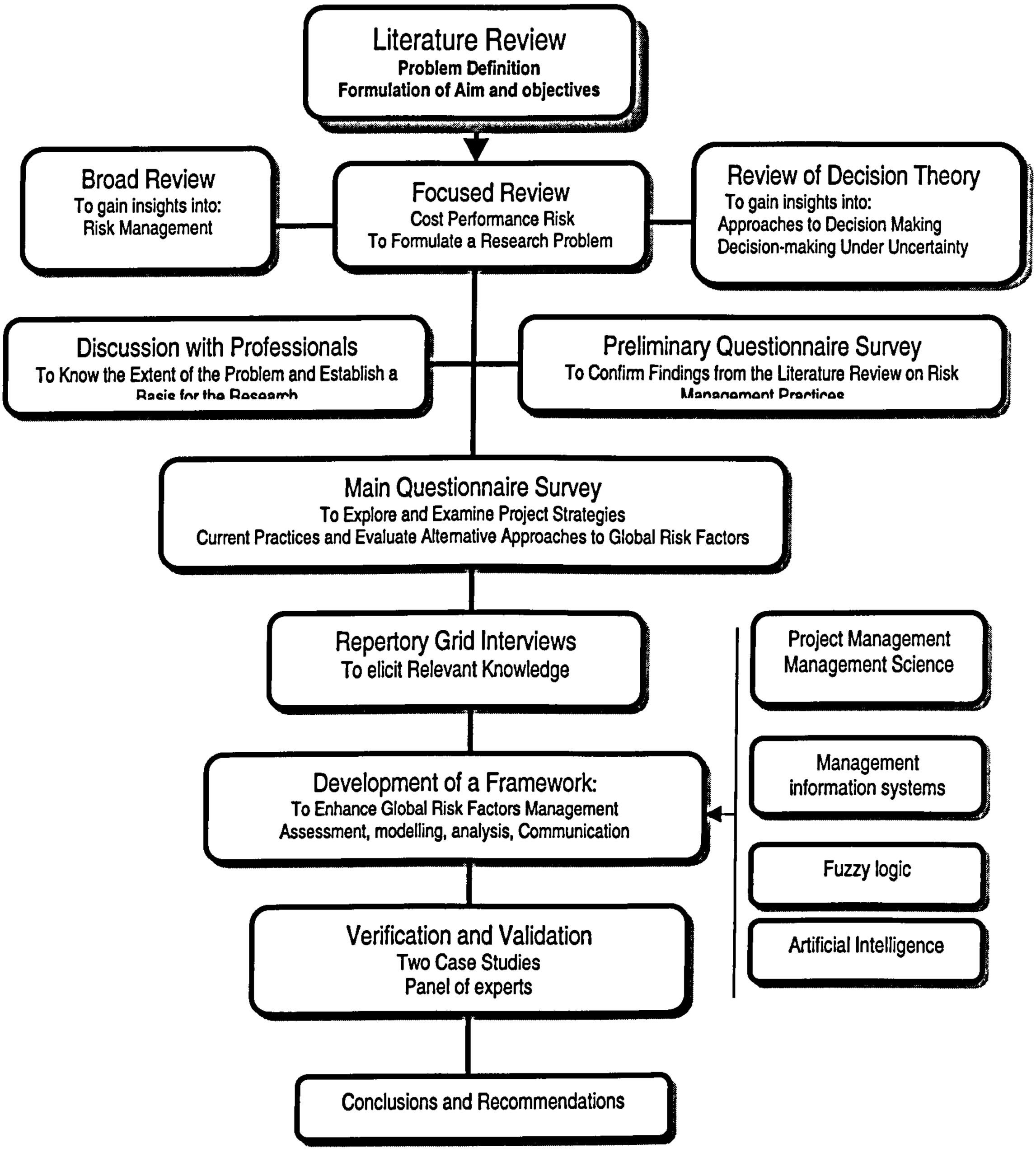

Figure 1.1: Research methodology flow chart

1.6. Achievements of the research

Management research is the systematic and objective process of gathering, recording and analysing data for improving managerial decision making. The present research has established important findings and suggestions on risk management that will be valuable to decision making in the construction industry in general and to both construction contractors and clients in particular. The most important contribution to the construction management body of knowledge was to establish both the framework and techniques and tools for structuring, assessing, analysing and managing global risk factors that affect cost performance of construction projects. The findings and suggestions of the research can be summarised as follows.

1. The research has identified risk management as an important function of construction project management within the construction management discipline. Risk can affect cost, time, quality and productivity of a construction project and therefore it must be managed effectively and efficiently.

2. The research has established that construction organisations operate within an environment and not a vacuum. They are inevitably influenced by and constantly interacting with their environment. As such, construction organisations and projects are open rather than closed systems, which are rigid and do not adapt to changing environments. Construction organisations' efficiency and effectiveness largely depend upon how managers scan the external project environment, identify the critical factors and adapt their organisations accordingly.

3. The research has established that the environment surrounding construction organisations and projects is nowadays very dynamic and highly complex. The dynamism is represented by the degree of change of the domains. For example, it is not easy to determine the economic environment the will prevail in the course of a project to be undertaken in the future. The complexity is largely due the large number of variables

involved and the level of knowledge required in the operation of the organisations. The amount of uncertainty in the internal, operating and general environment and the approach taken to its evaluation are important factors to the success of a project. Furthermore, global risk factors seem to pose more challenges to construction contractors than other categories of risk.

4. The research has established that poor cost performance of construction projects is widespread and it is particularly acute in Mozambique where construction contractors face far more severe constraints in terms of human, material, and financial resources than their counterparts in developing world. These constraints include an unbalanced distribution of the industry throughout the regions, management skills, shortage of skilled labour, low productivity, shortage of supplies, bad quality of supplies, inadequate contract strategies and shortage of equipment. Furthermore, most of the time the political and legal frameworks are not conducive to good business.

5. Existing techniques and tools for risk management built upon statistical decision approach are rarely used by construction contractors because contractors do not have enough knowledge to handle them. Furthermore, since projects have been perceived as being unique, it has been difficult to gather sufficient and reliable historical data on which to elicit objective probabilities. Instead, most construction contractors have relied upon experience, intuition and professional judgement in the process of risk management. Current techniques and tools do not fully recognise and incorporate rules of thumb, professional judgement and experience of construction professionals. Many risk management systems fail due to the lack of expert support to inexperienced or novice model users. In summary, there is gap between the existing techniques and tools and their practical application.

6. There is a need for pursuing new directions in risk management since risk has become more complex than ever before. Particular attention should be concentrated on innovative technologies that are able to effectively take into account the features of the actual practices of risk management by construction professionals. Expertise from

various sources can help to reduce bias in the process of decision-making. The technology of KBS is a viable alternative in that purpose.

7. The research has made a synthesis of the different global risk factors that were treated separately and using different approaches in the past. Furthermore, the research provided a new mechanism for conceptualising and measuring risks originating from the general environment. Knowledge-based decision support systems can a play a significant role in the process of improving decision making among construction organisations particularly risk decision-making.

8. Most of the current risk management systems are developed on the base of mathematical models derived from management science and from the point of view of rational decision model. Although some of these models work effectively for certain types of problems they fall short in modelling risk management problem which, to a large extent, is an humanistic system rather than mechanistic. Humanistic systems involve a great deal of human perception and reasoning. Although the conceptualisation of the external environment is available, its formal measurement has received little attention by researchers due to the complexity of the environments.

9. The research has shown that fuzzy set theory can be a powerful technology for handling poorly-defined and complex problems due to incomplete and imprecise information that characterise real-world systems. Risk management belongs to this group of problems. According to Zadeh (1965), as the complexity of a system increases human ability to make precise yet significant statements about is behaviour diminishes until a threshold is reached beyond which precision and significance become mutually exclusive. Using fuzzy logic to model risk means sacrificing precision while gaining significance. The technology is intended to complement rather than to replace other approaches such as those based on statistical decision theory.

10. The research has enabled the development of a fuzzy decision model for analysis and management of global risk factors affecting construction cost performance. The model employs the technology of fuzzy logic and uses linguistic variables to express risk instead of numeric expressions thus enhancing the interaction between the system and the user. The model can be taken as an aid to strategic thinking and it can be viewed as playing two important roles. First, it offers a perspective for structuring the process of risk decision making by providing the overall framework; secondly, it offers techniques and tools for evaluating and analysing the problem in terms of the different components of risk.

1.7 Guide to the thesis

The thesis flow-chart is presented in Figure 1.2 and the its details are presented in the following sections.

Chapter One of the thesis serves as an introduction to the research and comprises the introduction to the subject, research background, justification for the research, aim and objectives, guide to the thesis and the research findings.

Chapter Two presents the research methodology. It discusses the issue of research design and explores different research perspectives, methodologies, methods, research types and techniques for data collection. The chapter also explains why the present study selected questionnaire survey and Repertory Grid Technique as the most appropriate methods.

Chapter Three presents the review of risk management theory, practice and research, and builds the theoretical foundation for the research. It discusses risk management and the related body of knowledge particularly the concepts related to risk, risk identification, risk analysis, risk response, contract strategies, contract types, bidding strategies and cost estimating. Finally, the chapter summarises the current state of the art and issues that need attention and further research.

Chapter Four presents the review of global risk factors affecting construction cost performance. It sets out to discuss systems theory and the concept of environment and the interaction between the environment and the organisation or project. It also explains the grouping of risk factors adopted in the present research and lays down the framework for managing global risk factors.

Chapter Five reviews decision making and uncertainty and places risk management decision-making into context. The chapter discusses the two main decision models namely rational and administrative and explains why the administrative model suits better risk management than the rational model. It further presents the main classical techniques used to aid decision making as well as the most recent technologies namely decision support systems and knowledge based systems.

Chapter Six reviews knowledge based systems as the technology selected to build the decision framework for the present study. The chapter distinguishes the various classes of decision problems and presents the features of the problems that are best handled by knowledge based systems. The features and the role of knowledge based systems in supporting decision making is explained and the different stages involved in the development of knowledge based systems are detailed and discussed.

Chapter Seven presents the Theory of Fuzzy Sets as the technology selected to handle uncertainty in the knowledge-based system in the present study. The main concepts such as linguistic variable, degree of membership, membership functions, fuzzification, inference, defuzzification, linguistic approximation and operations of fuzzy sets are discussed. The strengths and weaknesses of the technology are also discussed.

Chapter Eight is devoted to data analysis and discussions on the questionnaire survey in order to extract meaning from data. The chapter explains how the questionnaire was designed and administered as well as the approach taken to the data analysis. The

responses to the questionnaire and their frequencies and percentages distributions are thoroughly discussed.

Chapter Nine analyses and discusses data collected through Repertory Grid interviews. The different techniques used to analyse data such as visual focusing, descriptive statistics and clustering analysis are presented and the findings are discussed.

Chapter Ten presents the process of decision framework development including the knowledge-based system. The system conception, knowledge elicitation, knowledge analysis, knowledge encoding are described. It also describes the main feature of the system namely the knowledge base, user interface, inference and the working memory.

Chapter Eleven addresses the crucial process of verification and validation of the development framework in order to ascertain the logical soundness, completeness, accuracy, acceptability, practicality and effectiveness. The importance of verification and validation are highlighted and the validation methodology and criteria are described.

Chapter Twelve summarises and discusses the results of the research within the context of research questions, theory and literature. The discussion is conducted in line with the objectives and aim of the research.

Chapter Thirteen presents the main conclusions of the research drawn from the findings, as well as the recommendations for the industry and suggestions for further work.

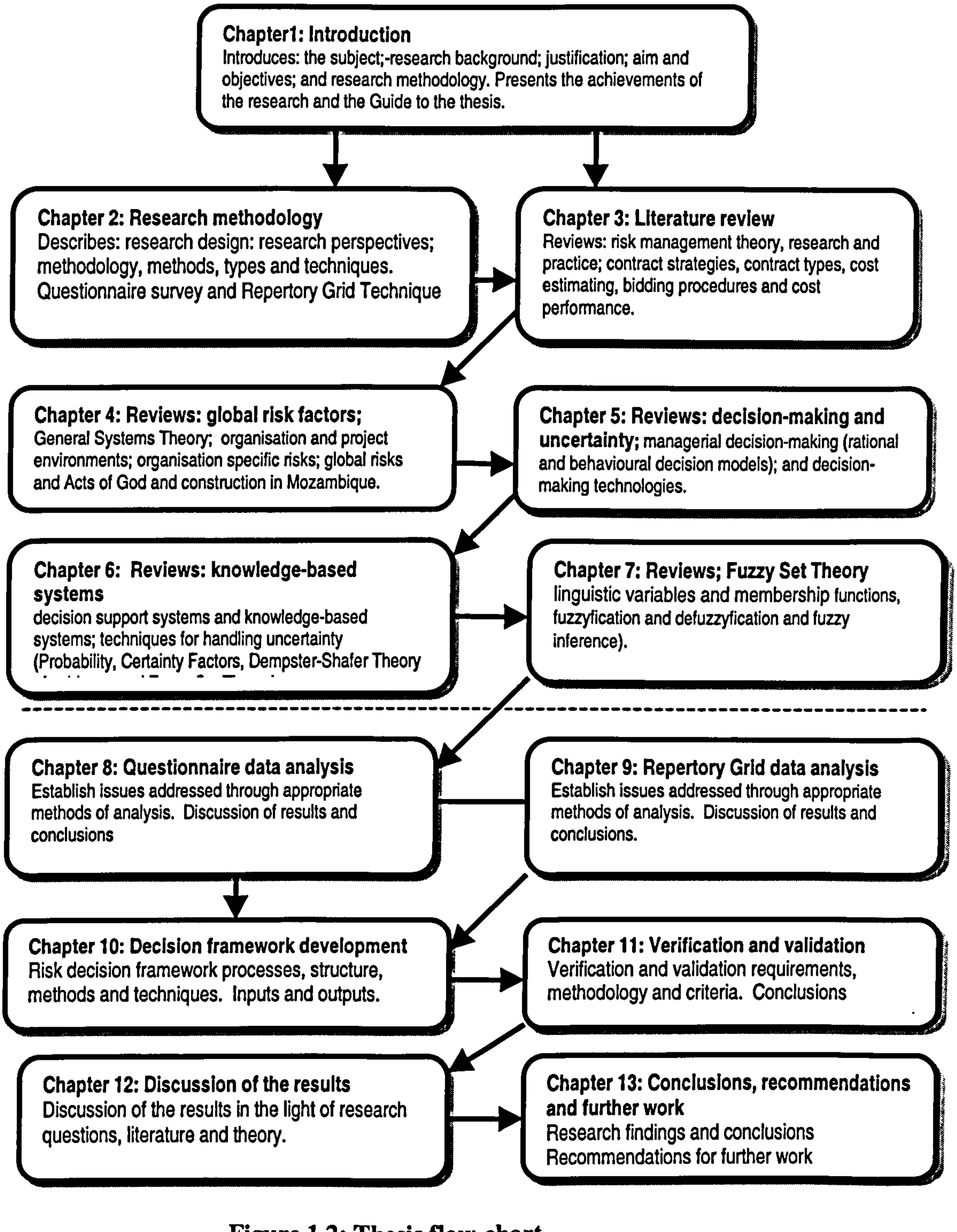

Figure 1.2: Thesis flow-chart

Chapter Two

Research methodology

2.1 Introduction

Chapter 1 provided the general outline of the research. The aim of Chapter 2 is to describe how the research was conducted in order to realise the aim and objectives. The aim of the research is to develop a decision framework for analysing and managing global risk factors affecting construction cost performance. The research is, therefore, a typical management research since it aims to enhance the practice of management in construction organisations. The development of the decision framework requires that relevant knowledge be elicited from construction organisations. The process of knowledge acquisition is complex, lengthy, difficult and fraught with difficulties. The chapter discusses the different research strategies and the choice of the most appropriate ones for the present study. The chapter deals with the whole issues of research design, namely research perspectives, research types, research methods and data collection techniques. The data collection methods adopted namely questionnaire survey and repertory grid interviews, are discussed at length. Then, the chapter goes on to discuss the issues of sample design, measuring instruments and data analysis details.

2.2 Definitions and concepts associated with research design

2.2.1 Research methodology

The issue of methodology and methods lies at the core of every research work. Research methodology is concerned with the philosophical and theoretical foundations upon which the research is conducted in order for the knowledge yielded to be acceptable, (Edum-Fotwe et. al., 1996). Therefore, research methodology should explain the rationale for the particular method or methods used in a given study.

2.2.2 Research methods

Methods, on the other hand, are techniques and tools by which data is collected, analysed and presented. Although sometimes they are used interchangeably, data collection methods and data collection techniques are considered different concepts in this study. A method is defined as a systematic and orderly approach taken towards the collection of data so that information can be obtained from those data. A technique is a particular step-by-step procedure that can be followed in order to collect data and analyse them to obtain information. A technique tells how to do something rather than what is being done.

2.2.3 Research strategy

Research strategy or design can be defined as the basic research plan or strategy, as well as its inherent logic that aims to enable the viability and validity of the research. Essentially, research strategies seek to answer questions such as how, why, who, when, where, how much, how many in order to provide explanations, descriptions, classifications, associations, relationships and causalities. Selecting an appropriate research methodology is a difficult task and involves, among others, not only setting a very clear definition of the aim and objectives to be achieved, research questions or hypothesis, but also an understanding of data collection methods and techniques, type of data, data sources, measurement instruments and data analysis strategies.

There are close linkages between research questions, methodology, data collection techniques, type of data and data analysis and they can not be treated in isolation. Yin (1994) considered this logic connection as a chain of evidence. There are many research methods and data collection techniques ranging from experiments, surveys, case studies, historical, questionnaire, interviews and observation, to video and photography. Some of these methods are more appropriate to certain research works than to others. However, no single method fits all research questions and research situations. Each design provides

answers to a specific set of questions. Therefore, the best approach is one that is important to the kind of questions the research wishes to respond, taking into account the extent to which it complies with reliability and validity criteria.

Many times research is conducted by combining several methods since the different methods are not mutually exclusive. Also, there is no straightforward set of rules that can be followed when selecting a specific method for one set of circumstances and another method for another set of circumstances. Table 2.1 presents the two main research paradigms namely positivism and phenomenology as well as the underlying assumptions.

Table. 2.1 Main features of quantitative and qualitative researches. Adapted from (Easterby-Smith, 1980; and Bryman, 1988).

Attributes	Quantitative	Qualitative
Underlying paradigm	**Positivism**	**Phenomenology**
Beliefs	World is external and objective	World is subjective
	Observer is independent	Observer is part of the subject under observation
	Science is value-free	Science is driven by human interests
	Rationalist	Naturalist
Main research methods	Experimental	Historical
	Survey	Case study
Research types	Causal relationships	Exploratory
	Emphasis on measurement	Descriptive
	Facts are at the core	Search for meanings
	Hypothesis testing	Inductive reasoning
Comparison of data collection techniques	Structured observation	Conversation
	Structured interview	Individual interview
	Telephone interview	Focus group
	Structured questionnaire	Key informant interview
	Attitude scaling	Repertory grid
Type of data	Hard and reliable	Rich and deep
Main role	Fact-finding based on evidence	Measurement of attitudes and perceptions based upon opinions and views.

The following research design crucial issues depicted in Table 2.1 are thoroughly discussed in the next sections:

- research perspective;
- research types;
- levels of rigour;
- data collection methods;
- data collection techniques;
- data sources; and
- research questions.

2.3 Research perspective: qualitative and quantitative approaches

Most research builds on specific philosophical grounds and, therefore, understanding philosophical issues is crucial for devising an appropriate research strategy as it provides useful insights and guidance on all aspects of research design. The two most important philosophies from which the different research methodologies and methods have been derived are **positivism** and **phenomenology.** Positivism asserts that the reality is external and objective, and knowledge is only of significance if based on observation of this external reality. Underlying these statements there are several assumptions. Phenomenology or social constructionism asserts that the world and reality are not objective and exterior but they are socially constructed and given meaning by people. Positivism and phenomenology are associated with quantitative and qualitative research perspectives, respectively. Essentially, quantitative and qualitative researches differ in the methods, perception of the problem and in the type of data.

Many authors, (Kirk and Miller, 1986; Bennett, 1983; Easterby-Smith et al., 1991; Mason, 1996; and Bryman, 1988) have attempted to outline the intrinsic characteristics of these approaches in order to help understand the main features of each one, but it is hard

to establish sharp and clear boundaries between them. In this regard, Kumaraswamy et al (1998) suggested that despite the distinction of qualitative and quantitative approaches being well delineated, often such differences have become unclear.

Furthermore, Jankowicz (1991) argued that although research perspectives are classified as qualitative or quantitative no approach is entirely qualitative or quantitative. Quantitative methods are frequently considered much better or more scientific than qualitative methods, however, this may be only due to the wide use of structured techniques which tend to be more quantitative than qualitative. Even if considering the strong belief that many scientific disciplines move from qualitative to quantitative approach as understanding progress. Kumaraswamy further suggested a classification of research methods in accordance with the extension of how structured the main data collection techniques used in each method are. In this regard, historical and case study research methods tend to be more qualitative whereas survey and experimental methods tend to be quantitative.

In general, qualitative research is said to be of subjective nature where much emphasis is placed on descriptions, experiences, perceptions, attitudes, beliefs, feelings and meanings of individuals or groups of individuals about the world. Therefore, qualitative perspective is often concerned with exploring, describing and explaining a phenomenon (Glatthorn, 1998; and Naoum, 1998). Nevertheless, it should not be confused with a pure absence of numerical data but as a perspective strongly linked to field activities, (Kirk and Miller, 1986). Exploratory and attitudinal are the two major categories often considered in qualitative research. Qualitative research has faced criticism by those with a good background in quantitative research who argue that it lacks objectivity mainly due to a generalised use of less structured data elicitation techniques.

Quantitative research, on the other hand, stems mainly from positivist epistemology perspective which theorises that the social world exists externally and that its properties should be measured through objective methods rather than being inferred subjectively through sensation, reflection or intuition. It is thus a highly structured approach.

Objective methods place much emphasis on the application of measurement or numerical approach to the issue under scrutiny, hypothesis testing, theory and causalities. The variables are measured through numbers and analysed with statistical procedures. Moreover, quantitative data are not abstract, but hard and reliable; they are measurements of tangible, countable and sensate features of the world, (Bouma and Atkinson, 1995).

Despite these distinctions, Abrahamson (1983), Bryman (1988) and Morgan (1997) all argued that very often both qualitative and quantitative research perspectives can be combined in a coherent, consistent, imaginative and methodic way so as to conduct objective research and achieve valid results instead of concentrating efforts trying to explain differences and incompatibilities. Some alternatives of doing such combination are the triangulation of methodologies, triangulation of theories, triangulation of data and triangulation by researchers. In addition, Mason (1996) suggested that qualitative research should not be seen as necessarily in opposition to, and uncomplementary to quantitative research. In this way, quantitative methods can also be used to study human perceptions and qualitative methods to investigate objective realities, usually based on hard data.

2.4 Research types

Research types are concerned with the different levels of scientific sophistication. The scientific sophistication varies according to the area of knowledge, the objective of the research, the importance and the approach of the research. Different areas of knowledge have established different states of knowledge.

Disciplines such as chemistry and physics, for example, are more oriented to quantitative, hard approaches aimed at obtaining accurate predictions. Therefore, experimental research followed by rigorous data analysis is typical of these fields. On the other hand, disciplines such as organisational behaviour and sociology rely heavily on observation, interviewing and recording in order to describe and explain certain phenomena.

Resistance to change in organisational settings or employees motivation are common problems studied in social sciences. By nature, these problems do not require accurate measurement but explanations and description of their relationships. The following sub-sections discuss the five main levels of research types namely evaluation, description, causal-comparative, experimental and explanatory.

2.4.1 Evaluation

The main objective of the evaluation research, also known as formative in management research, is to make judgements about the merit, value, importance, significance of an organisation's policies, programs, projects, plans, products and other resources. Evaluation type of research is usually conducted to help senior management to make better and more informed decisions.

2.4.2 Description

Description is considered the most basic level of research. Its main aim is to describe an event, a phenomenon, a population etc. Results of this type of research are usually based on frequencies, averages and other techniques of descriptive statistic rather than measures of association and relationships between events or variables. Descriptive studies are designed to provide answers as to how many and how type of questions rather than revealing associations and relationships. An example of descriptive study is a census of the number, size, turnover and, financial capabilities of contractors in a country or region. Because of this feature, this kind of research is very often less appreciated by most researchers, particularly the experts. Most of the detractors argue that descriptions do not contribute to the advancement of knowledge. Despite being less appreciated, descriptive research is useful as a starting-point in earlier stages of some research projects that build on descriptions.

2.4.3 Exploratory

Exploratory type of research seeks to identify the most relevant variables and potential relationships among variables. It is usually undertaken when less is known about a specific problem and there is a need to establish a foundation for further analysis, for example, employing more scientific strategies aimed at testing hypothesis. Therefore, exploratory studies are not concerned with rigour and control. They are usually conducted in the following situations: diagnose of a problem; screening alternatives; and discovery of new ideas.

2.4.4 Classification

Classifications are very useful in setting up similarities and differences of the events, variables categories and subjects under consideration. This approach helps in categorising variables according to specific predefined features. Establishing a

classification of construction risks according to their source, impact and other characteristics, is an example of classification study.

2.4.5 Explanation

Most research seeks explanations of what is happening and why certain events occur. These questions are important because they enable the researcher understand what is going on and to bring this into the models and propositions. Both descriptions and classification are valuable approaches towards theory development. Furthermore, they are complemented by explanatory studies in order to determine the way and the causes events take place.

2.4.6 Prediction

Prediction is a state where it is possible to foresee the value of a variable or an outcome based on the knowledge of the input. Ideally, if it was possible to make such predictions with high accuracy there would be no uncertainty in decision making. In real-life only few fields such as physics and chemistry have reached such level of prediction.

2.5 Levels of rigour

According to House (1970), rigour is seen as the extent to which the research method employed is suitable to the fundamental requirements of the research design problem. Different branches of knowledge have different research design requirements and, thus, distinct levels of rigour. Management research has drawn much of its philosophy and ideas from social research which, in turn, have employed methods originally develop in natural sciences. There are three levels of rigour: first; second; and third. It should be stressed that despite being different, all rigour levels are important for distinct research approaches. The application of any level of rigour depends on the specific research problem and it is suggested that any research be at the highest level of rigour appropriate to the study. There is no best method.

2.5.1 First level

The first level is the lowest level of rigour. It is mostly related to the research methods that employ qualitative and narrative approaches to the analysis of the variables. The methods associated with first level rigour, exploratory in nature, are mainly used because they help in discovering, identifying significant variables and generating hypothesis which may subsequently be used (tested) with more rigorous scientific methods. However, the first level is still very important for research since it handles well those aspects that high level rigour tools can not handle effectively.

2.5.2 Second level

The second level of rigour has quantitative measurements at its core. Research methods associated with this level include uncontrolled experimentation and survey. Unlike the first level of rigour where description of events and variables is the most important feature, the second level focuses on measuring and manipulating variables as well as on establishing their relationships without necessarily providing insights into cause-effect relationships.

2.5.3 Third level

The third level of rigour is closely linked to the very hard, more scientific experimental (both laboratory and field experiments) research approaches such as experiments in chemistry, biotechnology and physical sciences. These methods aim to manipulate variables so as to establish not only simple relationships but also the directions of such relationships, that is, the cause-effect relationships. Therefore, they are mainly concerned with why some events occurred.

2.6 Data collection methods

There are many different data collection methods in management research. Indeed, data can be collected in a variety of ways, in different settings and from different sources. In general, there are conceptual overlaps among different data collection methods, (Smith 1997; and Yin 1994). For example, despite being distinct methods, case studies and surveys are mainly exploratory and descriptive. As a result, the choice of data collection method is fraught with difficulties. Despite the large number of data collection methods it should be noted that some are widely used by researchers than others and there are no universally accepted definitions of these methods, (Bell, 1993). The most employed methods are: case study; historical; ethnographic; action; archival study; survey and field experiment.

2.6.1 Case study

According to Yin (1994) "a case study is an empirical inquiry that investigates a contemporary phenomenon within its real life context; when the boundaries between the phenomenon and the context are not clearly evident; and in which multiple sources of evidence are used". Case is the name given to a unit of analysis. The unit of analysis can be an organisation, a person, a group of persons or a particular project. Each case has within it a set of interrelationships, which are intrinsic to it, and interacts with the external environment.

Cases allow an in-depth study or intensive examination of a unit of analysis for a period of time with the objective of improving general knowledge or solving practical problems. They can be used in different ways but the following are the most common: as illustrative examples of particular groups; in evaluation studies; in exploratory studies where the researcher seeks to ascertain the relevant variables as well as potential relationships; and in comparative studies, where the researcher compares two or more units of analysis in order to find out differences and similarities. One of the most important concepts in case

studies is triangulation, which is the employment of several perspectives. In fact triangulation can occur in several ways of which the most common are: methodological triangulation, participant or hierarchical triangulation, researcher triangulation and mixed triangulation. Methodological triangulation is the use of several data collection techniques. Participant triangulation involves collecting data from several participants; whereas researcher triangulation is the use of more than one researcher in the data collection process.

The main advantage of case studies is the in-depth analysis of a problem or phenomenon. The major disadvantage of case studies is that they do not allow generalisations. Since a case may be unique instance of its class it may not be representative of another classes. Therefore, it is difficult to generalise the findings or the theory to other similar cases.

2.6.2 Historical

The main objective of historical review method is to describe what happened in the past in order to improve present and future procedures. In this sense historical method is useful since it helps solving current problems by examining what happened in the past. This approach is widely used in management research to solve problems in areas such as marketing, quality control and financial management. In essence, all research is historical in that it is not possible to analyse data at exactly the same time as they are being collected and the interpretation of data is based on the past, (Bennett, 1983).

Historical method can take two main forms: it may be concerned with an historical problem in any discipline or it may be an historical perspective of a problem under consideration. Two particular features of historical problems are cross-sectional and longitudinal. In a cross-sectional study, a researcher collects, analyses data and reports the findings at a single point in time or at more or less the same time. They are, thus, snapshots of the setting at a particular point in time. An example of this type of study can be the investigation of causes of contractors' failures in Mozambique in the 70s. Longitudinal studies, on the other hand, seek to check whether there has been a change over a specific period of time. The researcher observes the development of a problem

during an extensive period of time. Thus, the measures from the same groups are taken repeatedly at several interval intervals. Investigating factors of labour efficiency in building projects between 1995 and 1997 is an example of longitudinal study.

2.6.3 Action research

Action research implies active and deep involvement of the researcher in the processes of identification, evaluation and solution of a problem under consideration. The rationale behind action research derives from the idea that if one wants to understand something well the researcher should try changing it. Because of the collaborative approach between the researcher and the researched, researchers are more likely to learn a great deal from the process. Usually, action research involves working with individuals or groups. Many times action research takes form of applied research where the main objective is to find solutions to specific problems. An example of action research can be the involvement of a site manager in the identification of the causes of low labour productivity as well as the measures necessary to overcome such problem and enhance productivity.

2.6.4 Ethnographic

Ethnographic study originates from anthropology theories and has now been widely applied in organisational settings to study cultural patterns. It involves the participation of the researcher, in the environment under consideration, who observes behaviours, attitudes, norms, symbols and similar characteristics.

2.6.5 Experimental

Experimental method is usually undertaken when a researcher is sufficiently familiar with the problem under study as well as the events involved in order to clearly identify the most important variables. Experiments are often carried out in laboratories but they are also conducted outside laboratories, field work, in some domains such as economic,

political, social and industrial. The experimental method stems from the positivist traditional deductive model, as in the case of biology and physics, where the search for causality lies at the core. Therefore, the main feature of the experimental approach is the determination of the effect that a change in one variable has upon another – cause-and-effect relationships. The test of hypothesis based on the experimental evidence is of paramount importance.

The knowledge of the variables, independent, dependent and controlled, form the base for the investigation of the potential relationships and associations, as well as the direction of such relationships. The concepts of **control** and **experimental** groups are critical to the experimental method. Control groups aim to examine whether changes might not be occurring anyway (i.e. without intervention) or there might be external factors that might be studied. Data are collected under controlled conditions because the researcher wants to make sure that only the variables under consideration have effects on the study, that is, the results are not due to something else. It is crucial that the researcher has some control over variation in the independent variable and is able to control the influence of other variables.

Several forms of control are available: exclusion; holding them constant; and randomisation (Oppeinheim, 1996). The dependent variables, also known as effects-variables, are subject to the influence of the independent variables. The experimental variables, also known as predictors or causes, are the independent variables. Two common alternatives of experimental method arise: the examination of the effect of a variable A on a variable B – cause-effect study; and the examination of potential changes over time or before-after/before-and-after- study. This is done using two sets of observations, before and after. The findings from experiments will enable explanations of the events and, in some circumstances, to contribute to the advancement of a theory.

The advances achieved in construction structural design (strength of materials, theory of elasticity) are largely due to experimental research work. The design of construction

structures (concrete, steel, timber and composite materials) is now possible with high degree of accuracy.

2.6.6 Surveys

Surveys are employed to find out people's beliefs, feelings, values, motives, attitudes and other factors about an issue or problem under investigation. The data collected in surveys can be used to compare, describe, explain situations emerging in a wide variety of disciplines. Surveys are probably the most used research method in management.

Surveys imply necessarily contact with people or human respondents in different forms and build on asking questions to a sample of a population. They are very useful methods when it is important to contact large number of people to obtain data on specific issues. Surveys deal with verbal reports, either written or oral. The most important survey methods are thus written questionnaires and face-to-face interviews. There are two main groups of surveys: descriptive and analytical. Descriptive surveys are basic methods of fact-finding and descriptions. Although not providing explanations of events or phenomenon, they play an important role in research. Often results from descriptive studies serve as foundation for more scientific research, such as research that seeks for causality and correlations.

Analytical surveys mainly aim to answer "why" type of questions, that is, they are designed for relational studies or analysis of causes. Therefore, analytical surveys focus on explanations, associations and relationships among variables. Furthermore, they enable making predictions. In this sense, analytical surveys are often considered similar to experiments. A simple example, could be a survey designed to identify predictors of construction delays in order to take corrective measures. Based on the results of the survey it is possible to build a linear model that includes the most significant variables identified.

2.7 Data collection techniques

Data collection is one of main stages of the research process. While the review of the theory and literature enables the development of the theoretical or conceptual frameworks, which are the foundations of the research, data collection facilitates the testing of such frameworks, to answer research questions, through the process of analysis and reasoning.

There are many ways of collecting data but the major categories can be grouped in the following headings: questionnaires; interviews; observations; and motivational techniques. In terms of degree to which the techniques are structured, data collection techniques can be grouped into semi-structured open-ended techniques and fully structured techniques. The former comprises the following: individual interview; conversation; key informant interview; repertory grid; and the focus group. The later include structured questionnaire, structured face-to-face interview, computer-assisted interviews, telephone interview, attitude scaling and field experiment. The following sections discuss the most frequently used data collection techniques namely face-to-face interviews, telephone interviews, personally administered questionnaires, mailed questionnaires and repertory grid technique.

2.7.1 Questionnaires

Questionnaires are often taken to mean only self-administered postal questionnaires. Other practitioners include interview schedules in the family of questionnaires. In the context of the present research a questionnaire is defined as a predefined set of questions to which respondents record their answers. Questionnaires can be either personally administered or mailed. They are probably the most frequently employed technique in social sciences and, particularly, in management research. The quality of a questionnaire is largely dependent upon three issues, namely the wording of questions, data

categorizing/scaling/coding and the general appearance of the questionnaire, (Sekaran, 1992). Questionnaires have the advantage of wide coverage in terms of topics and respondents, low processing cost, avoidance of interviewer bias, more accurate and access to dispersed respondents. The main disadvantages of mailed questionnaires are delay in getting feedback, flexibility, low rate of responses, no opportunity to correct misunderstandings, unsuitability for respondents of poor literacy, expensive when personally administered in a spread geographical area.

2.7.2 Interviews

The objective of an interview is to collect relevant data through face-to-face or telephone contact. Interviews have been used for many different purposes in various forms. For example, interviews can be used in press, therapeutic, employment, market research as well as associated with different research methods such as case studies, surveys and historical studies to explore and describe events, ideas, attitudes, procedures etc. Interviews allow in-depth exploration of complex issues and provide rich data.

There are two broad categories of interviews: unstructured; and highly structured. Unstructured interviews are very informal with broad, open-ended questions. Therefore, although they provide valuable data, unstructured interviews require a great deal of expertise and control from the interviewer as well as much effort in data analysis. This type of interviews is usually used in exploratory, preliminary studies to enable further in-depth investigation. Structured interviews, on the other hand, are highly standardised, with predetermined set of questions, thus making it is easier to aggregate, quantify and analyse data.

They are used in situations where frameworks are well defined and the significant variables known. The advantages of interviews are: high rate of responses; deep exploration of meanings and interpretations; and they yield rich data. Telephone interviews are particularly helpful for geographical dispersed respondents.

Disadvantages include factors such as time consuming, lengthy data analysis, difficult arranging and high costs.

2.7.3 Observations

The observational data collection technique involves, among others, the observation of events, situations, activities, attitudes, procedures and behaviours without asking questions to subjects. Data are collected through observation of people in their natural environment or in a "laboratory". An observer records, usually taking notes, video or audio recording, and subsequently analysis data. Interviews provide useful insights into how people perceive what happens but not what actually happens, (Nisbet and Watt 1980). Direct observation is regarded as more reliable technique than what people feel in many occasions. It can be extremely important in search for whether people do what they say they do.

There are two main types of observations: participant; and non-participant observations. Participant observation approach implies direct involvement of the researcher in the process being observed, for example as an employee or a manager. In non-participant observant the researcher just observes and records the ongoing processes over a specified period of time. Observations can also be unstructured and structured. Like unstructured interviews, unstructured observations are exploratory in nature. They are advantageous in that they draw attention to the contribution of the user and help overcome preconceived ideas.

The major disadvantages of observations are that they are lengthy, time consuming, very costly analysis and very sensitive. Observational technique originates from sociology and anthropology where it has been used to understand people's behaviour, but it has been extended to management and organisational research over the years.

2.7.4 Repertory grid technique

Repertory grid is a technique used to produce an individual's perceptions or mental map on some topic. Retrieval of such individuals' maps is extremely important in research areas that feature humanistic systems and involve decision- making. Branches of knowledge such as organisational behaviour work to a large extent with a wide variety of mental maps ranging from people's perceptions on the workplace environment, motivation for work and cultural dimensions.

It was first originally developed as a tool in clinical psychology to investigate the relationship between patients and their families, friends and colleagues and to evaluate the relationships between a patient's cognitive map about people. The repertory grid technique builds on the Personal Construct Theory PCT developed by Kelly (1955) which regards individuals as scientists. According to the theory individuals continually explore, develop understanding of their world and build cognitive maps of their experience. The cognitive maps define and limit their potential repertories. As a consequence, it follows that if it is possible to draw individuals' maps then it would be possible to understand their behaviour or, if necessary, to influence it.

The components of a repertory grid are the elements and constructs. Elements are objects, usually people and inanimate objects or abstract ideas. Constructs are the qualities used by an individual to describe and distinguish between the elements. The common procedure to develop a repertory grid interview is as follows: definition of the objective of the grid that is, the topic under study; elicitation of the elements by the interviewee; elicitation of constructs by asking the respondent to compare and contrast the elements in groups of two or three; and rating each of the elements against each of the constructs using a predefined scale. The results of the ratings are organised in matrix format. The final step is data analysis of the grid in order to draw conclusions.

2.8 Data sources

Data can be collected from two main sources: primary and secondary. Primary sources, also known as fieldwork, are those that allow data to be collected first hand. These include focus groups, individuals and panels of respondents. Research methods such as surveys and field experiment use mostly primary sources. Secondary sources, or desk study, refer to those collected using desk study since data is retrieved from other sources rather than the first hand.

Secondary sources include government publications, major publications, archives, promotional literature, financial statements, organisations' records and so on. The subjects of data sources can be people's opinions, ideas, emotions feelings, experiences, understandings, behaviours; texts, stories, documents, archives, organisations, events, images, photograghs (Mason, 1996) and unobtrusive sources which are sources that are not people (e.g. organisation's records).

2.9 Research questions for the present study

The "best" research methodology and methods are those that fit the problem under consideration and thus help to answer research questions. The aim of the present research is to develop a decision framework to help managing global risk factors affecting construction cost performance. As such, knowledge of the problems and issues inherent in risk analysis and management is crucial.

The review of the theory, literature and current practices have provided valuable insights into risk management as well as related disciplines that include cost estimating, procurement routes, contract types, conditions of contracts and bidding strategies. It was then possible to develop the theoretical framework that is the basis upon which all the research rests. The theories and literature reviewed include risk management, classical rational decision model, behavioural decision theory, fuzzy set theory, management

research and project management principles. The theory and literature coupled with the discussions with construction contractors enabled the formulation of the research problem and research questions that can be summarised as follows:

- what is the extent and significance of poor cost performance in construction projects and what are the most critical factors affecting construction cost performance?

- are construction contractors aware of the obstacles posed by risk factors in general and global risk factors, in particular to project success?

- to what extent risk management is influenced by project strategy variables such as procurement routes, contract types and conditions of contracts?

- how do construction contractors currently deal with risk analysis and management, as an intrinsic part of project management, in view of a large number of techniques and tools which seem inappropriate or ineffective?

- are construction contractors sufficiently equipped with appropriate knowledge, techniques and tools to face risks that permeate construction projects?

- are the current underlying theories behind risk management decision making the most appropriate background to the development of techniques and tools for tackling risk issues ? and

- how can risk management be enhanced in order to help construction contractors make better and informed decisions?

The answers to these broad questions and other details will be obtained through the application of the different research process elements.

2.10 Research strategy adopted for this study

The research strategy was devised in the light of the findings from the theory, literature, current practices within the construction industry, the subsequent theoretical framework and the set of research questions that arose. This study adopts a mixture of both qualitative and quantitative research perspectives, being the quantitative perspective the first and the qualitative the primary, as with (Bryman 1988).

The research methods adopted are survey and case studies. Questionnaire survey and repertory grid interviews were selected as the most appropriate data collection techniques. The combination quantitative first/qualitative primary means that a quantitative approach to data collection is used in the first stage of the research as a basis for collecting and interpreting the more qualitative data in the second step. A questionnaire was used in the first stage to collect data and the repertory grid interviews were conducted in following stage although qualitative data lie at the core of the research.

Primary in this context means the most important or the main approach. The reasons behind the choice of the methodology, and the design and administration of questionnaire survey and repertory grid interviews, as the fundamental research instruments are fully explained in the following sections. The methodology flow chart is depicted in Figure 2.1.

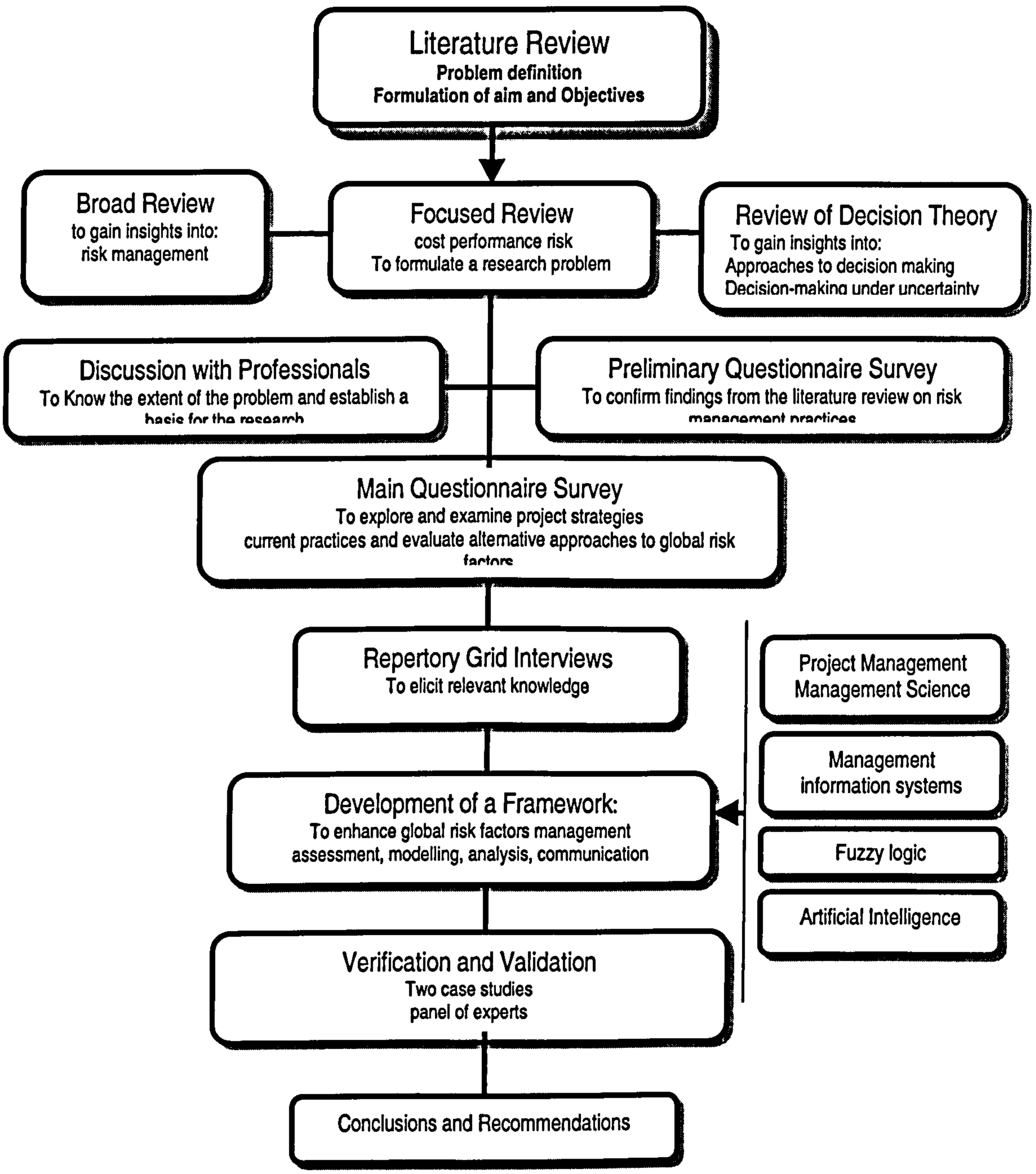

Figure 2.1: Research methodology flow-chart

2.10.1 Reasons for using this research strategy

The rationale for selecting the present research strategy has its roots on the approach of risk management that is being taken in this study. Traditionally, risk analysis and management has been taken to be a numerical discipline built upon statistical decision theory.

This research adopts a different approach of risk analysis and management. It considers that to be effective and efficient the techniques and tools for managing risk need to incorporate explicitly experience, intuition, subjective judgement, opinions, feelings and perceptions of the decision-makers. As such, the study incorporates both classical rational and behavioural decision models as complementary, and not mutually exclusive, theoretical approaches.

The statistical decision approach is prominently prescriptive/quantitative whereas behavioural decision model builds upon the concept of "satisficing" concept which is more qualitative. It is worth stressing that risk decision making in construction has incorporated a great deal of subjectivity because most decisions have to be made in complex and dynamic environments where the information available is rarely perfect and complete. As a result, the decision-making process is not only about the formal mathematical models but also, and importantly, a behavioural and attitudinal issue. Therefore, human judgement plays an important role in this regard.

Mixing methods is necessary in this study since a single method would not enable realising the aim and objectives in an effective manner. Furthermore, the combination of methods provides more and diverse perspectives on risk management from different settings and wide audience. The following sections provide more details on each the research methods namely questionnaire, repertory grid interviews and case studies.

- the questionnaire survey enables to take advantage of a significant number of contributions from construction organisations on the issues related to the topic under

consideration. Surveys are useful in situations where it is necessary to contact a large number of people. The data and information from the survey contribute helped to establish a good background, test the significance of the study, acquire an overview of current practices and delineate a primary synthesis for the development of the framework for risk analysis and management of global risk factors affecting cost performance. The data to be collected at this preliminary stage served as a background for further steps namely repertory grid interviews and follow-up interviews.

- the repertory grid interviews focus on the synthesis of the previous information. They enabled to conduct an in-depth study of the issues under scrutiny, namely construction organisation's attributes, project strategy and risk factors. Repertory grid technique is a qualitative technique taken from cognitive psychology used to produce an individual's mental map on specific topic or domain. In the present study it is used to derive managers' constructs of risk factors affecting construction cost performance and related issues. The method helped to evaluate executives' attitudes and perceptions as well as to refine and improve the development of the decision framework; and

- case studies are used to validate the decision framework developed using data and information derived in the last two steps. They provided the opportunity for a detailed examination of each of the units of analysis.

The combination of surveys and case studies seems to yield a better consistency of the results since it will allow a systematic comparison of different organisations by exploring different stances, management features and examining different levels of the variables involved. Combining various data collection methods provided a complete picture of the issue under investigation if it is admitted that it has more than one dimension (Mason, 1996). The following sections present the issues involved in the design of the questionnaire and the application of the repertory grid technique.

2.11 Survey questionnaire

Surveys are considered economical due to their high coverage and limited time frame but their rate of return has been very low. Usually, this fact brings problems related to data analysis as well as on findings generalisation, which is one of essential features of surveys. Interviews, on the other hand, are a very powerful tool for an in-depth exploration of data but they pose some problems such as cost, time and sampling (Bennett, 1983). In addition, they may limit the data amount to collect in a wide geographical area.

2.11.1 Preliminary workshop

Preliminary contacts with construction industry practitioners were considered important to know their opinions about the research problem and related issues. The main purpose of the workshop was to formulate the research problem clearly. Fifteen contractors were invited but only eight participated. Cost performance and risk management are, above all, management issues, so experienced managers were seen as the appropriate individuals who could provide useful information with regard their organisations. The workshop provided useful insights into the subject under study. The participants regarded cost performance as a crucial topic.

Contractors suggested that although they could identify most of the risk factors affecting cost performance they lacked effective tools to tackle them. The usual practice among them was using contingencies to hedge against risks regardless of project characteristics such as size, complexity, duration and type. Besides organisation-specific risk factors such as equipment, finance, human resources and management styles, the most cited risk factors were business environment, economic factors and political factors.

2.11.2 Questionnaire objectives

The questionnaire was designed to gather data to enable responding the above mentioned research questions. It is a preliminary data collection instrument and the information produced served as a foundation for the subsequent research step, which consisted of the administration of the repertory grid interviews. Therefore, the specific objectives of the questionnaire were to elicit the following:

- general information related to the construction organisations, namely company identification, address, type, size, age, type and number of projects undertaken, size of turnover and contact person;
- project performance indicators used by contractors, incidence of cost overruns, the most common contracting strategies, tendering procedures and types of contracts;
- risk identification, analysis and management practices used by construction contractors in cost estimating and construction process; and
- the most significant and critical global risk factors affecting cost performance of construction projects.

The questionnaire comprises twenty-seven main questions and one hundred and seventy sub-questions in total which is a large number for a questionnaire.

2.11.3 Questionnaire design

The design of a good questionnaire is a very difficult, hard exercise (Bell, 1997). Producing a good quality questionnaire is usually a matter of exercise, practice and experience. According to Moser and Kalton (1971), Oppenheim (1992), Sekaran (1992) and Rothwell (1995) when designing a questionnaire the following general issues should be taken into account:

- principles of wording (questions should be clear, easy to answer, unambiguous);

- content and purpose of questions;
- language and wording of the questionnaire (avoidance of jargon and specialist language);
- type and form of questions;
- sequencing of questions (starting with easy, factual questions and then opinions);
- appearance and layout of questionnaire (fonts, spacing, box positions, number of pages);
- introduction to respondents;
- instructions for completion;
- memory and knowledge (recalling is not easy; respondents may not know about a subject, so asking them to search for information may reduce the rate of success); and
- double and leading questions.

This research attempted to address the above mentioned issues in order to improve the quality of the questionnaire.

2.11.4 Layout, wording and sequencing of questions

There was an effort to make the questions, clear, brief, simple and still meaningful in order to remove ambiguity. As a rule of thumb, Oppenheim (1992) suggested that a question or a statement should not exceed twenty words or exceed no full line in print.

The questionnaire was organised in sections, which correspond to specific categories of issues as above mentioned. Each section of the questionnaire contains an explanatory introduction stating the overall purpose as well as specific details. Each question is preceded by a concise and clear instruction on how to respond to it. This is necessary to help respondents through the filling process. Suitable font types and formats where chosen so as to facilitate making distinction between instructions and questions.

The sequence of questions was given a careful thought in order to create a logical and sequential structure throughout the questionnaire, being a major concern to start from the least difficult questions to much complex ones and from general to more specific ones. This funnel approach facilitates an easy and smooth progress of the respondents. In order to avoid problems related to central tendency i.e. the tendency of people to avoid an extreme stand and to choose the middle answer on a question an even number of categories was provided. The questionnaire uses several types of measures as suggested by Youngman (1982), namely list, category, ranking, scale and quantity. The choice of each measure was based upon the specific nature of question and the subsequent analysis.

2.11.5 Type of questions

According to Atkinson (1967) there are three types of questions: factual; knowledge; and opinions. Factual questions refer to specific, determined facts with straight responses. These are considered the least sensitive type of questions whereas opinions are the most sensitive. Response to opinions is wide and depend on the respondent perception. In order to reduce the impact of such sensitive questions on the rate of non-responses, an initial piloting was conducted.

On the other hand, questions may be either close or open-ended. Open-ended questions allow respondents to give answers, opinions and views in their own way or in their own words. This type of questions is important in eliciting unanticipated answers. The major constraints of open-ended questions are the difficult in interpretation and analysis of data, time-consuming and cost. Closed questions imply predefined set of possible responses and thus, respondents have to choose among them. They lack spontaneity, expressiveness and introduce bias in answer categories. In addition, it should be ensured that they are mutually exclusive and collectively exhaustive. However, they have the advantage of being easier and quicker to answer, facilitating interpretation and statistical analysis.

With very few exceptions, this research adopted closed questions because: most concepts are well defined; respondents' words are not essential; potential responses are known in advance; and most questions are factual. Other types of questions such as open-ended are not appropriate for this study since it involves some construction management issues which may have a wide scope and different understanding.

2.11.6 Improving the rate of success

Non-responses and inadequate responses are among the commonest problems of questionnaires. According to Kahn and Cannel (1957) the rate of success is highly influenced by the following elements: non-responses; partial responses; irrelevant responses; inaccurate responses; and verbalised response problem. To a large extent this problem can be greatly reduced by adequate piloting. To minimise the above mentioned problems this research addressed the following issues, (Oppenheim, 1992): preliminary notification of the respondents through phone calls; covering letter stating the objectives of the questionnaire; assurance of confidentiality; explanation how the respondent was chosen; and personalisation of the questionnaire.

2.11.7 Population and sampling

Defining the target population and selecting sampling technique lie at the core of survey research. First, the population must be clearly defined to ensure that accurate and unambiguous and reliable conclusions are obtained. That is, defining the population is crucial in that research findings can only be legitimately applied to the population under study.

Generalisations can not be extended beyond that population. For this reason, a sample must be representative of the population from which it was drawn. Since a sample is considered a reproduction of the population, a representative sample is one that accurately reflects the distribution of the relevant variables in the target population. An improperly drawn sample can render the data collected ineffective. In the light of the above mentioned, this research adopted a top-down approach starting from the analysis of

the population to the analysis of the sample as suggested by (Moser and Kalton, 1971). Thus, in order to delineate the target population, the following aspects were given due consideration in the design of the research: content; units; extent; and time.

In this study, content refers to the construction contractors, unit refers to the units of analysis which are organisations rather than individuals, the extent is the geographical coverage which is Mozambique and, finally, with regards to time, this study is cross-sectional, in contrast with longitudinal studies.

2.11.8 Sampling frame and sample selection

Moser and Kalton (1971) mentioned that bias in the selection of the sample can be introduced if: the sampling is not random; and the sampling frame that serves as the basis for selection does not cover the population adequately, completely or accurately; and some sections of population are impossible to find or refuse to co-operate.

Information concerning construction organisations was drawn from the National Association of Construction Contractors EMPREMO, Ministry of Public Works (licensing department) and National Institute for Statistics. The sampling frame consisted of about four hundred registered construction contractors in Mozambique of which 75 percent are small-scale contractors. The size of construction contractors is determined by their capital, fixed assets and number of qualified personnel. The size determines the ranges of contract amounts or project size that contractors are allowed to undertake.

Contractors fall into the following categories or groups: Class 1, Class 2, Class 3 and Class 4. Class 1 represents very small contractors whereas classes 2, and 3 are medium contractors in local standards. Class 4 is the top class and thus contractors holding this license can undertake any contract regardless the size.

The sample selection procedure adopted is non-random sampling. The target sample in this study is composed of the Top 100 contractors falling into classes 2, 3 and 4. This was deemed the most appropriate target for any research seeking to apply scientific management techniques in construction project management. The following factors

served as the basis for selecting the sample: size; experience; share of the industry's business; expertise; and specialisation.

For logistic and cost reasons, the sampling was restricted to contractors located in Maputo region. Covering the whole country would be is costly and lengthy due to inefficient postal services. Moreover, it was assumed that the vast majority, around ninety five per cent, of medium and large construction contractors are based in Maputo. Later on, the research confirmed that almost all medium and large contractors, are based in Maputo and thus the distribution of contractors approximates that of the country. On balance, it is believed that although the survey did not cover the whole country the level of distortion of the sample was kept to a minimum.

2.11.9 Piloting the questionnaire

Piloting is a crucial step in questionnaire design to ensure that it works effectively. Typically, designing a questionnaire is a process involving formulation, specification, construction, revision and refinement. Therefore, before administering it, it was decided to give the questionnaire a trial run to test how long it would take the respondents to complete it, to check the clarity of instructions and questions as well as to revise and refine the questionnaire in accordance with the feedback.

The respondents were asked how long it took them to complete the questionnaire, if they had any comments, recommendations, felt any difficult is completing it and if they had found any question ambiguous. Moreover, the piloting was also intended to establish the most appropriate respondents. The piloting was done using a sample of eight contractors although the total number of invited contractors was fifteen.

2.11.10 Administration of the questionnaire

The questionnaire was personally administered. Questionnaires and follow-up interviews with construction organisations were directed to executives due to both the sensitivity of most data and the fact that they are the key individuals dealing with current day-to-day

activities. Furthermore, senior position individuals are difficult to contact, possess general information and they tend to delegate current affairs to the executives. Construction contractors were the targeted organisations.

2.11.11 Data analysis

The data analysis is organised in accordance with the sequence of the sections of the questionnaire. The objective of data analysis is to establish the following:

- general information related to the construction organisations, namely company identification, address, type, size, age, type and number of projects undertaken, size of turnover and contact person;

- evaluate the executives' attitudes towards project risk factors;

- project performance indicators used by contractors, incidence of cost overruns, the most common contracting strategies, tendering procedures and types of contracts;

- establish the common communication networks used by construction contractors;

- risk identification, analysis and management practices used by construction contractors in cost estimating and construction process with emphasis on both qualitative and quantitative approaches; and

- the most significant and critical global risk factors affecting cost performance of construction projects.

2.11.12 Measurement

The nature of research questions and, subsequently, the objective of the questionnaire has led to the inclusion of three types of data namely categorical, ordinal and interval:

- categorical, classificatory or nominal scales were adopted to identify the different categories in which certain variables are classified, for example companies' turnover and number of employees. In using categorical scales effort was made to ensure exclusivity and exhaustiveness;

- ordinal scales were assumed not only to classify but also to establish a rank order of the attributes under study. In this sense, variables can be arranged in series ranging from the highest to the lowest in accordance with the characteristics under investigation; and

- an interval scale was adopted to measure the significance of global risk factors affecting cost performance. It was deemed the most appropriate because, apart from rank-ordering the data, it can help establish how far apart the different factors are and, thus, in determining the most critical. Additionally, interval data can be converted into categorical and ordinal whenever necessary.

- Ratio scales were discarded because they correspond to the highest level of measurement that is rarely achieved or even practical in management research as it is the present study.

The analysis of data was performed through the use of both descriptive and statistical inference. Descriptive statistics were used to determine measures of central tendency, variability and relationships, whereas inferential statistics tools were used to estimate parameters as well as test hypothesis based on inferences made about population parameters from sample measures.

In view of type of data collected, parametric and non-parametric tests were used to analyse interval data, frequency counts, relative frequency distribution, and non-parametric statistics were used for categorical and ranking statistics for ordinal data.

The data analysis process was preceded by an adequate preparation that comprised editing, coding, categorising and subsequent stages getting a feel for data, testing reliability and validity and, finally, hypotheses testing.

The first step comprised the calculation of central tendency parameters. This helped to initially determine the quality of the measures as well as the respondent's reaction to the questions posed. In addition, some sort of biases on the responses was detected at this stage. Associations among variables were evaluated by means of correlation measures. Correlation was carried out with the objective of checking the extent and direction of their relationship.

2.12 Repertory grid technique

The repertory grid is a knowledge elicitation technique developed by (Kelly, 1955) based upon the ideas of Personal Construct Theory (PCT). PCT is a theory of individual and group psychological and social processes. PCT states that throughout his life each individual builds a construct or representative model of the surrounding environment. Such representative model or model of human thinking is then used to guide his behaviour.

The model is continuously updated through questioning, exploration and revision of the constructs based on new observations. The core aspects of PCT are: perceptions influence expectations and expectations influence perceptions; the medium through which this happens is known as the construct system; and construct systems are unique to the individual and develop throughout life. The Repertory Grid Technique can be seen as a particular form of structured interview that is used to explore another person's construct

system through conversation. The technique allows the interviewer to, with the minimum of observer bias, get the mental map of how the interviewee views the world. Therefore, it is essentially an instrument intended to collect data concerning individual's constructs.

It is a construction matrix or two-way classification of data in which elements and constructs are interlaced. The grid serves the purpose of formalising the process and assigning mathematical values to the relationships between different individual's constructs. The technique has had a wide application on subjects such as management science, education, health, psychology and knowledge based systems.

2.12.1 Objective of the Repertory Grid

Repertory Grid interview comprises the following steps:

- definition of the purpose of the grid;
- selection of the elements;
- elicitation of constructs;
- rating or ranking each of the constructs; and
- analysis of the grid.

The two most important components of a Repertory Grid are elements and constructs. Elements define the area under study whereas constructs are the ways that a subject uses to differentiate between elements. Rating, ranking or dichotomising are the main forms used to establish linkages between elements and constructs, that is, they show how each element is being assessed on each construct.

2.12.2 Definition of the purpose of the repertory grid technique

The main purpose of the repertory grid interview is to elicit relevant knowledge regarding global risk factors affecting cost performance. The process of knowledge elicitation entails translation from mental model to conceptual model followed by the analysis involving translation from conceptual model to the knowledge model. This involves

stating clearly the topic under investigation as well as the intended use of the grid. The type of grid varies in accordance with the area and purpose of the study. For example, they are used in market research studies, psychology, education, organisation behaviour, KBSs etc. With respect to grid design, Easterby-Smith (1980) suggested the following: small grids in order to avoid lengthy elicitation process; and clear definition and specification of the elements.

2.12.3 Elements

Elements can be defined as concepts in the domain. The elements are the focus of the grid and they are selected to represent the area over which construing is to be investigated. Therefore, elements comprise the subject under investigation, which may be in form of objects, ideas, entities, activities, interpersonal relationships, people, organisations etc. They are commonly formed by nouns and verbs. Some examples of elements are factors considered in bidding, factors affecting productivity and risk factors affecting cost performance such as inflation, weather conditions and competition. The number of elements in a grid vary largely in accordance with the area and the objective of the study. Most of grids used in clinical psychology, for example, have between 15 and 25 elements whereas in organisational settings the usual number of elements is below 15.

2.12.4 Elicitation of elements

It is very important that the elements chosen be specific as much as possible and be representative of the area under investigation. There are general specifications to be met by elements, as suggested by Kelly. According to Kelly, the elements have the following characteristics:

- be within the range of convenience of the constructs to be used, that is, since constructs are discriminations made about people, events or objects they apply only to specific number of people, events and objects and not to all circumstances;

- represent of the area under investigation. This means that the elements must belong to the specific area under investigation;
- be homogeneous, that is, they should all be drawn from the same category. Mixing different categories of elements, for example people and objects, can bring serious obstacles to the constructs elicitation; and
- be discrete. Elements must be clearly delimited and precise. Examples are people, objects, events and activities.

There are several methods for the elicitation of elements in Repertory Grid interview technique and the most important are the following:

a) Supply elements

This is the simplest method and consists of providing a list of elements by the interviewer.

b) Provide a role or situation descriptions

In this case the subject provides his own specific examples to fit general descriptions of experiences or type of activities, objects and concepts given by the interviewer.

c) Defining a pool

The subject is asked to name specific elements from the area under investigation. For example, the subject must be asked to name six most critical economy-related risk factors.

d) Elicitation through discussion

In this category the interviewer and the subject discuss the topic of interest based on previously prepared prompts by the interviewer. The final result of the discussion is the production of a list of elements.

2.12.5 Constructs

In general, constructs can be seen as the qualities that people attribute to the elements, therefore, unlike elements which are names, constructs are qualifiers or attributes dimensions that group elements into varying clusters according to their similarities and differences within an individual's frames of reference (Smith, 1978). In other words, constructs are relationships between elements and correspond to a scale along which elements can be rated. Bannister and Mair (1968) defined construct as "any form of sorting task which allows for the assessment of relationships which yields these primary data in matrix form".

Kelly (1955) defined a construct as " a way in which two or more things are alike and thereby different from a third or more things". Kelly retains the notion that constructs are bipolar because people never affirm anything without denying something. In this sense the notion of construct is different from a notion of concept. Often people do not explicit contrast pole but they make sense out of the their world by simultaneously noting likenesses and differences. It is in the contrast that the usefulness of constructs subsists. Thus, constructs values in a grid are given for each element on a scale between the two end points or poles (left and right poles). This procedure allows the assignment of intermediate values of constructs instead of considering the extremes only.

2.12.6 Elicitation of constructs

Construct elicitation lies at the core of repertory grid technique. Indeed the particular appeal of the grid is the opportunity it provides to deeply map out individual's construct system as well as measuring later changes. According to Kelly (1955), several assumptions should be taken into account with respect to constructs:

- the constructs should be permeable, that is, the person should be able to apply the constructs elicited to people or interpersonal situations other than the three elements from which the construct has been elicited;

- the constructs should represent subject's understanding, right or wrong, of the way other people look at things. If the subject gives only responses which describe his relationship to other people as if they were unthinking animals, the test has failed to elicit role constructs. The subject's measure of understanding of other people may actually be inadequate or preposterous; but if it is the basis of a real social interaction with them, it is indeed related to his role construct systems; and

- constructs should be explicitly bipolar, that is, by stating the qualities of a thing or situation the subject is also stating the qualities that such thing or situation does not possess.

2.12.7 Methods of constructs elicitation

Constructs can be elicited in various ways but the most important are triadic, dyadic, laddering, supply, free-response and combination (Kelly, 1955) as discussed below:

a) Triads of elements

This is the classical approach to generating constructs and involves the selection of three elements at a time from the full list of elements. The subject is then asked to distinguish in what ways two of the elements are alike and in what way the third element is different from the other two. The main aim of this approach is to produce two contrasting poles for the construct.

The main disadvantage of triadic elicitation lies on the fact that often it produces logical opposites rather than opposites in meaning which is the core of constructs. Additionally, the selection of triads can affect the final grid particularly when successive triads are

chosen (for example repeating two elements in successive triads). Ideally, the selection process should be random. Otherwise some elements will tend to dominate the type of constructs being produced and subsequently distorting the overall grid;

b) Dyads of elements

Eliciting elements using triads can be very difficult in some circumstances particularly when elements are complex and the subject is not able to generate constructs from triads. An alternative way is to use dyads of elements where two elements are selected at a time and the subject is asked to say whether they are alike or different as well as what makes them alike or different. Again, this approach poses the dangerous of producing logical rather than opposites of meaning;

c) Laddering

Laddering is a technique usually used in conjunction with one the above mentioned approaches. It is applied after the elicitation of few initial and original constructs. Based on the initial constructs the subject is asked to look closely at them in order to say which ends (poles) of the constructs are preferable or important to him. The main objective of laddering is to elicit more constructs by moving either downwards (laddering down) or upwards (laddering up). It is a kind of refinement process in which one moves from wider to the core concepts. This is usually accomplished by asking why and how types of questions. It is argued by Kelly that "why" tends produce constructs of greater generality while "what" and "how" produce more specific constructs;

d) Supply constructs

In this approach the investigator supplies pre-determined constructs for the subject to rate or rank. It is the quickest way of all elicitation techniques. The technique is very useful in some circumstances particularly when the constructs supplied are representative of the area under investigation and the subject has a thorough understanding of what they mean;

e) Free response elicitation

It consists of the subjects providing instinctively their own constructs through conversation between the parties; and

f) Combination

Combination involves eliciting and supplying constructs in a grid. Care should be taken to ensure the supplied constructs focus important dimensions under study. Furthermore, it is recommended that supplied constructs be given after constructs have been elicited in order to avoid influencing interviewee.

2.12.8 Linkages between elements and constructs

The linkage between elements and constructs is an essential feature for most applications of grids since it is the way the construct is used in relation to the elements which indicates the meaning of the labels given to each pole. Three forms are used to establish the links between elements and constructs namely, dichotomising, ranking and rating scales.

a) Dichotomising

Dichotomising is the technique that employs ticks and crosses to indicate how close an element is to the left or to the right pole of the construct. If the element is closest to the left pole of the construct a tick is placed in the appropriate box. If the element is closest to the right pole of the construct a cross is placed in the appropriate box. Dichotomising is seen as a rating scale with only two points. Dichotomising is often used when the analysis of the grid is done manually.

b) Ranking

Ranking involves rank-ordering the elements in a grid. For example, if there are five elements is a grid they are placed in order from one to five on each construct.

c) Rating

It is generally accepted that rating elements is less confusing to the respondents than ranking, particularly when there is a large number of elements. In rating the respondent assigns rates along a linear scale from the emergent pole to the contrasting pole of each construct. The exact number of points in the scale depends on personal preference but in most cases five-point or seven point scales have been used. The choice between ranking and rating depends on the purpose of the grid. However, Shaw (1980) revealed that about 70 per cent of published works used rating methods.

2.12.9 Analysis of the grid

There are several ways in which a grid can be analysed but the most common techniques are frequency count, content analysis, visual focusing, cluster analysis and principal component analysis. Content analysis and frequency count analyse the content of the grid whereas visual focusing, cluster analysis and principal component analysis are not only concerned with content but also with interrelationships (correlations). The analysis of a grid can broadly be grouped into manual and computer analysis. Manual analysis includes frequency counts, content analysis performance appraisal and visual focusing (Stewart and Stewart, 1981). Computer analysis comprises cluster and principal component analysis.

The classical approach adopted by Kelly was the dichotomous form of grid where the subjects were asked to place ticks or crosses across elements for each of the constructs. This is an example of grids that can be easily analysed manually. However, they fall

short in terms of discrimination on each construct. The main disadvantage of this approach is that it makes it difficult to discriminate between elements or constructs. The dichotomous grid may produce spurious relationships due to lopsidedness, too many ticks and few crosses or vice versa on a particular construct. The use of computers in the analysis is justifiable when grids are large, there are time constraints or when there is a need for precise measurement. The various techniques are described in detail in the following sections.

a) Visual focusing and correlation matrices

This form of analysis is primarily used with classical tick/cross grids rather than rated grids. Visual focusing analysis consists of getting the patterns of ticks or crosses given to a certain element, for example element 1, and comparing them to the patterns of other elements in the grid. This comparison enables determining the number of times there are agreements on the ticks or crosses by inspecting the rows and columns of the matrix.

With this information it is possible to draw an agreement matrix involving all possible pairs of elements and thus examine relationships between constructs and elements. Moreover, correlation matrices can be derived separately for elements and constructs simply by counting the number of matches in pairs of columns or rows. The numbers of matches are placed into their position in the correlation matrices. In this way the associations between elements or constructs can be easily spotted. The higher the number of matches or correlation coefficient the stronger the association. Both visual focusing and correlation matrices are helpful in that they allow identifying the patterns present in the grid.

b) Frequency count

The frequency count analysis involves counting the number of times particular elements or particular constructs are mentioned. It is usually applied in situations when the elements are very well defined and have consistent meanings to the respondents.

Furthermore, it can be applied both for individual and groups of individuals in order to uncover and look for common trends. Much benefit of frequency counts is achieved in situations where it is important to take before-and-after measures of individual's constructs after an intervention, for example, after a training course. In principle, individuals have fewer constructs about a subject when they have little knowledge or experience.

c) Content analysis

Content analysis involves selecting series of categories into which the elements and constructs fall and then assigning the elements and constructs to these categories according to their similarity in terms of content. This process enables wider latitude than in the case of frequency count since the categories may be much wider as required. Accordingly, several elements and/or constructs can easily be placed on distinct content areas. Examples of content areas with regards to risk factors can be competition-related factors, resource availability-related factors and resources quality related factors. Frequency count analysis is usually preceded by content analysis.

d) Computer analysis

As the size of the grid increases, the amount of work involved in the analysis rapidly increases and become difficult to deal with manually. Computer packages for the analysis of grids provide statistics about the features of a grid but they do not add more to the information or the meaning inherent in a grid. What can be computerised is the elimination of redundancy in a construction matrix.

There are several software packages available for the analysis of grids. The traditional and best known package is the GAP (Grid Analysis Package) which includes several programs used for measuring the content and structure of the cognitive system. GAP comprises programs such as INGRID, FOCUS, DELTA, SERIES, ADELA, PREFAN, GRANNY and COIN. GAP was originally developed by (Slatter, 1977) at St. George's

Hospital, London, and is owned by the School of Management at UMIST. In recent years, many others software packages have been developed. Some are available for purchase (GRDLAB, OMNIGRID, G-PACK, FLEXGRID, ENQUIRED WITHIN, GRIDCOR and SPSS), while others can be downloaded for free in the Internet (WINGRID, WEBGRID, GRIDSTAT and GRIDSCAL). These programs can perform a wide variety of analysis according to specific purposes and objectives of the grid and can operate in Windows, MS-DOS and MacIntosh environments. The choice of a specific program depends on the objectives of the analysis. Most of them can be used to perform descriptive statistics, correlations, cluster, principal component and other type of analysis.

- Cluster analysis

The cluster analysis, also known as dendritic analysis, is typically a computer-based technique. The classical program for this purpose is FOCUS developed by Shaw and Thomas (1976), at Brunel University, in an attempt to group or cluster similar elements or constructs in order to form categories derived from original data. FOCUS operates in a similar way to the manual analysis techniques described above except that while manual analysis highlights differences, FOCUS establishes correlations. The calculations are made by first looking at the elements to find which two are most closely correlated.

The program re-sorts the visual matrix in order to place them next to each other and "producing" a virtual element. It then drops the two correlated elements and takes the virtual element searches for the next two correlated combinations and re-sorts the grid again until all correlations have been calculated. In this way the elements are grouped in clusters of closely correlated elements by means of a tree (dendogram). The same calculation process is followed for constructs. The rationale behind this analysis is that elements and constructs that are very closely-correlated have similar meanings. The next process is the differentiation in which the interviewer tries to establish whether the degree of correlation represents the truth. If the interviewee confirms then the process moves to the next group of correlated elements. Otherwise, it will be necessary to produce new constructs in order to differentiate the elements. Summing up, FOCUS produces a linear

re-ordering of elements or constructs to highlight similarities in the way they are construed. The main outputs of FOCUS analysis are as follows:

- original raw data;
- matching score matrix between all pairs of elements;
- matching score matrix of the relationships between all pairs of constructs;
- re-ordered grid with threes diagrams attached showing the patterns of relationships in the data; and
- a statement as to which constructs, if any, should be reversed.

- Principal component analysis

Principal component analysis, PriCom, is a type of multivariate statistical analysis technique used to identify a relatively small number of factors that can be used to represent the relationships among sets of large number of interrelated variables. The technique is based on analysing the matrix obtained from the ratings of elements against constructs by searching for the smallest number of independent variables which could account for the relationships in the matrix. PriCom or factor analysis builds upon two matrices of similar measures: an element matrix that includes the measure of similarity of every element with every other; and the construct matrix which shows the measure of similarity of all pairs of constructs.

The position of each element and construct are plotted on the visual diagram (using X and Y axis) so that that ones which are similar are close to one another, and so on. That is, each element and construct is located in relation to the first two components. Thus, the measures of similarities can be viewed as distances in space. Since PriCom spatially clusters cases and attributes within a sub-domain it prompts individuals to add higher level attributes structuring the domain. The components are strictly linked to the elements with the greatest variance (most extreme ratings) which are assumed to indicate the main dimensions of constructs.

2.12.10 Cluster and PriCom analysis

The difference between cluster analysis and principal component analysis is that the former searches out the greatest variation in the grid and imposes mathematical axes. In addition it expands the grid and keeps all details. PriCom or multivariate relies on building up series of hierarchical groups based on the strongest associations in the matrix. It condenses the information in the grid and loses some of the details in the process.

The INGRID program has the advantage of enabling a visual mapping of the elements and constructs to be made as well as showing the linkages between elements and constructs. On the other hand, the FOCUS program provides a very limited picture of linkages between constructs and elements. It has, however, the advantage of simplicity in analysis. The choice of one or another is dependent on the type and context of the grid. Easteby-Smith (1980) suggested that FOCUS is suitable for operational applications where the grid is completed and interpreted by the subject and the INGRID for research applications.

2.13 Summary

This chapter has presented and discussed the different research strategies in an attempt to lie down the foundations for the study. It has presented the main philosophical views behind research methodologies. Different research perspectives, research types, data collection methods, data collection techniques and data sources were thoroughly explored. The chapter explained in detail the reasons behind the selection of survey questionnaire, repertory grid technique and case studies as the most appropriate research methods for the present study. The design of the questionnaire survey and the repertory grid were fully described and explained. The following chapter presents the review of the theory and literature in the context of risk management.

Chapter Three

Review of risk management theory, practice and research

3.1 Introduction

The literature review plays an important role in the research process as it allows the identification of the boundary of knowledge or research topic and the formulation of the research problem. The aim of this chapter is to build the theoretical foundation upon which the research is based. For that purpose, the chapter reviews the theories, relevant literature and discusses current practices on risk management in construction. Apart from focusing on risk management, the review of the literature and theory attempts to show the links between risk management and the related body of knowledge. The wider body of knowledge includes cost estimating, procurement routes, contracting strategies, organisational structures, bidding procedures and management styles. Finally, the chapter addresses the matters arising from the review and considered worth researching as well as the identification and delineation of the research problem. The chapter comprises two major parts: the first dealing with general aspects of risk management principles, concepts and definitions; and the second discussing narrow issues of the research problem domain namely cost performance.

3.2 Methodology adopted for literature review

Before embarking on an explanation of the methodology adopted for the literature review it is important to define some concepts used hereafter, namely research topic, research problem and problem statement. Research topic is used to denote a very broad area of study, for example risk management. Research problem is a more narrowly defined issue within the research topic and it represents only one of the different approaches to a research topic. In this study, the research problem is "Risk Factors Affecting Construction Cost Performance in Mozambique. The topic of the research was identified through the literature and researcher's own experience in construction and project

management. The review of literature is not considered an end in itself, but a means to the end of delineating and formulating the research problem, also known as problem statement. As such, after identifying the topic for the study there was a need to structure and organise the process of literature survey in order to realise the aim of identifying and delineating the research problem. The literature review flow-chart is presented in Figure 3.1 and a brief explanation is provided in the following sections.

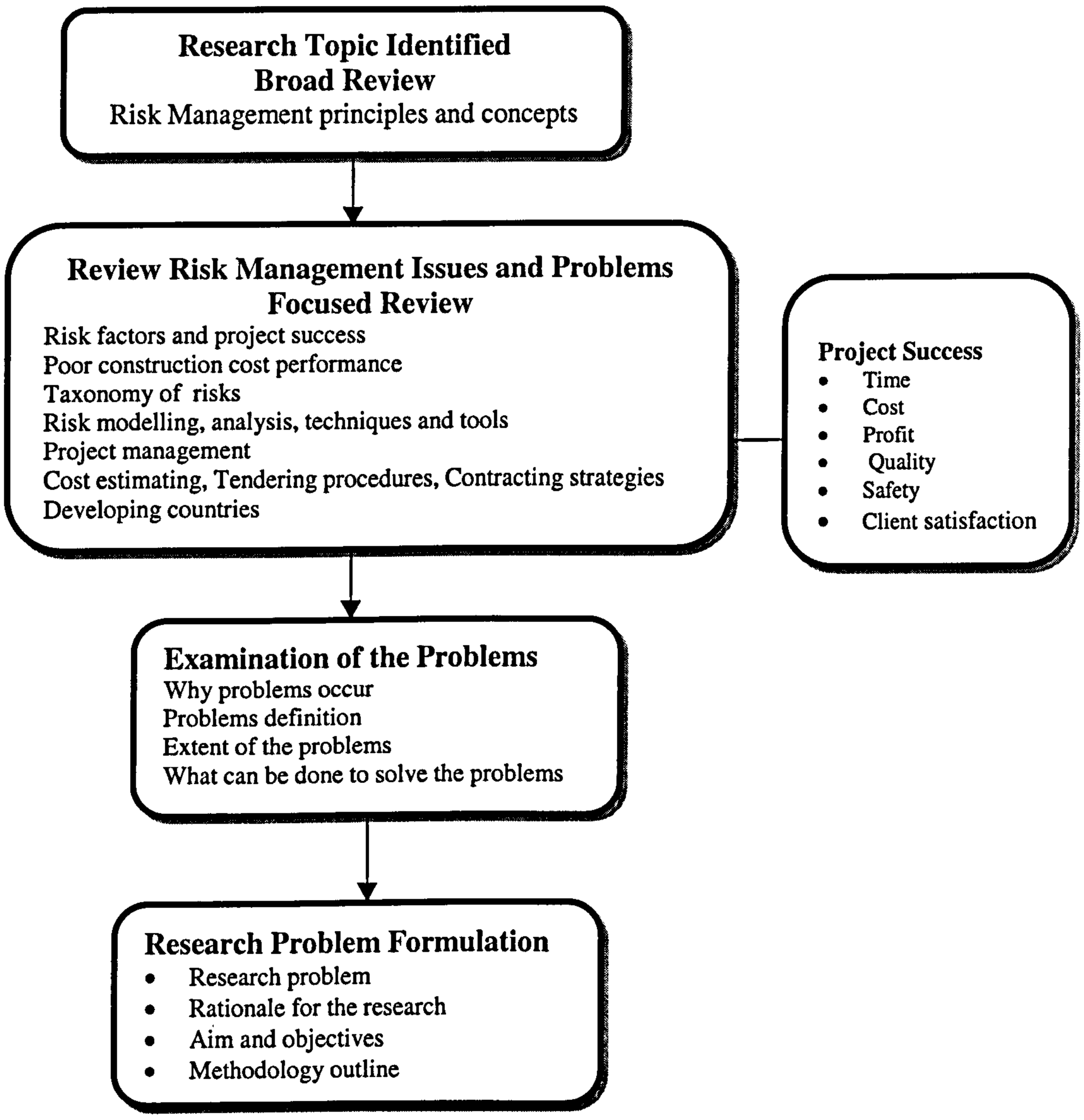

Figure 3.1: Literature search flow chart

The literature review comprised two main steps, namely:

- an initial broad review on risk management in order to gain insights into the theory and main concepts associated with risk in construction projects; and
- a more focused an in-depth review intended to study the existing body of knowledge, to ascertain the state-of-the-art in risk management and to uncover potential problems that deserved being investigated. The theories and different risk modelling approaches were thoroughly reviewed and compared.

The broad literature review was an important step for increasing the researcher's knowledge base on the research topic as well as for delineating the research problem. At this stage the review did not only concentrate on the construction industry but also on healthcare, insurance, oil exploration and financial sectors because these are the fields with well established risk management practices. After firming up the research topic there was a need to move to the research problem. Then the second stage of the review was conducted.

The review did not only concentrate on the area of the research problem but also attempted to focus on the links between the research are problem and the wider body of knowledge. Parent or associated disciplines and related issues, such as cost estimating, procurement routes, contracting strategies, bidding procedures and project performance indicators were regarded very important in understanding risk management process and environment. For the purpose of identifying the research problem, several questions were raised around the research topic in the light of the others researchers' contributions to the body knowledge of the subject. Furthermore, a close examination of the most relevant previous work was carried out. This extensive review combined with researcher's experience, helped to identify potential problems and prospect new directions for the future. The focused review, together with discussions with construction professionals,

enabled building a foundation for formulation of the research problem, its background as well as the aim and objectives.

Most of the literature search was carried out in the library of Loughborough University. The literature sources included serials, articles, periodicals, books and on-line databases. The main searched databases are the following:

- Bids Compendex;
- OCLC First Search;
- CD – ROM CITIS; and
- OPAC – Loughborough University

Finally, a critical examination of the above mentioned works was performed so as to preliminary formulate the research problem. The preliminary formulation of the research problem was complemented by a workshop with construction contractors in order to ascertain the causes, significance and extent of the problems as well as the prospective measures to overcome or minimise them.

3.3 Why risk management is important

The pace of change in the construction industry has imposed additional demands on construction project management. Risk management is a vital project management planning and control tool of project management and its role has increasingly been recognised as a tool for reducing uncertainty, improving decision making and thus maximising opportunities, (Astley, 1998 and Hillson, 1999). All construction projects involve risks of various kinds and according to Pender (2001) project managers have long known that managing risk is important, but formal recognition as a project management function has been relatively recent. For example, risk management was only separated into its own knowledge in the 1986/87 update of the Guide to the PMBOK (Project Management Body of Knowledge). A recent survey of researches into project risk management by researchers and practitioners identified 241 references (Williams, 1995).

Thus, risk management is a key to the success of construction projects and should, ideally, be embedded within project management practice. If properly implemented, project risk management can provide a decisive competitive advantage to both clients and contractors. The main performance indicators in construction are cost, time, quality, safety, profit, competitive advantage and client satisfaction and the relationship between project success and risk is very strong because project success is measured by the potential impact of risks on the achievement of project targets (Hillson, 1999).

Although different measures of success are used according to project objectives and the parties involved in a project, budget performance has always been considered (Sidwell, 1983; Jaselskis and Ashley 1991; and Sanvido et. al., 1992). Despite the importance of risk management the construction industry has been very slow when to recognise (Mulholland and Christian, 1999). This attitude can help explaining, to a great extent, the bad reputation the industry has had for poor cost performance.

3.4 Definitions and concepts associated with risk

Risk has different meanings to different people, that is, the concept of risk varies according to perception, viewpoint, attitudes and experience. Engineers, designers and contractors view risk from the technological perspective; lenders and developers tend to view risk from the economic and financial side; health professionals, environmentalists, chemical engineers take a safety and environmental perspective. Risk is therefore generally seen as an abstract concept whose measurement is very difficult (Raftery, 1994).

The *Oxford Advanced Learner's Dictionary- 1995 ed.*, defines risk as the: "chance of failure; the possibility of meeting danger or of suffering harm or loss". Cooper and Chapman (1987) defined risk as the "exposure to possible economic and financial loss or gain, physical damage or injury". In construction projects, risk may be defined as the likelihood of a detrimental event occurring to the project.

Since the objectives of construction projects are usually stated as targets established for function, cost, time, quality and safety the most important risks in construction are the failure to meet these targets. However, risks are not always associated with negative outcomes. Risks may represent opportunities as well, but the fact that most risks usually have negative outcomes has led individuals to consider only their negative side. The most important elements of risk include the likelihood, the frequency of occurrence, the impact of an occurrence and the relative importance. The elements and concepts are discussed below.

- Risk event: is the description of what may happen to the detriment of the project. For example, the sudden devaluation of currency is a risk event that may cause project cost growth.

- Risk probability: represents the probability or likelihood of a risk event occurring, i.e., how likely is the risk event.

- Risk impact: is the consequence, outcome or damage resulting from the risk event occurrence, i.e., the extent of loss or gain from its occurrence. Although commonly expressed in financial terms it can also be expressed in qualitative terms using linguistic expressions such as high risk and low risk. The amount of risk impact is calculated as follows:

Risk impact = Risk probability x Potential of loss **(Equation 3.1)**

- Expected value: is the average impact of the risk event over a large number of similar projects.

In principle, any risk has a cause and an outcome. In practice, though, one risk may have several causes and many effects. This adds complexity to the management of risk. Thus, it is of paramount importance to distinguish between causes and effects, since actions should be taken against the causes and not the effects.

- Risk and hazard: there is a difference between risk and hazard. Risk was defined in section 3.4 as the likelihood of a detrimental event occuring. Hazard is taken to mean a situation that in particular circumstances has the potential to harm, mainly physically, or cause a loss. Therefore, the degree of risk from the hazard depends upon circumstances.

- Risk and uncertainty: risk is a situation where it is possible to attach probabilities of occurrence of a risk event. Uncertainty, on the other hand means that probabilities to estimate riskness are completely unknown. Many times, though, risk and uncertainty are used interchangeably, that is, uncertainty is transformed and treated as risk.

3.5 Taxonomy of risks

Many different classifications of risk have been developed over the years, however, most of these have considered the source criteria as the most important. Following this criteria, a broad classification of construction project risks could be: technical; construction; legal; natural; logistic; social; economic; financial; commercial; and political (Thompson and Perry, 1992; and Flanagan and Norman, 1993). However, apart from the source criteria, there have been other forms of classifying risks, which take different perspectives. A classification taking into account the location of the impact of risks in the elements of the project was suggested by (Wirba et al., 1996). Furthermore, (Grey, 1995) proposed a classification based both on the source and location in the project work breakdown structure. It is also usual to categorise risks into dynamic/static, corporate/individual, internal/external, positive/negative, acceptable/unacceptable, short term/long term and insurable/non-insurable.

Although all these classifications are useful, the best results in the subsequent steps of risk management in construction projects may be obtained by adopting a combined perspective of classification, namely by considering the source, nature and impact dimensions. As stated earlier, whatever the classification adopted, any risk can be fully

characterised by its elements namely risk source, risk event, risk frequency, risk likelihood and risk impact. These elements determine the approach to follow in its assessment and subsequent management.

Risk classification provides insights for formulation of response strategies. Response strategies that may be appropriate to some risks may result completely unsuitable for others types of risks. Additionally, classification is very useful because it gives indications about the responsibility for any given risk in contractual terms, that is, who should, in principle, bear the risk. Risks are said to be dependent when the magnitude of one influences the magnitude of the other. Dependence can be total and partial. In the absence of dependence risks are said independent. Most risks in construction are dependent due to the interaction of several activities involved. The following sections provide detailed descriptions of the main phases of risk management.

3.6 Risk management

Risk management is nowadays considered one of the most important management functions (Grey, 1995; and Wideman, 1986) that help in project planning and control. It is essentially a tool aimed at anticipating for potential events that can jeopardise the success of the project in advance rather than reacting to them. Risk management has been performed by consultants, clients and contractors with different purposes. The consultants and clients do it because they want to ascertain the viability of their projects, to know the likely costs of realising a project as well as the potential return on investment. Contractors often perform risk management in order to make bid/no bid decision, evaluate the level of competition and profitability. The risk management process comprises the following three steps, as suggested by Healy (1983): risk identification; risk analysis; and risk response. These steps are described in detail in (Flanagan and Norman, 1993; and Raftery, 1994).

3.7 Procurement routes and risks

There are two main crucial factors that clients should consider for the development of the project execution strategy: appraisal; and organisational structure. The appraisal aims to determine whether or not to proceed with the project based on specific criteria such as technical and economic viability. Once the decision to proceed has been taken, there is a need for the development of a project strategy that includes selecting the project structure, type of contract, conditions of contract and bidding procedures.

The project structure establishes the framework within which the design, construction and commissioning will take place. The project structure is, therefore, selected in response to specific project characteristics, for example, size, technical complexity, risks, and client's requirements. Since risks inherent in projects are mainly apportioned between the parties through organisational structures and contract types it is crucial to understand their mechanisms. Organisational structures are discussed at length in Murdoch and Hughes, (1992). There are many different of project structures and the choice of any one depends on various factors, the most crucial of which are: flexibility; competition; tendering procedures; responsibilities of the parties; risk allocation; project type; project size; project complexity; project location; certainty of price; separation of design from management; implementation speed; methods of management; and political, social and economic constraints. The main organisational structures for construction projects are:

- traditional (where the design and construction are separated);
- design and build (where the contractor designs and builds a facility);
- management methods (management contracting and construction management); and
- Build, Own and Transfer - BOT.

3.8 Contract types and risks

The main objectives of a contract are to allocate and define responsibilities between the parties. Risk allocation has been made through either organisational structures or contract

type. As a principle, risks should be allocated to the party in a better position to manage them. However, in practice, each party tries to pass most risks to another party. The two main categories of contract types, namely cost and price-based contracts have been used in different perspectives. The basic difference of these types of contracts is the cost responsibility. The allocation of risk according to contract type is schematically presented in Figure 3.2 and explained in the following sections.

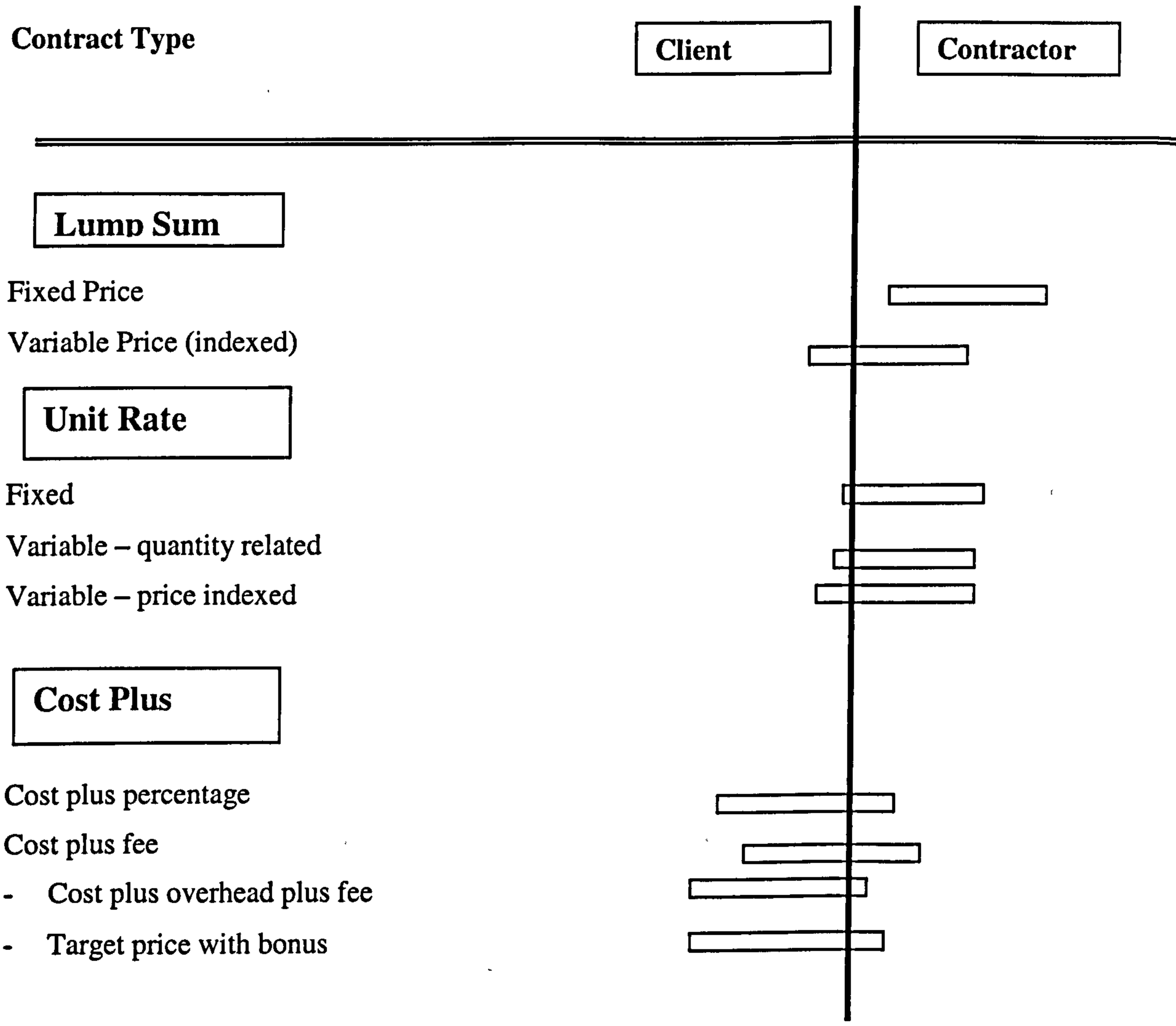

Figure 3.2: Risk allocation according to contract types (Adapted from Schuette and Liska, 1994)

3.8.1 Price-based contracts

Lump sum and unit rate are examples of price-based contracts. In lump sum contracts the contractor agrees to undertake the works at a determined global sum. Unit rate contracts are based on the bill of quantities and, the contractor estimate a sum for the completion of a determined package. The estimated price is paid by the client irrespective of the actual cost incurred by the contractor. Since the contractor can not be 100 per cent sure about the actual cost of the works he/she is in disadvantage should any detrimental event occur. Thus, this type of contract tends to allocate risks toward the contractor.

3.8.2 Cost reimbursable contracts

- In cost-reimbursable contracts, the client agrees to reimburse the contractor for all construction costs incurred and pay a fee for the services provided. Thus, the client shares the cost responsibility. The main features of cost reimbursable contracts are the deep involvement of the client; incomplete design scope; minimisation of design and construction time; client-contractor trust.

3.8.3 Incentive-based contracts

In general, cost reimbursable and fixed-price contracts tend to shift risks towards the client and contractors, respectively. Because of that characteristic, cost-plus-fee and fixed price contracts are considered to be the extreme situations, and in between lies incentive-based type of contract, (Scherer, 1964). The rationale behind incentive-based contracts is that deviations from the estimated cost are shared between the client and the contractor. Basically, this type of contract tries to motivate the contractor to put in much effort towards projects objective.

However, the major obstacle to the application of this type of contract has been the difficult in achieving an agreement between the parties on the right sharing fraction. In principle, the right sharing fraction is reached through negotiations among the parties.

Scherer, (1964) showed that contractor's and client's optimal sharing fraction are equal only when expected cost overrun and firm fixed price contractual covers are optimal for both parties. Recently, Al-Harbi (1998) argued that incentive-based contracts are only acceptable when both the client and contractor wish to share the risk of overrunning the target cost and share the savings in the case of a better than expected contractor performance.

3.9 Cost performance of construction projects

The cost performance of a single project can be measured in terms of cost growth, i.e. the percentage difference in cost between the final contract amount and the initial contract award amount, (Minato and Ashley 1998; and McKim et al., 2000). The final contract amount includes all additional costs occurred as a result of changes to the base contract. Moreover, the use of cost growth as a measure of performance must be clearly defined when the performance of different companies due to their different approaches to cost estimating and the allocation of contingencies.

Poor cost performance of construction projects has been considered a commonplace in the construction industry. Recent history of construction industry is full of examples of construction projects that were completed with significant cost overruns. According to Raftery (1994) the construction industry in general has had bad reputation for time and cost overruns. Tah (1993) also stated that poor performance in terms of cost overruns and delays is widespread in the construction industry. There are hardly cost underruns records of construction projects. Morris and Hough (1989) examined records of some 4000 different types of projects funded by the World Bank between 1974 and 1988 and concluded that the overall rate of success was very poor. The study concluded that 63 per cent of projects had experienced significant cost overruns and 86 percent had suffered severe delays.

Several authors have studied construction cost performance and results show that despite of the large number of reported cases there has been an increasing rate of cost overruns in all type of projects from the simplest building to the most complex such as dams, transport systems, oil and gas platforms, nuclear plants, environmental restoration and tunnelling (Berkeley, 1991; Elinwa and Buba, 1993; Kaming et al. 1997; and Astley, 1998). In this regard, Hulett (1996) suggested that "projects often overrun their cost estimates, sometimes by staggering amounts. This occurs even with carefully-constructed bottom-up cost estimates completed to a very detailed level by experienced project teams".

Furthermore, Nelson et all (1991) suggested that estimating is imprecise and thus can not be reduced to precise formulas and equations. Yet a cost estimate may be mathematically correct it can not be claimed that an accurate construction cost has been achieved because estimating is never an exact science. It largely depends on estimator's experience and judgement. According to Perry and Hayes (1985) many cost and time overruns are attributable to either unforeseen events, which may or may not have been anticipated by an experienced project manager, or foreseen events for which uncertainty was not appropriately accommodated.

There are many reasons for poor cost performance in construction but all of them stem from the risky and uncertain nature of construction projects.

3.10 Cost estimating and control

By definition an estimate is an expression of an approximate judgement or opinion regarding the value, size or weight of something. Estimating in construction is an expression of opinion or the prediction of the probable future costs of certain construction activities, usually based on some data having an acceptable degree of reliability, (Hardie 1987; and Nelson 1991). The estimated costs for contractors refer to the likely costs necessary to complete the project in accordance with contractual documents and the actual costs of the project represent the costs at project completion.

Hardie (1987) argued that the success of business is directly proportional to the quality of estimating process and the reliability of its results. Indeed, to secure a contract the contractor must have a tender that is low enough to win the contract and yet high enough to provide the opportunity for making a profit. For example, given the low profit levels experienced in UK construction, this represents a narrow band within which to work. An error of one or two per cent in estimating may represent a 30 to 60 per cent loss of profit, (Smith, 1995).

From the contractor's point of view it is very important to both prepare good estimates at the beginning as well as establishing an effective cost control system throughout construction phase. Depending on the contract strategy, the contractor's profit margin is largely influenced by his cost performance. In lump-sum contracts, for example, contractor's profit margin depends largely on his ability to minimise costs. An effective cost control system is helpful in determining the cost items with significant impact on project costs. Cost data records can be used then for future similar projects.

Cost control should ideally be approached as an application of Pareto's law, which states that 80 per cent of the outcome of a project is determined by only 20 per cent of the included elements. A typical contractor's cost estimates include the direct and indirect costs as presented in Figure 3.3.

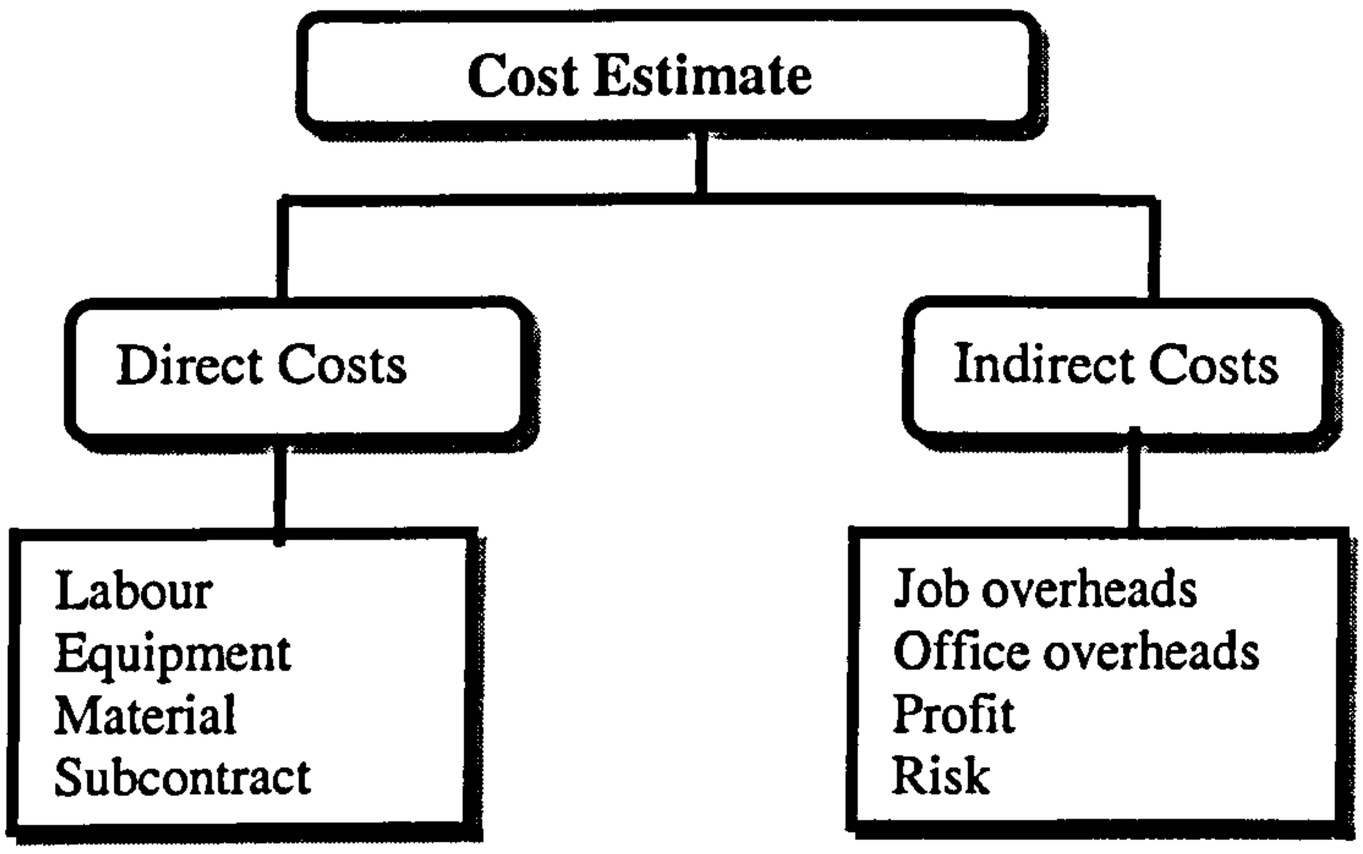

Figure 3.3: Basic components of a cost estimate

3.10.1 Deterministic estimating approach

Traditionally, cost estimates prepared by contractors are made on the basis of deterministic approaches which means that single value estimates result in single value overall outcomes. In doing so, it is supposed that all cost variables are known with certainty. In reality risk factors affect cost variables significantly so that they can not be known precisely. However, some authors, suggested that traditional single value estimating is adequate under stable conditions, (Newton, 1992), and has a more powerful capability of incorporating risk than probabilistic approach since the latter is normally subjective in nature and, therefore can not be described by standard probability distributions, (Lewellen and Long, 1972).

The traditional and widespread use of bills of quantities among contractors has indeed influenced single value estimating practice over years due to its adequacy to this procedure. Usually, contingency allowances are not based on a sound assessment of risks. Projects with different risk profile may end up with the same contingency amount. The expression of a contingency is often, at best, an educated guess of a stab in the dark (Perry et al, 1985). Clients and contractors have typically used contingencies amounts to protect themselves against inherent project risks, however, a "standard contingency" may be inadequate to protect against the risks associated with today's construction challenges, or may be so large as to be non-competitive, (Lockhart and Roberds, 1996).

3.10.2 Stochastic estimating approach

Alternatively, estimators can make use of stochastic techniques that build on probability theory. Probabilistic estimating is said to increase estimates accuracy because it introduces risk management into cost elements and produces a range of likely results on which to base decisions, (Flanagan and Norman, 1984; Cooper and Chapman, 1987; Raftery 1990; Uher, 1990; and Newton 1992).

This second estimating procedure takes risk and uncertainty into account in a more formal and appropriate way rather than setting up a contingency sum arbitrarily. In probabilistic estimating the cost items are expressed in terms of ranges: i.e. probability distributions. For this purpose bills of quantities are not appropriate due to a large number of cost items.

3.10.3 Current practices

Research by Uher (1996) into cost estimating practices in Australia confirmed the popularity of traditional single value estimating and highlighted the lack of use of probability cost estimating by general contractors. He further concluded that a change in the estimating paradigm towards probability cost estimating and the use of databases are unlikely to occur in the near future. Probabilistic estimating by contractors depends largely on the development of modelling tools, availability of data as well as human factors such as knowledge, skills and attitudes.

3.11 Bidding strategies

The tendering process involves two crucial decisions, namely bid/no bid decision and tender price. In the traditional cost plus mark up pricing model the contractor determines the direct and indirect costs of labour, materials and equipment and marks-up the estimated cost to cover overheads, contingency and profit. The survival of the business heavily depends, to a large extent, on the ability of the contractor to assign an appropriate mark-up that can generate enough work and reasonable profits.

The appropriate mark up size is that enables the contractor to be the lowest bidder and simultaneously maximising the profit. Successive failures to win contracts can lead the contractor to one of the following situations: reduce operating capacity; liquidate business; or declare bankruptcy. In general, there are two ways for contractors to get jobs. Direct negotiation with a client or his representative or through competitive bidding. The latter is the usual and widespread procedure in both public and private markets.

Given the importance of the tendering process, there has been an intense debate on the factors considered by contractors in tendering decisions. As a result several tendering strategies models have been develop over the years. Most of these mathematical models try to define the best tendering strategy for any contractor.

At first, it seems that contractors' decision to tender is only driven by the need to win jobs and make profits so as to remain in business. The decision to tender and the mark-up size determination are, however, largely qualitative and involve subjective assessment of many environmental factors. In arriving at the value of each of the elements in the estimate, the contractor and his estimating team combine known and reasonably reliable data with subjective judgements (McCaffer and Baldwin 1995).

The pioneering bidding model by (Friedman, 1956) is based on the premise that contractors' objective is to maximise profits which means they attempt to maximise their expected monetary value. Other authors, (Broemser, 1968; Gates, 1971; Morin et al, 1972; and Carr 1982) developed their own tendering strategy models founded on the Friedman's assumptions.

However, this view is challenged by several authors such as Neufville (1977) who argued that the models presented so far involve overly simplistic assumptions about what people want and how they make decisions. Neufville, instead, suggested that such models presume that contractors' desire is to maximise their average profits when, in fact, ample evidence demonstrates that they often hedge their bets conservatively, sometimes take gambles and generally choose consciously to do anything but decide according to the average. He suggested that contractors tend to maximise their utility function, instead. Apart from the issues considered in the previous standard tendering models he concluded that it is necessary to incorporate the effect of prevailing economic conditions, the size of the project and contractors' attitude to risk.

Despite the differences in the modelling approaches and the underlying principles, there appears to be some agreement on the following propositions: the optimum tender depends

on the probability of winning against other contractor; it also depends on the number of competitors.

Although there is a larger number of available bidding models, these are rarely used by contractors, (Ahmad, 1988; and Shash, 1993). Failure of previous mathematical models is attributable to several reasons namely incompletenesss and oversimplification of the real situation (Benjamin, et al. 1979, and Bell, 1969). Thus, often contractors do not rely on probabilities or mathematical bidding models to decide whether or not to bid and on the mark-up. They make an extensive use of subjective judgement, intuition and experience instead, (Fayek, 1998).

3.12 Current practices in risk management and risk analysis

Contractors must perform risk management in a systematic manner from the planning stage through project completion so as to make better and more informed decisions. Risk management should be viewed as a continuous loop and involve lessons learnt from previous projects. The unsystematic and arbitrary management of risks can endanger the success of the project since most risks are very dynamic throughout the project lifetime. Indeed, risks may vary from appraisal, design, tendering, construction and commissioning. To meet these demands, human and organisational dimensions play a key role in the whole process of risk management. In fact, risk management is both an art and a science. However sophisticated the analytical tools are, they are only a compliment to the process.

Despite the large body of knowledge and continuous developments of the risk discipline, it seems that practitioners have not fully appreciated its importance. Apart from the high-risk sectors, such as oil exploration and petrochemical, there is a significant gap between the existing theory and practice (Perry and Hayes, 1985; Thompson and Perry, 1992; and Flanagan and Norman, 1993).

Evidence shows that there is a gap between existing risk management techniques, mainly built on statistical decision theory, and their practical application by construction contractors (Perry and Hayes 1985; Thompson and Perry 1992; and Flanagan and Norman 1993).

Since construction projects have been perceived as being unique, it has been difficult or impossible to gather sufficient and reliable historical data on which to elicit objective probabilities, (Shen and Cheung, 1996). As a result, contractors tended to use subjective judgement based upon experience, (Wirba et al., 1996 and Smith, 1999). Common criticisms of existing techniques are on the following lines:

- handling statistics and probabilities is too complicated for most individuals in the construction industry (Mak, 1995);
- risk analysis is a complex task that entails the consideration of many parameters which are, more often than not, very difficult to quantify (DeRU and Eloffe, 1996);
- the sceptics argue that the analysts just rerun the analysis until they get the answer they want (Astley, 1998);
- construction risk analysis models are mainly based on quantitative techniques that require numerical data. However, very often, the construction project risk is difficult to represent numerically (Kangari and Bekheet, 1994). In addition, a model of a project is only as good as data that are fed;
- the individual nature of most construction projects results in little objective data that can be used to calculate probabilities of occurrence of specific risk outcomes. Thus, theories seem in quite distant from application, and practitioners have developed their own in-house approaches (Shen and Cheung, 1996);
- unlike other industries such as health, financial and insurance, there has not been an agreement among construction professionals on the accepted method of risk management. Furthermore, the construction industry is reluctant to recognise and incorporate risk management in project management, (Mulholland and Christian 1999); and

- Lack of knowledge and doubts on the suitability of risk analysis and management techniques for the construction industry activities, (Akintoye and MacLeod, 1997).

Various factors significantly influence construction costs from the estimating stage through to project completion. Furthermore, construction clients have introduced many new forms of procurement and contractors are thus having to take a greater proportion of the risk, most of which would have traditionally been taken by the client (Bedelian, 1996). Unfortunately, many contractors are unfamiliar with these risk factors and do not have the experience and knowledge to manage them effectively and efficiently.
Alternative approaches that clearly incorporate subjectivity and empirical knowledge, therefore, have to be addressed for the effective modelling and analysis of all risk factors especially global risk.

3.13 Research into risk factors affecting cost performance

Given the importance of risk factors that affect contractors cost performance several studies have been conducted. Research into the causes of poor cost performance of construction projects has pointed out several variables as risk drivers. The cost performance of a single project is usually measured by the cost performance rate, which is the percentage difference in cost between the final contract amount and the contract award amount at the outset. The final contract amount includes all additions occurred as a result of variations changes.

According to Jahren and Ashe (1990), Chan and Yeong (1995), and Levin (1998) a cost overrun has two major sources: change-orders; and claims. A change order is a formal change to the contract, which may involve changes in design, work quantity and technical specifications and consequently, changes in cost and time. These changes are usually increases. A claim is defined as: "a written demand or written assertion by one of the contracting parties seeking, as a matter of right, the adjustment or interpretation of contract terms, payment of money extension of time or other relief with respect to the

terms of the contract", (Levin, 1998). A claim occurs when the contracting parties can not arrive at an agreeable solution leading to a change order.

There is a wide variety of reasons behind claims but the most common causes are acceleration, restricted access, weather conditions, design changes, extra works, errors, delay caused by design team and unforeseen events, (Hiberd, 1986; and Semple et al, 1994). When claims can not be solved by negotiation between the parties, they are adjudicated by arbitration, litigation and alternative dispute resolution with the involvement of third parties. Change-orders and claims, in turn, originate from variations in the contract.

3.13.1 Variations

More often than not, variations are inherent in construction projects because uncertainties lead, invariably, to the need for adjustments in the contractual terms, (Ibbs, 1997). Variations have been defined in different manners in accordance with specific forms of contract. However, they can be defined in general terms as:

- increase, decrease or omission of any part of the work under the contract;
- change in the character or quality of any material or work;
- change in the levels, lines, positions or dimensions of any part of the work under the contract;
- execution of additional work; and
- demolition or removal of material or work no longer required by the principal.

Variations and claims have been the main reasons for disputes due to both conflicting interests of the parties and the complexity of contractual provisions dealing with valuation of variations and settlement of claims. Conflicting interests that lead to adversarial relationships between clients, contractors have strong economic roots, namely clients' costs and contractors' profits. These conflicting interests explain why clients,

contractors and architects have different reactions to variations. Clients are unwilling to accept additional costs and contractors try to maximise profit or to recover from potential losses and architects endeavour to prove that changes are covered by the contract documents, (O'Brien, 1998).

Levin (1998) argued that variations are an intrinsic element of construction projects and thus, they should be viewed as a management problem.

Hiberd, (1986) mentioned the following elements as the main drivers or sources of variations: design team; client; contractor; management; and unforeseen. Variations influence the whole project cost structure, i.e., both direct and indirect costs. The increase of costs due to changes are associated with material procurement, equipment, time lost in stopping and restarting tasks, change in cash flow, rework, acceleration, increase of overheads and decrease of labour efficiency.

According to Hanna et al (1999), clients have realised the effects of variations changes on specific works, but have failed to appreciate their impact on the whole project. In addition, Ibbs (1997), reported that few contractors maintained a reasonable number of job site records and as a result, they have not been able to evaluate change impact costs and do not realise that they have incurred impact costs until they produce final profit-and-loss account statements. The Construction Industry Dispute Avoidance and Resolution Task Force, DART, estimated that over USD 60 billions are spent annually on changes in the United States alone.

Several strategies for the reduction of variations have been proposed over the years. Among others, these strategies include clear project brief, detailing design, avoidance of nominated contractors, awarding contract to the right contractor, good cost control, good communication, use of alternative contracting strategies and good cooperation. Although these strategies provide useful indications into the factors influencing the occurrence of variations it is crucial to address them at a micro-level, that is, to investigate the risk factors.

3.13.2 Risk factors

This section reviews and brings together the most relevant previous studies on cost performance of construction projects.

Several researches have investigated change-order rate, which is defined as the ratio between the amount of change order and the award amount. Change-order rate is considered to be a major component of cost overrun rate that has been used as a measure of cost performance. Study conducted by Neufville (1977) on risk factors influencing change-order rate found the difference between the low bid and government estimate, level of competition and the size and type of the project as the major drivers.

Risk factors associated with political instability, fluctuations in currency, corruption, interest rates and material availability were considered the main causes of additional costs in privatised infrastructure projects in developing countries, (Rosenbaun, 1997). Kangari and Lucas (1997) mentioned that all government-funded projects in developing countries were political in nature. Political risk, in turn, lead, invariably, to bribery and corruption. Abdelkhalek (1997) studied the influence of politician owners in the private construction industry sector in Egypt and concluded that political factors highly influenced construction projects objectives.

Ashley and Bonner (1987) developed a model for political risk assessment in international construction using influence diagramming and probabilistic modelling. The modelling approach focused on the project consequence variables namely cost-related and revenue-related variables as the main factors influencing cost performance. Cost-related variables included labour, material and overheads whereas revenue-related variables included taxation, repatriation restrictions and foreign exchange rate. Ashley and Bonner proposed alternative approaches for handling the complexity inherent in risk management. These approaches include database management, decision trees and knowledge-based systems.

A study conducted by Chalabi and Camp (1984) on causes of delays and consequent cost overruns common to the majority of projects in developing countries of South America concluded that foreign contractors may not be familiar with the material and human resources of the country nor have the knowledge of the social, religious and government factors affecting the project. It is worth noting that local contractors are also unfamiliar with these factors. This lack of knowledge is a serious factor of delays and cost overruns. They concluded that adequate planning, a practice that is not encouraged in most developing countries, at early stages of the project is an important factor to limiting delays and cost overruns.

Causes of high construction costs in Nigeria were investigated by Okpala and Aniekwu (1988) who argued that delay and cost overruns can be minimised since they derive from factors related to human inefficiency and thus, removable to a great extent. Okpala and Aniekwu also noted that the causes of cost overruns are often discussed but it appears that little has been done to minimise the problems. Price fluctuations, delay and fraudulent practices and kickbacks were identified as the most important factors.
Additional work, shortening of contract period and inaccurate estimates were also considered important factors. Research carried out by Elinwa and Buba (1993) on construction cost factors in Nigeria seems to recognise factors mentioned by other researches. According to the findings of the research, cost of materials, fraudulent practices and kickbacks and fluctuations of prices are the most relevant reasons for high costs of construction.

Kaming et al (1997) studied factors influencing construction time and cost overruns on high-rise projects in Indonesia and concluded that inflation, inaccurate estimates, project complexity, weather conditions, project location and local regulation were the most important contributors. They argued that cost performance could be enhance by minimising the factors behind poor performance.

Stukhart (1982) argued that inflation has become a chronic problem whose effects permeate the entire construction industry. Contractors are faced with severe uncertainty in tendering and financing construction projects. The influence of inflation on profit and on contractors' price determination were studied by Warszawwski (1982) who concluded that the element of uncertainty introduced by inflation has an overall influence on construction prices. In addition, if not protected against risk by an appropriate agreement the contractor tends to include in his price an allowance for excessive escalation of his input prices.

Potts and Patchell (1995) studied major projects and mentioned the following reasons for works failure to finish on time and within the budget: underestimating; technological advances; design changes; adverse site conditions; funding availability; quantity increases; shortage of materials; contractors' financial difficulties; inappropriate contract strategy; inflation; interest charges; exchange rates; and political factors.

Jahren and Ashe (1990) investigated predictors of cost overruns and concluded that they included change orders and claims. Project size and the difference between the low bid and the government estimate were considered as being the major factors of project cost overrun rate. Apart from the above-mentioned factors, other several factors were regarded as contributing to cost overruns. These factors include quality of contract documents, the nature of interpersonal relations on the project, and the policies of the contractor. Jahren and Ashe suggested that no quantitative studies were found in the literature that analysed that factors.

In recent work on cost monitoring and control within construction organisations in the United Kingdom, Abubacar (1992) reported construction contractors' experience with cost overruns. According to the survey, factors such as design, technical, managerial,consultants, suppliers, clients and contingency were cited as being the main reasons for cost overruns. In addition, some organisations pointed out the structure of the industry and forms of contract as contributors of cost overruns, as well.

This work, however, does not go further into explaining the nature and relationships among the mentioned factors nor the process by which they affect contractors' costs.

Dawood (1996) asserted that risk management could be seen to be a vital source of efficiency and awareness improvement of the risk factors that affect costs. Further, he used historical cost data from reservoirs projects to investigate and establish relationships between some relevant risk factors, namely contract sum, admeasurement, unforeseen conditions, client changes, design changes and claims, and project costs.
He concluded that client changes, unforseen conditions and design development contributed with 82 per cent, 38 per cent and 30 per cent to project cost, respectively.

In a recent work on cost growth in public sector buildings, Giritli (1996) developed a linear model describing the relationship between cost overrun and the difference between the final price and the contract amount as to enable construction organisations to take account of influencing factors on estimates. The author used a data base consisting of 31 housing projects being the independent variables the gross area, contract amount, contract periods, percentage difference between the award amount and the estimated tender value and number of bidders. The author reported that the percentage difference accounts for about 55 per cent of cost overrun rate.

Studies conducted by Odeyinka and Yusif (1997) on the causes and effects of construction delays on the completion cost of housing projects concluded that loss and expense claims have significant effect on cost overrun. Similarly, fluctuation claims have significant impact. Both loss and expense claims due to delays and fluctuation claims during delay period account for about 51 per cent of cost overrun, thus, impacting significantly on the completion costs of housing projects. Odeyinka and Yusif proposed the development of linear models to enable the prediction of cost overruns due to fluctuation, loss and expense claims.

Dinassayaka and Kumaraswamy (1999) grouped factors affecting cost performance into procurement and non-procurement. Procurement factors include payment modality, procurement system, contract conditions whereas non procurement factors include project location, design complexity, new technology, change orders, claims, client experience and cost control. They then developed predictors of cost performance using multiple linear regression and artificial neural networks.

McKim et al., (2000) investigated project performance control in reconstruction projects and found that unforeseen site conditions, scope change by owner, design change, procurement design co-ordination and regulatory requirement were among the most significant factors of poor cost performance.

Factors affecting contractor's risk of cost overburden were reviewed by Akinci and Fisher (1998). Their work focused on external risk factors such as economic, political, design, clients, subcontractors, weather and ground conditions related factors. It seems to be an agreement between this review and the points of view of previous researchers, for example Al-Bahar and Crandal (1990), Flanagan and Norman (1993), Raftery (1994), Lockhart and Roberds, (1996) and Uher (1996) on the need for an adequate consideration of both internal and external risk factors in the process of risk management. However there is evidence that shows that most construction organisations tend to consider those risk factors that are easily measured quantitatively, (ICE, 1998), and to pay little attention to other group of factors.

3.14 Matters arising from the review

Factors affecting cost performance of construction projects seem to be well appreciated in the literature. However, there are some gaps that need to be bridged in order to improve risk management decision-making.

- Firstly, a general conclusion drawn from some earlier studies was that, among other factors, poor cost performance of construction projects was largely affected by the difference between the contract award amount and the estimated tender value. The estimated tender value is the cost estimate prepared for the client prior to the bidding process to enable the appreciation of probable cost involved in the project. Then, linear analytical models were developed to formalise the relationship between cost overruns and their causes, as well as to propose corrective measures. Subsequent effort has been placed on the refinement of such analytical models in order to reduce the difference, (Giritli, 1996). Yet such difference is significant in explaining cost overruns causes, it should be stressed that project cost overrun largely depends on the way risks associated with unforeseen and foreseen events are identified, anticipated and accommodated, (Perry and Hayes, 1985). Linear models are excellent prediction tools. However, their development process requires a large amount of data to be as accurate as desired and reliable predictors. Bazerman (1990) suggested the use of linear models based on expert judgement as a way to improve decision making in complex situations where judgement is the fundamental feature as it is with risk management.

- Secondly, there is a common limitation of the previous studies since most of them considered the immediate and easily quantifiable variables only, as recognised by Jahren and Ashe (1990), Giritli (1996) and Akinci and Fisher (1998). Jahren and Ashe, for example, stated that considering additional factors, other than those mentioned, would lead to the lack of soundness, because they were difficult to quantify. The main reason for the supreme use of quantitative approaches, statistical decision analysis models, is that risk management has been seen as a quantitative method founded on prescriptive models of decision making. With regard to quantitative methods in construction, Chalabi and Camp (1984) suggested that quantitative techniques were not generally accepted in some developing countries because it was felt they lacked appropriateness to suit local conditions. Then, most domestic contractors prefer in-house methods and intuitive judgement. In addition, risk management decision making is mainly based on experience, intuition and

judgement. In this regard Walker (1996) commented:" *For many years management has been synonymous with a hard system approach. Project management has emphasised quantitative techniques in project planning, scheduling and control. Project-network analysis using PERT or CPM, variance analysis, cost estimating techniques, risk analysis, Monte Carlo simulation, sensitivity analysis, cost modelling and lately expert systems are almost synonymous with "modern" project-management approaches and techniques. It is remarkable that project managers have taken so long to recognise that, in spite of the many advanced techniques, projects in many fields have still been subject to large cost overruns and delays. The engineering background of many project managers has meant that they instinctively adopt a numerical approach to solving problems even when problems do not respond to such advances".*

- Thirdly, despite general agreement on the above-mentioned factors, there is little evidence of an in-depth investigation of those factors, including the underlying root causes. It is not enough to focus on the immediate causes. Rather, it is crucial to uncover the underlying the root causes since the occurrence of a particular risk event depends on the occurrence of the underlying causes. The root causes of poor cost performance seem to be risk factors and the difference between low bid and government estimated largely cited in the literature as being the major cause is simple a consequence of risk factors permeating construction projects.

Some studies provide general recommendations and suggestions on how to improve cost performance. However, it seems that these suggestions need to be structured so as to facilitate the analysis, particularly with regard the most complex risk factors with which contractors are unfamiliar. To succeed contractors need to recognise and plan in advance, rather than gambling.

Furthermore, it would be of great importance to integrate the different groups of global risks into a single model to generate a wider picture, as well as to analyse their interrelationships. The literature presents different and scattered models that correspond to specific and particular situations.

Thus, the recommendations and models produced so far need to be complemented and improved. Although some sources of uncertainties are very difficult to assess, analyse and to communicate, reliance on arbitrary assumptions may be misleading and controversial. Furthermore, overlooking or ignoring risks does not make them go away, (Hullet,1996). All potentially serious risks should considered for management. Both internal and external environments of a project must be scanned and the uncertainty considered, since it is crucial in determining potential failure in performance. Many risks are often impossible to control, but they have to be taken, monitored and accommodated, (Mulholland and Christian, 1999). The present research is an attempt to review, bring together and systematise global risk factors affecting cost performance in order to build a model for their assessment, analysis and management using a blend of both prescriptive and behavioural decision perspectives.

3.15 New directions

Alternative approaches to the traditional techniques based on statistical decision analysis have been advanced to help in management of risks. Kangari and Boyer (1989) investigated the feasibility of using fuzzy expert systems in risk management. Diekman et al (1996) proposed a combination of Monte Carlo simulation for internal risks and influence diagrams for external risks. The latter technique was considered more suitable than Monte Carlo simulation for handling external risks.

Sigurdsen (1996) developed a methodology called "objective cost risk analysis methodology". Wirba et al (1996) argued that there was a need to develop new techniques and tools to manage construction risks since they are becoming much complex. They performed a case study involving management of internal risks in a building project to evaluate the applicability of fuzzy set theory. Yeo (1990) suggested a rule-based expert system for the classification of risk.

Wang et al (1999) suggested the introduction of innovative and effective risk management techniques for some types of risks such as political and financial.

3.16 Summary

This chapter has reviewed the theory and literature on risk management and parent disciplines with the primary aim of identifying the boundaries of knowledge and delineating the research problem. The chapter has thoroughly discussed the theory, practice and researches into risk management in construction projects. It has also examined the literature on different and significant risk factors and their relationship with cost performance of construction projects.

The parent and related disciplines examined included contracting strategies, bidding models and procedures, cost estimating, contract types, cost performance, variations and claims. The review has uncovered several practices and problems related to the management of risk within construction organisations. Overall, it was found that poor cost performance of construction projects has the norm rather the exception. The findings of the review can be summarised as follows:

- risk management has increasingly had an important role in project management both from theoretical and practical grounds;

- construction industry has had bad reputation for failing to meet project objectives particularly budgets. Time and cost overruns are widespread and have continually caused significant financial losses to both contractors and clients;

- poor cost performance of construction projects seems to be a norm rather than the exception. Both owners and contractors suffer significant financial losses due to cost overruns. However, contractors in general and particularly in developing countries often have to bear most of the financial burdens resulting from construction risks;

- the amount of uncertainty in both the internal and external environment is crucial for the contractors' survival. By correctly assessing the surrounding uncertainty they will be able to identify risk factors, plan and adopt management strategies that improve the chance of success. Contractors are generally unfamiliar with risk factors associated with the external environment which are very complex in nature;

- the traditional procurement route where, design and construction are separate entities, still prevail to a large extent although in recent years new alternative approaches namely, management methods, design and build, partnering and privatisation schemes, have been adopted;

- contractors' bid/no bid decision in competitive bidding is highly influenced by a large number of factors. Because of the overwhelming number of factors modelling the bidding process is very complex and there is no generally acceptable and reliable bidding model so far. Contractors have made bidding decisions on the base of experience, intuition and guess. Competitive bidding was found the most employed bidding procedure for construction projects;

- operational and unit-rate are the main estimating techniques used by construction contractors. On the other hand, unit, cube, floor area, storey enclosure, approximate quantities, elemental cost analysis and comparative estimates are the most used techniques by designers;

- the main groups of global risk factors that affect construction cost performance are social, economic, political, design, project, competition and fraudulent practices. These correspond to the most important environment domains surrounding construction business, which are social, economic, political, technological, competitive and physical. The complexity associated with these factors stems from either unavailability or incorrectness of information regarding them. The process of risk management decision making is thus fraught with uncertainty that can be

categorised as follows: uncertainty regarding information availability, accuracy and clarity; uncertainty regarding cause-effect relationships; and uncertainty regarding alternative options consequences. As a result, risk management decision-making is a typical problem of decision making under uncertainty;

- lack of good quality, reliable historical data is commonplace in construction industry. The reasons are that construction projects tend to be unique and there is poor data recording. Consequently, it has been very difficult to elicit probabilities to feed into probabilistic models in order to assess and manage risks. Therefore, decision-making problems in construction are mainly based on assumptions, intuitive judgement, experience and rules of thumb, rather on mathematically laws. Formal risk analysis and management techniques are rarely applied due to the lack of knowledge and doubts on the suitability of these techniques. In this regard, Flanagan and Norman (1993) mentioned that there is a gap between the theory and the techniques proposed to manage risk and what practitioners do in practice.

- construction contractors in developing countries suffer from an unfavourable operating environment with complex procedures and regulations, delays in payments, unsuitable contract documents and low and fluctuating overall levels of construction activity. Thus, the need for contractors to scan external environment is crucial for success;

- contractors in developing countries have to bear the majority of construction risks. Typical problems of developing countries such as lack of skilled people, unfair contracting practices, shortage of material and equipment pose them serious risks than those born by clients;

- past studies did not give much importance to the significance of global risk factors, probably due to the difficulties concerning their modelling and assessment. There are, though, evidences that global risk factors are determinant in the successful completion of construction projects, particularly in developing countries;

- several models for risk analysis and management have been developed but few of these are used in practice, largely, because they do not suit the actual practices of construction contractors. A need remains for models that are designed to suit the actual practices of construction contractors so that they will be more realistic and thus accepted and used;

- there is little evidence in the literature that an in-depth work has been undertaken to integrate and investigate the nature and the impact of the different global risk factors influencing contractor's cost performance at the project level;

- risk analysis and management has relied solely on quantitative techniques with the inherent degree of subjectivity. There are evidences showing that many contractors use experience and subjective methods in risk analysis management;

- decision-making under uncertainty makes extensive use of empirical knowledge, which in most cases is not numerical but expressed in natural language; and

- there is a need to explore new directions for risk analysis and management so as to enhance contractor's cost performance.

Summing up, alternative approaches that clearly incorporate subjectivity and empirical knowledge have to be addressed for an effective modelling and analysis of risk factors in general, and global risk factors in particular. Recent developments in the field of information technologies create great potential for the development of decision support systems and knowledge based systems. Due to the characteristics of risk management, emphasis on human judgement, knowledge based decision support system seems to be an appropriate methodology. Several techniques for decision support systems development and uncertainty encoding procedures are available and can be used in this regard.

Chapter Four

Review of global factors affecting cost performance

4.1 Introduction

This chapter is built upon the theoretical framework developed through a review of the theory and literature. The chapter sets outs to explain the environment domains and dimensions within which construction organisations operate. Systems theory is briefly presented in order to place construction organisations into context. Understanding factors and forces that influence the performance of organisations and projects, on a daily basis is crucial for management, and, consequently, risk management that is mainly a planning and decision-making exercise. The chapter also discusses the main categories of risk factors affecting the performance of construction organisations. These factors are grouped according to their source or cause into organisation-specific, Acts of God and global risk factors. A more detailed discussion of global risk factors affecting construction cost performance is presented at a micro level, since the study focus upon construction projects rather than at a corporate level.

4.2 Organisations and their environment

Construction organisations operate within an environment and not in a vacuum. Construction organisations, like living organisms, can be regarded as systems, which were defined by Ackoff (1963) as entities consisting of interdependent parts and where each element is connected to every other element directly or indirectly. The concept of system was originally developed by Bertalanffy (1968), from biological sciences. He later devised the general systems theory (GST) applicable to a wide range of disciplines including business.

The systems theory approach is a way of thinking about complex processes so that interrelationships of the parts and their influence upon the effectiveness of the total process can be understood, studied and enhanced. There are two types of systems,

namely open and closed. A closed system is one that does not respond to events and occurrences outside. It is, therefore, a rigid system and can not adapt to changes. An example of closed system is a computer that is designed to perform specific repetitive tasks within specific conditions. Open systems, on the other hand, are able to adapt to events outside them, that is, in the systems' environment.

Modern organisations are open systems and, as such, they are inevitably influenced by and constantly interacting with their environments. For this reason, management must have a close relationship with the environment since an organisation's efficiency and effectiveness depend largely on how its managers are able to continuously scan the environment, identify the critical factors, and adapt their organisations or projects accordingly. According to Walker (1996), one of the major jobs of a manager is to relate the project to its environment and he/she should not only focus on the internal regulation of the system. In this context, an organisation's or project's environment is the set of all factors and their properties, both inside and outside of the organisation, that have a potential to affect its functioning, progress and success.

It should be noted, however, that the environment does not only represent threats. It also incorporates a set of opportunities that need to be explored and channelled in a positive direction to achieve competitive advantage and success. Risk factors should therefore not be seen as only introducing downside effects, but upside effects as well.

The intensity with which the various elements of the environment influence organisation's operations depends on the type of business, the degree of complexity and many other factors. Certain organisations may be greatly influenced by specific set of environment elements, whereas others are influenced by different elements. Construction organisations, for example, are highly influenced by the state of the financial system and the state of the market. The environment structure of an organisation is presented in Figure 4.1, whereas the environment domains are depicted in Figure 4.2.

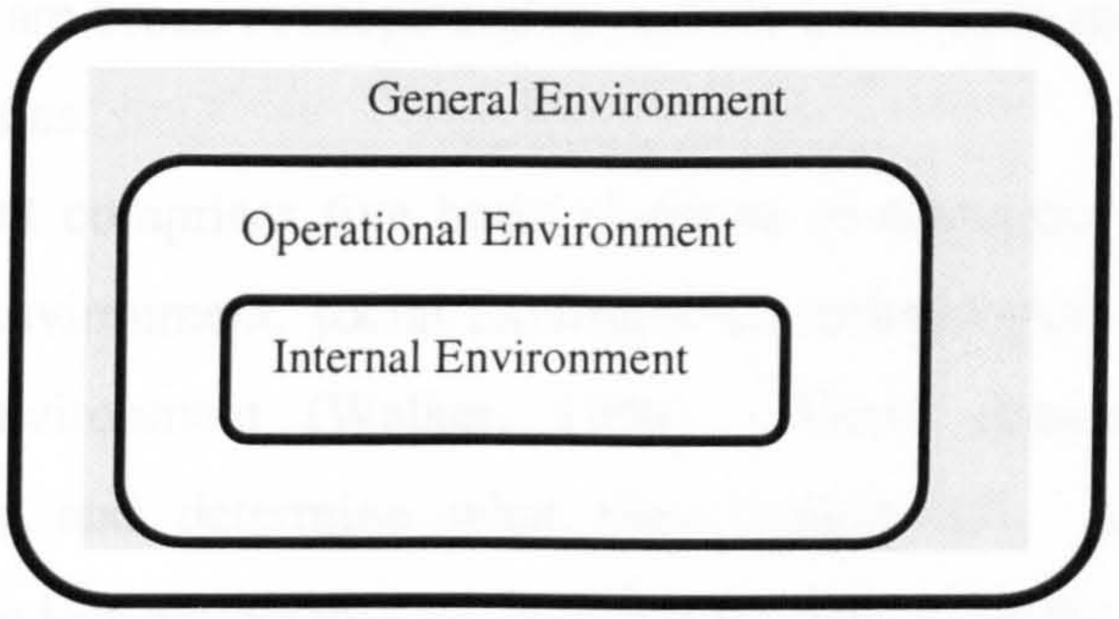

Figure 4.1: The environment structure of an organisation

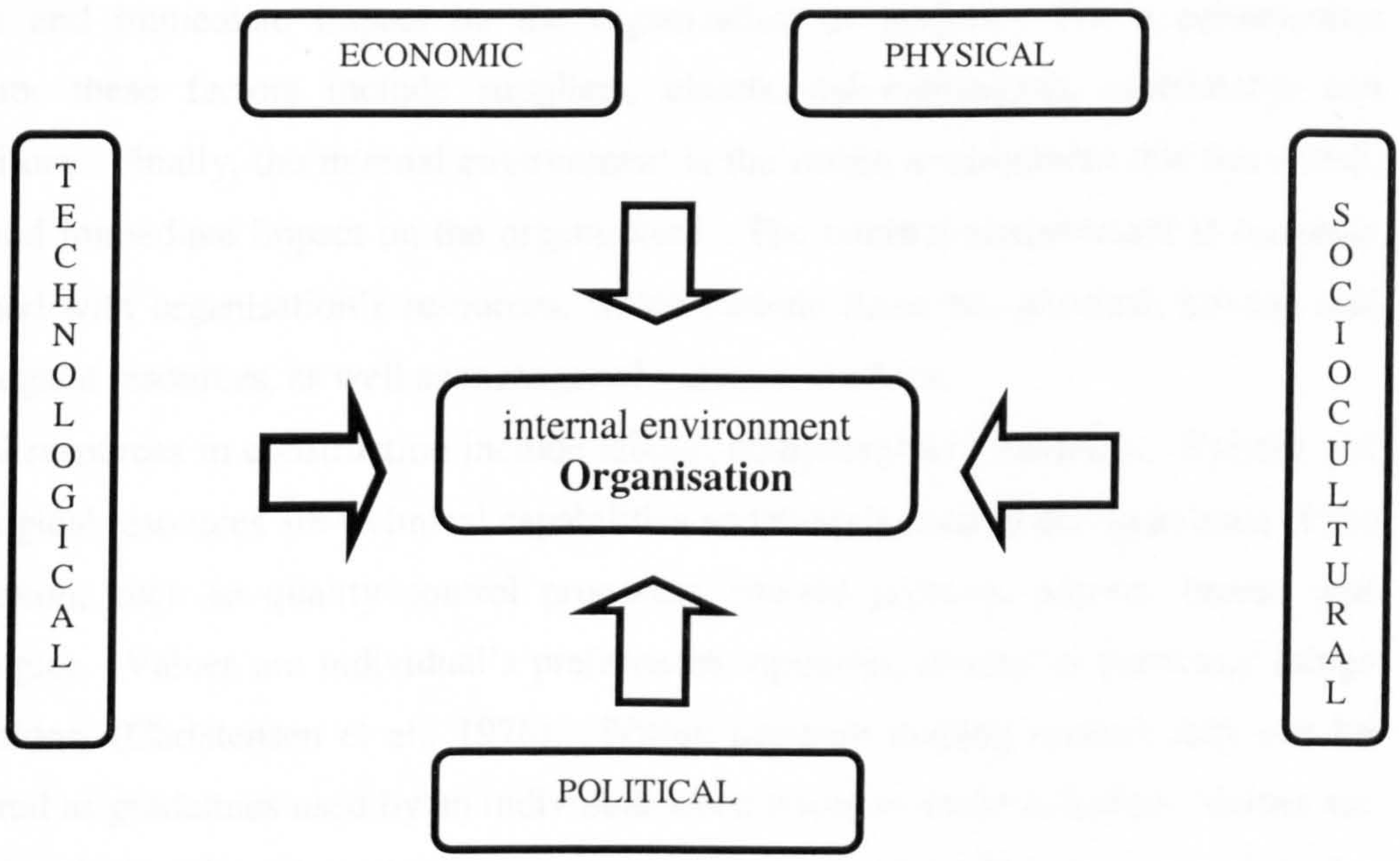

Figure 4.2 Organisation's external environment domains

4.3 Structure of an environment

The structure of an environment of an organisation or a project can be subdivided into three distinct layers: outer layer or general environment; operational environment; and inner layer or internal environment (Thomas, 1974). Both the general and operational

environments can be considered external environments. The general environment comprises domains that are broad in scope and have little immediate and direct impact on the organisation's activities.

The general environment comprises five basic elements or domains, namely economic environment, political environment, social environment, technological environment and physical or natural environment (Walker, 1996). These domains interact with organisations constantly and determine what they "might do". In general, some environment domains are less predictable and difficult to understand than others.

The operating environment is the external environment comprising factors that have more specific and immediate impact on the organisation or project. For a construction contractor these factors include suppliers, clients, sub-contractors, consultants and competitors. Finally, the internal environment is the inside environment that has direct, close, and immediate impact on the organisation. The internal environment is basically concerned with organisation's resources, which include financial, physical, human, and technological resources, as well as managerial values and ethics.

Physical resources in construction include labour, equipment and materials. System and technological resources are technical capabilities and models used in the operations of the organisation, such as quality control processes, reward policies, patents, brands and technologies. Values are individual's preferences, opinions, desires of particular things or situations, (Christensen et al., 1978). Within decision making context they can be considered as guidelines used by an individual when trying to make a choice. Values are acquired early in life and are basic part of an individual's thoughts. In conclusion, the internal environment of an organisation identifies its strengths and weaknesses, i.e., what the organisation "can do".

Based on both opportunities/threats/constraints from the external environment and strengths/weaknesses/constraints from the internal environment the organisation determines "what should be done". Opportunities and threats are current or future conditions in the environment, whereas strengths and weakenesses are positive and negative internal conditions of the organisation.

4.4 Roles of environmental analysis

There are three main specific organisational roles or purposes for which the environment scanning is designed. The term project scanning is also used to mean the process of analysing the project environment in order to detect the potential risk factors and determining the likelihood of their occurrence (Walker, 1996). The purposes for which environmental scanning is conducted are: strategic planning; policy formulation; and function oriented, (Daft et al., 1988). Strategic planning is the most time consuming and difficult analysis among all.

Policy oriented scanning aims to formulate organisation's policy at lower level than the strategic planning. Function oriented environment scanning serves narrow, specific objectives usually at the operational level, for example a project. Project management makes extensive use of function oriented environment scanning since projects are managed as single-use plans.

4.5 Relevance of environment levels

The degree of relevance of the environmental factors varies from one set of organisations to another. Some organisations are more sensitive to certain factors than others are. Generally, the degree of relevance of environmental factors depends on the size of the organisation and the nature of operations (national or international), (Filho, 1985). Multinational organisations exhibit the highest proneness to suffer from the three levels of the enviroment.

Large national and medium-sized national organisations are highly impacted by these factors, as well, but not as much as the multinational companies. Finally, small and very small organisations are much more affected by the internal and operating environments and less influenced by the general environment.

4.6 Environment dimensions

The environment comprises several domains. Besides domains, the environment is also characterised by its dimensions. The domains correspond to the elements of an environment and the dimensions are states used to describe the environment, (Mintzberg, 1979). The most important dimensions of an environment are the degree of change and the degree of complexity. It has been recognised that the external environments of organisations have become much more complex and are changing faster than ever before. The environment dimensions are shown in Figure 4.3 and the project scanning diagram at a micro level in Figure 4.4. The explanations and discussions of these are presented in the next sections.

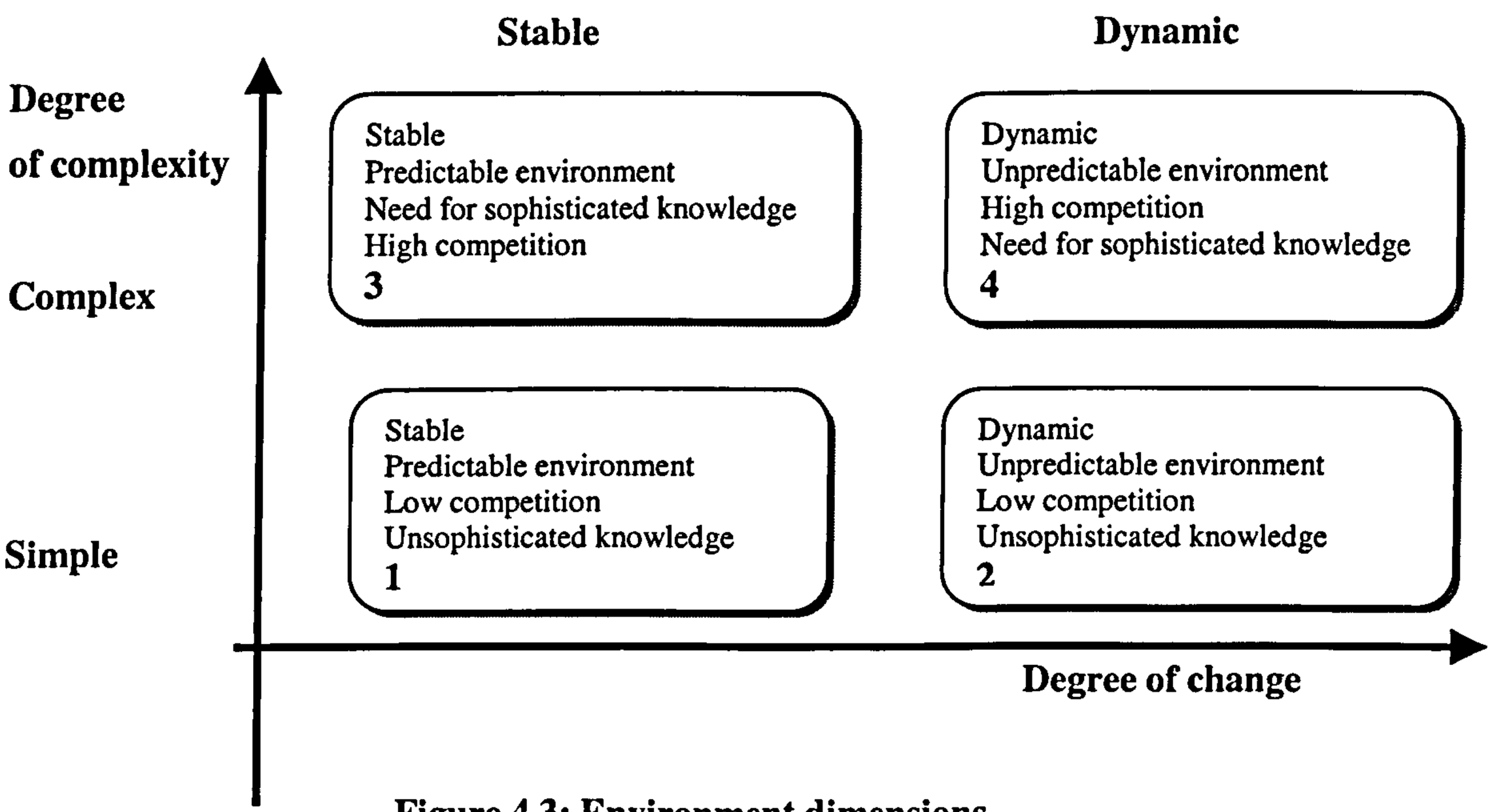

Figure 4.3: Environment dimensions

The degree of change describes the extent of stability and dynamism of the domains. Thus, the degree of change determines the predictability of future events by management. If a certain environmental domain occurs frequently, for example, then a manager is best

placed to predict its re-occurrence. The degree of complexity, on the other hand, can be described as simple or complex depending on the number of domain's variables, and the level of knowledge required in the operations of the organisation, (Aldrich, 1979). Construction projects, for example, are generally complex in that they involve a large number of participants such as contractors, clients, suppliers, designers and government agents, as well as interrelated areas such as electrical, plumbing, carpentry, mechanics, earthmoving and masonry. One way of analysing the dimensions surrounding an organisation is by drawing quadrants as shown in Figure.4.3.

Each one of the quadrants presented in Figure.4.3 corresponds to a specific level of uncertainty. Dynamism refers to the degree of change in the environment. A low degree of change creates a stable environment and a high degree of change leads to an unstable environment. As the environment moves from Quadrant 1 forward, the incompleteness of information and lack of knowledge about the courses of action taken by the organisation increases until a point where the decision making process becomes highly uncertain.

In this regard, an environment can be considered turbulent, that is, complex, changing and erratic. In general terms, the uncertainty corresponding to each Quadrant can be described as follows: Quadrant 1 – low uncertainty; Quadrant 2 – moderately low uncertainty; Quadrant 3 – moderately high uncertainty; and Quadrant 4 – high uncertainty. According to Newcombe et al. (1990) changes that take place in construction can be described as continuous, rapid and sometimes unpredictable. In addition, Betts and Ofori (1992) characterised the construction industry as highly dynamic with its operating environment, structure and product requirements changing at ever increasing pace. The emergence of new markets, shrinkage of older markets, increase in competition and rise in inflation are the most concerning problems facing construction managers today.

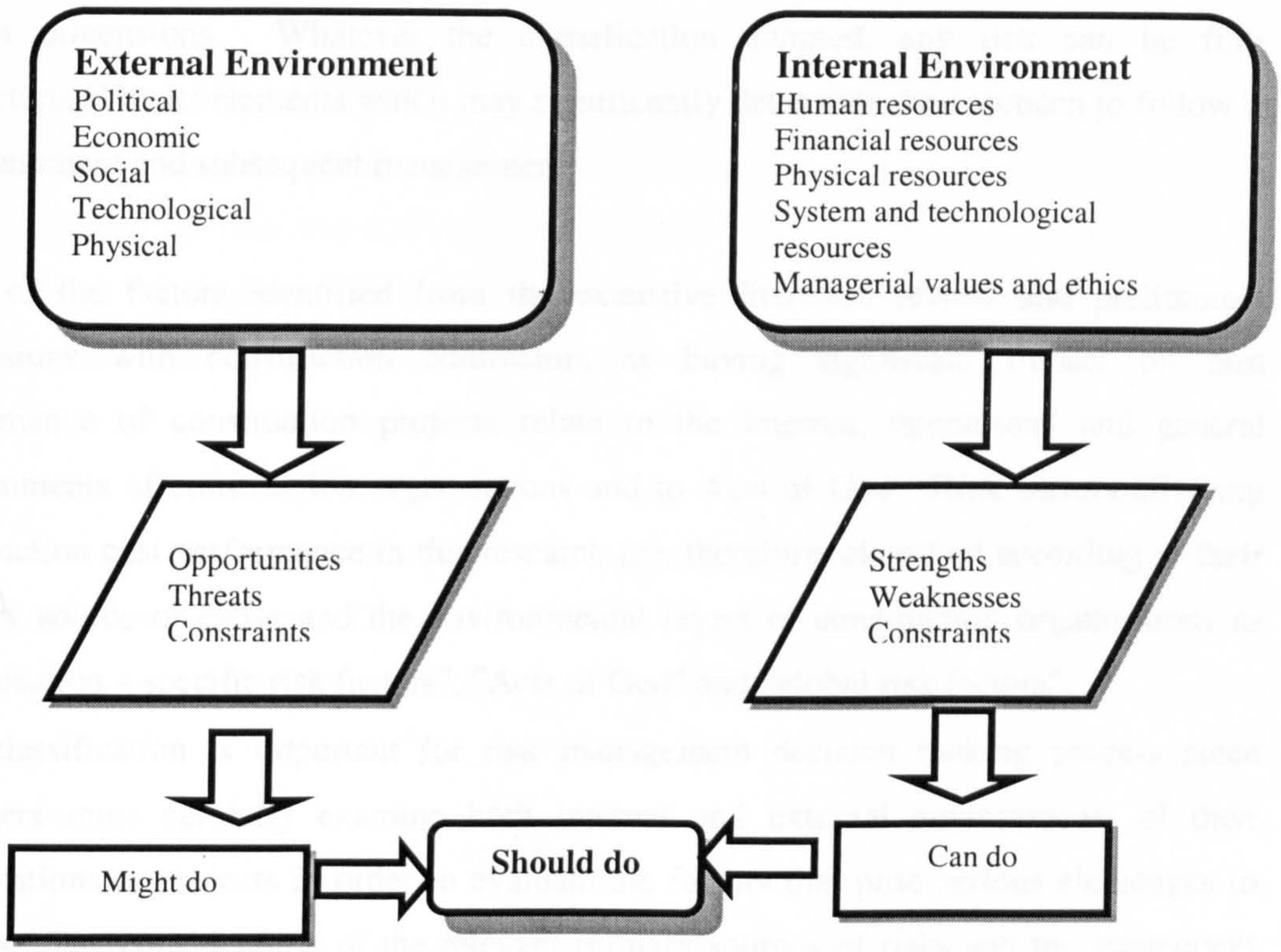

Figure 4.4: Project scanning diagram for construction organisations

Decision-making in risk management within organisations should ideally take place after a careful analysis of both the internal and external factors to enable managers to anticipate changes and thus enhance the chance of project success, as suggested by Mulholland and Christian, (1999).

4.7 Grouping risk factors

The importance of project scanning has been discussed in the previous sections. The importance of classifying risks was also thoroughly discussed in section 3.4 and it was stated that there are many different ways to categorising risks. Although all these classifications are useful, best results in the subsequent steps of risk management may be

obtained by adopting a combined perspective for classification, namely the source and impact dimensions. Whatever the classification adopted, any risk can be fully characterised by its elements which may significantly determine the approach to follow in its assessment and subsequent management.

Most of the factors identified from the extensive literature review and preliminary discussions with construction contractors as having significant impact on cost performance of construction projects relate to the internal, operational and general environments of construction organisations and to Acts of God. Risk factors affecting construction cost performance in this research are, therefore, classified according to their primary source or cause and the environmental layers of construction organisations as "organisation – specific risk factors", "Acts of God" and "global risk factors".

This classification is important for risk management decision making process since managers must carefully examine both internal and external environments of their organisations or projects in order to evaluate the factors that pose serious challenges to success. The consideration of the relevant primary sources of risks and the subsequent detailed examination of the risks linked to each primary source is crucial on any project. Perry and Hayes (1985), Wideman (1986), and Medley (1996) also suggested the grouping of risks according to the sources or causes and the ability to manage response strategies. These broad primary groups of risk can be broken down to achieve a detailed and comprehensive picture whenever necessary.

This research concentrates on the critical global risk factors affecting construction cost performance at a project level and from construction contractor's perspective. Focusing at a project rather than on corporate level, facilitates organisational learning. The organisation can further translate knowledge acquired from projects to develop corporate strategies. In addition, the management of projects has been crucial to organisations' survival and success since the impact of individual projects on the company's performance is very significant. According to Winch (1989), the effect of environmental forces is stronger in projects than in construction firms and the environmental uncertainty

emerges from the project's environment as well as the form in which projects are awarded.

It is argued that global risk factors pose more challenges to construction contractors than other categories of risks due to the difficult in predicting, modelling and assessing them. According to Venegas and Alarcon (1997), any action from a construction company is largely conditioned by the environmental characteristics. The main reasons for this difficulty is that global risk factors are: poorly structured; and the information and data related to them are often retrieved from a variety of sources. Also many organisations have traditionally devoted their attention on internal factors, over which they had greater control, since most external factors were more or less stable and predictable, (Appleby, 1987). This meant that organisations were considered self-contained, closed systems since no formal incorporation of interaction with the external environment was considered.

Examples that illustrate the latter assertion can be drawn from the original rational models of organisations advocated by Taylor and Fayol, as well as the natural models from Elton Mayo. Buchko (1994) suggested that although the conceptualisation of global risk factors is available, their formal measurement has received little attention by researchers due to the complexity of the environments. The following excerpt by Walker (1996) illustrates well the problem: *"There is no easy and precise method of quantitatively assessing environmental forces and their impact on construction projects. Indeed, if there were, it would be a large step towards solving problems faced by governments let alone by construction firms. Nevertheless, recognition of environmental forces and an understanding of how they affect construction projects do allow those involved in their management to construct a scenario for their work, which should allow them to anticipate and respond to changes in environmental conditions".* In this regard, Akinci and Fisher (1998) mentioned that contractors are unfamiliar with these risks. Still, Medley (1996) stressed the importance for managers to be familiar with factors affecting cost. Each group of risk factors is described in detail in the following sections.

4.7.1 Organisation-specific risk factors

Organisation-specific risk factors are those related to the organisation's resources namely finance, labour skills and availability, materials delivery and quality, equipment availability and efficiency, and management quality, (Schuette and Liska, 1994; and Smith, 1999). The most important organisation-specific risk factors are presented in Figure 4. 5.

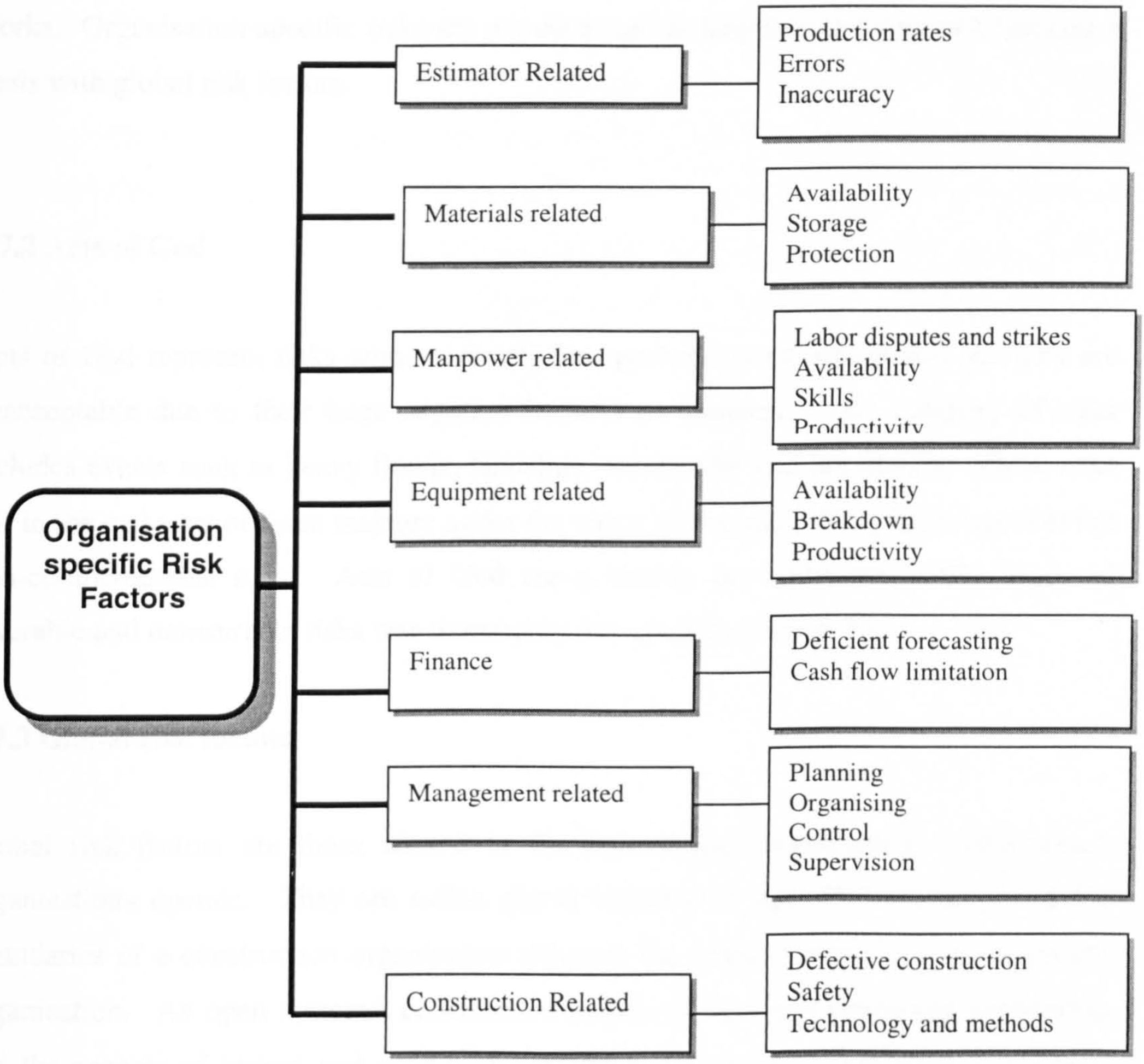

Figure 4.5: Groups of organisation-specific risk factors

These factors are generally considered under contractors' control, therefore, contractors are solely responsible for managing these risks. Under contractual terms, contractors can not request additional money to compensate losses resulting from these risks. For example the contractor must ensure that production rates are accurately determined so as to produce accurate cost estimates. It is also the contractor's responsibility that the materials are in place at the right time and according to specification. The same apply to the availability of equipment, funds, safety measures as well as the management of the works. Organisation-specific risks are not discussed at length in this research because it deals with global risk factors.

4.7.2 Acts of God

Acts of God represent risks with extremely low probability of occurrence, yet they are unacceptable due to their huge negative impacts on projects. This category of risks includes events such as heavy floods, landslide, earthquake and hurricanes. These risks fall in the category of force majeure under the terms of contract. They are excusable but non-compensatable risks. Acts of God are generally insurable risks. The issue of insurable and uninsurable risks was thoroughly discussed in Section 2.2.

4.7.3 Global risk factors

Global risk factors are those related to the surrounding environment within which organisations operate. They are called global because, in general, they transcend the boundaries of a construction organisation although they have the potential to affect the organisation. As open systems, construction organisations have permeable boundaries and the process of import and export between them and their environment is constant. Unlike the former; these risk factors are not directly present in cost estimates yet they may lead to significant financial disasters. In principle, contractors are not responsible for this type of risks and the contractual terms are deemed to provide a sensible and fair

allocation. In practice, nevertheless, contractors bear not only those risks for which they are responsible, but also all or the majority of global risk factors, (Bedelian, 1996; and Akinci and Fisher, 1998). This situation is even worse in developing countries.

Although not exhaustive, it is impossible to list all risks, the unique and main groups of global risks factors, identified from the literature and preliminary discussions with construction practitioners, include economic, political, project/design, level of competition, fraudulent practices and construction-specific.

Several authors, (Jahren and Ashe 1990; Ashley and Bonner 1987; Stobaugh 1969; Lowe and Whithworth 1996; Ogunlana and Thorpe 1991; Mansfield, 1994; Raftery, 1994; Walker 1996; Kaming et al., 1997; and Akinci and Fisher, 1998), have conducted relevant discussions on these risk factors. Global risk factors affect the project cost performance in two main stages: they influence construction cost estimates and the final construction costs since they lead to changes in both work quantities and input costs throughout the construction process. The main groups of global risk factors are presented in Figure 4.6 and fully discussed in the following sections.

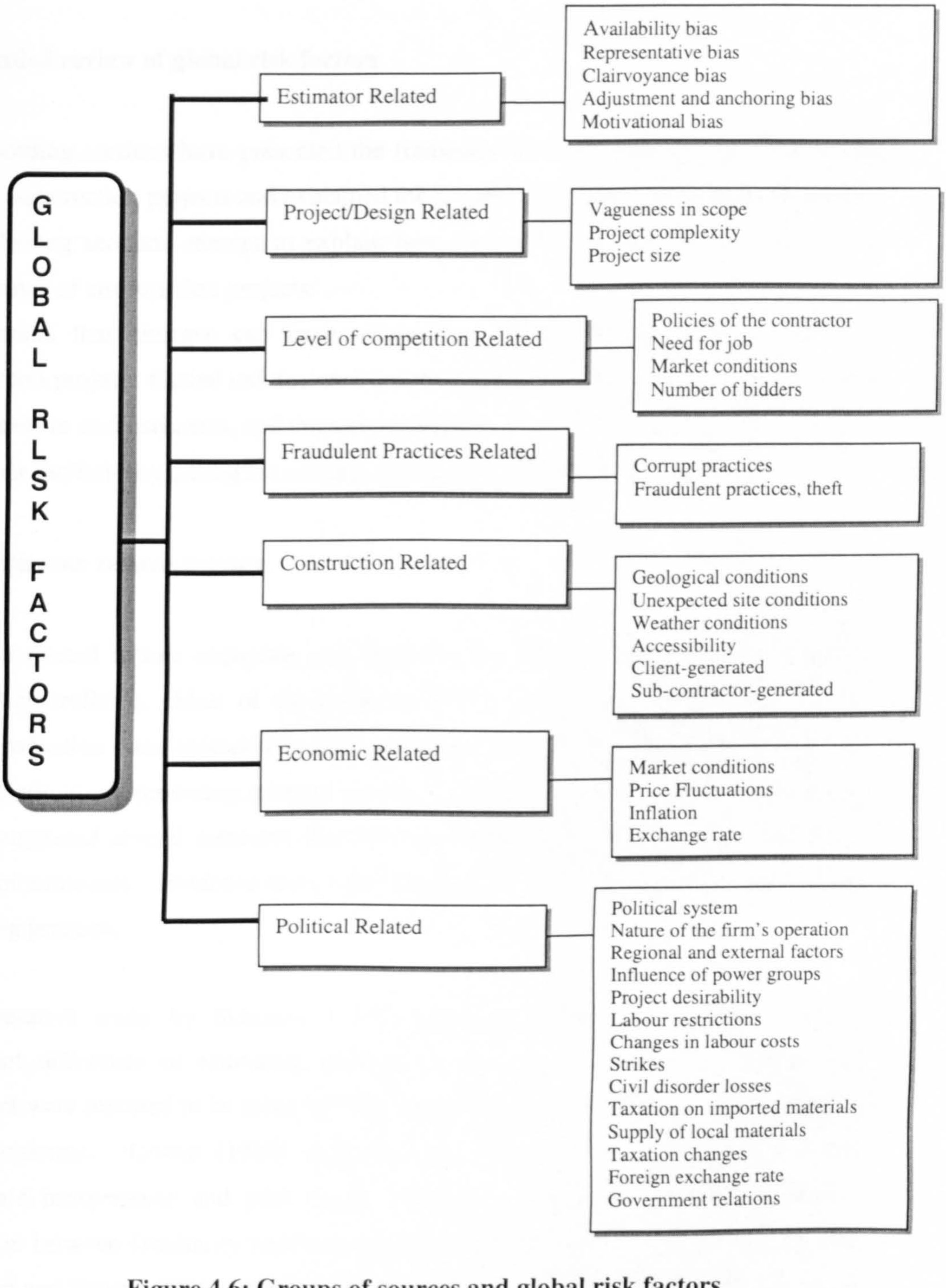

Figure 4.6: Groups of sources and global risk factors

4.8 Detailed review of global risk factors

The preceding sections have presented the framework for categorising risks permeating through construction projects and explained the reason for focusing on global risk factors. The following sections attempt to explain how global risk factors that can affect cost performance of construction projects.

It is argued that changes can have tremendous effects on the performance of a construction project. Global risk factors impact on project cost performance both through the increase in cost estimates, and through changes in quantities, prices, productivity loss due labour inefficiency during the construction process, (Schuette and Liska 1994).

4.8.1 Estimator related factors

Estimator-related factors impacting cost performance can be grouped into controllable and less controllable. Most of the estimator-related factors, like mathematical errors, wrong production rates, mistakes in calculation etc. can be easily managed by checking the calculations and providing relevant information to the estimator. Schuette and Liska (1994) suggested several measures that estimators should take in order to improve the quality of estimates. Evidence shows that experience plays an important role in cost estimating practice.

A comparative study by Skitmore (1985) involving experts and novices found a significant difference in estimating process between the two groups. Experienced estimators were reported to be more confident in selecting information for estimating and more consistent. Cowie (1987) suggested two causes of bad estimates, namely estimator's inexperience and poor scope definition. In general, there is a positive correlation between familiarity with a particular type of project and estimating accuracy, (Morrison and Steven, 1981). Whenever estimators have a high proportion of their work coming from a particular type of project their performance will be enhanced. Despite the

level of training and expertise, less controllable factors related to an estimator still exist at project level.

These factors comprise estimator biases that can mainly be motivational and cognitive biases, (Spetzler and Holstein, 1975). Biases in human judgement influence significantly the capacity to make good decisions. According to Birnie and Yates (1991) estimators, like other people, can be biased in performing their work depending on their background and incentives. Even though these biases can be controlled, to some extent, by changing the incentive system, it is very difficult to do so using project management tools as in the case of experimental work, (Akinci and Fisher, 1998).

Capen (1976) indicated that when technical people are faced with uncertainty have the following characteristics: a large number have little idea of what to do; and a large number overestimate the precision of their knowledge. As a result, in general, people with technical background are overconfident when estimating ranges in uncertain situations.

According to Smith (1991), motivational and cognitive biases are the two major causes of this overconfidence. Motivational biases occur when people tend to change the outcome of an event to their favour. For example, if estimators believe that they are going to be rewarded depending on their prediction then they will assign less and probably unrealistic contingency for their work to show their confidence in their estimates.

Cognitive biases, on the other hand, arise mainly from mind-based abstractions of reality, that is, they depend on the modes of judgement. These biases can often lead to incorrect assessments of uncertainty. The most common types of cognitive biases reported by Tversky and Kahneman (1974) and Spetzeler and Van Holstein (1975) are presented in the following sections.

a) Representativeness

Representativeness is the tendency to place something in a class if it seems representative of the class. Representativeness is closely related to stereotypes. An example of representativeness is when estimators tend to focus on the similarities drawn from recent projects and use them to assess risk and uncertainties of future projects. In such circumstances, the assessment of risks is significantly influenced by recent factors known by the estimator. Since projects may not have many similarities, or representativeness, cost estimating or the assessment of probabilities may be highly biased. In such situations estimators will have a tendency to concentrate on the similarities and overlook other variables of interest.

b) Availability

According to Tversky and Kahneman (1974), decision-makers assess the frequency, probability or likely causes of an event by the degree to which instances or occurrences of that event are readily available in memory. Essentially, the decision-maker uses recollection of his past experience to make decisions. Therefore, availability is related to the capacity of the memory. Usually, the decision-maker recalls and gives too much weight to an information that has produced strong impression due to its consequences as well as recent information.

Estimators, as with people in general, are not able to recall all past events and, therefore, they make estimates based on associations, which obviously, are not always reliable. For example, past adverse construction experiences – be they errors in quantities or delays - may lead estimators to become much more conservative in future projects.

c) Adjustment and anchoring

This is perhaps the most important heuristic in decision making. Very often estimators start with an initial value or parameter that will be subsequently subject to adjustments until a final value is reached. The initial value is retrieved from several sources such as historical records and sampling. The initial value is the anchor and the use of new information aims to adjust the initial anchor. Clearly, the major concern about this bias is that different starting points or values lead to different results that can be biased towards the initial values.

4.8.2 Project and design related factors

This group consists of project size, vagueness in scope, and design complexity which in turn is a function of constructability of the design, utilisation of advanced technology, specialised equipment and methods and the integration of multiple disciplines.

a) Project size

Project size seems to have an influence on cost performance. Some authors mentioned project size as being one of the most influencing factors, (Neufville et al., 1977; Elinwa and Buba, 1988; and Jahren and Ashe, 1990). It should be mentioned, however, that there is some disagreement on how the project size affects cost performance. For example, Randolf (1987) found that cost-overrun rates decreased as contract size increased. On the other hand, Rowland (1981) suggested that cost-overrun rates increased with the increase in contract size.

Research by Jahren and Ashe (1990) on 1,576 construction projects concluded that the median cost overrun rate increased as the project size increased. The reason put forward is that projects become more complex as they become larger and so, prone to cost overruns. Ogunlana and Thorpe (1991) studied estimating accuracy and mentioned project size as one factor to take into consideration. According to the authors, large

projects have higher levels of inherent uncertainty while smaller ones have lower levels of uncertainty.

b) Project/design complexity

Complex projects, usually multi-disciplinary and innovative projects, pose serious difficulties to producing cost estimates with the desired accuracy. Estimating quantities, production rates and unit costs thus becomes a hard job and, as a result, cost estimates have been less accurate. Usually, project/design complexity comprises: use of advanced technologies; constructability; highly specialised equipment; and methods of construction. According to Napier and Chang (1988) the inherent risk of using advanced technologies and methods is a function of newness and its performance history in simulated and actual use.

b) Vagueness in scope

Scope definition lies at the core of all construction projects. Poor project scope definition has a potential for bringing disputes among the parties. Scope describes the work to be performed. The success of estimating process depends therefore heavily on the scope definition. Additionally, future progress of a project is significantly influenced by a clear scope definition so as to avoid changes, which have subsequent implications on costs. Cowie (1987) stated that the lack of a proper scope definition has been stated is often a major source of bad estimates. One important aspect related to scope definition is the detail of the design and it is argued that the accuracy of cost estimating increases with the level of design detail.

4.8.3 Level of competition related factors

It is generally accepted that projects with high number of bidders are prone to show wider variability among tenders. The number of bidders is directly related to the level of competition. Competition may be low or high according to several factors of which market conditions is the most important. According to Neufville et al., (1977) contractors show willingness in undertaking less attractive projects, sometime at loss, in periods of low market activity. Conversely, tender levels are expected to rise and competition less tough in periods of good performance of economy. The assessment of changes in utility of the projects to the contractors is not easy to model and, therefore, affects significantly the estimating accuracy. Several authors have pointed out that there was a negative correlation between low bid and the number of bidders.

4.8.4 Fraudulent and corrupt practices related factors

Fraudulent practices include all sort of actions intended to distort the facts to the benefit of a single party in detriment of others. In construction projects, specifically, fraudulent practice can be defined as a misrepresentation of facts, by one or more parties, in order to influence the procurement process or the execution of a contract to the detriment of any other interested parties.

Misrepresentation in tendering usually materialises by means of collusive practice among bidders prior or after bid submission designed to establish bid prices at artificial non-competitive levels and thus distorting the rationale for free competitive bidding. As mentioned by Wills (1986) contractors may submit a low bid with knowledge that some items in the bill of quantities have been over-measured or knowing that a sum of money will be made available by a friendly client in order to inflate a final tender price. On the other hand, a corrupt practice means the offering, giving, receiving or soliciting of any thing of value to influence the action of an official in the tendering process or in contract execution.

The problems of corruption and fraudulent practices were outlined by Okpala and Aniekwu (1988) and Elinwa and Buba (1993) as one of the major factors of high cost of construction projects in Nigeria. According to Wills (1986) cheating in tendering in developing countries is a widespread practice. In a recent article, Rosenbaun (1997) reported that risk management problems have caused waste of hundreds of millions of dollars annually in developing countries. The costs associated with uncertainty have lead many proposed projects to failure. The risks in question, included those associated with political instability, currency fluctuations, material availability and corruption.

Kangari and Lucas (1997) indicated that all government-sponsored programs have considerable political content and infrastructure projects in developing countries are political by nature. In addition, foreign projects to a domestically oriented audience have elicited remarks about bribery and corruption. Schuette and Liska (1994) emphasised the need for construction companies follow ethical principles. They mentioned that acts of collusion or conspiracy have occurred frequently. Architects, for example, have used "weasel clauses" in the specifications with the intent of placing inequitable risks to contractors (Schuette and Liska, 1994).

4.8.5 Construction -related Factors

This group consists of accessibility, geological conditions, weather conditions, client - related and subcontractor related factors. These are briefly presented in the following sections.

a) Accessibility related factors

Accessibility to construction sites often creates serious problems. The issue of accessibility arises when there are poor or no links to the construction site namely roads, railways or others. Many projects in developing countries are located in remote areas without reasonable communication infrastructures. Typically, these locations have no roads or have unpaved roads, which deteriorate badly in rain seasons. In such

circumstances access becomes very difficult and consequently communication, supplies of materials, equipment and goods can be severely hampered.

b) Geological conditions factor

Ground conditions are difficult to determine with the required level of accuracy in construction projects. Even the employment of sophisticated technologies can not ensure certainty about the physical and mechanical properties of the ground. As emphasised by Littlejohn et al (1992), there is no other element of the structure about which less is known yet the properties and behaviour of the ground must be known to achieve a safe and economic structure. Inadequate site investigation can be caused by many factors, being the most important are: lack of expertise and technology; pressure and shortage of time during design; financial problems; and lack of awareness.

According to Rusteika and Boomer (1992), adverse geological conditions may include subsoil factors, obstructions and contaminants. Over the past three decades the sciences of geotechnics has benefited from much research so as to improve the quality of the services provided. Several specialist companies have emerged and the contractual framework for geotechnical services was recently formalised.
Despite this effort, it seems that very little progress has been made in this regard. The fact the "principles of good practice" were only established in 1989 is testimony to this, (Whyte, 1996). Whyte reported that ground investigations were no better than ten years before when the standards were very low. According to Peacok (1990), there are several problems that hinder the quality of ground investigations, namely lack of competent site investigations managers, the inadequacy of most work procurement methods and a lack of client's awareness of financial risks associated with ground conditions.

Although building projects face risks related to ground conditions, major civil engineering works and environmental projects are the most exposed projects to this kind of risk due to the high amount of soils excavation involved. Environmental restoration

projects, particularly, have been very risky because of their relative novelty as compared with other civil engineering works.

To sum up, unforeseen geological conditions always force contractors to undertake additional work activities with the inherent time and cost overruns.

c) Weather conditions factor

Adverse weather is known as an important factor of risk in construction projects. It has been possible, to some extent and based on the available information, to foresee the conditions of the weather so as to minimise its effects on projects. This is the case of cyclical weather patterns related to the seasons. However, many times unexpected changes of weather conditions occur. These factors can create a significant increase of costs and time overruns. According to Nkado (1995), weather conditions such as extreme heat and humidity adversely affect construction productivity.

As suggested by Akinci and Fisher (1998) contractors should not only concentrate on the assessment of the probabilities and cost consequences but also on the exposure and the consequences. A large number of developing countries lie on tropical regions where factors such as humidity, extreme heat, heavy rains have had great influence in construction. Study conducted by Stabb (1989) on a construction project in Somalia states that critical problems related to corrosive environment, high solar radiation, high wind speed, sand abrasion and dust have contributed to delays and increase on project costs.

c) Client-related factors

Client information is crucial for global risk factors assessment by contractors. The main issue related to the client is the reputation or ability to pay for the services provided by contractors and consultants. Among the most important causes of business failures, client related factors rank high, (Dun and Bradstreet, 1986) and construction is no exception.

According to Kangari (1988), late payment impact seriously contractors' cash flows. Kometa (1995) also reported that one of the major causes of business failure was client-related. Failure to meet the terms of payment as established in the contract clauses can cause cash flow problems to contractors and may increase project costs and cause delays. In countries where the most important clients are the public agencies, as generally is the case in developing countries, considerable concern arises due to delayed payment record. The reasons for such delayed payment are mainly institutional weakness and bureaucracy, and dependency on foreign loans, aid or grants. Institutional weakness materialises in the form of lack of skills and poor organising, planning and control. Clients all too often commence projects without any planning at all and, as a result, contractors and consultants only get paid when funds become available, (Jaselskis and Talukhaba, 1998). As common practice to avoid this risk, contractors have relied on the client's record with regard construction projects. However, they can not indefinitely avoid clients if they are to remain in business.

d) Subcontractor-related factors

The role of subcontractors in construction projects has increased over the last two decades. In fact, the technical complexity of projects and the need to optimise companies' resources in an increasingly tough market environment drive the need for specialist contractors, since single contractors can not embark on all sort of works. Even the technological complexity of building systems (e.g. heating, floor, security, insulation and mechanical systems) has increased beyond the capacity of any one firm or organisation to easily maintain control over the design/manufacture/construction of a subsystem.

Despite subcontractor's important role in construction projects they are frequently faced with uncertainty in securing contracts due competition. To overcome or minimise this problem they have adopted a collaborative approach with main contractors to secure jobs. To ensure their continuity in business they depend heavily on the performance and successful completion of works. However, contractors face many risks in subcontracting

works mainly due to the subcontractors' financial and technical capability, since contractors have no direct control over these aspects even in cases of long-term collaboration with certain subcontractors. In addition, the variability of subcontractors' bid has put serious risks on contractors. These two aspects of uncertainty related to subcontractor reflect on the project targets for which the main contractor is responsible before the owner. Poor financial and technical capabilities usually result in cost and time overruns and poor quality. The variability of subcontractor's bids make it difficult for a contractor to select the right subcontractor to undertake the works and may easily lead to a wrong choice.

4.8.6 Economy-related factors

a) Introduction

Construction contractors operate in an increasingly competitive economic environment. With few exceptions, since the fall of the communist system, construction contractors in most countries around the world operate in a free-market economy. The economic environment includes contractors, suppliers, clients, sub-contractors, consultants and others. Economy-related factors are highly influenced by events that have no direct relationship with the construction industry but have a strong impact on construction costs. Therefore, it should be recognised that economic factors are always present in construction projects and they have implications on the input costs (Smith, 1999).

b) Modelling

The consideration of economic factors on cost performance varies in accordance with a specific region or country and has an emphasis on the economic instability, which is reflected in terms of market conditions, financial system, inflation rate, exchange rate and interest rates. Common characteristics of an unstable economy are high and unpredictable inflation and unpredictable exchange rates. In principle, the various

economic variables are interrelated and, thus, instability in one of them reflects the instability of the others.

For example, spiralling costs due rising inflation lead invariably to the increase in interest rates and discourage investment in property development and the cost of borrowing money can make difference between a viable and not viable project.

The nature of price fluctuations stems from highly complex effects of several economic and financial indicators such as demand and supply, balance of payments, wage rates, value of money and interest rates. The problem of inflation is more serious in some countries than in others. Developing countries are the regions where economic instability is widespread.

The prediction of inflation rates has been based on subjective judgement and the analysis of existing data. The available approaches applied to predict the inflation rates each have their own advantages and disadvantages. The simplest way is to select the most likely, the optimistic and the pessimistic values, based on the last period or several recent periods and expert judgement.

c) Analysis and management

Currently, the modelling and assessment of economy related risk factors are based on subjective methods, which produce country risk indexes. Country risk is defined as the likelihood of financial losses due to problems arising from macro-economic and political events in a country. Such information is very broad since it refers to micro-level variables and, therefore, not of direct application for specific business ventures. At a micro-level the assessment is performed through deterministic forecasting techniques such as time series analysis, regression analysis, econometric models and, more recently, using simulation methods. The common limitation of these models is that they depend on economic indicators, which are subject to forecasting with no guaranteed accuracy.

Levy and Yoon (1995) recently developed a model for modelling global market risk entry using fuzzy logic. The model incorporates both political and economic macro variables.

They argued that traditional models were ineffective when dealing with complex interactive influences, inaccurate measures, uncertain environment and decision making because the information required is ambiguous, inconsistent, incomplete and deficient. Although not specific to certain businesses this model seems to be valuable in terms its contribution to the modelling and assessment of economic and political related factors.

4.8.7 Political Risk Factors

a) Introduction

Political risk factors have been widely studied from the perspective of multinational companies because international operations are considered more risky than domestic ones. Political risk has gained much interest with the latest cases of companies that suffered significant financial and economic losses and even bankruptcies due to political related factors. It should be recognised, however, that not only companies involved in international business ventures suffer from the consequences of political risks, but all other firms operating in a home country are also exposed to these risks. Managers must learn to adapt both in their own country and in the international context. Political instability occurring in a country, for example, will impact, to some or another degree, all business ventures taking place at that moment, regardless the nationality. Therefore, contractors should not ignore the presence of political risk while operating in their own country.

b) Political risk definition

According to Ashley and Bonner (1987), a major problem with the identification of political risks is that they are highly subjective and business-specific. There has been much discussion among academicians and decision-makers with regard an acceptable political risk definition. In fact what may represent a high risk to one type of operation

may not necessarily represent a risk to another. Therefore, it is difficult to come up with a list of political risk factors applicable to all situations.

Political risk is a multidimensional task involving several hundreds of political, economic and social and cultural factors, (Rummel and Heenan, 1978; and Haendel, 1979). This view is shared by many experts, which argue that political risks are directly related to the stability of a country's political system. For this reason, political risk has been measured taking into account social, economic and political variables.

Robock (1979), however, argued that political instability alone does not necessarily lead to political risks. From the point of view of an investor, political risk is the probability of occurrence of some political event that will change the profitability of a given investment. For many decision-makers, political risk is assessed from prevailing attitudes, where first impressions and current events are dominant. Despite these difficulties it is still possible to approach political risk in a systematic way. Therefore, political risk as applied to construction projects, may be defined as the occurrence of political motivated events affecting contractor's ability to operate effectively.

c) Categories of political risks

Robock (1971) classified political risks into macro and micro risks. Macro risks are political related events that impact foreign businesses in a general sense whereas micro risks are those impacting specific businesses. Ashley and Bonner, (1987) grouped political risk factors into "political source" and "project consequence variables". Rummel and Heenan (1978) considered four independent dimensions that influence the political destiny of a country, namely domestic instability, foreign conflict, political climate and economic climate. The approach by Ashley and Bonner has merit in that it not only identifies the sources of political risk but also the potential consequences to the projects. The latter approach by Rummel and Heenan basically highlights political sources.

d) Modelling and analysis

Current practices of political risk analysis are mostly subjective rather than objective. Some of the most important approaches used to analyse risks are the Delphi methods and quantitative methods, (Rummel and Heenan, 1978). Quantitative methods using multivariate analysis have been widely used to assess complex political environment and to confirm intuitive impressions based on subjective approaches. Multivariate analysis is mainly used to predict future political trends and to describe relationships of risks affecting a country.

Basically, the Delphi technique involves an analysis of the elements that influence a nation's political destiny. The Delphi method is an established technique for obtaining consensus estimates from several experts with different backgrounds. In the field of risk management, a wide range of experts are asked to rank the importance of those factors for the country under consideration. The ranked variables are then aggregated and an overall measure or index of political risk is produced. These indexes are usually marketed as a political risk product.

However, indexes of political stability have some shortcomings since they depend on factors that often are difficult to assess, such as: comprehensive and accurate listing of the major determinants of political risk; well reasoned and timely opinions of knowledgeable professionals; and an appropriate mechanism of weighting and combining individual opinions. Ashley and Bonner (1987), who stated that political risk indexes do not provide decision-makers with good quality information since they are too general in nature and not specific to the projects. Passive use of indexes or countrywide reports is not informative enough for proper decision-making. Ashley and Bonner (1987) suggested a systematic analysis of risk according to their nature.

Stobaugh (1969) outlined four methods for foreign investment climate analysis used by companies. These methods include "go-no go", "premium for risk", "range estimates" and "risk analysis". In go-no go approach decision-makers consider one or two variables,

for example inflation and exchange rate to make a decision. There is no in-depth investigation of the situation. In premium for risk, companies basically demand higher return on investments in countries with poor investment climates than in those with good climate. Range estimates use profitability better estimates for several potential risk factors.

The basic framework suggested by Ashley and Bonner for political risk analysis appears to be well structured and suitable to construction business. They proposed a macro-micro framework combined with systematic analysis considering the most important project elements. A systematic approach comprises: identification of political risks; assessment of the probabilities of the occurrence of the events; assessment of the impact should the events occur; and devise a response strategy. In order to perform political risk analysis the authors suggested a desegregation of project cash flows and desegregation of risk factors.

Cash flows are divided into costs, labour, material, overheads and revenues. On the other hand, political risks are grouped into two categories, namely political source variables and project consequence variables. Political source variables correspond to macro risks and influence the project indirectly through their impact on project consequence variables. Project consequence variables correspond to micro-risks, which impact the project directly. Political sources variables and project consequences variables are described below.

e) Political variables sources

- Nature of the firm's operation

This decision variable is one of the most important and it is related to the overall strategies and operations of the company within the surrounding environment. The company should adapt its strategies according to the local or regional social, cultural and political factors. Moreover, it is fundamental for company to decide on the kind of

relationships to establish with public institutions, government, power influence groups as well as, at a lower level, other firms in the construction industry.

- Regional and external factors

These factors comprise vandalism, terrorism, religious conflicts and political conflicts between the host country and external forces. In this regard it is important to first evaluate the relationships between the host country and the neighbouring countries.

- Influence of power groups

The influence of power groups has played a significant role in developing countries. Power groups represent powerful factions outside formal power structure and very often they influence important decisions in projects. Such groups include labour unions, environmental organisations and civil associations.

- Nationalists' attitudes towards the firm

This is particularly related to companies operating abroad. It is likely that some hostilities arise against multinationals in the host country due to several factors, being political motivated, the most important.

- Project desirability

Projects that bring major benefits to the government or power groups are more likely to have a strong support from those. On the contrary, controversy will always surround project environment adding more risks to the contractor.

- Government policy

This refers to change in the government and changes in the government policies in the form of legislation. Some legislation may have strong impact on the projects particularly those related to environmental issues.

f) Project consequence variables

Project consequence variables consist of two distinct groups namely cost-related variables, which in turn can be divided into labour, material and project overhead categories and revenue-related variables.

- Cost –related variables

Cost-related variables category comprises variables that can lead to changes in the estimated costs of labour, material and overheads. These variables are:

Labour cost

- ✓ labour restrictions
- ✓ changes in local labour costs
- ✓ changes in operating unit cost of labour
- ✓ strikes
- ✓ labour impacting delays

Material cost

- ✓ civil disorder losses
- ✓ taxation on imported materials
- ✓ supply of local material

- ✓ per unit cost of material

Overhead cost

- ✓ civil disorder losses
- ✓ strikes
- ✓ delays

g) Revenue-related variables

- taxation changes
- repatriations restrictions
- foreign exchange rates

Although sound in terms of project risk elements structure, the framework proposed by Ashely and Bonner needs further improvement with regards the modelling and analysis. It evaluates political risk in construction projects by subjectively assigning financial impact (in percent terms) and probability estimates to the project consequence variables. Furthermore, it evaluates linguistically the potential magnitude of each project consequence variable.

The output is the expected value of the impact expressed in monetary terms. Ashley and Bonner suggested that further developments in the modelling and assessment of political risk should be in the exploration of information technologies. These include technologies of knowledge based systems, database management software and decision-tree analysis.

4.9 The role of contracts

The contract terms define not only how risks are allocated between the parties but also, and in particular, how cost overruns are distributed between a client and a contractor.

Hence, the contract determines the magnitude of contractor's financial burden once a cost overrun occurs on a project. A cost overrun will affect both client and contractor.
The allocation of risk between a client and a contractor depends on two contract-specific factors, namely the type of a contract and the documents comprising the contract. Thus, it is extremely important that adequate contract strategies are adopted in order to reduce risks and successfully complete a project.

Evidence shows that contractors still bears more financial risk than clients during the execution construction of a project, (Bedelian, 1996; and Akinci and Fisher, 1998). Therefore, no matter what type of contract is administered, contractors should be aware that they bear the majority of the risks pertinent to the construction of a project. Ibbs and Ashley (1987) reported that on average, contractors are at risk 46 per cent of the time, whereas clients are at risk 11 per cent of the time. In addition they identified contractual clauses with potential for disputes such as design changes, construction changes, workmanship variations, cost reporting and control, schedule reporting and control and scope definition.

Since these are the most problematic contractual issues mentioned both by contractors and clients they deserve a deep attention. In addition, others clauses that apparently aim at reducing risks such as change order clauses can even lead to heavy disputes with consequences on overall project performance. The problem is that many of such clauses carry a large amount of ambiguity. In conclusion, it is worth stressing that both the type and context of contract indicate that contractors are exposed to more risk than clients.

4.10 Developing countries

As stated by Ofori (1993), "structural problems of construction industry in developing countries are more fundamental, more serious, more complex, and, overall, much more pressing than those confronting their counterparts elsewhere". Abdelkhaled (1997) highlighted the common problems affecting construction industry in developing

countries. He mentioned lack of management skills, shortage of skilled labour, low productivity, shortage of supplies, bad quality of supplies and lack of equipment. Imbert (1990) also, addressed the problem of human resources.

Apart from technical issues, management-related problems are one of the most important aspects facing construction contractors since they have to deal with substantial constraints such as incomplete information, unpredictable client behaviour, and uncertain project circumstances. Jaselskis and Talukhaba (1998) stated that construction projects in developing world posed more risks to contractors and highlighted key bidding informational requirements for contractors. These bidding requirements include laws and regulations, import restrictions on materials, equipment and labour, client and subcontractor information, construction, economic and political risks. Similar facts were also outlined by Chalabi and Camp (1984) who established that project cost and time overruns were commonplace.

4.11 Mozambique

Mozambique is a typical developing country situated in southern east Africa. It has 801 km^2 and 17 million inhabitants. After a long period of stagnation, Mozambique has experienced a steady and reasonable economic growth, average rate of 10 per cent, over the last five years. This has been a major boost for economic and social development. An increasing number of investors from across the world are demanding the country's products, year after year. The political and economic environment seems to be more attractive in comparison to many others sub-Saharan African countries. Despite these positive trends a great deal of problems still prevails.

4.11.1 Economic and political systems

Mozambique has experienced a dramatic shift from planned economy to market economy within a short period of fifteen years (1975 – 1990). Obviously, it is not an easy change since it implies severe adjustments in the economic system. In order to overcome

economic problems due to underdevelopment and the consequences of civil war, the country joined the World Bank (WB) and Intenational Monetary Fund (IMF) in 1984.

Under the guidance of these international financial institutions Mozambique started implementing "structural adjustment" and "stabilisation" programs in 1987. Structural adjustment a World Bank program) is basically a long-term program aimed at promoting development of the economic sectors and building capacity. The WB focuses, therefore, on the economic growth by stimulating the strength of the markets. The stabilisation (IMF program) aims to "stabilise" macro-economic variables. From the point of view of the IMF payment balance problems are caused by inflation and thus before embarking on the economic recovery program it is crucial to slow down and control inflation. To achieve this goal the borrower must increase exports, reduce imports, reduce internal expenditure (which reduces purchasing power) and reduce credit and the flow of money in the economy. Therefore, the IMF concentrates on macro-economic short-term objectives of reducing and controlling inflation.

There is a strong controversy and criticim on the feasibility of these programs around the world because the results have been very disastrous in most countries so far. The appendix provides important information on inflation, interest rates, exchange rates and per capita GNP.

Politically, Mozambique is considered an emergent democracy. The shift from Marxist orientation to Neo-liberal system occurred in 1990 when a new constitution was adopted. The sudden turn from communist state to a very aggressive market economy was a rude shock to the majority of people. During the past ten years there have been efforts to strengthen and consolidate democracy but it should be recognised that there is still a long way to go. The roots of democratic and civil freedom have barely been implanted. As such, there is still a close identification of the ruling party with the state. The emerging political parties are still incipient. On the other hand, ethnic and regional fragmentation and unfair distribution of the resources are serious threats to stability.

4.11.2 Characterisation of the construction industry

The construction industry is incipient, deeply fragmented and the sectors of the industry are unevenly distributed over the country. The largest construction volume is concentrated in Maputo, the capital, and surrounding areas that account for 90 per cent of the total volume. General problems include unfavourable economic conditions, institutional weakness, shortage in supply of construction materials, shortage of equipment, shortage of skilled human resources and ineffective and inefficient management.

For example, most of construction materials are imported, mainly from South Africa, Zimbabwe and Portugal. Many times, companies have to employ expatriate personnel to fill the gap due to lack of local trained technicians. Since the industry is heavily dependent on the external markets the effects of economic variables such as inflation, exchange rates, interest rates and currency convertibility have significant importance on the construction input prices. In the last ten years, for example, there were several changes on import duties, business taxes and customs duties that created additional problems. Import procedures, in particular, are very complex and time consuming.

Building construction and services have been the largest construction market in Mozambique, but in recent years there have been a significant growth in civil engineering projects due the impact of infrastructure projects in the development the country. These projects include roads, bridges, power lines, dams, water supply, irrigation and industrial projects.

4.11.3 Contracting strategies and risks

The most common type of construction contract strategy in Mozambique, where public sector dominates, is the traditional method associated with price-based contracts, namely lump-sum and unit prices. Design and construction are separated and contracts are usually awarded through competitive tendering based on the bill of quantities, regardless the type and size of the project.

All too frequently, clients and contractors have adversarial relationships. Government forms of contracts are drawn up to suit government's needs and public officers have been reluctant to recognise uncertainties that permeate through cost estimates. Culturally, contractors are considered to be rich and thus, better placed to coupe with all financial burdens resulting from risk events.

Clients are usually suspicious of contractors and assume that lack of trust help to protect their interests. In this regard Jannadia et al., (2000) noted that often fairness is an elusive concept. In addition, the common practice of most local design teams is to prepare contract documents simply by adding or deleting elements from previous documents. They do so not only to save time but also to reduce costs associated with hiring specialists to do thorough and genuine work.

However, this practice brings serious problems because the documents are not prepared as a whole with a proper structure and sequence and thus increasing the likelihood of unfair allocation of risks to the contractor. Despite this attitude, contractors are not willing to challenge government procedures since they have to keep good relationships for future projects. Consequently many contractors have taken high risks even in situations where profit margins are extremely tight.

The current standard forms of contract in practice now were introduced decades ago and despite changes and new developments in technological, economical, political and social spheres, they have not been altered or amended so far.

In recent years, there has been a widespread increase in the use of both international and foreign contract documents in Mozambique. Financing agencies such as The World Bank, European Union, to name a few, have imposed their own forms of contracts which are, by far, very different from the local forms. In addition, there are hundreds of NGO (Non-Governmental Organisations) operating in the country and many are engaged in construction projects. This diversity has created serious management problems, not only to clients, but also and mainly to contractors who have systematically been forced to embark on diverse and unfamiliar contracting models.

Although the aim of some of these forms of contracts is to improve construction standards, direct application of such documents has created serious flaws since they are out of context. They are rarely amended to suit local conditions and the characteristics of the concerned projects. For example, most building projects funded by the World Bank (the largest financier of the public sector) use Standard Bidding Documents for Works, (SBDW) based on Part I – General Conditions of Contract of the FIDIC conditions, (World Bank, 1995). The SBDW are divided into two parts: one for major; and another for smaller works.

Major works are those exceeding USD10.0 millions in cost. Most projects undertaken in Mozambique use "Smaller Works Standard Form of Contract" since they rarely reach USD 10.0 millions. However, within the Mozambican context a USD 2.0 millions project is a major project for two reasons: the amount of money involved is huge in local standards; and such project makes a significant difference in terms of work volume, employment generation and duration. The large portion of construction costs is spent on materials – about 60 per cent. The cost of labour accounts for about 20 to 30 per cent of the total cost.

In principle, the SBDW were prepared for civil engineering works and are supposed to be adjusted to suit local conditions or specific contract. For this purpose Part II – "Conditions of Particular Application" is provided. In practice, though, little or nothing is done to protect both the interests of the client and contractor since the client tries to protect his own interest.

The SBDW clauses dealing with definitions, quantities interpretations and variations, changes and alterations, extra-work, compensation for changes, authority of the engineer, measurement of quantities, progress payments and retentions, contractor's risks, employer's risks, time control, cost control and quality control are those causing more concerns. In most circumstances "The Engineer" has the power to take the final decision on the rates to apply to variations. Ideally, contract clauses need to be reworked on a

contract-by contract basis if risks are to be reasonably, systematically and fairly allocated between the parties.

It is unlikely that the situation will change in the near future, because multilateral and bilateral financing will remain the most important financing sources. Local money markets are still in their infancy.

As a consequence, contractors failure to meet project objectives of time, cost and quality is a systematic occurrence and the adversarial relationships between clients and contractors prevail.

4.11.4 Perspectives

Contractors' need for improving management styles in Mozambique is now crucial than ever before. The process of globalisation creates additional difficulties because competition has become tougher. Contractors can no longer use their mark-ups to sustain financial burdens. They have to produce realistic estimates, be competitive and still make profits so as to remain in business. Then, awareness of risks and their effective management should be an integral part of project management. By doing so, they can mitigate risks and improve their rate of success.

4.12 Summary

The chapter has discussed the different risk factors affecting the performance of construction projects with the main focus on global risk factors. The importance of the different environments surrounding organisations and construction projects as well as both the inherent dimensions and domains were presented and fully described. In this regard, the concepts of structure of an environment, the role of environmental analysis and the roles of environmental levels were presented. It was also explained how the degree of change and the degree of complexity impact on performance of construction projects. The need for managers performing project scanning in order to identify potential problems that could impact the success of projects was highlighted. A

classification of risks based upon the concept of environment was presented and discussed. Risks were classified as "organisation-specific", "Acts of God", and "Global". The main focus was placed on global risk factors because they are poorly-structured and complex, their environment is difficult to predict and they are less understood by most construction contractors. Furthermore, it is argued that although the conceptualisation of environmental uncertainty is available its formal measurement has received little attention by researchers. Global risk factors are grouped into estimator, project, level of competition, fraudulent, construction, economy and political factors. The chapter also discussed the typical problems permeating through developing countries and Mozambique in particular as the country where the present study focuses.

Chapter Five

Review of uncertainty and decision-making

5.1 Introduction

Risk management is a particular form of decision-making in construction and, as such, it is crucial that managers understand the framework and concepts related to decision-making. The preceding chapter placed global risk factors into context and provided a detailed discussion of them. This Chapter discusses the decision-making process and the corresponding decision-making techniques. The concepts of decision, decision-making processes, rational decision-making models and behavioural decision-making model (bounded rationality) are thoroughly presented and discussed. Heuristics and cognitive biases associated with decision-making are also considered.

The Chapter goes on to identify and distinguish the different states of nature or environments (certainty, risk, and uncertainty) and the classes of decision problems (structured, semi-structured and unstructured) are described. It is argued that classical decision-making techniques that have been mainly from management science need to be suplemented in order to improve the quality of decisions. Finally, decision support systems and knowledge based systems are identified as the emergent decision-making technologies and presented and their main features discussed.

5.2 Managerial decision-making

Decision-making is one of the most important management functions within construction organisations. All managerial activities such as planning, organising, leading and control involve decision-making. Senior, middle and operational managers make a large number of decisions daily so that.their organisations can function, adapt, progress and take advantages of opportunities and avoid potential problems.

The decision problems, for example risk management, that face construction organisations are often made in conditions where data and information are very scarce or unavailable at all. As a result, decision-making is often complex, irrational and chaotic. Decision-making is the process of selecting the best feasible alternative among several options. It is considered as both an art and science because it is a blend of hard and soft approaches, (Drummond, 1996). According to Drumond (1996), a problem exists if an objective exists and there are obstacles to its realisation (problem = objective + obstacle).

5.2.1 Classification of decisions

According to Mintzberg (1976), decisions can be broadly classified into strategic and operational. Strategic decisions are related to organisation's long-term objectives and goals. They are closely related to the organisation's environment and they are key to growth and success. Operational decisions, on the other hand, are concerned with daily management activities of organisations. They represent an effective implementation of strategic decisions, thus strategic and operational decisions are closely linked to each other and should not be viewed separately.

Decision on profit size for a contract is an example of an operational decision often taken by construction managers. Decisions may also be classified according to the frequency and information conditions. Frequency refers to the recurrence of a particular decision problem. Information conditions describe the amount of information available for making certain decisions. Within this perspective decisions are categorised into programmed and non-programmed respectively. Programmed decisions have high recurrence and therefore enable the development of decision rules. Programmed decisions are related to structured problems, which are generally routine and repetitive in nature. A structured problem has clear objectives, defined decision making procedure and established source and channels of information, (Simon 1960). On the other hand, non-programmed decisions correspond to less structured or unstructured decision problems, which are almost unique in nature because the information is scarce and unambiguous.

Thus, there are no standard routines for their solution. These types of decisions require a great deal of creativity and judgement from the decision-maker.

5.2.2 Approaches to decision-making

There are two main distinct perspectives of decision theory: normative or rational and descriptive or behavioural. Normative theories are concerned with how decisions should be made to achieve the objectives. Normative theories are rationalist, seek optimal decisions and are mainly linked to economics. Linear programming and decision trees are examples of normative models. Descriptive theories are mainly psychological explanations of how people make decisions. In practice, both normative and descriptive have been put together in a pragmatic way, (Moorhead and Griffin, 1995). The background and paradigms of the two main decision models are illustrated in Figure 5.1 Given the importance of the two decision models, the rational and behavioural decision-making models are discussed in the following sections.

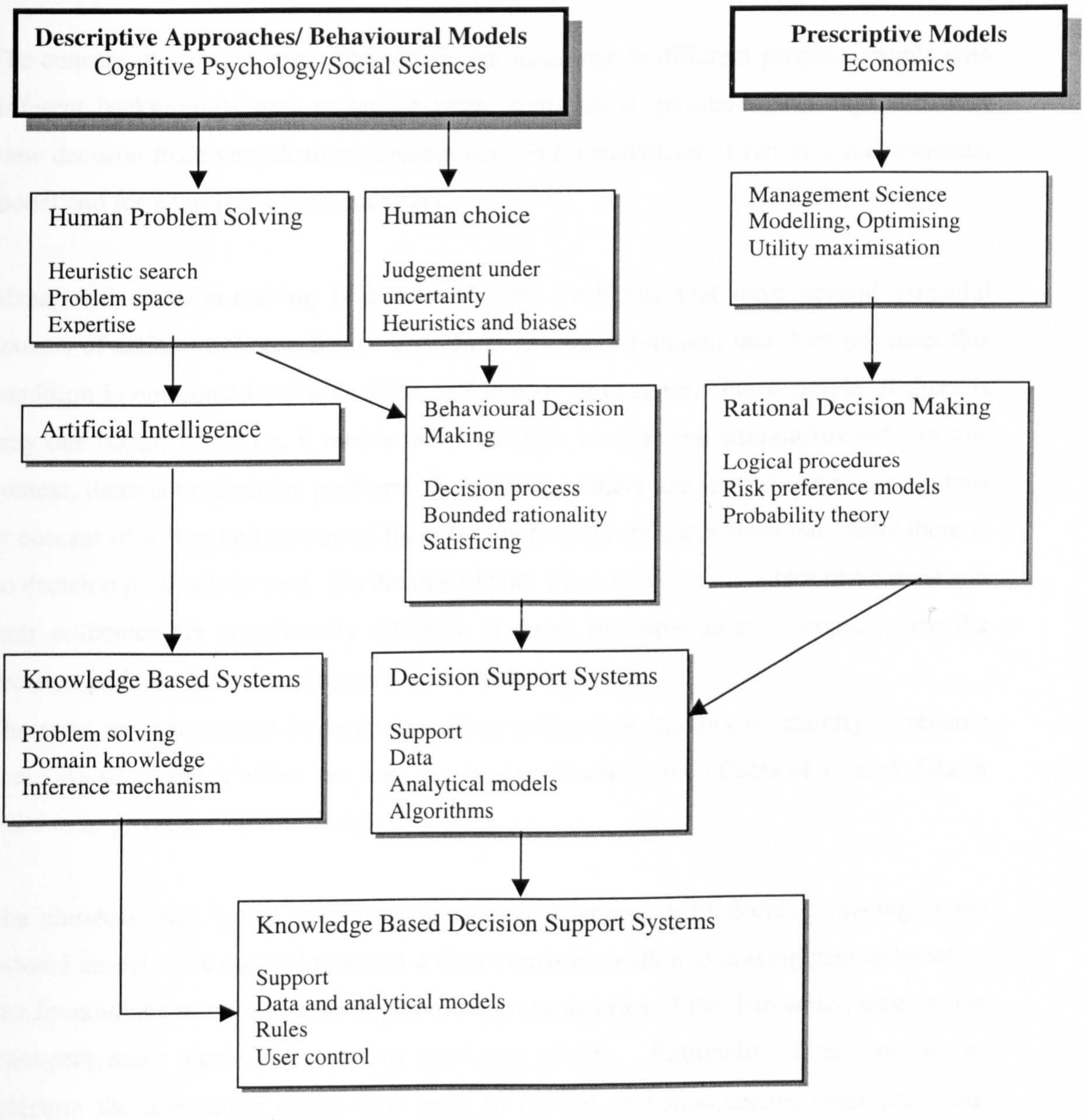

Figure 5.1: Background and paradigms for DSS and KBS (Klein, 1995)

5.3 Rational decision-making model

The concept of a decision has many different meanings to different people. People with different backgrounds such as businessmen, statisticians, psychologists, engineers may view decision from very distinct perspectives. For a statistician it can be a mathematical model and for a lawyer, a legal construct.

Managerial decision-making is concerned with problems that have several potential courses of action to choose from. Therefore, any other problem that does not meet this condition is not considered a decision problem in strict sense. For example, if there is only one course of action, it means that a decision is clear and straightforward. In this context, there is no decision problem. In addition, if there are several alternative options or courses of action and no one of them is significantly different from the others there is no decision problem, as well. On the other hand, when two or more alternatives exist and their outcomes are significantly different in terms of importance or impact, then the decision problem becomes of interest and worth of analysis.
The most important issue in decision-making is the unavailability or scarcity of reliable data. As such, much effort has been devoted to minimise the effects of lack of data in order to improve decision-making.

The classical, also called normative or statistical, approach to decision-making is the rational model. The rational model is a view consistent with maximising gain or benefits. The foundations of rational model are rooted in the theories of the firm which assume that managers make decisions so as to maximise profits. Rationality, then, consists in selecting the alternative option that leads to the set of consequences most preferred, (Simon, 1954). The classical decision theory is characterised by: a set of decision alternatives (decision space); a set of states of the nature (the state space); a relation assigning to each pair of a decision and state a result; and the utility function which orders the results according to their desirability.

Rational decision-making is a method based on logical thought sequence aimed at achieving rational decisions, that is, decisions are considered a result of logical analysis of available information and the evaluation of alternative options against their expected value to the decision-maker. Rationality is, therefore, associated with logic, reasoning and sense-making. There are now several elaborations of rational decision-making models but all of them essentially comprise the following elements:

- problem identification;
- objectives set up;
- alternative generation;
- model set-up;
- prediction of outcomes;
- alternative selection; and
- decision implementation and evaluation.

Similarly, risk management, as a typical decision-making problem, includes the following steps (Vaughan and Vaughan, 1995): determination of objectives; identification of risks; evaulation of risks; consideration of alternatives; selection of option; implementation of the decision; and evaluation and review.

5.4 Behavioural decision making model - Bounded rationality

The classical theory of rational model of decision-making has been challenged in recent years. It is argued that decision-makers make decisions on the base of available information. Because the desired information is rarely available, decision-makers often have to use subjective judgement, creativity, skills, effort, experience and intuition.

Rational or optimal decision model implies perfect knowledge of the states of nature and complete information – decision-making under certainty, (Haimann et al., 1985). In such ideal conditions, the decision-maker has all the information needed at the right time and the cognitive mechanism evaluates the information quickly, accurately and objectively so

as to reach the optimal alternative options. Therefore, rational decision models suppose that decision-makers are able to:

- clearly identify the problem;
- generate all possible alternative options;
- predict the outcomes of alternative options;
- evaluate them through preference-ordering criteria that enable ranking all sets of consequences from most preferred to least preferred; and
- make the best feasible choice with high accuracy and implement it.

However, since most decision problems are fraught with complexity and uncertainty, decision-makers can not make completely optimal decisions. According to Haimann et al., (1985), decision-makers are always making decisions under risk or uncertainty because information is rarely perfect and complete. In these circumstances, alternative options are not all known, the consequences or outcomes attached to each alternative option are not known, and decision-makers lack complete order-preferencing criteria. Therefore, due to incomplete information, time pressure and limited mental capacities, decision-makers do not and can not make completely optimal decisions. In this regard, Simon (1957) argued that people have limited information processing capacities or cognitive limitations and, therefore, they tend to "satisfice" or simplify in order to judge and reach decisions (optimising). That is, people tend to make satisficing, rational decisions within the human boundaries limitations – "Principle of Bounded Rationality".

It is, however, important to realise that rationality enters in both optimising and satisfacing, but in the latter case the rationality is bounded or limited. The cognitive limitations inherent in humans include: limited short-term memory with a capacity for only a few pieces of information; difficult in handling multiple problems simultaneously; limited computational ability; and different evaluation of information based upon how it is presented.

Decision-makers have their own criteria of an acceptable decision. To reach satisficing decision they go through the process of search and selection. They search, within a

problem space until they find an alternative option that meets the criteria, i.e. the first alternative option found to be satisfactory is accepted. An alternative option is satisfactory when there exists a set of criteria that describe minimally satisfactory alternative options and the alternative option under consideration meets or exceeds all these criteria. The problem space is essentially an individual's internal (mental) representation of a problem and the place where the problem-solving activity takes place.

5.4.1 Satisficing decisions

The term "satisfice" is a combination of the words satisfactory and maximising. Satisficing means selecting the first acceptable alternative option instead of looking for the best. Simplifying strategies aim to reduce the complexity of problems and make them manageable within mental limitations. March and Simon (1958) suggested that the decision-makers often may forego the best alternative option in favour of one that seems satisfactory or acceptable.

The fact that decision-makers tend to make rational decisions does not mean they will always manage to do so. Very often they make intuitive decisions based on their past learning experience. It is argued by Simon (1987) that as managers go through the rational sequence thought, they may see patterns they encountered previously and consequently gain useful insights to improve the quality of decision. This means that intuition and rational decision-making can complement each other in the process of decision-making. Furthermore, the bounded rationality model emphasises the need for decision-makers combining the rational decision-making methodology with a thorough thinking to expand the cognitive boundaries, as much as possible.

As an illustration of the difference between optimising and satisficing, March and Simon gave the example of searchin a haystack to find the sharpest needle (optimising) versus searching a haystack to find a needle sharp enough to sew with (satisficing). Another example of satisficing criteria in business environment are the concepts of "market share ", "adequate profit" and "fair price".

5.5 Heuristics and biases in decision making

Heuristics are generalisations or guidelines involving intuition, past experience and common sense used by individuals to reduce mental effort in processing information when dealing with highly unstructured problems. Harmon and Sawyer (1990) defined heuristics as rules of good guessing. They are frequently employed by decision-makers in their judgement and choice. Decision-makers use heuristics because they are often efficient and produce satisfactory results most of the time, although they may lead to errors, as well.

5.5.1 Heuristics in decision making

In the light of the concept of bounded rationality, Tversky and Kahneman (1974) reported that decision-makers rely on several assumptions, namely heuristics and rules of thumb in the complex process of decision-making under uncertainty. Heuristics aim to reduce complexity to simpler judgmental operations. These heuristics provide an important support in the process, but they may lead to systematic predictable errors. Only a better understanding of both heuristics and the associated cognitive biases would enable an improvement of decision quality.

Gigerenzer (1991), however, suggested that people do not use heuristics when experimental problems are re-cast into a relative frequency paradigm. Instead, they can reason about uncertainty with frequencies rather than using heuristics. The rationale behind this is that people's memory for frequency information is reliable enough for them to use past records for their judgement. Hacking (1975) argued that human cognition did not naturally compute probabilities, which only emerged formally in the seventeenth century, but used stored frequencies, instead. The frequentist approach in the assessment of likelihood of events was also supported by Hasher and Zacks, (1984).

According to these authors, a particular judgement is either based on stored frequencies or in heuristic and therefore, there was no conflict between the two views – heuristic and frequentist.

Kahneman and Tversky (1973) reported that people judged likelihood and frequency by the ease with which instances of the event could be brought to mind – availability heuristic.

Although other theories explaining the nature of human judgement under uncertainty have emerged, it seems that there has been a wide consensus around the work of Kahneman and Tversky. Thus, the theory of human decision-making recognises that decision-makers rarely apply formal principles and they tend to violate normative rules.

Kahneman and Tversky (1973) identified the following main heuristics associated with human judgement in decision-making: representativeness; availability; anchoring and adjustment. These heuristics were discussed in chapter 4.

5.5.2 Cognitive biases associated with heuristics

Judgement is a cognitive process that involves attitudes and perceptions of the decision-maker towards both the internal structure of the organisation as well as the states of the nature or environmental factors. Generally, the cognitive dimensions are called soft data in contrast with technical quantitative techniques and tools - the hard approach.

Biases can be defined as prejudices, pre-dispositions and influences in processing information. It is argued that decision-makers do not process information objectively. Instead, there is a great deal of subjectivity related to the prejudices of the individual or decision-maker. Biases affect the whole process of decision-making and they are almost inevitable. The main biases associated with representativeness are insensitivity to base rates, insensitivity to sample size, misconception of chance and regression to the mean. Biases associated with availability are ease of recall, retrievability, and presumed associations. Bias associated with anchoring and adjustment are insufficient anchor adjustment and overconfidence.

5.4.3 Corrective measures of decision making

Although decision-making is a complex process heavily influenced by a large number of factors it is still possible to achieve good quality decisions. The barriers associated both with hard and soft approaches can, to some extent, be partially removed from the process and thus enhance decision-making. Several corrective measures of errors associated with soft approaches such as heuristics and bias have been proposed to help improving intuitive judgement towards rational decision-making. According to Bazerman (1990), the following strategies are important in that process:

- adjusting intuitive predictions;
- debiasing;
- experience and expertise;
- linear models based on expert judgement; and
- knowledge based systems

5.6 Classes of decision problems

Based on the amount and quality of information available to decision-makers in order to make predictions about the future, decision environments may be classified into the following groups: certainty; stochastic/risk; and uncertainty.

5.7 Decision-making techniques

One of the most important tasks in the process of decision-making is the analysis of the different alternative options available. In the past, the calculations involved in the analysis were performed manually, but with the advent of computers these can now be quickly and effectively. Most of the techniques in use for this purpose are quantitative

and are generally known as management science methods. Management science can be defined as the application of the scientific method and a set of quantitatively based logic decision models used to assist decision-makers.

The decision-making techniques from management science can be grouped according to decision environments. That is, there are techniques for deterministic problems, techniques for stochastic problems and techniques for uncertain problems. The rationale for different modelling lies in the extent of complexity inherent in each type of problem. In addition to the classification based on the states of nature, the techniques can be further subdivided according to their field of use. In this regard, they can be: inventory control techniques; resource allocation techniques; scheduling/sequencing techniques; and prediction techniques. The first three techniques are not related to risk management as far as construction projects is concerned. Risk management is about predicting the occurrence of future events and the associated consequences. As a result, only the prediction models are of interest in the present study.

5.7.1 Deterministic techniques

Many textbooks, particularly on quantitative methods and operational research literature, provide a thorough discussion on deterministic models. Since detailed discussion of these models falls beyond the scope of this study, they will not be addressed here. They are mentioned to enhance the understanding of further discussion, instead:

- inventory models (economic order quantity and inventory control models);
- resource allocation models (linear programming, transportation models, assignment models);
- scheduling models (PERT, project scheduling, dynamic programming, integer programming); and
- prediction models (regression, break even analysis, sensitivity analysis).

5.7.2 Stochastic techniques

Recent developments in information technologies have made it possible to improve the formulation of poorly structured problems so as to aid decision-making. The following techniques are now available:

- scheduling (simulation, queuing); and
- prediction (decision trees, expected value analysis, Monte Carlo simulation).

The application of decision trees, expected value analysis and Monte Carlo simulation in construction projects risk management was discussed in chapter 3.

5.7.3 Alternative and complementary technologies

In recent years there has been an intensive research effort towards formulation of alternative approaches for decision making. Such effort is an attempt to bridge the gap between the actual performance of the existing techniques and the expected performance. Most of the classical techniques fall short in capturing the main features of decision systems and most of research into new technologies for decision-making aims to complement rather than to replace the traditional approaches.

Several new developments lie on the horizon. Among the most valuable and promising technologies that have emerged in recent years, decision support systems (DSSs) and knowledge-based systems (KBSs) are at the forefront.

a) Decision support systems

The use of computers is not new. Computers have been recognised as tools that could process data and produce information for management decision-making. The broad area of use of computers in decision-making is called Computer Based Information System

(CBIS), that comprises several subsets such as Management Information Systems (MIS), Office Automation, (OA) and Decision Support Systems (DSSs). Recent developments in the field of information technologies have enabled the emergence of new decision techniques and tools. The need for new decision techniques stems from the increasing shortcomings associated with the classical approaches as the complexity of a project increases.

The concept of DSS emerged in the early 70s as an effort to channel computer applications in decision-making. The pioneers of DSSs, (Gorry and Morton, 1971), classified decision types in terms of problem structure as ranging from semi-structured to structured. This classification has its foundation on Simon's work who classified decision problems into structured and unstructured. Structured problems are those in which the decision-maker follows Simon's stages when solving a problem, namely intelligence activity, design activity and choice activity. In other words, structured means there are algorithms or decision rules for making optimal decisions. Unstructured problems are those in which none of the above mentioned three stages, are structured.

Finally, a semi-structured problem, as defined by Gorry and Morton, is one in which at least one stage is structured. Further, based on Gorry and Morton's work, Alter (1976) developed a taxonomy of six DSS types in accordance with the degree of problem-solving support. These DSS types are: retrieve information elements; analyse entire files; prepare reports from multiple files; estimate decision consequences; propose decisions; and make decisions. Retrieve information elements offer the least support to the decision-maker. In general, the first three types enable decision-makers to query databases and get reports. The last three build on mathematical models.

Klein and Methlie (1995) defined a DSS as:

"A computer information system that provides information in a given domain of application by means of analytical decision models and access databases, in order to support a decision-maker in making decisions effectively in complex and ill-structured (non-programmable) tasks". The major characteristic of DSSs is the inclusion of a

modelling capability. The need to support decisions accrues from the benefits of better and informed decisions since the success of an organisation is largely dependent on the quality of the decisions made daily. Keen and Morton (1978) stated the objectives of DSS as:

- assist managers in making decisions to solve semi-structured problems;
- support the manager's judgement rather than try to replace it; and
- improve the manager's decision-making effectiveness rather than its efficiency.

Sprague and Watson (1986) mentioned several major drivers of DSS as being personal computer revolution, decreasing cost of telecommunications, availability of databases, and growth of artificial intelligence techniques. Therefore, the key features of a decision support system are:

- confront poorly-structured problems;
- computer-based systems;
- help decision makers;
- through direct interaction; and
- with data and analysis models.

The analytical models include methods of decision analysis, optimisation algorithms, scheduling techniques, inventory models and others. Developing DSSs from scratch can be a lengthy and hard process. Because of this complexity there have efforts in order to provide developers with development tools also known as generators. A typical DSS generator provides the following services:

- database management module;
- modelling module;
- report definition module;

- functions module (mathematics, statistics, finance etc.); and
- user interface definition module.

b) Knowledge based systems

Knowledge based systems are particular applications of the DSSs. A knowledge based system is a computerised system that uses knowledge about some domain to arrive at a solution to a problem from that domain. This solution is essentially the same that concluded by a person knowledgeable about the problem domain of the problem, (Gonzalez and Dankel, 1983).

Knowledge based systems allow computers to accept knowledge from external sources as well to store, access and use that knowledge to solve problems or make recommendations on alternative options. The knowledge incorporated in KBS consists of facts that have been discovered, learned, perceived, inferred and understood in certain domain of knowledge. This knowledge is collected from many sources such as journals, statistical records, information systems, databases and expert opinions. KBS are different from conventional computer programs due to the following features:

- KBSs contain expert knowledge represented in a form comprehensible to man and computer;
- there is a continuous search of knowledge within a KBS in order to reach a solution required by the user; and
- the system is able to give explanations about how it arrived at determined recommendations.

KBSs enable a user with a specific problem to consult the computer system as they would an expert advisor to diagnose the causes of the problem or to give a recommendation/solution to the problem. Furthermore, the user can extract detailed information from the computer system by asking appropriate questions, including explanations about the reasoning steps to reach conclusions.

5.8 Decision support and knowledge-based systems development techniques

There are several techniques for application in the development of KBSs and DSSs in the field of AI but the most promising include the following: rule-based systems; case-based systems; model-based systems; neural network based systems; genetic algorithm based systems; and fuzzy logic, (Goldberg, 1989; and Li, 1996). The choice of an appropriate technique depends, among other factors, mainly upon the specific type of problem, the difficulty at knowledge acquisition, the form of knowledge representation, type of required data, explanation capacity, difficulty at development and appropriate domain, (Gonzalez and Dankel, 1993; and Li 1996).

5.7.1 Rule-based systems

Rule-based systems are systems where knowledge is represented in the form of rules. This technique has had a large predominance in the development of KBS. A rule-based system consists of knowledge base, representing and storing the expert's knowledge and facts about the specific domain as rules, inference engine, memory and the user interface.

A simple form of a rule is: IF A THEN B, where the IF part is the antecedent and THEN part, a consequent. The antecedents are considered patterns and the consequents, the conclusions or actions to be taken. The antecedent part of a rule is matched with the content of the working memory and when all the conditions in the antecedent are satisfied the rule is fired. The major advantage of rule based systems is that they facilitate explanations because the antecedent-consequent format can be transformed into questions.

5.7.2 Case-based systems

Kolodner, (1993) defined a case as " a contextualised piece of knowledge representing an experience that teaches a lesson fundamental to achieving the goals of the reasoner". Thus, the concept of case-based reasoning is founded upon the idea of using explicit, documented experiences to solve new problems, that is, remembering past similar problems as a way to solve current decision problems. It is assumed that human problem solving is based somewhat on the application of experiences. Experts become experts by doing and experiencing. Case-based reasoning consists of case retrieval and case adaptation. Previously solved cases are stored in case-bases on computers from where they can be retrieved when a similar problem is encountered. Then, situations are interpreted through comparison and contrast with previous similar ones. By comparing and contrasting past and current situations decision-makers can make inferences.

Therefore, case-based systems can be considered models of reasoning that involve learning, understanding and memory processing (Kolodner, 1993). Case-based systems are different from rule-based systems in that case-based systems store expert's knowledge in the form of cases rather than in the form of rules. It is argued that because case-based reasoning is based on concrete instances it has the ability of providing better guidance than other methods which are based on abstract instances, (Kolodner, 1993). However, since most practical real decision making situations tend to be unique, as in construction projects, there are serious constraints to take into account in developing case-based systems. According to Kolodner, (1993) the following premises determine the quality of a case-based reasoner's reasoning:

- the experience it has had;
- its ability to understand new situations in terms of those old experiences;
- its adaptness at adaptation;
- its adequatness at evaluation and repair; and
- its ability to integrate new experiences into its memory appropriately.

Therefore, the construction and organisation of a library of cases have been considered a critical task that, if not properly executed, can hinder the performance of the systems.

5.7.3 Model-based systems

Model based techniques attempt to overcome one of the main disadvantages of KBSs – knowledge acquisition. Model based systems eliminate the need for knowledge elicitation from experts. Instead, they develop a general model of underlying causes of behaviour. Unlike KBSs that use associational knowledge (rules) model based systems use deep knowledge. Knowledge acquisition is replaced by a representation of the system model usually in form of schematic diagrams. They represent and reason with deep understanding of the application domain (similar to causal models). The domain is generally embodied in the context of physical systems, artificial or natural, which model based technique represents both structurally and functionally. Model based systems have been widely applied to most diagnosis problems. The generic diagnostic procedures are embedded in an algorithmic process that makes use of a device-centred causal model of the target physical system. This model is then used to identify possible causes of failure.

The model-based reasoning algorithms are similar to special-purpose inference engines while models can be likened to knowledge bases in KBSs. In model-based reasoning systems the generic diagnostic knowledge is incorporated in the inference engine, while the model (knowledge base) represents the schematic of the system being diagnosed.
It should be mentioned that for some systems the development of the models could pose serious difficulties at times.

Another advantage of model based systems is that every possible malfunction does not need to be explicitly identified ahead of time as it is required in some systems. In essence, these systems assume that every possible component described can be a cause of a failure. The main disadvantages are that they can not handle heuristic knowledge and are unable to handle uncertainty easily. In model based systems the observed behaviour

is compared with the predicted behaviour and the margin difference gives an indication of the existence of a defect in the process. If a defect exists the system must identify both the location and type of the defect through hypothesis definition, testing and discrimination. Based on this procedure, the system generates several hunches that are subsequently tested using certain methods of which the fault model simulation is the most employed.

5.7.4 Neural networks based systems

An artificial neural network (ANN) is a computer program that emulates human decision-making at a low level in an attempt to replicate the capacity of human reasoning. Neural networks are designed to model the brain learning, thinking, storage and retrieval of information, that is, they are information-processing technologies of artificial intelligence. ANNs learn from experience, generalise from previous examples to new ones and are capable of abstracting essential characteristics from inputs containing irrelevant data. ANNs are based on a simplified model of the anatomy and physiology of the human brain. The brain is regarded as a collection of cells (neurons) connected by nerves (synapses). Neurons, also referred to as cells, nodes or units, supply information (signals that are transmitted to other neurons through synapses – synaptic transmission). Each neuron maps one or several signal inputs to a single signal output.

Neurons are organised in layers, usually an input layer, a hidden layer and an output layer, and each layer comprises one or several units. The input and output layers are the only ones that communicate with the external environment. The input layer receives data from the external environment whereas the output layer provides the response of the network to the external environment. The remaining intermediate layers are called hidden layers. These provide crucial computational abilities to the net particularly for complex problems with non-linear relationships. The number of layers is determined in accordance with a specific problem.

a) Development and application of ANNs

The development of an ANN consists mainly of designing and training the ANN. Detailed development stages can be summarised as follows: domain selection; system attributes selection; selection of a net model; neural paradigms selection; training; testing and validation. Domain selection is an important initial stage since not all problems are suitable for ANNs applications. After the design has been completed, the next step is the training that consists of presenting the ANN with past examples and have it to modify its connection weights until the correct functional mapping between input and output is reached.

Examples of areas where ANNs are good include signal processing, character recognition, robotics and vision systems and forecasting. Systems attributes are both input and output variables from the specific domain. It should be born in mind that data must exist and be obtained. Successful training and testing of a net depends heavily on the existence of data drawn from the problem domain. Data can be elicited in different forms that include interviews with experts, historical data from projects, surveys, etc.

Development of ANNs requires selection of appropriate development environment. Nowadays there is a wide range of tools for ANNs development and the choice must be based on thorough analysis of important factors such as the importance and size of the project, cost of the tool, maintenance requirements and performance of the tool.

5.7.5 Genetic algorithm based systems

Genetic algorithms are stochastic computation techniques, based on the mechanism of natural selection and natural genetics, used for search in artificial systems. They are very good at exploring large search spaces for optimal or near optimal solutions. Instead of searching a restricted region. GAs search for a solution from a broad spectrum of possible solutions. GAs were devised to mimic the features of natural systems namely

self-organisation, adaptation, evolution, co-evolution, metabolism etc. Natural systems are robust, that is, efficient and effective as they are able to adapt to a wide range of environments in order to survive.

The first genetic algorithms were developed by John Holland at the University of Michigan in the early 70s. He was impressed by the easy in which biological systems could perform tasks that eluded even the most powerful super-computers such as the ability of animals to recognise objects, understand and translate sounds. Since then, research efforts have been directed on the replication of these capabilities in machines, (Goldeberg, 1989; and Davis, 1991). It is believed that any complex biological system that exhibits these qualities has evolved to that stage.

Genetic algorithms now belong to the family of artificial intelligence techniques used to solve optimisation problems. They have the ability to combine numerical parameter optimisation with combinatorial searches within a specific domain. The underlying concept of GAs is the evolutionary model operation from Darwin's principle – survival of the fittest. According to this principle natural selection will tend to bring together those genes that constitute a balanced system.

a) How GAs work

Typical optimisation problem with GAs starts with the definition of the objective function and the constraints. Then, the system randomly generates the initial population also called set of chromosomes. Each chromosome stands for a possible solution. The second step consists of generation of a new generation of chromosomes (improved chromosomes) with a large fitness function in order to survive to the next generation.
This process involves crossover and mutation. Crossover merges two parent chromosomes at a pre-specified point (n^{th} digit of the chromosomes) which cause digits to change and thus bringing a new generation. Mutation randomly selects a digit and changes it (from 0 to 1 or 1 to 0). Using these procedures the system performs many consecutive generations to find the fittest elements.

If after many runs no improvement is observed in the maximum fitness the GA terminates. Although being randomised, GAs are a complex search optimisation procedure as they efficiently exploit past information on new search points with expected improved performance, (Holland, 1992).

The whole process can be explained as follows: different possible solutions to a problem are created; these solutions are tested for their performance (to check how good a solution they provide is); among all possible solutions a small portion of good solutions is selected, whereas others are discarded (survival of the fittest) and the selected solutions pass through crossover and mutation to create a new generation of possible solutions which are expected to perform better than the previous generation. The process of selection, crossover and mutation is repeated until a convergence within a generation is noticed.

The development of GAs involves a certain number of steps as described earlier. In general, the following steps are considered: definition of the problem and its suitability for GAs analysis; determination of the objective function; selection of decoded parameters and auxiliary information; determination of selection, crossover and mutation operators; and computer coding of algorithms. Selection, crossover and mutation operators depend on random choice since GAs use probabilistic operators rather than deterministic ones in their exploitative search. The whole process of evolution is fully controlled by these operators.

5.8.6 Evaluation of the techniques

The techniques for developing KBSs are all valuable. However, they must be used within specific contexts or domain problems because of their own strengths and weaknesses. For example, case-based reasoning technique requires less development effort when compared with rule-based systems but they fall short when it comes to provide explanations about the reasoning process. Genetic Algorithms are very effective for optimising resource-allocation problems in construction but they lack an effective

knowledge representation method and for problems with a large number of constraints they do not produce good results, (Winston, 1998). A general comparison of the techniques is given in the Table 5.1.

Table 5.1 Comparison of KB DSS development techniques

System	Type of Data	Knowledge Acquisition	Development Process	Explanation capacity	Suitable Applications
Rule-based	General knowledge	Very difficult	Average	Excellent	Planning, Diagnosis, Interpretation, Prediction
Case based	Cases	Average	Easy, minimum effort	Good	Planning
Model based	Models	Average	Average	Average	Monitoring, control, diagnosis
Neural networks	Examples	Low	Difficult	Very poor	Prediction, cost estimation, risk analysis, optimisation, decision making, DSSs, Classification, selection, Hybrid systems
Genetic Algorithms	Examples	Low	Average	Very poor	DSS, Optimisation, forecasting

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5.9 Summary

This chapter discussed the concepts of decision-making and decision-making under uncertainty. The most important features of decision-making within organisations have been covered. Rational decision-making and behavioural decision-making have been presented as the most prominent approaches to decision-making.

The chapter also explained heuristics and bias associated with the process of decision-making as well as the corrective measures employed to improve the quality of decisions. The different environments within which decision are made, namely certainty, risk and uncertainty were described and the corresponding classes of decision problems identified. It was argued that risk decision-making falls into the last category because it is a poorly-structured problem for which acceptable algorithms or mechanical methods are unavailable. Indeed, risk management relies heavily on experience, intuition and human judgement. Unlike deterministic and stochastic problems, poorly-structured problems can not be formulated at the desired level of precision due to the surrounding uncertainty.

Management science was considered as an important source of quantitative techniques commonly employed to help in the analysis step of decision-making. It was argued that although being useful, most of these techniques and subsequent tools often fall short in capturing the main features of decision-making and, as a result, efforts have been channelled to find new directions that could help improve the quality of decision-making. With new developments in information technology it has been possible to explore new techniques from AI such as DSSs and KBSs in recent years. The DSSs and KBSs as well as the different development techniques and approaches have also been covered.

It was concluded that KBSs are more appropriate techniques for management of global risk factor than DSSs because these risks are so complex and require expertise in addition to the capabilities present in traditional regular DSSs. KBSs have several

additional advantages over traditional DSSs because, apart from databases and models, they possess knowledge bases, the ability to reason about knowledge and data, the flexibility in terms of knowledge addition and alteration and the ability to explain how they reach certain recommendations or solutions. The use of KBSs represents a shift from hard to soft systems that would bring many benefits to the construction risk management (Daniel 1990).

Chapter Six

Knowledge-Based Decision Support Systems

6.1 Introduction

The preceding chapter presented different models and concepts of decision-making under conditions of uncertainty. It also reviewed several frameworks for decision-making, of which decision support systems and knowledge-based systems were considered as being at the forefront. Knowledge-based systems have additional capabilities than traditional decision support systems. This chapter introduces the concept of knowledge-based decision support systems. The need for knowledge-based system for managing global factors risk management is thoroughly explained. The discussions then extend to the concepts of artificial intelligence and its main applications. It goes on to describe the components of Knowledge-based systems, the development process of KBSs, and the tools used in this process. The advantages and disadvantages of KBSs, as well as the different types of KBSs are also discussed. The chapter ends with the discussion of the different types of uncertainty and the techniques used to handle uncertainty in knowledge-based systems.

6.2 Reasons for developing a knowledge-based system

The complexity of risk has already been described, and it was explained why the modelling, assessment, analysis and management pose difficulties. The preceding chapter also characterised the management of global risk factors as a poorly structured decision-making problem, because the available information is often imprecise, incomplete and the amount of uncertainty is high. Conventional analytical models from management science are not effective enough in dealing with poorly structured problems since these do not have tractable algorithmic solutions. As such, there is a need to explore new potential methodologies and techniques to deal with this class of problems.

The emerging area of artificial intelligence, particularly the decision support systems and knowledge-based systems, have huge potential in this regard. In comparison to a DSS a KBS handles well incomplete and imprecise information, handles better changing environments, is concerned with making judgements and handles well problems that have no path or rail that can be followed from inputs to conclusions. A KBS possesses additional capabilities compared to a DSS. The KBSs are therefore potentially suitable for tackling poorly structured problems such as the management of global risk factors affecting cost performance.

According to Feignbaum (1971), human experts are very well placed to eliminate implausible structures from the solution space by using domain knowledge. The focus of KBSs is on domain knowledge and the most important characteristics of poorly-defined problems are:

- the preferences, judgements, intuition and experience of the decision-maker are essential;
- the search for solution implies a blend of the search of information, formalisation, problem definition, computation and data manipulation;
- the sequence of the above operations is not known in advance because it can be a function of data, it can be modified, it can be a function of the user preferences;
- there are several and sometimes conflicting criteria for the decision-making; and
- problems evolve rapidly.

According to Adeli (1988), KBSs are most effective in situations where judgement and experience are significantly determinant and there is no underlying theory or this is inadequate for a satisfactory solution to the problem. Fenves (1983) suggested that KBSs are recommended when: there are recognised experts in the domain; the task is primarily cognitive; and algorithmic methods are either not feasible; too cumbersome or too restrictive.

6.3 Application of KBSs in construction

Compared to other areas such as manufacturing, the role of KBSs in the construction industry has not been well appreciated. Harmon et al, (1988) reviewed the application domains of KBSs and reported the following most important areas: financial management; computing; manufacturing; office automation; medicine; science; transportation; and equipment maintenance.

No applications in construction industry were mentioned. In fact, only a small number of KBSs have been developed and implemented in construction, (Ludvigsen et al, 1986; and Mohan, 1990). Despite this gap, it seems that the industry is becoming aware of the potential importance of management information systems (MIS) and KBSs, in particular. In recent years, there has been a tremendous research effort in AI applications in construction. Most of the KBSs in construction are rule-based, running in microcomputers and have been implemented with the use of commercial shells. According to Levitt (1987), KBSs can be grouped into the following categories:

- operational KBSs – KBSs that have already been validated and are currently in use;
- operational prototypes – KBSs that have been prototyped and run but need further validation and refinement; and
- developemental KBSs – KBSs that have passed the conceptual development stage but still lacking definite prototyping.

The most important areas of construction that may potentially benefit from knowledge based systems include (ASCE, 1986; Mohan, 1990; and Ayyub, 1996): structural engineering; project management; construction methods; equipment management; project planning; risk management; human resources management; and legal issues.

Mohan, (1990) outlined the main features that make certain and specific construction industry problems suitable for KBSs. These characteristics include the following:

- construction is non-repetitive since each project is different in terms of design, layout, materials, construction methods and management;
- construction environment is full of uncertainties in respect to labour productivity, equipment productivity, market forces, material availability and changes, weather, change in regulations;
- enough construction engineering and management knowledge has not been formalised and encoded in textbooks so far;
- typical construction activities are carried out under pressure due to lack of time;
- most construction decision problems such as safety management, labour relations, decision to bid and risk management are qualitative and subjective in nature and thus more suitable for heuristic approaches rather than algorithmic ones;
- information on a subject is almost never completely known and the decisions have to be taken on the basis of incomplete information;
- many construction professionals and managers do not have enough knowledge of computer science to be able to use and updated algorithmic computer programs; and
- KBSs development requires domain experts and there are highly knowledgeable experts in the construction industry who have successfully completed several projects and who are recognised in the profession.

6.4 Application of KBSs to risk management

There is considerable applications of KBSs in the field of risk management but structural engineering is at the forefront. Adeli, (1988) described several KBSs developed in the fields of structural engineering, construction engineering and management, environmental engineering, water resources engineering and geotechnical engineering. Mohan (1990) surveyed the state of application of KBSs in construction and identified 37 KBSs, of which seven were operational, fourteen were operational prototypes and the remaining sixteen were at the developmental stage. Within this group only three KBSs focused on risk management. In recent years, Raftery (1993) and Wirba et al. (1996) proposed new

approaches for tackling risk analysis and management in construction. Raftery argued that the adoption of KBSs would help overcoming unresolved problems inherent to probabilistic view. Wirba et al., (1996) considered the use of fuzzy logic in risk analysis as a departure from the traditional statistical decision analysis in the modelling and assessment of construction project risks. Despite the efforts reported here with regard to the application of new technologies to handle risk in construction projects it seems that there is still a long to go before KBSs are fully implemented.

6.5 Definitions and concepts related to Knowledge-based systems

KBSs are a particular branch of artificial intelligence (AI). According to Holsapple and Whinston (1987), "Artificial Intelligence is the activity of providing computers with the ability to display behaviour that would be regarded as intelligent if it were observed in humans". AI attempts to simulate human reasoning by working both with qualitative and quantitative information. AI is a wide area that includes machine learning, robotics, knowledge representation, cognitive modelling, knowledge-based systems, natural language processing and heuristic problem solving. Although AI has been active for about thirty years, only in recent years it has known significant developments and widespread research.

6.5.1 Knowledge

Knowledge can be defined in different ways. Knowledge can be defined as facts, information, understanding and skills that a person has acquired through experience or education. Knowledge comprises facts and heuristics. Harmon, (1990) classified knowledge into: heuristic or surface knowledge; domain knowledge; and deep or theoretical knowledge.

6.5.2 Expert

According to Johnson (1983), an expert is: "A person who, because of training and experience, is able to do things the rest of us cannot. Experts are not only proficient but also smooth and efficient in the actions they take. Experts know a great many things and have tricks and caveats for applying what they know to problems and tasks. They are also good at plowing through irrelevant information in order to get at basics issues, and they are good at recognising problems they face".

6.5.3 Decision support systems

Klein and Methlie (1995) defined a DSS as "a computer information system that provides information in a given domain of application by means of analytical decision models and access databases, in order to support a decision-maker in making decisions effectively in complex and ill-structured (non-programmed) tasks". The root of DSS are the quantitative models from management science. Thus, the essence of DSS is the accessibility and display of information as well as numeric computations using analytical models.

Emphasis of DSS is placed on support, since decision support systems are systems developed to assist decision-makers. Their main objective is to help decision-makers to make informed and better decisions, rather than replacing them. Examples of DSSs include construction cost estimating programs, bidding models etc. Decision-makers have used judgement, skills and experience in combination with the aid provided by a DSS.

6.5.4 Knowledge-based systems

According to Gonzalez and Dankel (1983), knowledge-based system is a computerised system that uses knowledge about some domain to arrive at a solution to a problem from that domain. This solution is essentially the same that concluded by a person

knowledgeable about the problem domain of the problem. Knowledge-based systems allow computers to accept knowledge from external sources as well to store, access and use that knowledge to solve problems or make recommendations on alternative options.

The knowledge incorporated in KBS consists of heuristics and facts that have been discovered, learned, perceived, inferred and understood in certain domain of knowledge. This knowledge is collected from many sources such as journals, statistical records, information systems, databases and expert opinions. Knowledge-based systems are also called expert systems. KBSs are different from conventional computer programs due to the following features:

- KBSs contain expert knowledge represented in a form comprehensible to man and computer;
- there is a continuous search of knowledge within a KBS in order to reach a solution required by the user; and
- the system is able to give explanations about how it arrived at determined recommendations.

A KBS enables a user with a specific problem to consult the computer system as it would an expert advisor to diagnose the causes of a problem or to give a recommendation/solution to the problem. Furthermore, the user can extract detailed information from the computer system by asking appropriate questions, including explanations about the reasoning steps to reach conclusions.

6.5.5 Knowledge-based decision suport system (KB-DSS)

Klein and Methlie (1995) defined KB-DSS as computer information system that provides information and methodological knowledge by means of analytical decision models and access to data and knowledge-bases to support a decision-maker to tackle poorly-structured, complex decision problems effectively.

KB-DSS form a new framework resulting from the combination of knowledge-based systems, which incorporate domain knowledge, and decision support systems. The need for a KB-DSS stems from the fact that a system capable of processing data and numeric relationships, on the one hand, and transforming these computations, through reasoning, into judgement, opinions, evaluations and advice, on the other hand, would increase the quality of data processing and thus provide better support to decision-making, (Klein and Methlie, 1995). A KB-DSS comprises three models namely knowledge model, database model and analytical model.

- Knowledge, databases and analytical models

The importance of databases and analytical models in addition to knowledge in KBSs need to be thoroughly examined before they are incorporated into the systems. With regard to databases the following considerations need to be made: maintenance; performance; and data sharing. A database can be used to externalise some portions of the knowledge base that changes frequently. In general, separating data from knowledge makes the knowledge-base easier to modify, because it is easier to read and the system's rules become clearer due to the absence of declarative data.

Sometimes a knowledge-base can become filled with tabulated data which can hinder its good performance in terms of speed and memory. A database management system (DBMS) can handle better such type of data than a knowledge-base. Sometimes databases can be implemented with the objective of data sharing with other applications. Model bases of KBSs include financial, statistical, management science or other quantitative models that provide the system's analytical capabilities and the appropriate software management. It is managed by a model base management system (MBMS). The models in the model-base can be sub-divided into strategic, tactical and operational categories.

6.5.6 Knowledge engineer and knowledge engineering

Conventional software developers are called software engineers. The problems of conventional software are generally well defined when compared to those of knowledge based systems. The term knowledge engineer is used to designate knowledge-based systems developers, and the process of development of KBSs is known as knowledge engineering. Apart from programming language knowledge, the knowledge engineer must possess additional skills such as good communication ability, patience, empathy, persistence, domain knowledge and cognitive methods and techniques.

Knowledge engineering can be defined as the acquisition of the knowledge in some domain from one or more non-electronic sources, and its conversion into a form that can be utilised by a computer to solve problems that, typically, can be solved by persons extensively knowledgeable in that domain, (Gonzalez and Dankel, 1993). . Knowledge engineering goes beyond knowledge elicitation and its transference to machines. It involves selecting, categorising and determining the representation form of the relevant knowledge. Collection of irrelevant or incorrect knowledge and poor representation can seriously risk the power and quality of a KBS, (Graham and Jones, 1988).

6.6 Components of a KBS

A KBS has the following main components: knowledge-base, inference engine, working memory and user interface. Figure 6.1 presents the main components of a typical KBS.

6.6.1 Knowledge base

A knowledge base is the central part of a KBS that contains the domain knowledge and problem solving knowledge in the form of factual rules and heuristic rules. This knowledge is derived from heuristics, including judgement, experience and intuition from

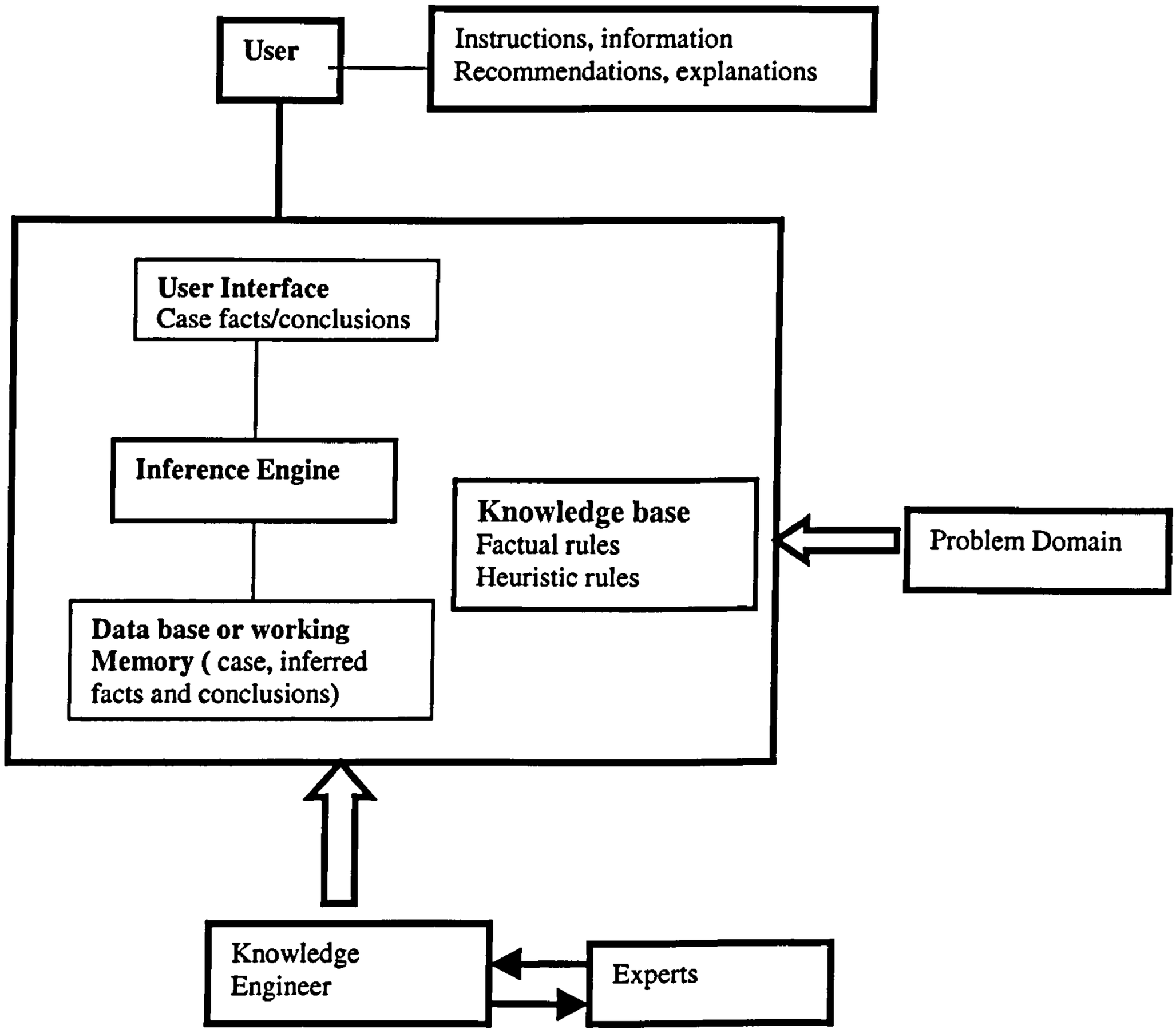

Figure 6.1: Knowledge-based system components

domain experts. The knowledge contained in the knowledge base has two main characteristics: format and nature. The format of the knowledge refers to its representation in the knowledge base.

Several representation formats are available and they include rules, predicates, frames, associative networks and objects. The several forms of knowledge representation will be discussed later in this chapter. The nature of knowledge determines whether it is heuristic or algorithmic. In practice, though, most applications of KBSs are in poorly-defined problem domains where classical algorithms are either ineffective or inexistant at all.

6.6.2 Inference engine

The inference engine is basically software designed to control the reasoning operations of the KBS. Its main function is to manipulate and examine domain knowledge encoded in the knowledge base together with the input information from the user about the current problem and databases. In the light of these information, it derives additional data and conclusions. Therefore, the inference engine can be considered a general purpose thinking machine or interpreter of the knowledge contained in the knowledge base.

The inference engine is activated when the user starts the consultation session with the KBS. Then, the engine decides on which rules to execute and in which order, that is, during the consultation, the inference engine examines the rules of the knowledge base, one at a time and when a condition is true the specified action is taken. In KBS terminology when the action is taken the rule is said to have "fired". Most engines perform this task based on "modus ponens", concept explained later in this chapter. Based on this interpretation of knowledge and data, the inference engine is capable of making assertions, hypothesis and deriving conclusions and recommendations. According to Forsyth (1984), there is a close relationship between the inference engine and knowledge base. The following sections discuss some important concepts associated with the inference engine.

a) Reasoning

It has been seen that the inference engine attempts to find connections between facts and knowledge and the solutions or recommendations. These connections are established through reasoning that is the process of working with knowledge and facts, as well as problem solving strategies so as to draw conclusions. The reasoning process is seen as an activity aimed at drawing conclusions based upon facts gathered through research methods. For example, scientific method is basically a reasoning process which takes

two main forms namely deductive and inductive reasoning. Another, yet less "scientific", form of reasoning also used is plausible reasoning. The choice of reasoning technique to incorporate in a KBS depends on the specific problem under consideration.

b) Hypothetical-deductive reasoning

Formal logic has several rules that are used to draw conclusions from a set of premises. Deductive reasoning starts from general, established principles or laws and assesses a specific fact or case that seems to fit the principle or law. Therefore, the reasoning starts from the general to the particular (or from cause to effect). Deductive reasoning enables people to infer new facts from what is already known. Humans often use deductive reasoning to deduce new information from logically related known information.

Most KBSs are built on "modus ponens" reasoning technique which is one of the basic rules of deductive reasoning. "**Modus ponens**" takes the form: if C is true and (C→ D) is true, then D is true. Another rule of inference is "**modus tollens**" and it states that if the implication (C→ D) is true, and B is false, then A is false, where C=A+B.

c) Inductive reasoning

It consists of evaluating and analysing some individual situations so as to develop generalised conclusions. Humans use inductive reasoning to arrive at a general conclusion from a limited set of facts by the process of generalisation. Therefore, it is considered the transition from a few to all or the process of learning by experience.

d) Plausible reasoning

Abduction has to do with plausible explanations or conclusions from a set of available information. However, more often than not, plausible explanations are not true, that is, abduction allows false conclusions. In abduction the conclusion drawn from a set of premises may not be true, even if the premises are true. Abduction is a probational

adoption of an hypothesis and can be thought of as a special case of "modus tollens", (Ribeiro et al 1995).

Despite these shortcomings it should be recognised that abduction is widely used in reasoning. Typical human problem solving involves generating plausible solutions that are verified later. For example, if the contractor uses first grade materials, then the quality of the building will be good. The conclusion seems to be plausible but it is not completely true, since the quality of the final product depends on other factors, such as workmanship.

e) Inference

Inference is the process used in KBSs, through inference engine, of deriving new information from available information. In this sense, KBSs attempt to emulate the reasoning process of humans.

f) Inference mechanisms

An inference mechanism is the process by which the inference engine examines and apply rules contained in the knowledge base. The mechanism begins with a set of data and after an examination it moves towards a solution or recommendation. There are several forms of computer-based reasoning mechanisms, namely generate-and-test-systems, goal reduction paradigm, means-ends analysis, back-tracking and rule-based or production systems. However, the most common reasoning mechanisms in KBSs are forward- chaining and back-ward chaining.

g) Forward-chaining

Forward-chaining, also known as antecedent reasoning, forward reasoning or data-driven control, implies that the program has no a-priori knowledge of the possible solutions. The starting point is the data collected through observation that is used to reach a conclusion. Rules are scanned one after another in a certain order until one is found

whose antecedents match the information for the problem entered into the working memory. Subsequently, the rule is applied and the working memory is updated. The process is repeated until the goal state is achieved or no usable rule is found. The order in which rules are examined may be the sequence in which the rules were entered into a rule set or other sequence specified by the user.

When a condition is true, the rule is fired and the following rule is examined. When the rule is false, the rule is not fired and the next rule is examined. In some circumstances a rule can not be said either true or false because the condition part of it has one or more variables with unknown variables. In this case, the rule condition is considered unknown and the rule is not fired and the reasoning process continues with the examination of the following rule. The basic steps in forward-chaining can be summarised as follows, Davis (1983):

- matching – the rules are compared to the known facts to decide which rules are satisfied, that is, if all situations premises of the rule have been found true;
- conflict resolution – often the matching stage can find several rules that are satisfied. The conflict is solved by selecting the rule with the highest priority from the set of all rules; and
- execution – the final step is the execution or firing of the rule. Two possibilities can arise in the firing process stage: new facts can be derived and added to the existing facts; and a new rule or rules can be added to the set of rules.

g) Backward-chaining

In backward-chaining, also known as consequent reasoning, backward reasoning or goal-driven strategy, the system has a built-in method for making an initial hypothesis as to what a solution is. Backward-chaining starts with the desired conclusion and decides if the existing facts support the derivation of a value for this conclusion. In other words, the inference engine selects a rule and considers it as a problem to be solved. The rules are scanned, and those whose consequent actions can lead to a goal are found. For each of

these rules, a check is made to find whether its antecedents match the information in the working memory. If they all match, the rule is applied and the problem is solved. If there exists an unmatched antecedent a new subgoal is defined. The process is applied recursively.

h) Forward versus backward chaining

Backward-chaining or reasoning is faster than forward chaining since it does not have to examine all of the rules and does not make multiple scanning through the rule set. Generally, backward-chaining is suitable in the following circumstances: there are multiple goal variables; there are many rules; and there is no need to examine all or almost rules to reach a solution. Forward-chaining works well when the problem naturally begins by gathering information and then seeing what can be inferred from it. The major disadvantage of forward-chaining is that it may not be able to recognise that some evidence might be more important than others. Some inference engines are capable of performing both backward and forward chaining and the choice of one or another depends on the user.

6.6.3 Working memory

The working memory is the part of KBS that keeps track of the problem domain by storing data such as user's answers to questions, facts obtained from external sources, intermediate results of reasoning process and conclusions arrived at, (Barret and Berrel, 1988). The system matches this information with knowledge in the knowledge base to infer new facts. These new facts are added to the working memory and the matching process proceeds. In addition, the working memory can receive information from external databases, spreadsheets and other external sources to be used during a working session. This information can be accessed either at the beginning of the session or at any appropriate time during the session. Working memory is a working space that is wiped clean after each session.

6.6.4 User interface

It is the communication channel between the user and the knowledge-based system. Its main objective is to guide and control the dialogue between the user and the system so that the information, facts, explanations and conclusions can be exchanged. It enables the user to enter instructions and information into the KBS and receive information from it. The instructions specify the parameters that guide the KBS through its reasoning process. The information, on the other hand, are values assigned to certain variables. In principle, the user can use four methods of input namely menus, commands, natural language and customised interfaces. The outputs from a KBS can be either solutions/recommendations and explanations. Explanations can be provided upon request by the user during the reasoning process or after the reasoning process. In the latter case, the KBS explains how it has arrived at a solution by displaying each of the reasoning steps leading to the solution.

6.7 Differences between conventional programs and KBSs

Knowledge-based systems have specific characteristics that distinguish them from the conventional algorithmic programs. These features are the following, (Avelino and Dankel, 1993):

- the separation of the knowledge from how it is used;
- the use of highly specific domain knowledge; and
- the heuristic rather than algorithmic nature of the knowledge employed.

Adeli, (1988) outlined the following characteristics of KBSs:

- KBSs are knowledge-intensive programs;

- KBSs use heuristics in a specific domain of knowledge in order to improve the efficiency of search;
- in a KBS knowledge is usually divided into many separate independent rules or entities;
- KBS are usually highly interactive;
- the output of a KBS can be qualitative rather quantitative; and
- KBSs tend to mimic the decision-making and reasoning process of human experts. They can provide advice, answer questions and justify their conlcusions.

According to Graham (1988), conventional programs differ from KBSs in that the former have richer data structures and permit higher levels of user interface. The latter, on the other hand, possess richer knowledge structures and are more intelligent systems. These characteristics are summarised as:

Expertise = inference + knowledge

Program = algorithm + data structure

Table 6.1: Comparison of conventional programs and KBSs

Conventional programs	KBSs
Numeric	Symbolic
Algorithmic	Heuristic
Information and control integrated	Knowledge separate from control
Difficult to modify	Easy to modify
Precise information	Uncertain information
Command interface	Natural dialogue
Final result provided	Recommendation with explanation
Optimal solution	Acceptable solution

6.8 Development of KBSs

The development of KBSs is an iterative process. It comprises several stages that may require several modifications and testing before a KBS is effectivelly implemented. These stages can be summarised as follows:

- initial specification;
- knowledge acquisition;
- knowledge analysis and representation;
- implementation; and
- validation, verification and maintenance

6.8.1 Initial specification

Initial specification is a general outline of the system parameters and delimitation that will guide the knowledge engineer in the process of knowledge acquisition and modelling. The specification should provide a clear delineation of the problem under study, as well as to explain how it will be solved including the inputs and outputs. It should also, ideally, include all the most relevant requirements such as the development tools, the inference mechanisms, knowledge representation, verification, validation and the hardware systems.

6.8.2 Knowledge acquisition

Knowledge acquisition or elicitation is the process of eliciting, analysing and interpreting the knowledge that a human expert uses in problem solving. Knowledge acquisition has been considered on of the most difficult step in the development of KBSs since the experts are not very efficient in explaining the way they reach conclusions and make decisions. Most authors consider knowledge acquisition a bottleneck of KBSs. The process can be time consuming and costly as it needs effective planning and design. The

knowledge engineer is very often faced with the unavailability of adequate development tools and must develop alternative ones.

Knowledge acquisition techniques can be classified into strategic and tactical. Strategic dimension is concerned with the way the knowledge acquisition process is conducted and includes knowledge engineer-driven, expert-driven and machine-driven. The tactical dimension is focused on the techniques that are used within each strategic category. These techniques include interviews, protocol analysis, visual modelling, and repertory grid method. Knowledge engineer-driven technique is the commonest approach and it involves direct interaction between the knowledge engineer with the expert. The most commonly used knowledge acquisition techniques in this category are the following: informal interviewing; protocol analysis; observation; questionnaires; introspection; simulated consultations; and prototyping.

In expert-driven knowledge acquisition, the expert encodes his expertise and enters the knowledge into the computer. Machine-driven approaches of knowledge acquisition are associated with machine learning. Learning by examples based on inductive reasoning is the main technique in machine learning. Basically, learning by examples refers to presentation to a machine of cases or examples with solutions that are used in a computerised algorithm to infer rules. The knowledge engineer-driven techniques are the most common techniques and therefore they are given much attention in this study.

a) Informal and formal interviews

Informal interviews are the most easy technique for knowledge elicitation since it provides a very relaxed environment and does not require through preparation. Knowledge engineer elicit concepts, facts and general rules. However, they have the disadvantage of being unstructured and incomplete. These factors often lead to a lengthy and time-consuming process of elicitation, as well as lack of detail. Usually, informal interviews are complemented by more structured formal interviews where the knowledge engineer sets specific objectives and controls the direction of the interview. Strategies of

interviewing technique are now very well developed and, thus, there are sound guidelines on how to perform questioning.

b) Verbal protocols

Verbal protocols are transcriptions of sessions in which the knowledge engineer asks an expert what he is doing and why is he doing it. They are used to obtain information about the cognitive processes of a subject dealing with a problem. All verbalisations are tape recorded, transcribed into protocols and then analysed for potential relationships.

There are several techniques for obtaining protocols namely introspective, retrospective, interpretative and concurrent verbalisation, (Klein, 1995). The technique is appropriate in situations where there are already selected cases. It is a very difficult technique since transcripts can be highly ambiguous and thus requiring much effort in interpretation and analysis. In addition, it does not provide the required assistance to the knowledge engineer in acquiring deep knowledge. Verbal protocols are extremely time-consuming and very often they can interfere with task performance, (Slatter,1987).

c) Observation

Observational strategy is used in specific circumstances and its importance lies in that it provides useful information on the order in which tasks are carried out, the roles played by experts and the constraints posed by the environment. It allows removing, to a great extent, barriers of biases or preconceived ideas and provides the actual picture of the activities. Observational technique involves tape-recording and often video-recording. The major drawbacks of observation are difficult transcriptions, lengthy elicitation and time consuming.

d) Simulated consultation

Simulated consultation involves a consultation between an user and an expert which pretends to be the machine or, conversely, asking the expert to set problems for the team members who act the part of the expert under supervision, (Graham and Jones, 1988). A similar simulation technique consists in administering an artificial test case to the expert and then monitoring his/her responses.

e) Repertory grid technique

Repertory grid is a technique taken from cognitive psychology and was developed by Kelly, (1955). The technique provides a means to produce a person's mental map on specific topic or domain. According to Kelly, each individual is a scientist with his own model of the world. Based on this perspective, Kelly developed the Theory of Personal Construct. The model of the world is made up of individual personal constructs.

A personal model consists of elements and constructs. Elements are the objects of the domain such as cases, examples that an expert will select. Examples of elements are inflation risk, need for job risk and cost overrun rate. A construct is a bipolar characteristic that serve the purpose of qualifying the elements. Considering the examples of elements given previously the corresponding consutructs can be the expressions high – low, very high – very low and very significant – insignificant.
Generally, a numeric scale is assigned to each construct for measurement purposes. There are several methods of eliciting elements and constructs that are then rated by the experts forming a repertory grid. This grid represents the expert's view of the domain. Repertory grid technique was explained in detail in Chapter 2.

6.8.3 Knowledge analysis

Knowledge analysis is carried out to find the most effective and approriate knowledge representation form. The knowledge is broken down into the components and the relationships among the parties, type of data , type of knowledge are examined. The analysis determines which representation to select among rules, semantics, frames, networks etc. In a production system, the analysis consists of identifying the goals, sub-goals, preliminary questions in order to design rules. In such systems knowledge analysis can be summarised as follows, (Allwood, 1989):

- determine the goals, sub-goals and preliminary questions. Goals are final recommendations or solutions from the KBS, whereas sub-goals are the intermediate conclusions or consequents. Very often, sub-goals serve as antecedents for the following rules;
- organise preliminary elements to form the objects and rules. This step must take into account the clarity and simplicity of the knowledge base; and
- iterative process of refinement involving experts in demonstrations and discussions of the knowledge base.

6.8.4 Knowledge representation

Knowledge representation is concerned with how knowledge is organised and represented in the knowledge base. There are several forms of knowledge representation in the knowledge base. The form of representation should take into account the way the knowledge is used in practice. Knowledge representation can be procedural and declarative. Procedural representation is commonly used in traditional algorithmic programming and has the advantage of being very efficient. This knowledge is context-dependent and embedded in the code. Declarative representation encodes knowledge as data and is therefore more understandable, easier to modify, semantically transparent and context independent. These are the major advantages of declarative representation and

are an essential characteristic for KBSs. Declarative knowledge representation includes several approaches namely semantic networks, logic, frames, rule-based or production rules and hybrid approach, (Hayes–Roth et al., 1983).

a) Semantic networks

Semantic networks consist of a collection of nodes for representation of concepts, objects, events and links for connecting the nodes and characterising their relationships. They are graphical representation of the concepts and relationships in a particular domain. The links are referred to as arcs and have an arrow to indicate the direction of the relationships. The knowledge engineer benefits much from semantic networks since they provide a structural representation of a complex set of relationships. The advantages of this representation lies in its flexibility, which means new nodes and links or arcs may be added, deleted or modified whenever needed, the power in representing relationships between objects and the inheritance facilities, which enables assertions to be made about relationship between two objects. The major disadvantage of the semantic networks is the impossibility of representing procedural knowledge without combining it with other methods.

b) Frames

Frames are used to represent both procedural and declarative knowledge. They are suitable for representing more complex and richer knowledge. Basically, a frame for a domain concept or object consists of a number of attributes, called slots, and the associated values in which different characteristics and features of an object or a chunk of information are described. They may contain default values, pointers or frames and procedures. The procedures consist of a set of instructions for determining the value of a slot. Typically, a KBS can be formed by a collection of frames that are linked together. These frames form a hierarchy with potential use for reasoning. A frame can be compared to a record in a database where a slot is the record's field.

c) Production rules

Production rules are the most popular technique of knowledge representation in KBSs They are used to represent relationships in terms of conditional relationships. KBSs that use production rules are called rule-based KBSs. The term production has its origin from cognitive psychology where it was used to describe the relationship between situations and actions. A rule takes the following form: If-Then.

Example:

Rule 1: IF A THEN B

Where A is the condition, premise, left-hand-side or the antecedent, B is the conclusion right-hand-side or the consequent. The rule 1 reads "if the condition is true THEN either the action should be taken or a conclusion has been reached". In other words, whenever the condition of the rule is true or satisfied then the consequent of the rule is said to have fired. A rule such as presented above represents an independent chunk of domain knowledge in the knowledge-based system.

The inference engine determines how the sets of rules are evaluated, then it compares the antecedents with the contents of the working memory or facts and executes the rule whose antecedents match the facts. Each rule has its associated number which serve identification purposes. Rule 1 is the simplest form of a rule and comprises one antecedent and one consequent, with these propositions linked by AND. In practice, both the antecedent and the consequent can be formed by several elements linked by other connectives such as OR and NOT. For example:

Rule 2: IF A And B Then C and D;

Rule 3: IF A And B Or C Then D.

The advantages of rule-based systems are: rules are easy to understand; modularity in design, which enables addition, deletion and change of rules independently; rules can represent procedural and declarative knowledge; small rule-based systems can be developed quickly; the simple representation in IF-THEN form facilitates the formulation of questions. Additionaly, production systems are suitable for parallel computations since the chunks of knowledge can be executed independently.

6.8.5 Implementation

In the implementation stage the knowledge engineer uses representation specifications to implement the knowledge base. The knowledge engineer examines the initial specifications to design the adequate interface, as well.

6.8.6 Validation, verification and maintenance

Verification and validation is a step aimed to ensure the consistency, completeness and validadity of a KBS, as well as to check for potential software bugs. This step is very difficult and little progress has been achieved so far. Maintenance involves the continuous update of knowledge in order to respond to changing environment and thus avoid the obsolescence of the system. In principle, the pace of change in domain knowledge is so slow to pose serious problems to maintenance.

6.9 Knowledge-based systems development tools

Development of KBSs is much more demanding than designing conventional software applications. As such, since the earlier stages of AI and KBSs, in particular, there has been much concern over the availability of tools to aid building KBSs. Work undertaken in the area has enabled the development of both software and hardware products to

support, accelerate and facilitate KBSs development. A general classification of software levels, as suggested by Adeli, (1988) is as follows:

- operating Systems (MS DOS, UNIX);
- high-level languages (Basic, Fortran, Pascal, Lisp, C, Prolog);
- application programs (Word, Excel, PowerPoint, Access);
- machine language;
- programming environments (OPS 5, Interlisp); and
- programming tools (spreadsheets, database management systems, shells).

Within these levels there are three major categories of knowledge-based systems development software, namely general purpose AI programming languages, KBSs environments and KBSs shells.

6.9.1 Programming languages

Artificial intelligence programming languages are different from conventional procedural programming languages such as BASIC, PASCAL, COBOL and FORTRAN. Procedural languages have instructions or commands in imperative form which are written in determined sequence. AI programming languages are declarative languages and the information is organised in a descriptive form and imitates well human thinking. PROLOG, developed by Alain Comerauer at the University of Marseilles in 1972, is an acronym for programming in logic and it is based on formal logic and a simplified version of the first order predicate calculus.

PROLOG is considered versatile for database systems but less suitable for KBSs due the large memory requirements, limitation in numeric data types and slow execution. More details on PROLOG are given in (Allwood, 1985). LISP is an acronym for list processing and was developed in 1959 by John McCarthy for non-numeric applications. It is regarded as a very powerful tool for symbolic expressions manipulation. Further developments on LISP can be found in (Adeli and Paek, 1986). PROLOG has been the

favourite programming language in Europe and Japan, whereas LISP is widely used in North America.

6.9.2 Environments

The environments incorporate several forms of knowledge representation. For this reason, environments are also called toolkits or hybrid tools. Environments use technologies of object-oriented programming (OOP).
The most known KBSs environments are KEE, KnowledgeCraft, ART, INTERLISP. OPS5 and OPS83. KEE stands for knowledge engineering environment and was developed by Intellicorp in the USA. KEE is a very powerful development tool and it provides a large number of facilities such as several reasoning strategies, several knowledge representation forms and graphical interfaces for users.

KnowledgeCraft provides several tools for knowledge representation, reasoning and interface, as well, (Morris and Read, 1989). INTERLISP is an advanced version of LISP. OPS5 stands for official production system, version 5 and is a LISP-based KBS programming environment, as well. It is a production system tool consisting of collection of production rules, working memory elements and data structure and an inference engine and a rule interpreter that matches the left-hand sides of the rules to the working memory elements. OPS83 is an advanced version of OPS5.

6.9.3 Object-oriented programming (OOP)

In recent years, the field of AI and KBS in particular has witnessed the emergence and growth in use of object-oriented languages. In this approach the problem domain (real world objects) can be modelled as a set of objects and relationships. In practice, this is an attempt to break-down complex problems into simpler components. As a result, the software obtained is much maintainable, adaptable and recyclable, (Hogoog, 1993).

Object-oriented is a mean of focusing upon objects and organise all the domain knowledge around objects and classes of objects. An object is described in terms of its appearance and behaviour, that is, its name, a set of descriptive attributes and some procedures that allow it to behave. An object can be defined as an independent procedure that contains both the instructions and data to perform some task and the code necessary to handle the various messages that it may receive. It can be a physical object, a concept or a procedure. An object has two main features: information that describes the object; and the information that specifies what an object can do. An example of an object is a dialog box in Word or Excel applications.

On screen a dialog box is physically distinct from any other object within specified boundaries and can be handled independently of any other object. There are many languages that provide object-orientation approach but the most common are C++, Smaltalk and CLOP (Common Lisp Object System). C++ and CLOP are extensions of C and LISP, whereas Smaltalk is a programming language on its own.
The main distinguishing characteristic of OOP from procedural languages is the encapsulation. An object is an independent program segment that in a sense has a life of its own separate from other objects in the program. Procedures, on the other hand, are mere set of instructions, possibly with their own local data, that have been created for convenience.

6.9.4 Shells

Developing a KBS from scratch is very costly and an extremely demanding exercise. An alternative to programming languages in the development of KBS is the use of shells. According to Edwards (1991) shells account for 56 per cent of KBSs development software. A shell is basically a KBS without a knowledge base. A shell provides the knowledge engineer with the following: an inference engine; user interface; database facilities for building knowledge base – editor; display and browsing facilities; and rule validator and debuging.

Shells have been the more preferred development tools than programming languages because the latter present some disadvantages. Shells are easier to use, enable quick implementation, most use production rules, have different inference mechanisms to cater for different requirements. Despite these advantages they are less flexible compared to programming languages. There are several shells available both in the market in academia, but most commercial shells are very expensive with prices ranging from hundreds to tens of thousands USD. Therefore, they are not usually affordable and economically viable for individual use. According to Adeli (1988), the selection of a shell for engineering applications is not straightforward. Many factors must be considered for analysis and evaluation. The most important factors are the following:

- type of application;
- type of machine;
- maximum number of rules allowed (rule-based systems);
- response time;
- type of control strategy and inference mechanism;
- user interface (graphics, natural language processing);
- availability of complex mathematical routines;
- the ability to interface with other programs written in the language of the shell or foreign languages;
- programming aids (editors, debuggers)
- portability;
- user support; and
- approximate cost

6.10 Advantages and disadvantages of KBSs

When compared to the conventional algorithmic software, knowledge-based systems have a number of advantages and disadvantages. The most important feature, however, is

the capability of tackling problems that can not be solved by conventional programs. The main advantages associated with KBSs are the following:

- wide distribution of scarce expertise;
- easy of modification;
- consistency of answers;
- perpetual accessibility;
- preservation of expertise;
- solution of problems with incomplete data; and
- explanation of solutions.

As mentioned previously, knowledge-based systems have some shortcomings. Among others, these shortcomings include:

- answers may not be correct;
- knowledge is limited to domain of expertise; and
- lack of common sense.

6.11 Types of KBSs

KBSs can be applied in a wide variety of fields. The field of application determines, to a great extent, the expected task to be performed by the KBS. According to tasks, KBSs can generally be grouped into (Durkin, 1994):

- diagnosis - infer malfunctions or faults from observable information;
- selection - identify the best possible choice from a list of several alternatives;
- advisory - provide recommendations under a set of specific circumstances;
- interpretation of data – infer situations from data;
- monitoring – compare observations and planned actions;

- control – govern the behaviour of a system;
- design – configure objects under a set of pre-requisites and constraints;
- instruction - diagnose, debug and repair systems;
- prescription – recommend what to do in given situations;
- planning – design courses of action to achieve certain goals; and
- prediction – infer likely consequences from given actions/sates.

In statistical terms diagnosis KBSs are the most used systems, representing 30 per cent of the total. In the second position lie interpretation systems, totalling 20 per cent and in the third place, perscription systems with 20 per cent of the total.

6.12 Uncertainty

The most critical obstacle to effective decision-making is uncertainty due mainly to the scarcity or lack of data and information. Future events are always fraught with uncertainty. No amount of sophystication, effort, study can eliminate uncertainty. It is inherent to all business and construction projects are no exception. Decision-making models aim to reduce uncertainty and improve the quality of decisions.

6.12.1 Uncertainty and risk management in construction

Construction risk management is mainly based upon experience, assumptions and human judgement. Risk management is therefore mainly cognitive in nature. Kahnemnan and Tversky (1982) and Spetzeler and Holstein (1975) uncovered important aspects of cognitive and non-cognitive types of uncertainty. Klir and Folger (1988) discussed two types of uncertainty namely ambiguity and vagueness.

a) Ambiguity

Ambiguity is generally due to a non-cognitive root causes. Ambiguity is a state in which an expression or word may have a number of distinct meanings and only the context may help clarifying the real meaning. For example, the expression "hot food" may either mean warm or spicy food. Evidence Theory proved to be the most suitable mathematical framework to handle ambiguity type of uncertainty.

b) Vagueness

Vagueness type of uncertainty is due to cognitive sources. Vagueness arises when the meaning of a statement or word is poorly-defined, that is, it lacks precision or sharpness. For example, the global risk factor "strong competition" does not have an exact meaning, because the qualifier strong may assume several degrees of intensity. Strong competition may involve a wide spectrum of human perceptions. Therefore, there is no rigorous definition of what "strong competition"" is.

A particular type of vagueness is fuzziness. Fuzziness is a kind of imprecision where the transition from a membership state to a non-membership of an element to a set is gradual. Fuzziness is a general characteristic in many areas such as management, engineering, manufacturing, and medicine. It is, nevertheless, most frequent in situations where human judgement is an essential feature such as reasoning, learning and decision-making process, (Zimmermann, 1991).

c) Randomness

A process is random when the outcomes of an event are rigorously a matter of chance, that is, it is impossible to predict the outcomes. For example, casting a die has several possible outcomes each with known probability (perfect die) or with unknown probability (defective die).

6.12.2 Handling uncertainty in KBSs

The knowledge contained in the knowledge base of a KBS comprises facts and heuristics. The theory of human problem solving recognises that people apply very few general formal principles and they violate normative principles. Therefore, most of the knowledge base derived through knowledge acquisition from experts and other sources is imprecise, unreliable and incomplete. Thus, heuristics do not guarantee precise and accurate results as those produced by conventional algorithms such as those incorporated in DSSs.

Despite this apparent shortcoming, they still provide good and very useful results most of time in certain knowledge domains that can not be tackled by conventional rational approaches. Therefore, rules and conditions of a KBS may contain, to some degree or another, uncertainty. Consequently, the reasoning process carried out by the inference engine on the knowledge base will contain uncertainty, as well. That is, the reasoning is performed with uncertain information – **inexact reasoning or approximate reasoning.** In the light of this fact, there is a need to take into account the uncertainty intrinsic to knowledge in the knowledge base. Three main issues related to uncertainty need to be properly addressed in the design of KBSs, namely how to represent uncertain knowledge, how to combine two or more pieces of uncertain knowledge, and how to draw inference using uncertain knowledge.

6.13 Nature of uncertainty and its management

Since the various types of uncertainty are different in source and nature, there is a need for a proper definition of it at the outset, so as to take the most appropriate approach. Some methods and techniques may be suitable in handling certain types of uncertainty but not effective for different types. For example, uncertainty inherent to the states of nature or general environment of a business venture is different in nature from that associated with the internal factors.

Uncertainty has many different sources, (Frost, 1986), and different types, (Krause and Clark, 1993; and Ross, 1995). The main types of uncertainty include error, imprecision, variability, randomness, ignorance, chance, vagueness, ambiguity and ignorance. The diversity in terms of the types of uncertainty makes the modelling process very difficult because the information concerning each specific uncertainty is very scarce. Several formal techniques for managing the different types of uncertainty have been developed, but there has not been any consensus on both the nature/meaning of uncertainty, (Adeli, 1988), and the suitability of such techniques. It seems that there is no best theory of uncertainty and therefore the choice of the most appropriate technique depends upon the specific problem, (Saffioti et al, 1994). Four main approaches have been used for handling uncertainty, namely probability theory, certainty factor theory, Dempster-Shafer theory and Fuzzy set theory.

6.13.1 Probability theory

Probability theory originated in the seventeenth century in gambling environment. Gamblers used the concept to assess their chance of winning and consenquently the risk associated with their bid. Probability theory has been used to model precisely described, repetitive experiments with observable but uncertain outcomes. The basic assumption in the classical theory of probability is that all types of uncertainty are frequentistic measures of randomness or subjective measures of confidence. In fact probability is usually defined as follows: "if a random experiment has **N** possible outcomes which are all equally likely and mutually exclusive, and **n** of these possibilities have outcome **A**, then the probability of outcome A is n/N". The basics of probability theory is thus the elicitation of probabilities, which may either objective or subjective, in order to predict the likelihood of uncertain events. Objective probabilities are those directly derived through experiments or statistical data. They apply to repeatable events only. Subjective probabilities, on the other hand, represent degrees of belief of the decision-makers.

Individuals with different backgounds are entlited to assess the likelihood of the same events differently.

The heavy reliance on the probability theory as the only effective and reliable methodology to deal with uncertainty has historical roots. Probability theory has well-established and sound scientific foundations and has been widely used for centuries in both social and hard sciences.

Bayes's theorem provides the possibility of deriving prior probabilities of an event, which can be used to interpret the present situation. It is very useful in situations where there is a great deal of prior statistical data since it enables the calculation of the likelihood of some hypothesis being true, given some evidence about the problem. Probabilists argue that random methods are the only effective methods for dealing with uncertainty. For example, as stated by Howard (1980), the structure of decision analysis builds upon the formal tools of decision theory, probability theory and mathematical modelling.
Deterministic approaches are commonplace in "hard" sciences and the pursuit for precision in such areas is more favoured than qualitative models.

The conditional probability P(A/B) enables the calculation of the probability of an event A given that the event B has occurred. In many occasions there is need to determine the probability of an earlier event given that some later on has occurred (a posteriori probability). Conditional probability is forward in time, whereas a posteriori probability is backward in time. Conditional probability can be illustrated as follows:

$$P(H\backslash E) = P(H) \times P(E\backslash H) : P(E); \qquad \textbf{(Equation 6.1)}$$

where

P(H\E) = probability that H is true given evidence E;

P(H) = probability that H is true;

P(E\H) = probability of observing evidence E when E is true; and

P(E) = probability of E

Rule 1: IF x is A THEN y is B

Bayes's theorem, Equation 6.1, is used to determine the probability of the hypothesis B given the evidence A. That is, if the premise is true then the consequent can be concluded with probability p.

It should noticed, however, that the Bayesian approach has some severe shortcomings. The most important is that probability theory considers all uncertainty random. However, not all types of uncertainty are random. A great deal of management issues in construction does not comply with randomness properties. They are mainly cognitive and thus do not lend themselves to precise measurement.

Several authors mentioned some serious drawbacks related to the Bayesian statistics. Cohen (1985) and Kahnman and Tversky (1987) suggested that the assumptions associated with Bayesian function namely, mutual exclusivity of events, conditional independence and exhaustivity of events do not always hold. Uher and Toakley (1997) noted that the uncertainty inherent in real risk situations was epistemic rather than aleatoric (matter of chance).

The main drawbacks of probability theory can be summarised as follows:

- it is assumed that events are mutually exclusive, exhaustive and conditionally independent. In real life with complex decision problems these conditions can not be guaranteed. First, there have been strong interrelationships among several factors of a system. The level of competition, for example, can not be isolated from mark-up margins;

- a degree of belief is stated in numerical terms using single-point estimate. Therefore, such estimate may be precise but not accurate (Cohen, 1985). In addition, since global risk factors are poorly defined and fuzzy in nature they can not be evaluated with such high precision inherent to numerical expressions. In this regard, Zadeh

(1965) observed that probability is not capable of handling the pervasive fuzziness of information present in the knowledge base (which is a collection of rules and facts) and, as a result, it is mostly ad-hoc in nature;

- there is no distinction between randomness and other types of uncertainty. Thus, it is difficult or impossible to distinguish between a degree of believe derived from evidence and that derived from subjective assessment (Cohen, 1985). In fact, the main assumption behind probability modelling is that uncertainty is always random in nature. From this assumption it follows that when decision problems involve non-random uncertainty, they can not be properly modelled and analysed which result in the outcomes obtained from the analysis being unreliable;

- according to Kahneman and Tversky, experts do not use probabilities any better than non-experts. They are prone to judgement errors and biases, as well; and

- the assumption that if each premise is associated with a numerical certainty factor then the certainty factors of the consequent is a number which may be expressed as a function of the certanty factors of the premises is open to question, (Zadeh, 1983). However, it regains its validity if the certainty factors are expressed in fuzzy terms rather than crisp numbers.

Probability theory is full described by various authors, (Bunn, 1984; Cheseeman, 1965; and Cheseeman, 1985).

6.13.2 Certainty theory

Certainty theory is a theory for handling uncertainty in KBSs developed by (Shortliffe and Buchanan, 1975) in Mycin rule-based expert system designed to assist physicians in the antimicrobial treatment of patients with serious infections such as bacterimia and meningites. It was developed in attempt to overcome some of the weaknesses of the so called "idiot Bayes" approaches for inexact reasoning (Duda et al., 1979). Certainty

theory relies on defining judgemental measures of belief rather than adhering to strict probability estimates.

Therefore, certainty factors (CF) are not probabilities but informal measures of confidence for a piece of evidence. They represent the degree to which people believe that the given evidence is true. Shortliffe, (1979) mentioned the following problems with regard bayesian approch: medical problems often lacks the large quantities of data and the numerous assumptions required by the Baye's theorem. Physicians seem to use reasoning methods that work without requiring such historical information and these methods generally provide accurate results even though the results are based on limited data; and there is a need to represent medical knowledge and heuristics explicitly which can not be done when using probabilities.

Certainty theory fundamentals are the concepts of "certainty measures" which are associated with "factual statements". The certainty measures or factors CFs consist of numbers ranging from –1 to +1 and factual statements, (rules). A negative value of the certainty factor indicates that one believes that a fact is not true and a positive value indicates the one believes that a fact is true with complete knowledge.

CF = 1, there is complete certainty that a proposition is true

CF = -1, there is complete certainty that a proposition is false

CF = 0, there is no information at all about or no change in belief

-1 < CF < 1, measure of the degree of belief about the proposition with decreasing and increasing beliefs respectively.

The use of CFs in knowledge-based systems have the following format:

If A Then B with certainty factor **CF = CF(rule)**

Where A is the antecedent and B, the consequent. The antecedent comprises facts (evidence) that support the derivation of the consequent (hypothesis). The CF is the net degree of belief in hypothesis, given that the evidence is observed (given). The formal

representation of evidence for, against the hypothesis and the composite certainty factors, that is MB, MD and CF, is defined in terms of hypothesised mathematical relationships governed by prior and posterior probabilities of the propositions that they describe, (Clark, 1990).

In practical applications of certainty factors rules, hypothesis and input data have an associated MB and MD. Then, the composite certainty factor CF is calculated by aggregating the values of MB and MD. If the information contained in the premise is not known with certainty (CF < 1), then the level of belief in the conclusion is reduced. The original function used in the aggregation is as follows:

$$CF[h,e] = MB[H,E] - MD[H,E]; \qquad \textbf{Equation 6.2}$$

This original formula is very often modified for convenience and it becomes

$$CF[H,E] = (MB[H,E] - MD[H,E]) : \{1 - \min(MB[H,E], MD[H,E])\}.$$

Where CF[H,E] is the certainty factor of the hypothesis H given the evidence E, MB the degree of belief, MD the degree of disbelief in h given e. Both MB and MD values vary from 0 to 1. CF is also known as the composite certainty factors and varies between –1 and +1. The value of MB and MD are calculated as follows, (Shortliffe and Buchanan, 1975):

$$MB[H,E] = 1, \text{ if } P[H] = 1$$
$$MB[H,E] = \{P[H \mid E] - P[H]\} : \{1 - P[H]\}, \text{ if } P[H] \neq 1$$
$$MD[H,E] = 1, \text{ if } P[H] = 0$$
$$MD[H,E] = \{ P[H] - P[H \mid E]\} : P[H], \text{ if } P[H] \neq 1$$

where, P[H] is prior probability of an hypothesis H; P[H,E] is the posterior probability of the hypothesis given some evidence E.

In the case of a single premise rule the propagation of CF is calculated by multiplying the CF value of the premise with the CF of the rule. Propagation is related to the determination of the level of belief in a rule's conclusion when the available evidence contained in the rule's premise is uncertain. Then, the propagation formula is:

CF[H,E]=CF[E]*CF[rule] for a single premise rule;

CF[H, E_1 and E_2.....]= min {CF[E_i]*CF[rule]} for a conjunctive rule; and

CF[H, E_1 or E_2.....]= max {CF[E_i]*CF[rule]} for a disjunctive rule.

In most occasions two or more rules in a KBS may have the same hypothesis or conclusion. When this occurs, there is a need to combine each rule's certainty factor with those of the other rules that have the same conclusion in order to determine the single certainty factor for the conclusion in question.

The advantages of certainty theory approach are the ease of computation, the possibility of expressing measures of belief and disbelief in each hypothesis, the effect of multiple sources of evidence and the ease in eliciting the CF values. In most KBSs applications it produces good results as a technique for handling uncertainty. However, there have been criticisms of the theory.

Certainty factor theory is seen as an ad-hoc approach and therefore, lacking a formal foundation, (Blockely and Baldwin, 1987). Heckerman (1992), criticised the use of parallel combination function for assuming conditional independence and the negation of each hypothesis evidence. He considered the theory, worse than the "idiot bayes model" which assumes only one of these propositions. Additionally, Krause and Clark (1993) asserted that the theory does not suit rule-based models because of its non-modular operational requirements.

6.13.3 Dempster-Shafer Theory of Evidence

Dempster-Shafer, (Shafer, 1976) theory of evidence is usually called epistemic probability because it provides an alternative model for the assessment of numerical degrees of belief. The theory emerged in the 60s but it was not formalised until the 70s. It is a result of work by (Dempester, 1967; and Shafer, 1976). Dempster-Shafer attempts to distinguish between uncertainty and ignorance. Instead of probabilities, belief functions are used.

The main distinctions between bayesian models of numerical degrees and Dempster-Shafer model are the following: belief functions of Dempster-Shafer are set funtions rather than point values; rejection of the law of additivity for belief in disjoint propositions; and Dempster-Shafer theory has an operation for the pooling of evidence from various sources. Dempster-Shafer theory is richer in terms of semantics since it allows an expression of partial knowledge. I ts main shortcoming is the elicitation and interpretation of belief functions, (Krause and Clark, 1993). Furthermore, the computational methods employed in the theory are very complex and thus, of little practical use, (Frost 1986).

6.13.4 Fuzzy sets theory

Fuzzy set theory is a branch of modern mathematics that was formulated by Zadeh (1965) to model vagueness intrinsic to human cognitive processes. Since then, it has been used to tackle poorly-defined and complex problems due to incomplete and imprecise information that characterise the real-world systems. It is therefore suitable for uncertain or approximate reasoning that involves human intuitive thinking.

The theory of fuzzy sets seems to handle vagueness type of uncertainty better than any other approach. Vagueness is by far a distinct type of uncertainty to be treated by probabilistic methods. The mathematical framework for dealing with fuzziness is fuzzy set theory. Zadeh stated that a meaning in natural language is a matter of degree. The

answer to the question " is the profit margin high ?" is not always simply yes or no. It largely depends on the subject who is to respond.

Fuzzy set is a powerful technology for handling complex decision problems that involve a great deal of human perception and reasoning – humanistic systems. However, as stated by Zadeh, fuzzy logic is not intended to replace classical logic but rather to complement it in situations where conventional approaches fail to model problems effectively.
The basic fundamentals of fuzzy set theory are the concepts of linguistic variable and degree of membership. Since most construction decision problems are very complex and imprecise, they might be better described by linguistic expressions rather than by numbers. Numbers are associated with precision, whereas decision problems like managing risks need not or do not have specific outcomes but approximate ones.
Furthermore, due the imprecision inherent to linguistic expressions the transition from one state to another is smooth. For example, the transition from "very high cost performance" to "high cost performance" is not sharp, but gradual. Linguistic expressions play an important role in this regard because description is at the very core of risk management in construction. Finally, fuzzy sets have the ability to preserve the uncertainty inherent to the problems throughout the analysis instead of making assumptions.

There is a strong controversy around the fundamentals of probability theory and fuzzy set theory. Some probabilist scientists have argued that fuzzy sets theory is no more than a false appearance of probability theory. For most of the critics, fuzzy sets has no well established mathematical or empirical methods to model human judgement as stated by (Lootsma, 1997). The main sources of the criticisms are probably the fundamentals of fuzzy sets theory which are clearly in contradiction with the dominant scientific view of the world - precision. Detractors of fuzzy set theory argue that it is probability theory in disguise, (Cheseeman, 1983).

6.14 Summary

This chapter presented and discussed the core issues of knowledge-based systems. The different components of knowledge-based systems namely knowledge base, inference engine, working memory and user interface were presented. The reasoning process and the main features of reasoning strategies such as deduction, induction, forward-chaining and backward-chaining were highlighted.

The chapter also explained the development process of knowledge-based systems. Finally, the chapter discussed uncertainty inherent in knowledge-based systems and the several technologies commonly employed for its management. In this regard it was concluded that Fuzzy Set Theory has much more advantages over the reamining technologies namely probability theory, certainty factors and Dempster-Shafer theory of evidence.

Fuzzy Set theory handles well vagueness type of uncertainty which is the most common uncertainty found in construction projects and global risk factors in particular. It has been used to model vagueness intrinsic to human cognitive processes and to tackle poorly-structured problems involving intuition and judgement. It is an effective technique for uncertain or approximate reasoning that involve human intuitive thinking. Fuzzy set theory is explained in detail in the following chapter.

Chapter Seven

Fuzzy set theory

7.1 Introduction

The preceding chapter discussed knowledge-based systems and the different ways of managing uncertainty. The main technologies used to handle uncertainty are Bayes Theory, Certainty Factors, Dempster-Shafer Theory of Evidence and Fuzzy Logic. It was concluded that Fuzzy Logic handles better the uncertainty inherent in construction decision-making and global risk factors in particular. The purpose of this chapter is to address the main concepts of fuzzy set theory. First, the theoretical framework of fuzzy set theory is presented. The strengths and weaknesses of the theory as applied to management are outlined. Then, a discussion on practical application of the theory to the field of decision-making under uncertainty, and risk management context, in particular, are presented.

7.2 Fuzzy set theory

Fuzzy set theory is a branch of modern mathematics that was formulated by Zadeh (1965) to model vagueness intrinsic to human cognitive processes. Since then, it has been used to tackle poorly-defined and complex problems due to incomplete and imprecise information that characterise real-world systems.

Zadeh stated that "as the complexity of a system increases, human ability to make precise yet significant statements about its behaviour diminishes until a threshold is reached beyond which precision and significance become mutually exclusive" - the Principle of Incompatibility. Then, it follows that modelling complex or poorly-defined systems can not be made precisely. According to Nguyen (1987), fuzzy set theory is not intended to

replace probability theory but rather to provide solutions to problems that lack mathematical rigour inherent to probability theory.

The application of fuzzy set theory has had a tremendous impact in various areas of knowledge particularly in planning, medicine, engineering, finance, computing, risk management, operations research and decision-making.

Essentially, fuzzy set theory is an extension of the classical Boolean or binary logic. In Classical Set Theory, a set is a collection of objects having a general property. As an illustration let us consider two sets, namely the set of clients CLT = [a, b, c] and the set of contractors CON = [x, y, z]. The client "b" is not a member of the class of contractors, that is, client "b" is not a member of the set CON. Consequently, it has a membership grade of zero (0). In turn, the contractor "y" has a membership grade of one (1) in the set CON and a membership grade of zero (0) in the set CLT. Therefore, in classical logic an element is either or not a member of a set, a statement is either true or false.

The boundaries between membership and non-membership are very rigid or "crisp" and there is no room for grey or "in between" states. There are no intermediate grades of membership between full and non-membership. This deterministic "yes-or-no" or dichotomous approach is a widespread practice in systems modeling, reasoning process and computing, nowadays.

The main problem with binary approach is that it fails to convey information effectivelly, that is, the states between full and non-membership are ignored yet they are very important. Meanwhile, most real-world systems are very complex and too poorly-defined to be well understood and modelled precisely. A great deal of information used in managerial decisions, political, cultural and social contexts is imprecise, therefore, many facts, events and states can not be completely described in precise terms.

The essence of fuzziness, in contrast to binary or dual logic, is that the transition from a membership to non-membership state of an element of a set is gradual rather than abrupt. Fuzzy Set Theory builds on the classical set theory and extends that logic to incorporate

the "grey areas" excluded in binary logic. A fuzzy set is a set whose elements have varying degrees of membership and, consenquently, it allows a generalisation of crisp set concept to model complex or poorly-defined systems. As an example, the set of "very competent contractors" is not a set in the classical sense. Indeed, it is difficult to determine with rigour what a very competent contractor is, that is, who really belongs or not to the set of very competent contractors. This is a typical example of a fuzzy set. The definition of very competent contractor involves a wide spectrum of human perceptions.

The main concepts associated with fuzzy set theory as applied to decision-making are linguistic variable, membership functions, natural language computation, linguistic approximation, fuzzy set arithmetic operations, set operations and fuzzy weighted average. Details concerning these topics can be found in the following references: (Zadeh 1965; Dubois and Prade, 1980; Schmucker, 1984; Dong and Wong, 1987; Ross, 1995; and Cox, 1999). The following sections provide a brief description of the main concepts of fuzzy set theory.

7.3 Linguistic variable

According to Zadeh (1965) natural language is vague and imprecise and a meaning in natural language is a matter of degree. Such vagueness and imprecision are an intrinsic part of natural language and derive from the complexity of the world. As a result, more often than not, humans rely on judgement, experience, intuition and heuristics to build models of the real systems.

In spite of such vagueness, humans can understand one another perfectly. Fuzzy Set Theory provides a mathematical framework for capturing such "nebulous areas" of natural language by introducing the concept of gradual membership.

Although natural language is imprecise it conveys valuable information. Due to their ability humans can easily manipulate fuzzy information and react accordingly in everyday life, that is, natural language is well understood by humans. Research on cognitive

psychology suggests that humans base their thinking on conceptual patterns and mental images rather than on any quantity or numbers.

The concept of linguistic variable lies at the core of Fuzzy Set Theory which manipulates linguistic expressions instead of numbers. The values assumed by a linguistic variables are words. A linguistic variable differs from a numerical variable in that its values are not numbers but words or sentences in natural or artificial language. Since words in general are less precise than numbers, the concept of linguistic variable serves the purpose of providing a means of approximate characterisation of phenomena which are too complex or too poorly-defined to be amenable to description in conventional quantitative terms.

A linguistic variable is defined as a quintuple (X, T(X), U,G, M), where X is the name of the variable, T(x) is the set of natural language terms assumed by X, U is the universe of discourse, G is the grammar to generate the names of T and M is a set of semantic rules for associating each X with its meaning. The universe of discourse is the the universe of all available information on a specific problem. Viewed from another perspective, a linguistic variable has two distinct components, namely syntactic, describing the set of natural language terms assumed as values of the variable, and the semantic component that links each value of the variable to a fuzzy subset.

A simple example of linguistic variable is the term "cost overrun". This variable may assume different values such as high cost overrun, low cost overrun, moderate cost overrun, slightly low cost overrun, etc. Each of these values has its grade of membership in the class of project cost overruns.

The definition of the linguistic variables can be provided either by the analyst or the user since different people may assign different degrees of membership to each of the values according to their own perception and judgement of the meanings of the terms. Each value of a linguistic variable is a fuzzy set. An example of a variable with its values is presented in Figure 7.1.

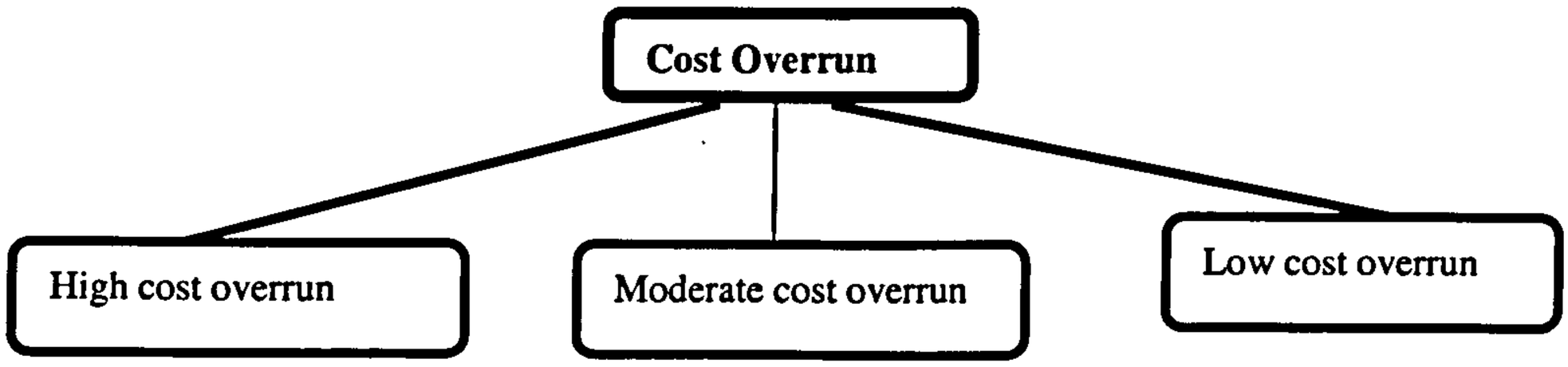

Figure 7.1: Linguistic variable cost overrun and three of its values

It should be noticed that the values of the variable shown above have a common characteristic - the qualifiers. These qualifiers, usually called linguistic hedges in Fuzzy Set Theory, are crucial in the construction of linguistic variables. Their main purpose is to modify the main terms in order to obtain different values of the variables with associated degrees of membership.

The number of linguistic hedges for a variable is normally unlimited. However, in most fuzzy problems three, five or seven values provide enough description of the variable. An example of five values to describe cost performance would be: very high, high; average; low; and very low. Depending on the problem under analysis, the decision analyst and any other conditions, the number of values may vary. By using linguistic variables, any risk factor can be characterised by its likelihood of occurrence and its impact severity. For example, the risk factor "need for job", being a linguistic variable may have a family of fuzzy sets that define its possible instances. These values of the variable can be: very low, low, average, high, very high, meaning very low need for job; low need for job; and so on. The severity can be described in the same way: very low; low; average; high;, and very high, meaning very low impact, and so on.

7.4 Fuzzy sets and membership functions

A fuzzy set is a set whose elements have varying degrees of membership. The degrees of membership of the elements of a set are expressed by a membership function. Membership functions are expressions of the degree of belief and, in fuzzy set theory they play a similar role that of probability distribution functions in probability theory. The membership functions are thus used to represent uncertainty. A membership function is a function that maps a universe of objects X onto the unit interval [0,1]. The universe of objects represent the elements of the set and the interval corresponds to the set of grades. A membership function is mathematically represented as:

$$A = \{\mu_A(x) \mid \ x \}, \qquad \textbf{(Equation 7. 1)}$$

where

$\mu_A(x)$ - degree or grade of membership of x in the fuzzy set A;

$\mu_A(x) \in [0, 1]$;

A - fuzzy set;

$\mid$ - delimiter; and

x – an element of the universe of discourse X.

As mentioned above, the grades of membership in fuzzy sets may fall anywhere in the interval [0,1]. A degree of 0 (zero) means that an element is not a member of the set at all. A degree of 1(one) represents full membership. This scale is similar to that of probability and this is one of the reasons why Fuzzy Set Theory is confused with probability theory.

A classical set or "crisp" set is a particular form of a fuzzy set with only one membership function. Instead, a typical fuzzy set may have a large number of membership functions. In general, such functions may assume different forms and shapes but the most common are normal and convex forms, (Ross, 1995).

An example of a fuzzy set is shown in Figures 7.2 amd 7.3. A linguistic variable *competition* is mapped into the universe of discourse [0,10]. The values from 0 to 10 represent the extent of competition, being 0 the lowest competition level and 10 the highest. Figure 7.3 shows the fuzzy sub-set *low competition,* which is one of the possible values of the variable linguistic variable *competition.*

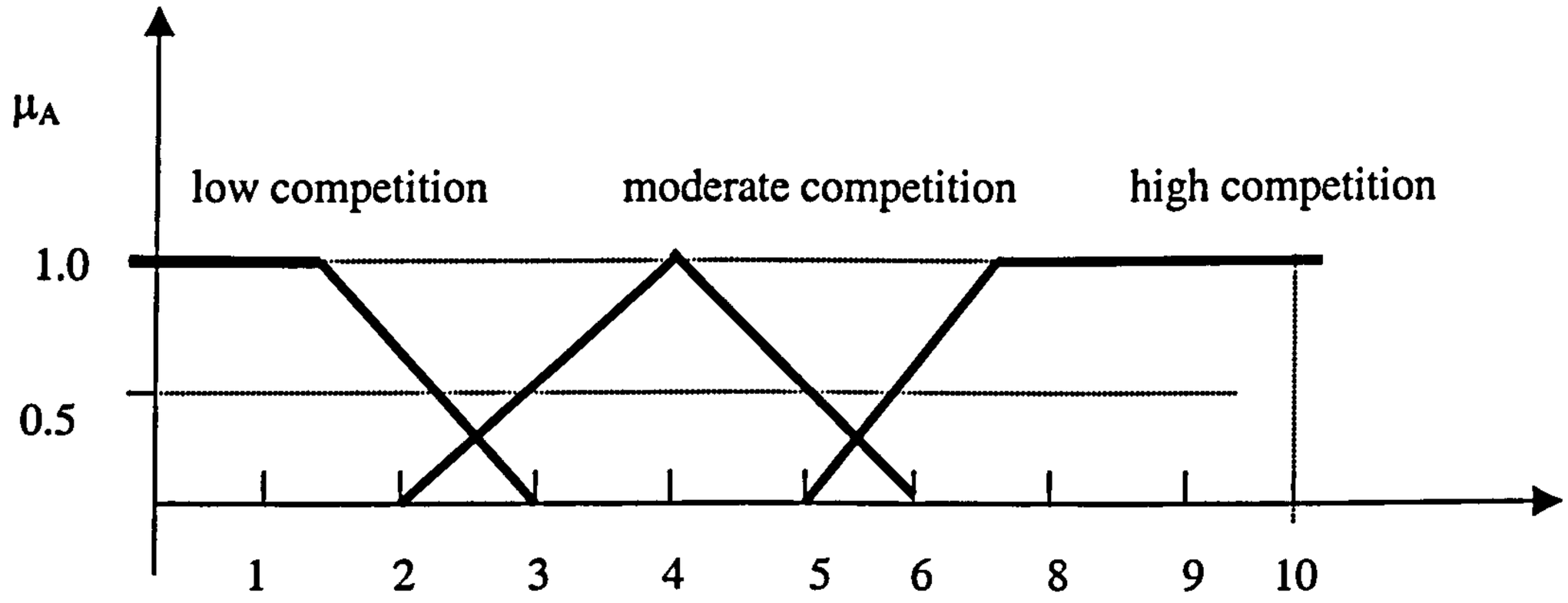

Figure 7.2: Graphical representation of the three fuzzy sets

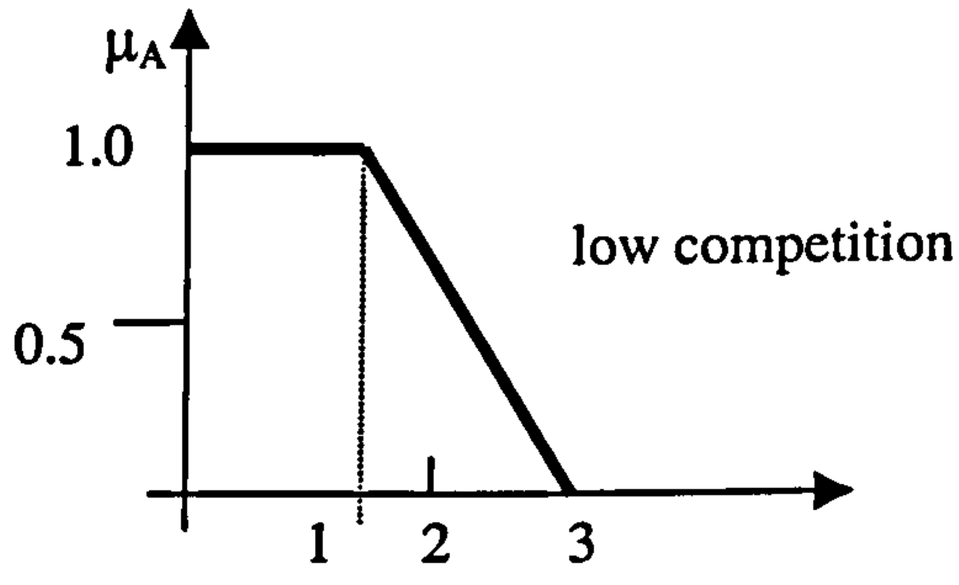

Figure 7.3: Graphical form of fuzzy set "low competition"

where

μ_A – grades of membership;

low competition – fuzzy set **A**; and

1, 2 and 3 - elements of the universe of discourse, i.e., the values of the variable competition.

This fuzzy set weak competition can also be represented analytically:

A (low competition) = [1.0/0, 0.6/2, 0.0/3], where 1.0, 0.6 and 0.0 are the degrees of membership. Thus, the membership function of weak competition is **[1.0, 0.6, 0.0].**
Apart from *low competition* other values would be *moderate competition* and *high competition*. The corresponding fuzzy sets for these values may be the following:

B (Moderate competition) = [0.0/2, 0.5/3 1.0/4, 0.5/5, 0.0/6]; and

C (High competition) = [0.0/5, 0.5/6, 1.0/7, 1.0/8, 1.0/10].

Important to notice, though, are the areas of overlap between low and moderate and moderate and high competition membership functions. These overlaps represent the "grey" zones, that is the gradual transitions from membership to non-membership properties. In a crisp set, as mentioned earlier, an object is either a member of a set or not. Considering the same example of *low competition*, the corresponding crisp set will be in the form (and as graphically represented in Figure 7.4).:

$$\mu_A(x) = \begin{cases} \text{if } x \in A \\ 0 \quad \text{if } x \notin A \end{cases}$$

or, graphically

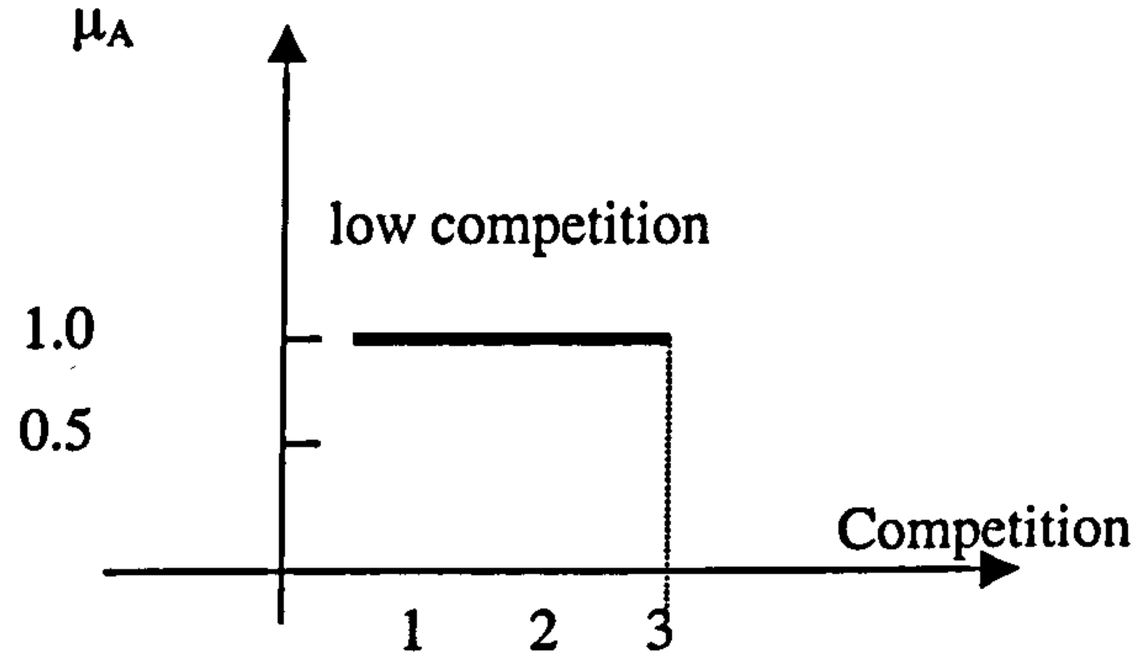

Figure 7.4: Crisp set "low competition"

The only grades of membership in the crisp set *low competition* are 1 and 0. Thus, competition levels from 0 to 3 are members of the set with a grade 1 and, all other elements of the universe are not, and they have grade membership of 0. As it can be seen, the change in the grades is quite abrupt. For example, 3.1 is not considered low co mpetition at all.

7.4.1 Generating membership functions

There are many methods to assign membership values or functions to fuzzy variables. In principle, the problem under analysis will determine the method, since there are no strict rules for that purpose. The membership functions should ideally represent the current problem as much as possible. The assignment of membership functions can be intuitive or based on some algorithm or logical operations. A thorough discussion of these methods can be found in (Dubois and Prade, 1980; and Ross, 1995). Such methods are the following: intuition; inference; rank ordering; angular fuzzy sets; neural networks; genetic algoritms; inductive reasoning; soft partitioning; meta rules; and fuzzy statistics. Neural Networks and Genetic Algorithms were briefly presented and discussed in chapter five. The importance of membership functions can be drawn from the following passage of (Dombi, 1990): "working without membership functions can be compared with dealing with probability theory where we have a calculus without probability functions, and anybody using this theorem can arbitrarily choose the density functions". The most popular membership functions in fuzzy systems are the **S** function and the π functions (Zadeh, 1975). The latter function is a combination of two S functions.

7.5 Possibility theory

Possibility theory focuses primarily on imprecision, which is intrinsic in natural language and is assumed to be "possibilistic" rather than probabilistic. Possibility theory models measure the degree of ease for a particular event occurring (Zadeh, 1978; Klir, 1988;

Zimmermann, 1996). If X is a variable taking values in an universe of discourse U, then the possibility distribution of X, $\prod_x$ is the fuzzy set of all possible values of X. For example if π_x (u) denotes the possibility that X can take the value u, where u ∈ U then the membership function of X is equal to the possibility distribution function π_x (u) : U > [0, 1] that associates with each element u ∈ U the possibility that X may take u as its value.

For example, the physical ability of a bricklayer laying x bricks, where x stands for a positive integer can be modelled via a possibility distribution over the integers values x =1, 2, 3 ...N. The distribution function equals 1 at x = 0, and decreases monotonically to 0 when x increases which denotes the degree of ease with which the bricklayer can work.

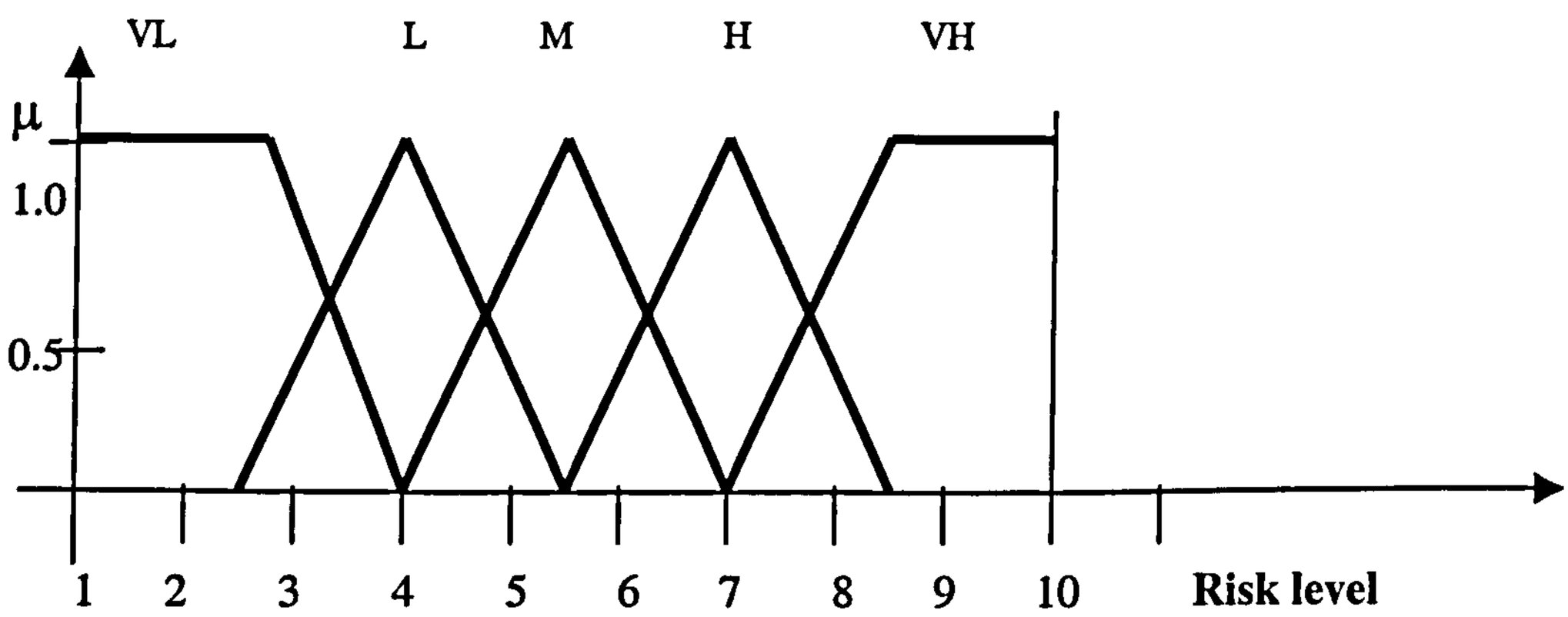

Figure 7.5 Membership functions for: very low - VL, low - L, medium - M, high - H and very high - VH.

To illustrate the concept of possibility, let risk level y = 3.0 (Fig.7.5) with a degree of membership in the fuzzy set VL is 0.7. The value 0.7 is interpreted as the degree of compatibility of 3 with the concept labelled VL. Then it can be postulated that the proposition "risk level is very low" converts the meaning of 0.7 from the degree of compatibility of 3 with "very low" to the degree of compatibility that risk level is 3 given the proposition "risk level is very low" to the degree of possibility that risk level is 3 given the proposition "risk level is very low". In other words, it can be said that the

compatibility of a value of risk level with "very low" becomes converted into the possibility of that value of risk level given risk level is "very low".

The possibility distribution function π_x (u) characterising the possibility distribution π_x is defined to be numerically equal to the membership function, (Zadeh, 1978). Possibilities may be treated as linguistic variables with values such as possible, quite possible and almost impossible. These values may interpreted as labels of fuzzy sets of the real line.

The possibility and probability are different measures of uncertainty. While the former measures vagueness the latter is concerned with randomness. Indeed the concepts of possible and probable carry different types of uncertainty. Possibility reflects the degree of ease with which a variable may take a value, that is, it describes whether an outcome can occur, whereas a probability describes whether it will happen. Probabilities are mathematical models used to describe random experiments. The consistency between probability and possibility distributions can be stated as follows (Zadeh, 1978).

- an event that is impossible is bound to be improbable;
- a high possibility does not imply a high likelihood; and
- the lessening of the possibility of an event tends to also lessen its probability, but not vice-versa. The role possibility theory plays for fuzzy sets is similar to that played by mathematical expectancy in probability theory.

7.6 Fuzzy set operations

Fuzzy set theory has its own mathematical operations, which are an extension of classical crisp mathematical operations. The arithmetic of fuzzy numbers and algebraic operations on fuzzy sets are based on the extension principle formulated by (Zadeh, 1975), and later improved by (Yager, 1986). The extension principle for discrete-valued function is formulated as follows:

$$\mu_B(y) = \max_{y=f(x1,\, x2,\ldots xn)} \{\min[\mu_{A1}(x_1), [\mu_{A2}(x_2).....\mu_{An}(x_n)]\}; \qquad \textbf{(Equation 7.2)}$$

where A_1 A_2 .....A_n are fuzzy sets defined on the universes X_1, X_2,.....X_n

B - is the mapping of the fuzzy sets, that is, B = f(A_1 A_2 .....A_n).

The equivalent programming problem is to maximise $\mu_B(y)$ subject to the constraints $\mu_B(y) \leq \mu_{Ai}(x_i)$, i = 1, 2, 3 ..... N $f(x_1, x_2, ... x_n) = y$;

Basically, the operations on fuzzy set theory are generalisations of interval analysis. A fuzzy number is considered a generalisation of the intervals of confidence (Kaufmann and Gupta, 1991). The extension principle enables the extension of the domain of a given function to include fuzzy sets.

7.6.1 Union, intersection and complementation

The main set operations in fuzzy set theory are union, intersection and complementation. In the classical set theory the intersection of two sets comprise elements that are common to both. As it was discussed earlier, in fuzzy set an element may be partially in both sets. As a result, it can not be said that a specific element is more likely to be in the intersection than in one of the original sets. In the light of this, the intersection operation takes the minimum of the membership values under study.

The union of two sets comprises elements that belong to one or both sets. The members of the union can not have a membership value that is less than the membership value of either the original sets. It takes the maximum of the membership values. Complementation operation is the negation operation. Let A and B be two fuzzy sets on the universe of discourse X. The set operations are formulated as:

- Union

$\mu_{A \cup B}(x) = \max (\mu_A(x) \vee \mu_B(x))$ **(Equation 7.3)**

- Intersection

$\mu_{A \cap B}(x) = \min (\mu_A(x) \wedge \mu_B(x))$ **(Equation 7.4)**

- Complement or Not

$\mu_A(\dot{x}) = 1 - \mu_A(x)$) **(Equatiom 7.5)**

where

$\vee$ is the **max** operator, also designated logical **OR**; and

$\wedge$ - is the **min** operator also designated logical **AND**

7.6.2 Arithmetic operations

In the same way, the arithmetic and algebraic operations follow the extension principle. Because of this and for demarcation purposes, the arithmetic operations are usually called extended addition, extended multiplication and extended division. The arithmetic computations involving fuzzy sets are very complex and therefore impractical for hand calculation. They are better handled by computers.

Lets consider two fuzzy sets, namely **A** and **B**, defined over the universe (1, 2, 3 ..... n). The operations of addition, multiplication and division are defined as follows:

$\mathbf{A} = \mu_A(x) \mid X, \quad 1 \leq x; x \leq n$ **(Equation 7.6)**

$\mathbf{B} = \mu_B(y)) \mid y, \quad 1 \leq y; y \leq n$ **(Equation 7.7)**

x, y and n are integers

- Addition

$\mathbf{A+B} = \max \{ \min[\mu_A(x), \mu_B(y)] \mid (x+y) \quad 1 \leq x; y \leq n \}$ **(Equation 7.8)**

- Multiplication

$\mathbf{A \times B} = \max\{ \min(\mu_A(x) , \mu_B(y)) \mid (xxy) \qquad 1 \leq x; y \leq n \}$ **(Equation 7.9)**

- Division

$\mathbf{A \div B} = \max\{ \min(\mu_A(x) , \mu_B(y)) \mid (x \div y) \qquad 1 \leq x; y \leq n \}$ **(Equation 7.10)**

A+ B, AxB are fuzzy subsets over the set of the integers. The operation **A:B** is a fuzzy subset over the set of reals. In practice, though, the set over the reals is reduced to only one set over the integers.

Therefore, if a quotient resulting from a division is not an integer it must be approximated. Clements (1977) formulated a method for such approximation that assumes: any quotient that is not an integer is automatically deleted; and any quotient greater than **n** is omitted. Furthermore, all the operations of addition, multiplication and division need to be normalised (Schmucker, 1984). Normalisation is necessary to reduce the fuzzy sets to the same base. In doing so, at least one element of the set has a membership of one. Normalisation consists in dividing the membership of each element in the set by the maximum membership observed in the same set.

7.6.3 Fuzzy weighted average

Fuzzy weighted average (FWA) is an extension of algebraic operations on real numbers in accordance with Zadeh's extension principle. The solution procedure of FWA corresponds to a non-linear programming problem. In particular, fuzzy weighted average is a fuzzy counterpart of the ordinary weighted mean and, apart from its applications in other fields, it has been widely applied in decision and risk analysis problems (Dong and Wong, 1987). Fuzzy weighted average is based on the concepts of α - cut representation of fuzzy sets, non-linear programming implementation of the extension principle and interval analysis. The classical interval analysis technique is modified into a combinatorial interval analysis technique so as to enable a much ampler application of the computational algorithm. The operations of addition, multiplication and division, follow the algorithm of fuzzy arithmetics. The general formula of the fuzzy weighted average has the same format as the classical weighted mean. A two-termed FWA is given as follows:

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

(Equation 7.11)

Where

R_A – fuzzy set representing the overall weighted average ratings of an alternative;

R_1 – fuzzy set representing rating of the alternative based on particular criterion 1;

W_1 – fuzzy set representing the weight or relative importance assigned to a particular; criterion 1;

R_2 – fuzzy set representing rating of the alternative based on particular criterion 2; and

W_2 – fuzzy set representing the weight or relative importance assigned to a particular criterion 2.

7.6.4 Fuzzification

Fuzzifying means turning a "crisp" quantity into fuzzy. Fuzzification aims to change real-world data, in any format, so that they belong to a particular fuzzy sub-set. The rationale behind this process is that very often fuzzy quantities are considered crisp while, in practice, they are not. Such quantities are fraught with uncertainty and to account for fuzzy type of uncertainty there is a need to fuzzify them. The fuzzification process implies assigning a membership function to the quantity under consideration. For example, if the index 70 represents a political risk in certain region it would be appropriate to consider the index as a fuzzy quantity because it is not deterministic at all. Therefore, the number 70 can be considered a fuzzy number 70. A fuzzy number is simply an ordinary number whose precise value is somewhat uncertain as shown in Figure 7.6.

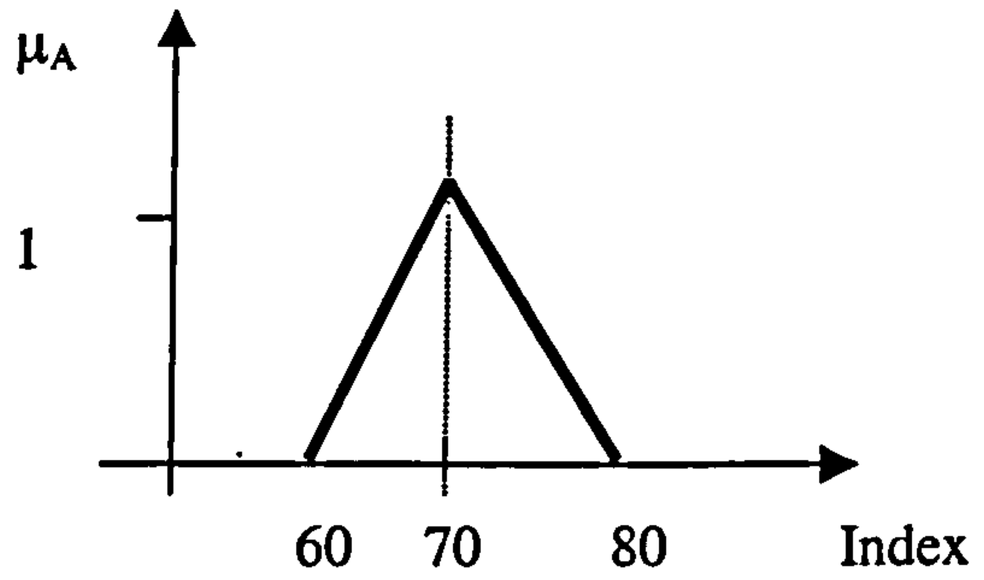

Figure 7.6: Fuzzification of a political risk index

7.6.5 Defuzzification

Defuzzification is an opposite process to fuzzification,that is, a process of finding a crisp quantity that best represents the information conveyed in the overall output fuzzy set. The crisp quantity or number is often called expected value of the solution of the variable under consideration. In other perspective, if the fuzzy set is a seen as a set of membership values or a vector of values within the unit interval domain, then defuzzification corresponds to the reduction of the vector to a single scalar quantity. The importance of defuzzification becomes clear in circumstances where there is a need to present results as crisp values rather than fuzzy sets.

This is the case of fuzzy control systems particularly in industrial processes that require a crisp reading. The output of fuzzy controllers must be crisp because some electrical and mechanical systems can only accept and use deterministic signals. As stated by Ross (1995), it is one thing to compute, to reason and to model with fuzzy information, and it is another thing to apply the fuzzy results to the real decision problems. For example, the fuzzy set in Figure 7.7 is the overall output of a fuzzy operation and represents the variable "profit margin". If the objective of the estimator is to evaluate the profit margin he/she will need a crisp quantity instead of fuzzy set. By mean of defuzzification, he/she may reach the value of 6 on a given scale.

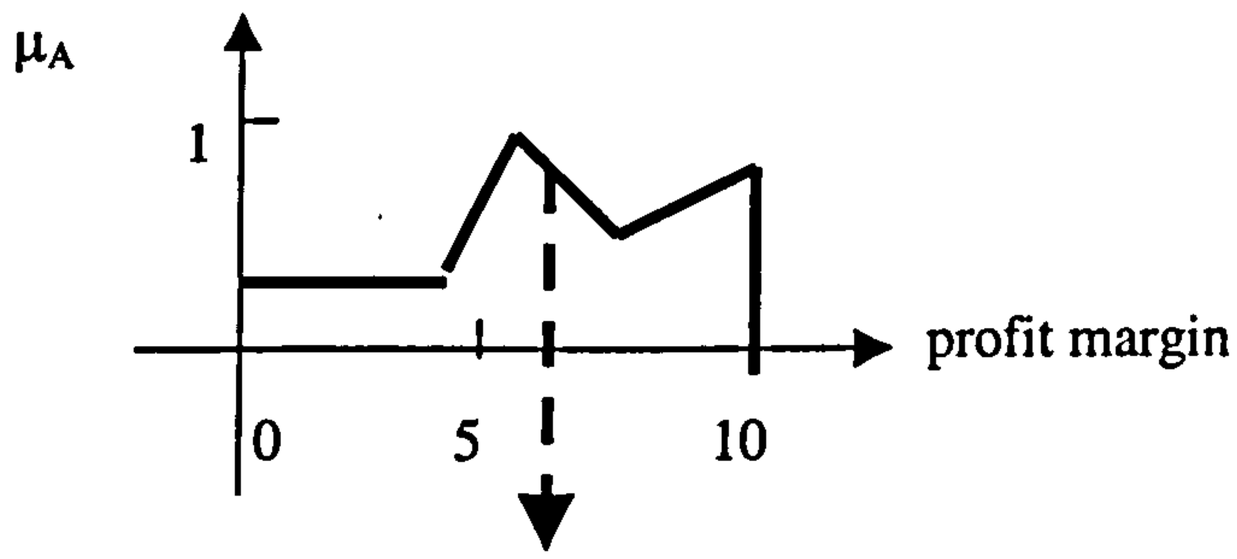

Figure 7.7: Fuzzy membership function output

a) Defuzzification methods

There are several methods of defuzzification in the literature. The choice of a specific method depends on the system under consideration, the modelling approach and the shape of membership function. The most common methods are weighted average, mean-max membership, centroid, max-membership, centre of sums, centre of largest sum and first of maxima (Ross, 1995). The centroid method is the most appealing.

- Centroid

The centroid method, also known as centre of area or composite moments method, is the most widely used because its calculation simplicity and representativeness of fuzzy region. It consists in finding the balance point of the solution by mean of the weighted average fuzzy region. For a fuzzy set A the centroid can be determined as shown in Figure 7.8:

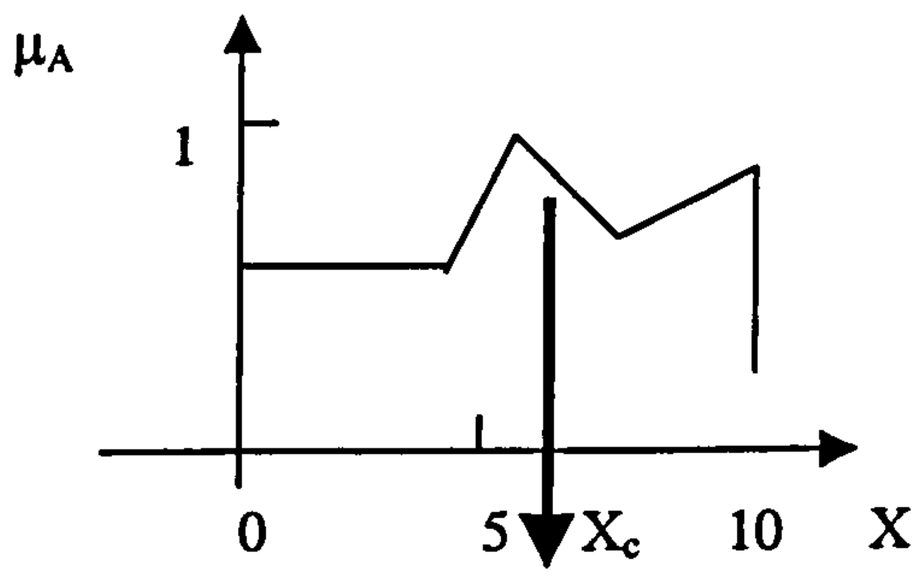

Figure 7.8: Centre of area defuzzification

7.7 Fuzzy inference

KBSs reason with uncertain and imprecise information. The knowledge they embody is often inexact, incomplete and not totally reliable, in the same way that human's

knowledge is imperfect. In addition, the data supplied by the user is uncertain, as well. As a result, the uncertainty in the information contained in the knowledge base induces some uncertainty in the validity of the conclusions. Therefore, the outputs or conclusions arrived at must, explicitly or implicitly, have attached some assessment of their reliability.

Providing KBSs with computational capability to analyse the propagation of uncertainty from the premises to the conclusions and associate the conclusion with the certainty factor is one of the most important issues in the design process. Fuzzy KBSs must have the capability of inferring from imprecise premises. In this concern fuzzy logic plays an important role. It is used to represent imprecise knowledge as well as for reasoning and inferring purposes in order to draw conclusions based upon imprecise information. The deduction of a conclusion from a set of premises using fuzzy logic is reduced to a solution of a non-linear problem through the application of projection and extension principles.

Fuzzy logic considers a fuzzy set as a fuzzy proposition. A fuzzy proposition is simply a statement in the form: X is A, where A is a fuzzy set in the universe of discourse X. Typical fuzzy rule relates two propositions as follows:

IF X is A THEN Y is B.

In fuzzy KBSs a fuzzy rule establishes a relationship or association between two propositions. Fuzzy KBSs store rules as fuzzy associations. In other words, if A and B from the above rule, are fuzzy sets, then they are stored in an associative matrix M. The fuzzy associative matrix M maps fuzzy set A to fuzzy set B. The fuzzy association or fuzzy rule is also called Fuzzy Associative Memory (FAM), (Kosko, 1992). The process of mapping a fuzzy set A to another fuzzy B is termed fuzzy inference. The purpose of fuzzy inference is to establish a belief in a rule's conclusion given evidence on the rule's premise, that is, a fuzzy rule is used to form a degree of belief that if X is A then Y is B.

As discussed in chapter 6, there are other inference techniques such as, probability theory, certainty factors and Dempster-Shafer evidence. The fundamentals of inference process in fuzzy systems are the consideration of propositions as fuzzy sets and the mapping of the premise set information to conclusion set information. For this purpose the fuzzy inference determines an induced fuzzy set from information about a related fuzzy set. The induced fuzzy set is produced by taking the available information on X encoded in A' (sub-set of A) and inducing a fuzzy set B' on B that quantitatively captures this belief. To determine the induced fuzzy set, fuzzy inference uses fuzzy vector-matrix multiplication operation that is an extension of classical vector-matrix multiplication.

Fuzzy vector-matrix multiplication uses a max-min composition that is defined by the composition operator "°" or max-min composition operator.

The matrix M is also known as fuzzy relation R, for relationship.

$$A \circ M = B \qquad \textbf{(Equation 7.12)}$$

The fuzzy associative memory FAM is used to store and represent fuzzy rules. To illustrate the concept of FAM lets consider two input variables X and Y each of which has three values (fuzzy sets). The output variable is Z with three values as well. These fuzzy sets are low, medium and high (LO, ME, HI). The FAM is as shown in Figure7.9.

	LO	**ME**	**HI**
LO	VL	SL	ME
ME	SL	ME	SH
HI	ME	SH	VH

Figure 7.9: FAMatrix 3x3 (x.y)

where VL = very low, SL= slightly low, ME= medium and SH= slightly high.

Each matrix entry is an output fuzzy set that represents the consequent of a fuzzy rule. For example, the shaded entry SL can be described as a rule: **IF** X is LO **AND** Y is ME **THEN** Z is SL. The number of fuzzy sets of Z is not restricted to the number of values of the inputs and thus Z can assume many more values.

Fuzzy inference takes a similar approach used in classical conditional probability theory, where the compositional operators are used in vector-matrix operations.

Accordingly, Zadeh (1965) proposed a possibility distribution matrix $\Pi_{B/A}$ such that if it was composed with the possibility distribution of A it would be possible to get back the possibility distribution of B. The technique is called compositional rule of inference and is expressed as follows:

$$\Pi_A \circ \Pi_{B/A} = \Pi_B$$

where Π_A is a 1x n vector, $\Pi_{B/A}$ is a n x p matrix and Π_B a 1x p vector.

Using this technique it is possible to put in some information on A' (sub-set of A) and obtain information on B' (sub-set of B). The distribution matrix $\Pi_{B/A}$ that is the same as matrix M (associative matrix) is derived from pairwise implications between A and B.

The most widely used fuzzy inference techniques are **max-min inference** and **max-product inference.** Max-min inference is also called Mandani inference and max-product is also known as correlation inference or max-dot inference. As shown earlier, the main operators used in fuzzy set theory are the **max** operator or **OR;** and **min** operator or **AND.** These operators are very important in the inference process since they are used to manipulate disjunctive and conjunctive rules respectively. The general rule format in fuzzy rule-based system is described as follows:

IF x_1 is A_{1j} AND x_2 is A_{2j} THEN y_j is B_j , where J=1, 2, 3 ..... r

A_{1j} and A_{2j} are the fuzzy sets representing the Jth antecedents and B_j are the fuzzy sets representing the Jth consequent.

7.7.1 Disjunctive system of rules

In this case the satisfaction of at least one rule is required. The rules are connected by "OR" connectives or operators. The aggregate output (derived from the overall set of inputs or consequents) is determined by the fuzzy union of all individual rule contributions.

$Y = y_1$ OR y_2 OR y_3 .....OR y_j **(Equation 7.14)**

whose membership function is $\mu_y(y) = \max[\mu_{y1}(y), \mu_{y2}(y), \mu_{y3}(y), ...\mu_{yj}(y)]$, $y \in Y$.

7.7.2 Conjunctive system of rules

These are jointly satisfied rules, that is, all antecedent conditions must be met for satisfaction. They use "AND" connectives or operators. The overall output or consequent y is determined by the fuzzy intersection of all individual rule consequents, y_j.

$Y = y_1$ AND y_2 AND y_3 .....AND y_j **(Equation 7.15)**

whose membership function is $\mu_y(y) = \min[\mu_{y1}(y), \mu_{y2}(y), \mu_{y3}(y), ...\mu_{yj}(y)]$, $y \in Y$

7.7.3 Max-min inference

Max-min inference technique uses "min" implication operator. Therefore, the fuzzy associative matrix is formed as follows:

$M_{ij} = \text{truth}\ (a_I \rightarrow b_j) = \min(a_I, b_j)$ **(Equation 7.16)**

Having determined M it is possible to derive the induced vector B' from a sub-set of A termed A'. The fuzzy set A' in KBSs usually represents input data (present in the working memory) either in crisp or fuzzy form. There are two possible cases in max-min inference namely crisp inputs and fuzzy inputs. Fuzzy set B' is in practice a clipped (truncated) version of fuzzy set B whose height is set by A'. In cases where the input is crisp the induced fuzzy set B' can be derived directly using the operator "min" - $\wedge$. Figures 7.10 and 7.11 provide graphical illustration of the inference process with one rule, one antecedent (input) and one consequent (output). For a set of disjunctive rules the aggregated output can be written as:

$\mu_{Bj}(y) = \max\{ \min[\mu_{a1j}(input(i)), \mu_{A2j}(input(i))]\}, \quad j = 1, 2 \ldots.r$

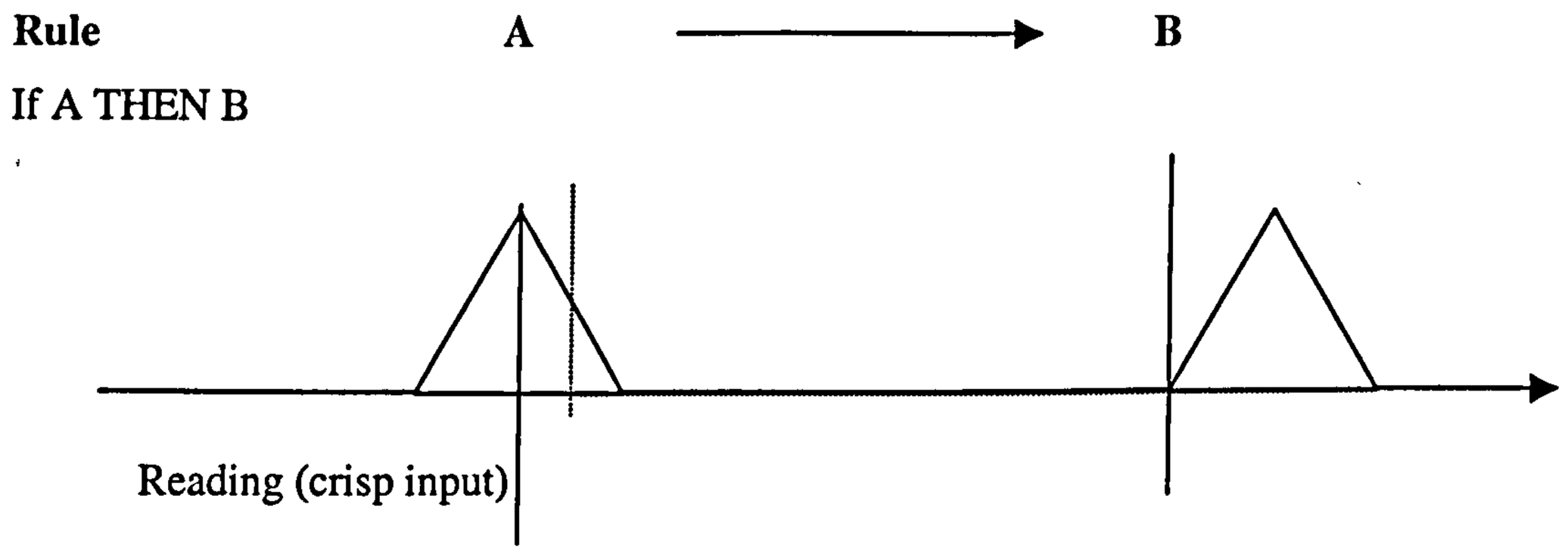

Figure 7.10: Graphical representation of Max-min inference for crisp input

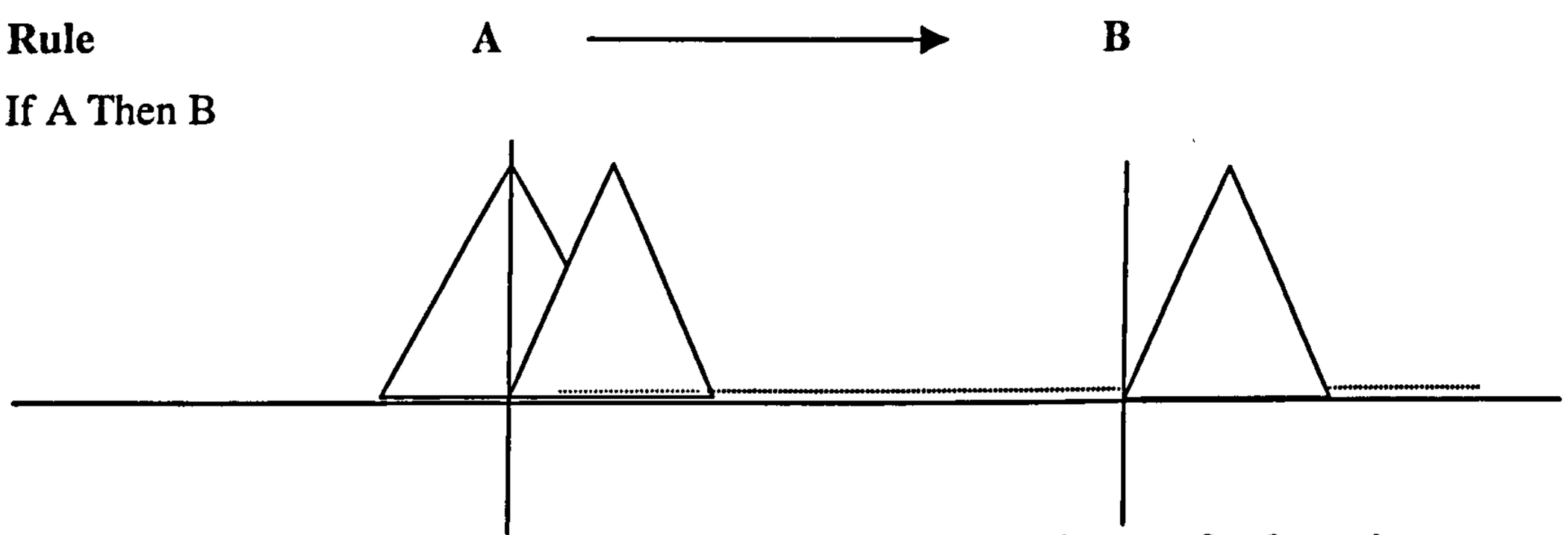

Figure 7.11: Graphical representation of Max-min inference for fuzzy input

Graphical representation of inference process is at times useful particularly for manual checking of the performance of computer execution of inference. However, such manual verification is only feasible for few rules since as the number of rules increases the number of operations grows largely. The principles applied to few rules graphical inference apply to any number of rules with several antecedents and consequents.

7.7.4 Max-product inference

Max-product inference employs standard product as the implication operator to form the elements of the associative matrix M.

$M_{ij} = a_i b_j$

The operations involved in the calculation of matrix M are similar to that shown in the example above. After determining the associative matrix M, max-min composition is used to derive the induced matrix B' from the sub-set vector A'.

The max-product inference produces a scaled version of B (max-min produces a truncated version of B). Similarly, as in max-min inference, two cases of inputs are possible (crisp and fuzzy inputs) as shown in Figure 7.12.

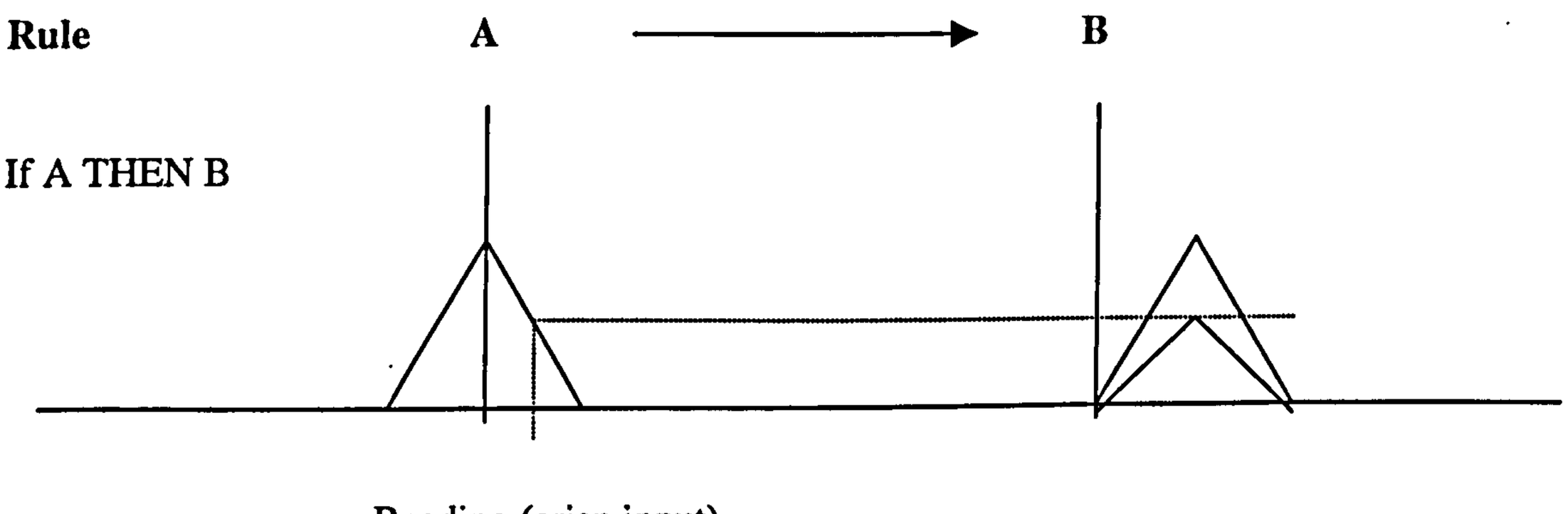

Figure 7.12: Graphical representation of max-product inference

Max-product inference is considered as preserving more information than max-min inference. The importance of this ability is evident in situations where several induced fuzzy sets from multiple rules are combined to perform defuzzification.

In conclusion, it can be said that in both max-min and max-product inferences the final output membership function for each output is determined by the operators associated to the fuzzy sets assigned to that output.

7.8 Summary

This chapter has discussed the core issues of fuzzy set theory, namely the concepts of linguistic variable, membership functions, natural language computation, fuzzy set operations, fuzzification and defuzzification. It has also presented and discussed the inference process within the context of KBSs, mainly max-min and max-product inference techniques.

Chapter Eight

Questionnaire data analysis and discussions

8.1 Introduction

This Chapter presents the analysis of data collected through the questionnaire survey. The analysis of data and discussion of the results are undertaken in search of their relevance to the research questions raised earlier in this study. The analysis is performed through both descriptive statistics and inferential statistics. Descriptive statistics are used to describe the features of the data. Where appropriate, data are tabulated and translated into graphical format in order to make it easier to see the patterns of the distributions. Inferential statistics is used to make generalisations from sample data to the populations from which data samples were drawn.

8.2. Objectives

Unless data are analysed for patterns, trends or relationships, they are meaningless. The questionnaire was designed to gather data to enable responding to the research questions posed earlier. The main purpose of data analysis is to assemble, classify and summarise the collected evidences in such a way that they yield answers to the research questions. The subsequent step of interpretation aims to search for the meaning of the answers provided by analysis by establishing a linkage with the available body of knowledge. The development of the decision framework entails, as pre-requisite, the establishment of the most important factors affecting cost performance. As such, the questionnaire survey focused on global risk factors affecting cost performance, as well as on the techniques used for their identification, assessment, modelling, analysis and control. In addition, risk management related subjects such as contract strategy, bidding procedures, cost estimating and control were also considered. The specific objectives of the data analysis were to establish:

- construction contractors' attributes, namely (company identification, main activities, number of employees, age, type and number of projects undertaken and size of annual financial turnover);
- the project performance indicators used by contractors, the cost estimating approaches and methods, incidence of cost overruns, the most common contracting strategies, the most used bidding procedures and the commonest types of contracts;
- construction contractors' awareness of risk, and the techniques, both quantitative and qualitative, used to identify, analyse manage and communicate risks within construction organisations; and
- the most significant or critical global risk factors affecting cost performance of construction projects.

8.3 Administration

The population from which sampling for the questionnaire survey was made comprised construction contractors in Maputo, Mozambique. One reason for this procedure is was that around ninety per cent of country's prominent construction organisations both in terms of both size and annual turnover are concentrated in Maputo. Large and medium contractors are based in Maputo and form the best population representation of the sector in the country.

The questionnaire was personally administered to construction contractors in Maputo region. It was established, through piloting, that construction executives, mainly head of estimating and planning departments, were the most suitable respondents due to both the sensitivity of most of data and the fact that they are the key individuals dealing with current day-to-day activities. Furthermore, senior position individuals are difficult to contact, possess general information and they tend to delegate current affairs to the executives.

The first stage consisted of a workshop intended to elicit input variables from construction contractors as to the factors affecting construction cost performance. The

contribution of contractors and the information from the literature review served as inputs for developing the questionnaire that was subsequently piloted. The piloting was implemented for a selected group of construction contractors comprising eight per cent of the target sample. After the piloting work the questionnaire was reviewed to take account of the feedback from contractors. After the questionnaires were received from construction contractors, follow-up interviews were conducted to ensure the correctness of data and to clarify any doubts and misunderstandings.

8.4 Analysis

The nature of the research questions and, subsequently, the objective of the questionnaire have led to the inclusion of three types of data namely categorical, ordinal and interval. Therefore, data analysis is divided into two main parts namely descriptive statistics and inferential statistics. Descriptive statistics were used to organise, summarise and interpret the data collected that correspond to individual variables. Inference statistics was used to make some generalisations from sample data to the populations from which the samples were drawn.

Categorical scales were adopted to identify the different labels regarding the following: number of employees; annual financial turnover; number of project start-ups; types of projects undertaken; contracting strategies; bidding procedures; contract types; incidence of cost overruns; cost estimating approaches and methods; cost overrun sizes and risk identification, analysis and response.

Ordinal scales were assumed not only to classify but also to establish a rank order of the attributes under study. These attributes included factors influencing the choice of contract strategy, performance indicators used by contractors, the degree of uncertainty of cost components, responsibility for risk management, risk response strategies and main obstacles to risk management.

Interval scales were adopted to measure the significance of global risk factors affecting cost performance. The scale was deemed the most appropriate because apart from rank-ordering the data, it enables users to establish how far apart the different factors are and, thus, in determining the most critical. These factors are analysed by means of descriptive statistics, measures of association and tested for statistical significance. The scale provides more detailed and meaningful information than could be drawn using the former two scales. Additionally, interval data can be converted into categorical and ordinal whenever necessary.

The ratio scale was discarded because it corresponds to the highest level of measurement that is rarely achieved or even practical in management research, as it is the present study.

8.5 General analysis of responses

A total of 100 construction contractors were surveyed. A total 42 questionnaires were completed and returned which represents 42 per cent return rate. However, only 32 questionnaires were fully usable. The remaining 10 were partial, incomplete or incorrectly filled and therefore, excluded from the analysis. Two responding contractors went bankrupt during the administration of the questionnaire. Three respondents responded incorrectly by ranking more than one variable the same. Questionnaires with missing data were also discarded because it was thought they would pose questions into the representativeness of the data. Therefore, the actual rate of response was 32 per cent. This rate of response can be considered reasonable taking into account that the questionnaire was long and very detailed. According to Easterby-Smith et al (1991), the expected response rate for industry is of the order of 25 to 30 per cent. Cochran (1977) argued that even response rate of 80 per cent could raise serious questions about the generalisability of the results. Smith and Glass (1987) mentioned that many surveys with response rates below 50 per cent are valid because there are no differences between respondents and non-respondents whereas some surveys with high response rates can be biased. The common reasons presented by contractors who did not complete the questionnaires were:

- lack of time due to workload;
- lack of confidence that the information would be kept secret;
- lack of interest; and
- lack of knowledge on issues raised in the questionnaire.

All respondents wanted to receive a summary of the findings. This fact suggests expression of interest in the research. For ease of presentation and understanding, the responses were either expressed as percentages or presented graphically.

8.6 Part I - Construction contractors' attributes

Construction contractors' attributes are measured by mean of categorical scales. The choices provided by the respondents are distributed across the label categories. The analysis of these data is performed with the use of descriptive statistics, namely frequency analysis. The relative frequency distributions, or percentage distributions, of each survey question are presented in graphical format. The frequency columns show the number of class members who received each grade. Percentage distributions are derived from frequency distributions that are tabulated and converted into percentages for easier interpretation, understanding and comparison. The choice of percentage distributions to present data is based on the limited number of categories inherent in this study, (less than ten scale points). The use of frequency tables and graphics is limited by the number of scale points. A dozen or less scale points are a suitable limit for this purpose. Since the data are categorical and, therefore, there is no continuum or relationships between the categories it is assumed that the analysis of individuals variables satisfies most of the information requirements and thus, the search for association is not necessary in this section. The most appropriate statistics to describe the distributions in such circumstances is the "mode" that represents the category with the largest frequency.

In summary, substantial meaning can be derived from the use of individual variables. The results of Part I, Part II, Part III and Part IV of the survey are contained in Figures 8.1 – 8.17 and Tables 8.1-8.7.

8.6.1 Directly employed labour force

Figure 8.1 presents the distribution of construction contractors by the average range category of employees directly employed at the time of the survey. It can be seen that over 65 per cent of construction contractors employ an average of 200 employees, whereas the remaining 35 per cent have less than 100 employees on average. The pattern of distribution suggests that most construction contractors try to keep a reasonable number of employees in order to cater for the fluctuating nature of market conditions. Construction contractors often hire workers on project-by-project basis, rather than long term contracts. This strategy helps them to find the right balance between periods of high demand and market shrinkage periods. With a staggering unemployment rate in Mozambique, over 60 per cent, job demand is so high that allows contractors to adopt this strategy easily.

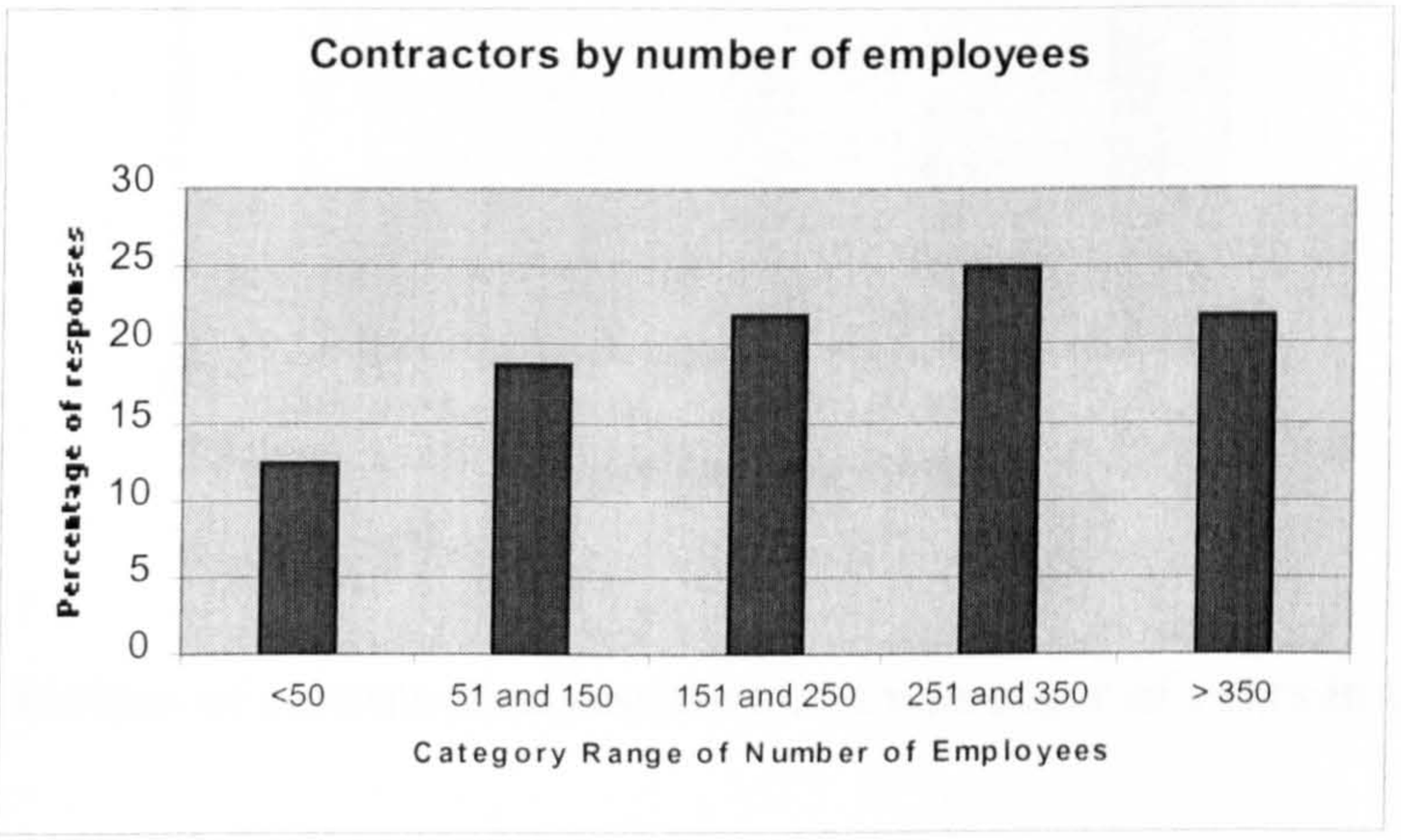

Figure 8.1: Distribution of construction contractors by average range for number of employees

8.6.2 Number of years in business

To establish the experience of construction contractors, questions pertaining to the number of years in business were asked. The distribution of construction contractors by age category range is presented in Figure 8.2. The majority of contractors have reasonable experience in business with more than ten years. About 75 per cent of companies have less than 20 years in business. The small number of companies with more than twenty years in business is partially explained by the restrictions imposed to private initiatives in the past (from 1975 to 1990). The only large companies allowed to operate at that time were state-owned. It was only from 1990 when individuals where first permitted to run construction businesses and an overwhelming number of new businesses started emerging.

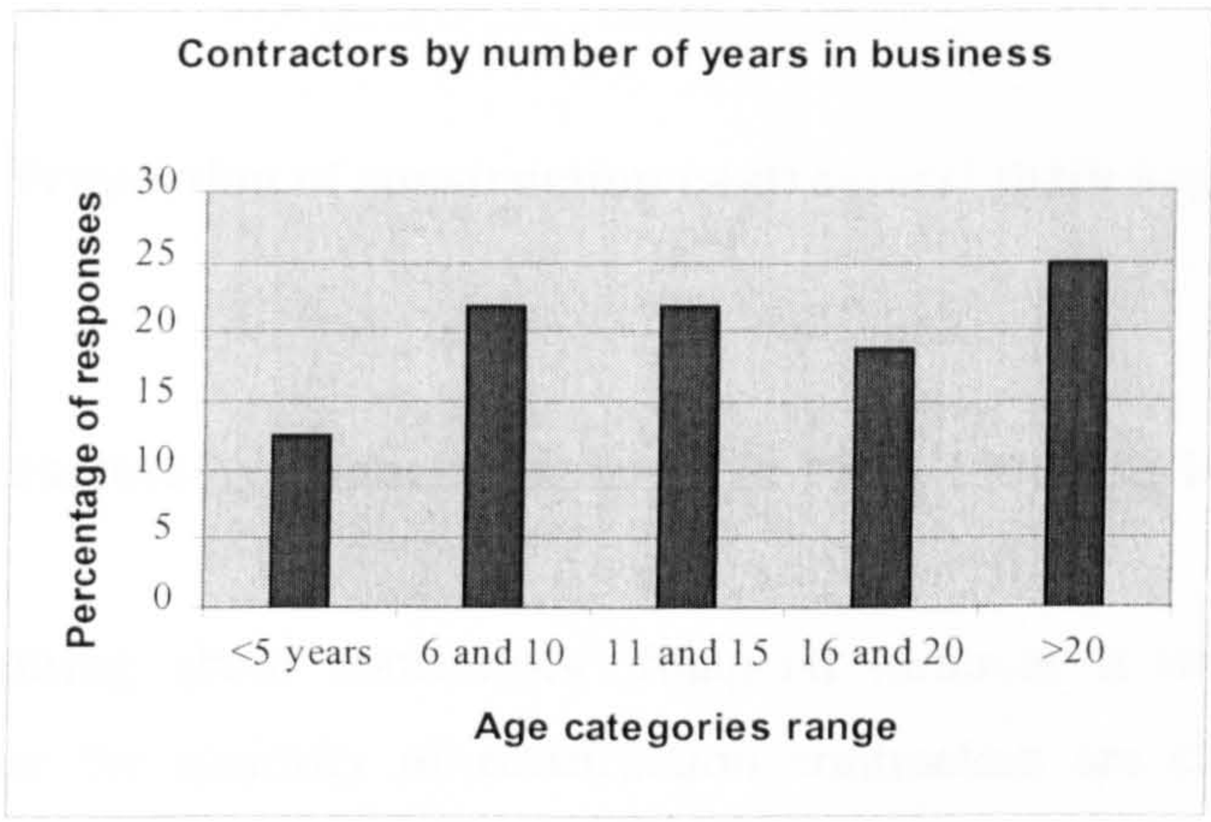

Figure 8.2: Distribution of construction contractors by number of years in business

8.6.3 Organisation's main activities

The main target of the survey was construction contractors. However, apart from their main activity several construction contractors provide additional services such as design, project management and consultancy in construction-related disciplines. The pie chart shown in Figure 8.3 presents the proportion of construction contractors' activities. The majority of them focus their attention on construction activities while a few number, seven per cent, do consultancy as well.

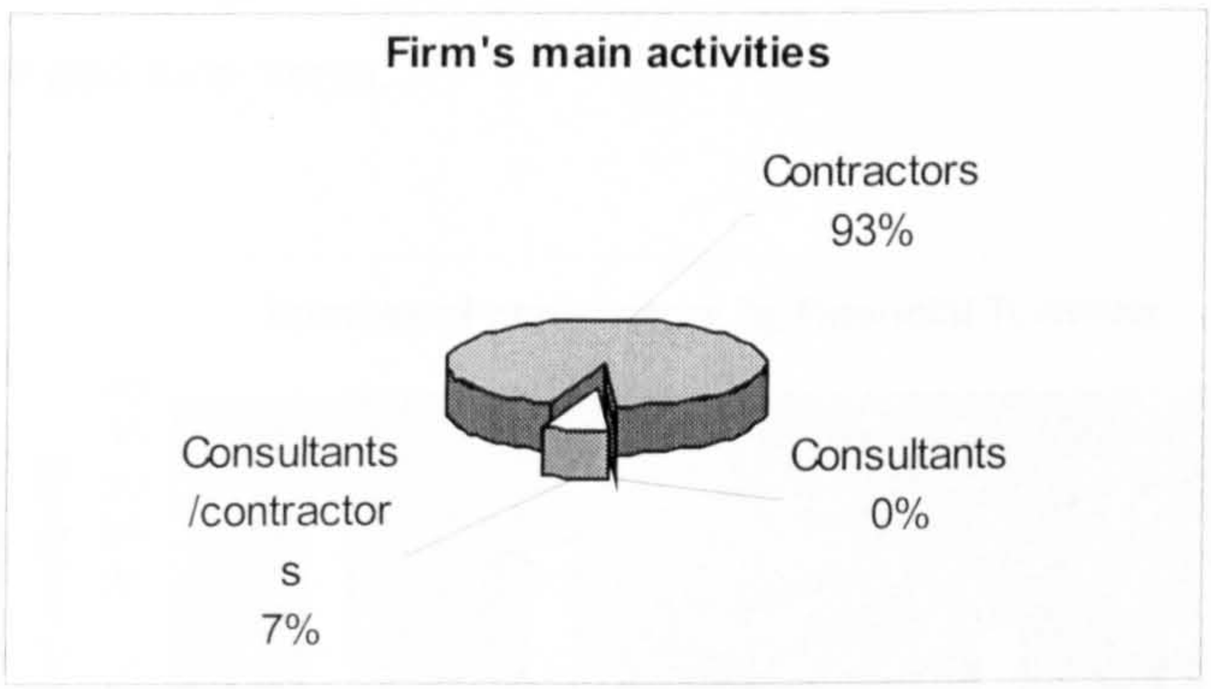

Figure 8.3: Proportion of construction contractors' main activities

8.6.4 Number of contractors by financial turnover in 1997, 1998 and 1999

To the question enquiring about contractors' financial turnover it was observed as Figure.8.4 depicts, that the majority of construction contractors are clustered around smaller values. The profiles show the gap that exists between small and large contractors. This gap is usually bridged by medium contractors, which are very few in this case. The large gap is a structural problem because the growth of construction contractors from small to medium and then to large takes much time. Since the annual financial turnover has often been used as a measure of a company's financial strength and physical ability to operate at a particular level of output small and medium contractors face much difficulties getting reasonable contracts. There are no noticeable changes in the distribution patterns

over the three years considered. The majority of construction contractors, about 75 per cent, have an average financial turnover between USD 1.0 million and 6.0 millions. Only 18 percent of construction contractors exhibit an average turnover of more than USD 10.0 millions. These values are expected for a typical developing country, with an average GDP of USD 4 billion. In this regard, Hillebrandt, 1984 argued that overall construction industries were characterised by a pyramid structure with many small firms and few large, but the gap between the large and small firms is very wide in developing countries than in developed ones. . The financial turnover is, among others factors, heavily dependent on the economic conditions of a region. In periods of high economic growth the level of turnover tend to increase and vice-versa.

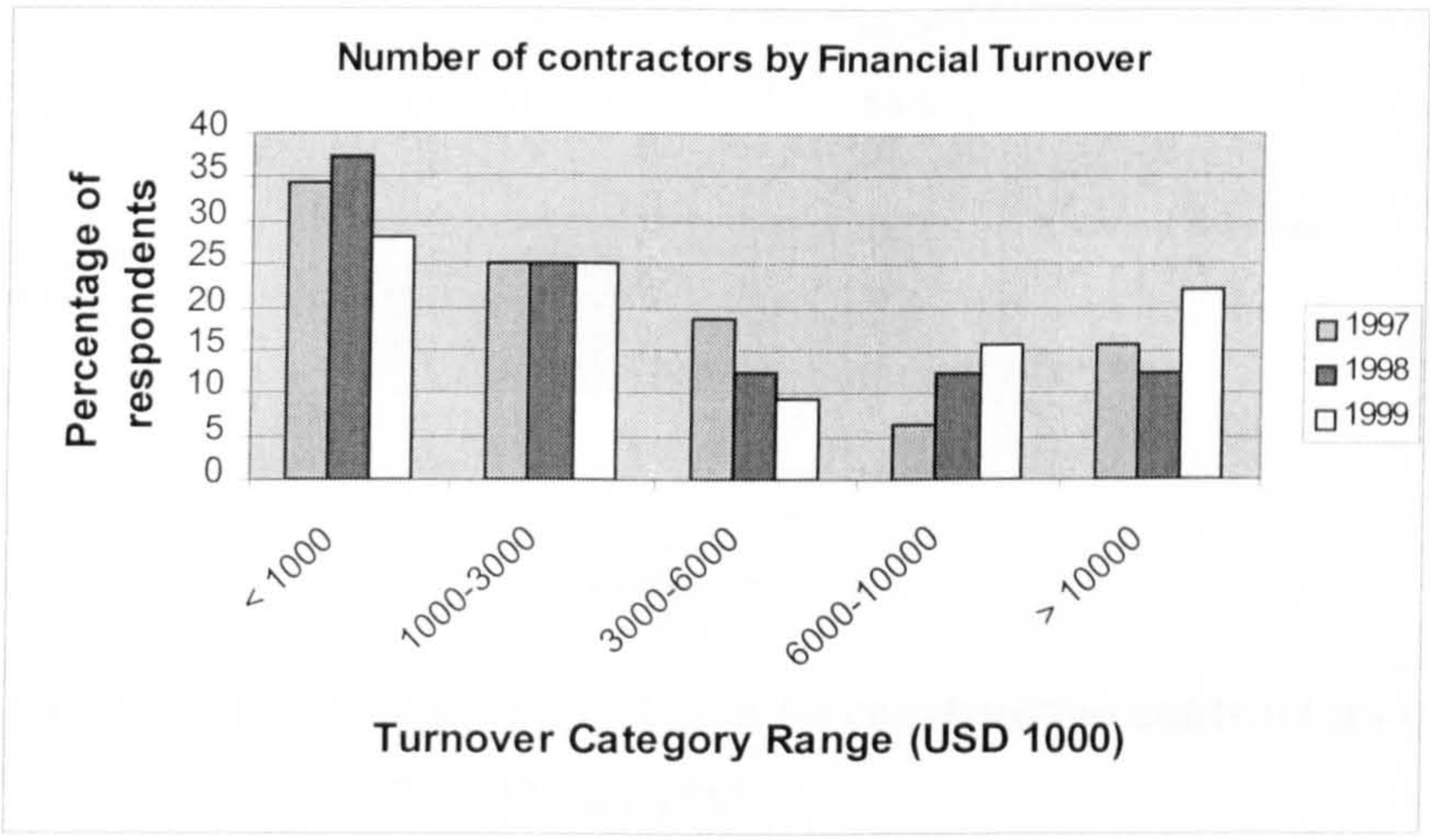

Figure 8.4: Distribution of construction contractors by average range for financial turnover

8.6.5 Project-start-ups in 1999

Figure 8.5 depicts the proportions of work undertaken by construction contractors in 1999. It clearly shows that building construction and building maintenance were the largest markets totaling about 92 per cent. It seems that building projects will still be dominant for the near future since the demand for residential, commercial and industrial

buildings is increasingly high, and in comparison to other project types they do not involve massive capital investments. The common building projects are residential, commercial, institutional and industrial. The current high demand for this type of projects can be attributed to the long period of construction stagnation. However, it is expected that civil engineering projects will experience a massive growth in the oncoming years due the need for public infrastructures particularly roads, railways, power lines, irrigation, water supply and sewage systems.

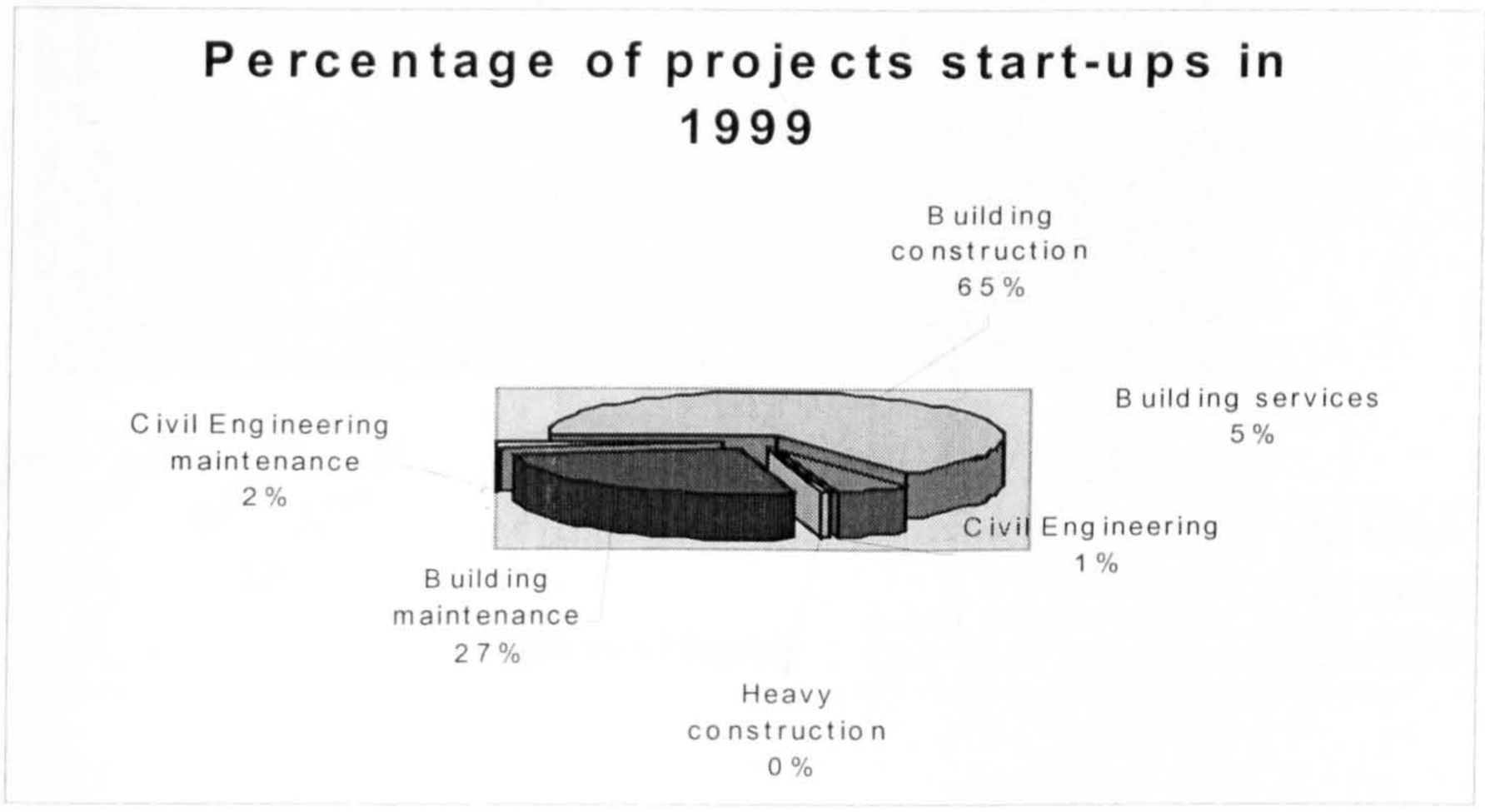

Figure 8.5: Proportion of project types undertaken by construction contractors in 1997, 1998 and 1999.

8.6.6 Project start-ups in different regions in 1997, 1998 and 1999

Figure 8.6 depicts a unimodal distribution and shows that the vast majority of construction projects are located in Maputo region which alone accounts for about 80 per cent of the total projects undertaken in the country. This fact derives from an unbalanced economic development of the country that has historical roots. Apart from being the capital, Maputo region has since benefited from the economic strength of neighbouring South Africa. Maputo has a relatively well-developed network infrastructure, has a large market segment and most key decisions are made there. These factors help to attract

many investors to Maputo than to other regions. It is very likely that the strong position held by Maputo will change soon since important massive projects have been identified and sanctioned in the other regions which possess huge development potential. These projects include gas exploration, mineral exploration and power plants.

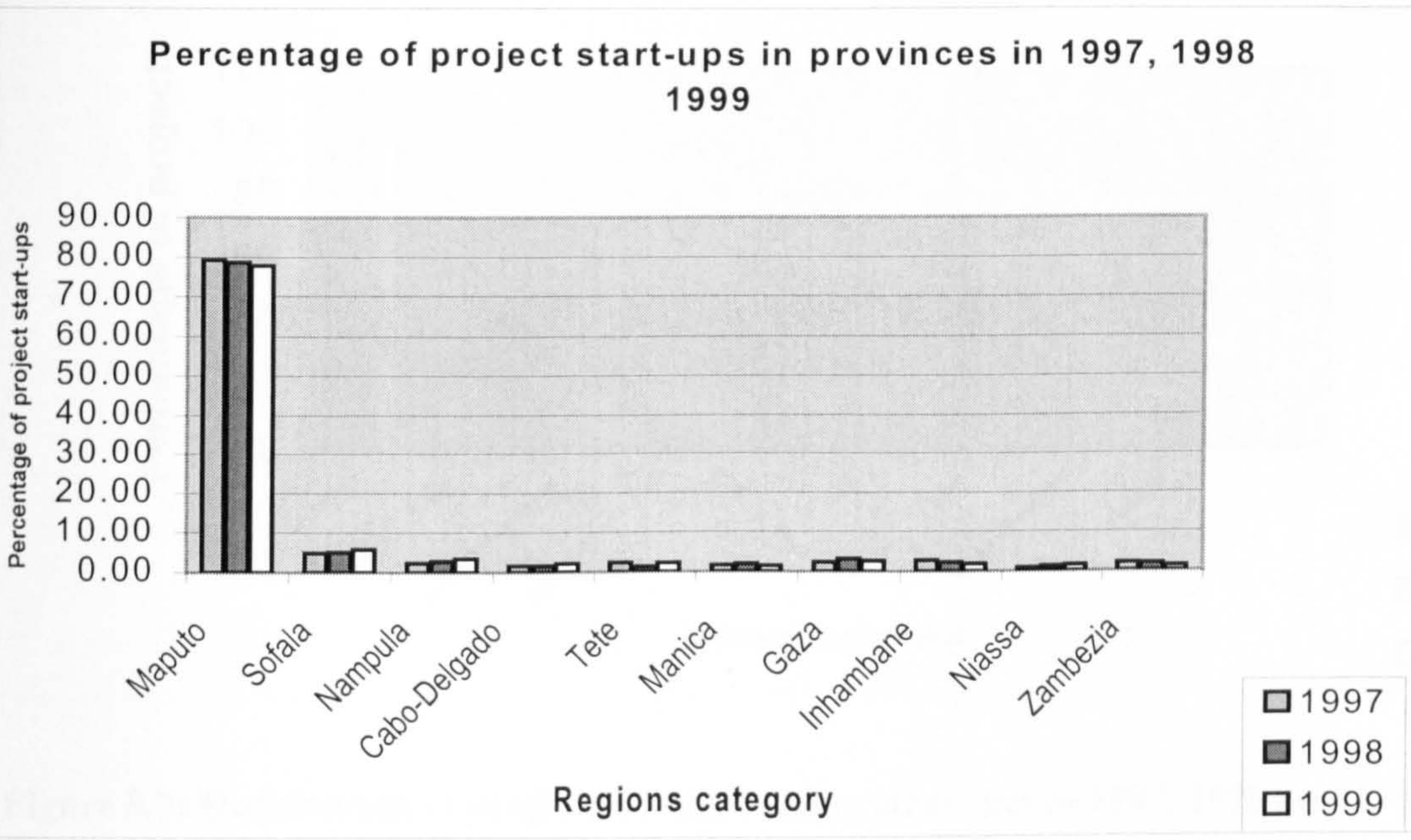

Figure 8.6: Distribution of project start-ups by region category in 1997, 1998 and 1999

8.7 Part II - Contracting strategies and cost performance

8.7.1 Projects undertaken under the different contracting strategies

The frequency of application of different contracting strategies has been presented in Figure 8.7. It clearly shows that the traditional method is the most predominant with about 95 per cent of projects implemented under this strategy. Design and build is the second most used strategy with about five per cent respondents. The massive use of the traditional strategy can partially be explained on historical grounds. The separation of design and construction has been used for decades and almost all public and private large

projects have relied on this procedure even in large industrial and civil engineering projects.

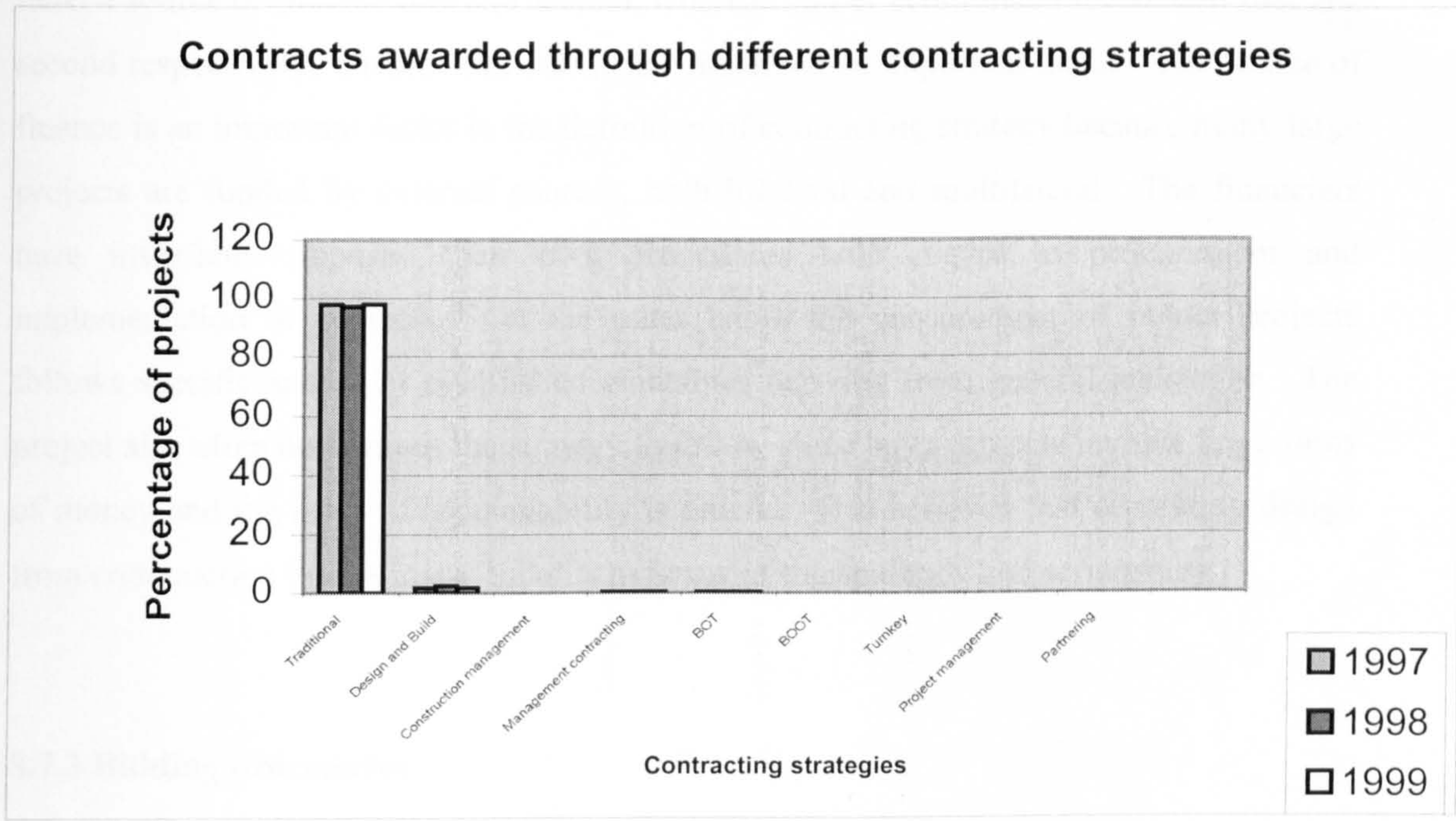

Figure 8.7: Distribution of projects by contracting strategies in 1997, 1998 and 1999

8.7.2 Factors influencing the choice of contracting strategy

Table 8.1: Distribution of respondents views' on the factors influencing choice of contracting strategy

Factor	1	2	3	4	5	Total	
Source of finance	46.8	31.5	9.3	6.2	6.2	100	
Legislation	62.5	12.5	15.7	9.3	0	100	
Practicality	12.5	21.7	31.5	28.1	6.2	100	
Project size	43.7	37.7	9.3	9.3	0	100	
Project type	25	34.4	9.3	12.5	18.8	100	

It was revealed that the source of finance, legislation and project size were the most influencing factors for choice of contract strategy. Over 77 per cent of respondents ranked source of finance first and second, whereas 75 per cent ranked legislation first and second respectively. Project size was also considered an important factor. The source of finance is an important factor in the definition of contracting strategy because many large projects are funded by external sources, both bilateral and multilateral. The financiers have invariably imposed their own procedures with regard to procurement and implementation of projects. On the other hand, the procurement of public projects follows specific and strict established guidelines deriving from general legislation. The project size often determines the strategy to follow since large projects involve large sums of money and the issue of accountability is crucial. It is believed that separating design from construction brings many benefits in terms of transparency and seriousness.

8.7.3 Bidding procedures

Figure 8.8 depicts a unimodal distribution with local competitive bidding (LCB) being the most widely used bidding procedure followed by negotiated and selective options. The reason behind the massive use of LCB lies on the need for providing equal opportunities to the different competitors, on one hand, and the empowerment policy being implemented by the government, on the other hand. It is believed that competitive bidding brings several advantages to the client, of which a "better" price is the most visible. When it comes to public funded projects the issue of accountability/transparency in the whole procurement process is of paramount importance. Despite these arguments, in many occasions the benefit of competitive bidding has proved to be illusory. There has been a large number of projects awarded to the lowest bid with tremendously bad results because the firm that wins a contract is simply the one submitting the lowest estimate, which is not necessarily the one with the lowest costs or the highest level of efficiency and effectiveness. Unlike the public sector, many private clients award a contract based on trust and record of a contractor. They consider open competition time-consuming and fruitless in terms of obtaining good value for money. International

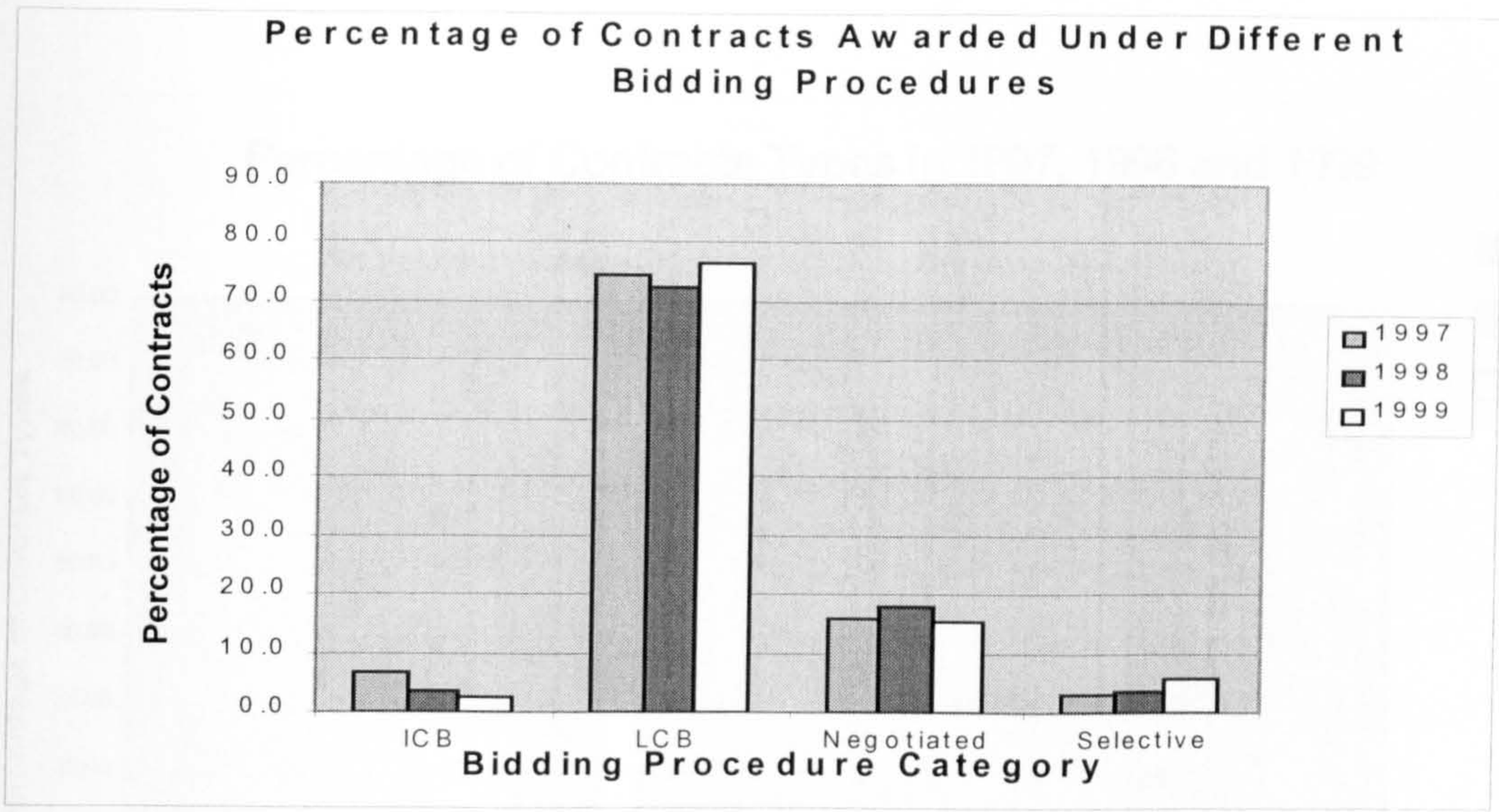

Figure 8.8: Distribution of contracts by bidding procedures

Competitive Bidding (ICB) is almost employed in very large, complex and multilateral projects where an attempt to seeking particular skills over the world is worth pursuing.

8.7.4 Contract types in 1997, 1998 and 1999

Figure 8.10 presents a unimodal distribution of contracts by contract types in 1997, 1998 and 1999. It was found that unit rate fixed price type of contract is the most used modality followed by unit rate variable type of contract. This distribution profile is highly associated with the traditional contracting strategy where design and construction are carried out separately and tenders are invited based upon bills of quantities. Clients tend to adopt unit rate fixed contracts because they are averse to paying additional money even in situations where variations are inevitable due to design errors, omissions and cost escalation. They attempt to protect their own interest to the detriment of contractor's position. Many contractors argued that this is often the main cause of poor quality.

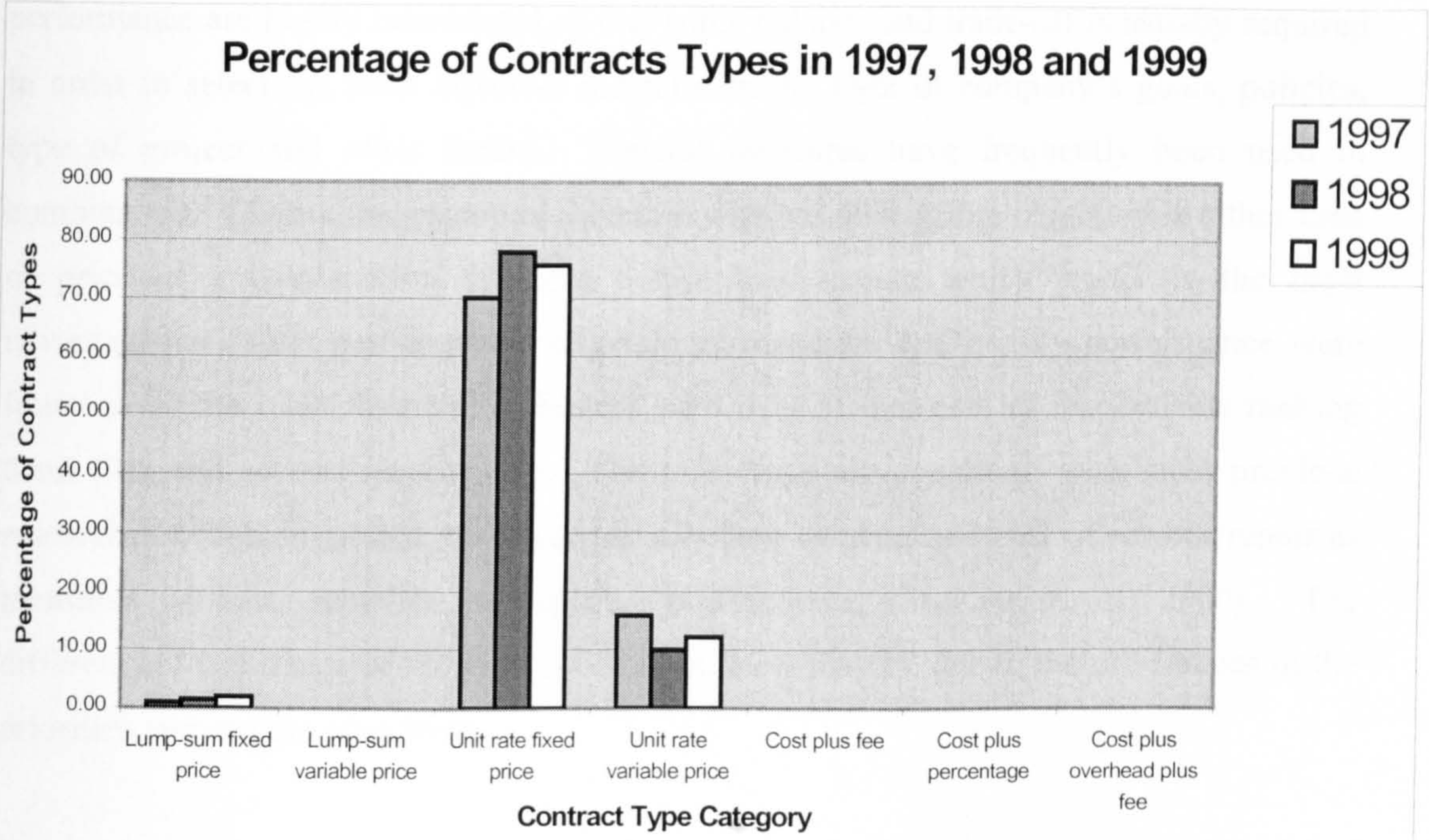

Figure.8.9: Distribution of contracts by contract types in 1997, 1998 and 1999

8.7.5 Performance indicators used by contractors

Table 8.2: Frequency distribution of project performance indicators

	1	2	3	4	5	6	Total (%)
Cost performance	31.3	25	18.75	9.38	9.32	6.25	100
Schedule performance	21.8	25	25	12.6	15.6	0	100
Quality performance	25	28.1	9.38	18.8	9.34	9.38	100
Safety	12.5	15.6	12.5	34.4	12.5	12.5	100
Profit	6.25	18.75	18.75	6.25	25	25	100
Client satisfaction	6.25	25	31.25	21.9	9.35	6.25	100

Table 8.2 presents contractors' frequency ranking of project performance indicators. In principle, no single indicator is used alone to measure project performance. Measures of performance are highly interrelated so that some balance and trade-off is usually required in order to select the most effective indicator in the light of company's goals, policies, type of project and other factors. Several measures have frequently been used in combination. Clients, for example, ascertain whether their prime objective is either time or price or a combination of these before they decide which tender is the most advantageous. Cost performance, schedule performance and quality performance were found to be the most favoured indicators with over 50 per cent of respondents ranking them first and second respectively. These findings are consistent with most previous researches which suggested cost overrun, schedule overrun and cost of rework/repair as measures of cost, schedule and quality performance, (McKim et. al. 2000). The differences in rankings of the groups of respondents may be due to the differences in the priorities and project objectives.

8.7.6 Frequency of construction project cost overruns

Figure 8.10 depicts the frequency with which the different types of projects experienced cost overruns in the period under consideration in this study. Almost all types of projects suffered cost overruns with varying magnitudes. Building construction, building maintenance and civil engineering projects suffered the most significant cost overruns with averages of 40 per cent, 50 per cent and 27 per cent respectively over the period under analysis. Understandably, building maintenance is the category presenting the highest frequency of cost overruns due the high uncertainty associated with these projects. Many buildings did not benefit from any kind of maintenance for more than two decades and deteriorated to such an extent that it was virtually impossible to prepare good quality projects.

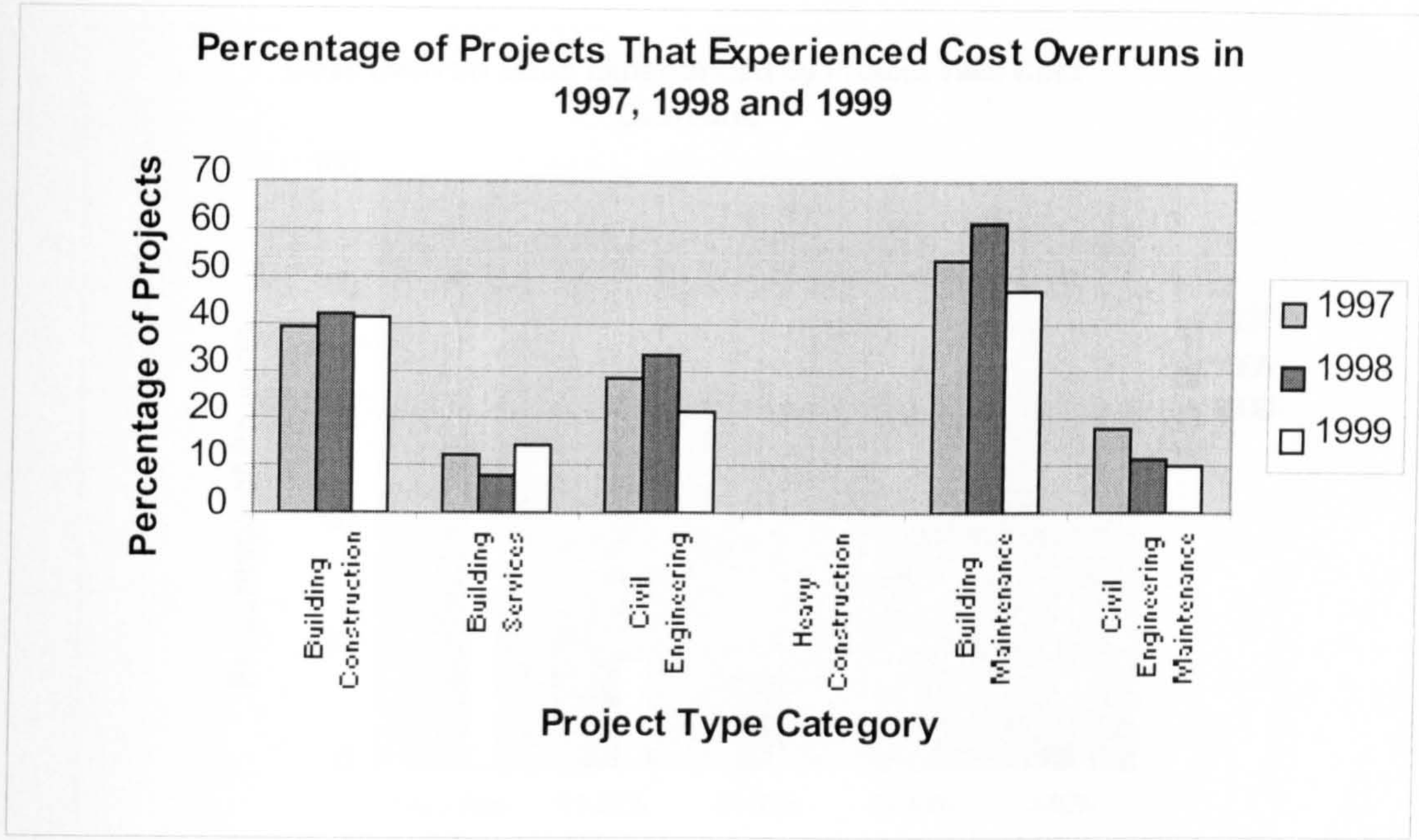

Figure 8.10: Frequency of construction projects cost overruns

8.7.7 Cost overrun sizes experienced by projects with cost overruns

Figure 8.11 depicts the distribution of projects by cost overrun sizes in the period under analysis. The distribution pattern indicates that the most frequent cost overrun sizes are of the order of 10 per cent and between 11 and 20 per cent. Although they occur, the other category sizes have low probability of occurrence. In circumstances where the market conditions are tight, even a marginal cost overrun can wipe off the planned profits and lead to severe losses. It is worth mentioning that often contractors are faced with difficulties in determining the cost impact of changes that are one of the main reasons for cost overruns. For example, they lack an objective methodology for assessing cost impact due to loss of productivity. Therefore, many times contractors realise they incurred in significant costs at the time they have produced profit-loss statements.

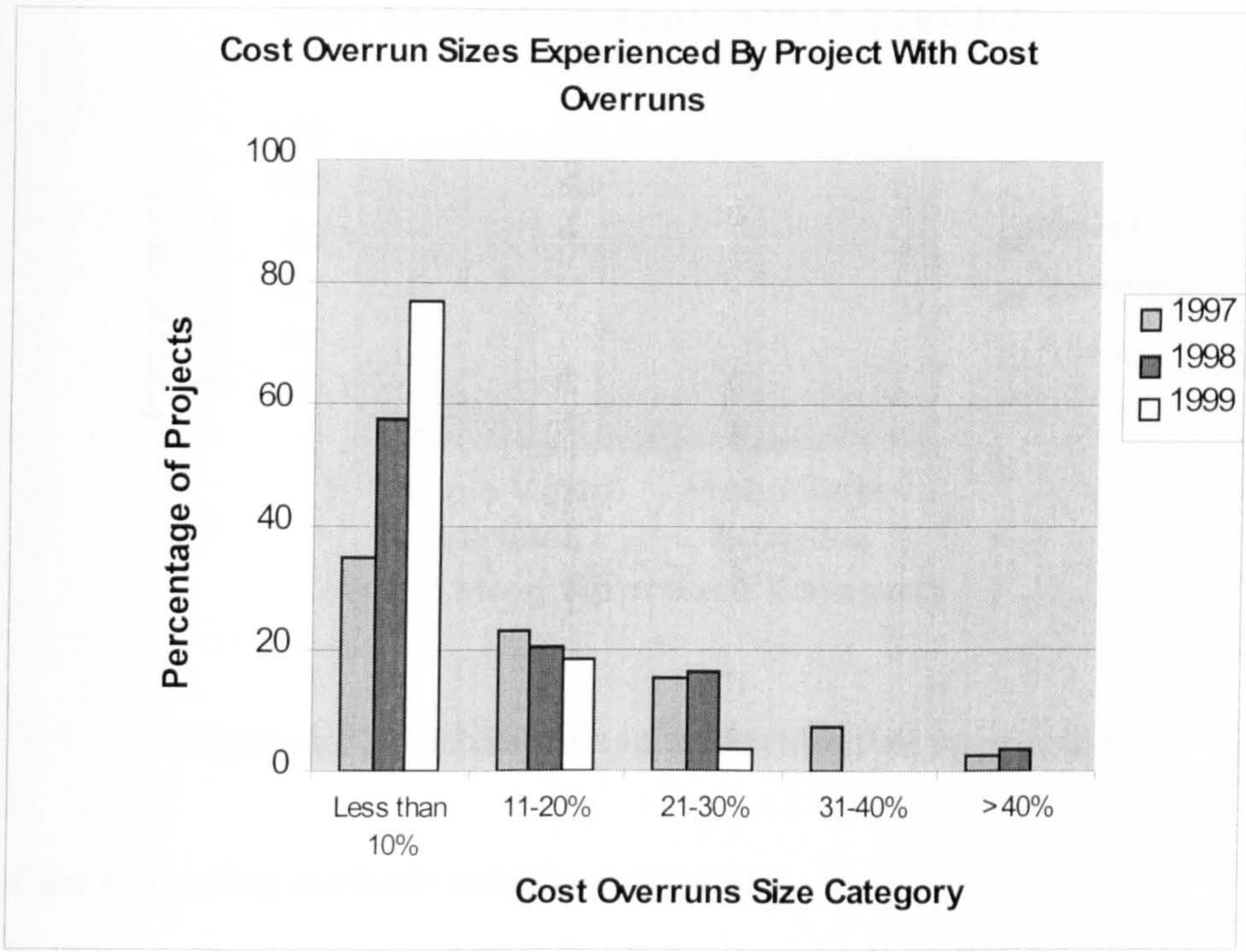

Figure 8.11: Distribution of percentage of projects by cost overrun sizes

8.7.8 Frequency of cost estimating approaches

Almost all construction contractors use single value estimates and very rarely they use stochastic (probabilistic) estimating. The percentage of the former is 99 per cent while for the latter is five per cent. About 95 per cent of respondents revealed that never used probabilistic estimates. This distribution pattern is no surprising since evidence from previous researches indicated that range estimating is rarely applied by construction practitioners, (Raftery, 1994; and Uher, 1996). Instead, point or single estimates have been the norm.

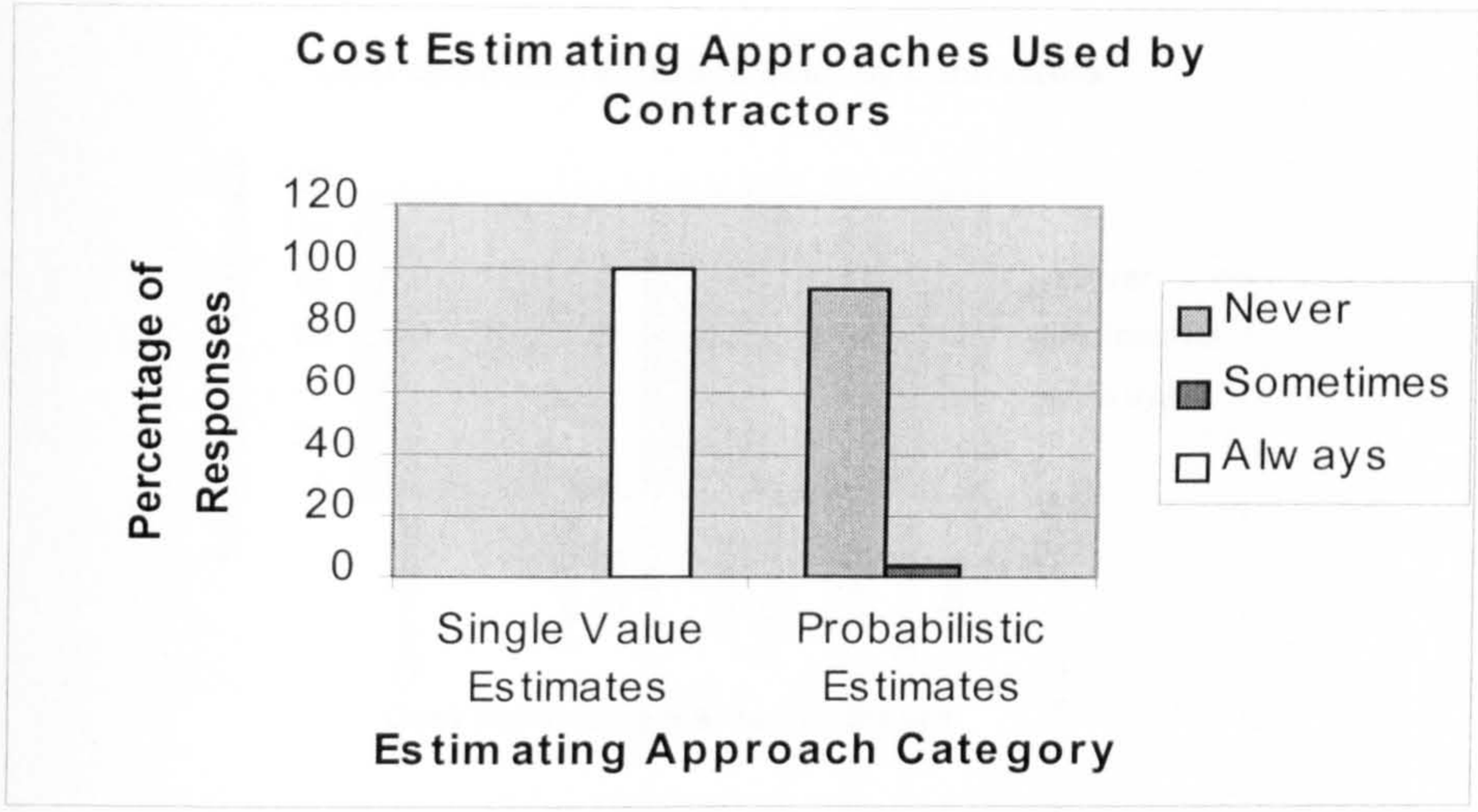

Figure 8.12: Distribution of cost estimating approaches

8.7.9 Cost estimating methods used by contractors

From Figure 8.13 it can be concluded that about 100 per cent of respondents use past unit rate and output rate cost always. The operational cost estimating method is almost never used by contractors, and the sub-contractor rate is used sometimes. The traditional bill of quantities approach to tendering explains the extensive employment of past unit cost and output rate cost while sub-contractor rate is driven mainly by the need to sub-contract some portions of work that main or general contractors do not regularly do.

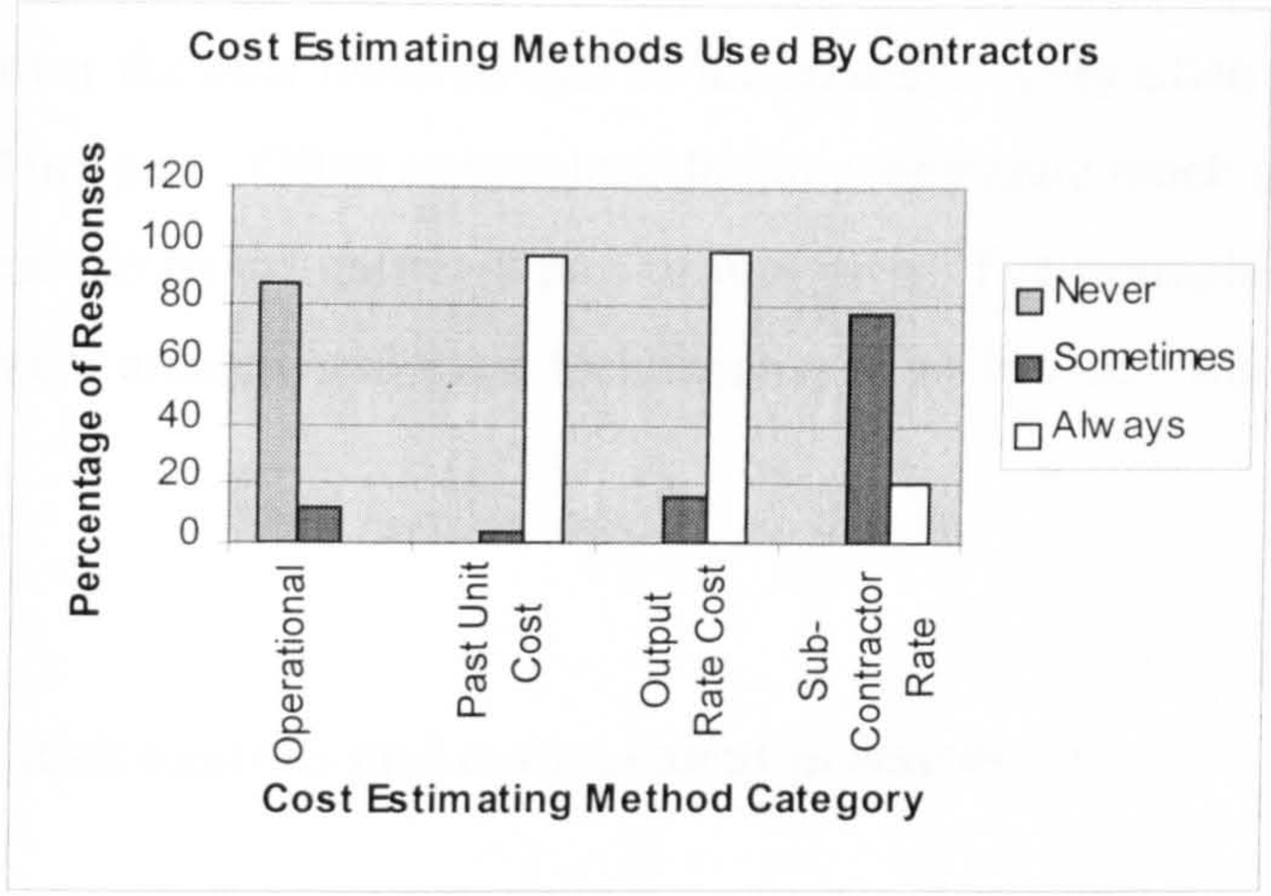

Figure 8.13: Distribution of cost estimating methods used by contractors

8.7.10 Most uncertain cost components

Table 8.3: Frequency ranking of cost components in order of their uncertainty

	1	2	3	4	5	Total (%)
Labour	0	18.8	12.5	28.1	40.6	100
Equipmt.	9.4	21.8	31.2	18.8	18.8	100
Materials	9.4	12.5	21.8	37.5	18.8	100
Indirect Costs	25	43.7	12.5	9.4	9.4	100
Contingencies	56.3	21.8	12.5	0	9.4	100

Construction contractors ranked indirect costs and contingencies as the most uncertain cost components faced with in the process of cost estimating with the corresponding percentages of 68 and 78 per cent respectively. The frequency ranking confirms the widespread practice among contractors (Raftery, 1994), since objective data for determining contingencies and indirect costs objectively is generally unavailable. The

common practice is to add a contingency sum as a percentage of mark-up on the base estimate, based on judgement, to ensure that the estimated project cost is realistic and sufficient to cover the cost incurred due to uncertainty. Very often this percentage is of the order of 10 per cent. Often contractors do not concentrate much in determining labour costs since these are an insignificant part of unit rates. For example, the average pay for labourer (different artisans and even technicians) is so low that the overall labour costs are negligible.

8.8 Part III – Risk analysis and management practices

8.8.1 Responsibility for managing risks within companies

Table 8.4: Frequency ranking for risk management responsibility

	1	2	3	4	Total
Estimating departament	56.3	25	0	18.7	100
Planning departament	0	37.5	37.5	25	100
Senior executives	50	28.1	15.6	6.3	100
Project personel	0	0	40.6	59.4	100

Asked to rank the responsibility for risk management within their companies, the majority of construction contractors mentioned the estimating department and the senior executives as the entities in charged of this task. As shown in Table 8.4, 56 per cent and 50 per cent of respondents ranked estimating department and senior executives first, respectively. Despite this distribution trend, planning department has been ranked second and third by 75 per cent of respondents, while project personnel is not considered as important as the other sectors in the process of risk management. In the light of this distribution pattern it can be concluded that risk management is performed by the

estimating, planning department as well as by senior executives. The estimating and planning departments have a key role in the planning and analysis, while senior executives make the final decisions on the response strategies to be adopted.

8.8.2 Risk identification techniques

In response to the frequency of use of the different risk identification techniques 100 per cent of the respondents mentioned experience as the technique they always employ, while 60 per cent and 40 per cent respectively use both historical data and experience. Checklists, brainstorming and questionnaire are rarely used by the majority of the respondents. These response distributions confirm findings of previous researches and risk management literature (Akintoye et al., 1998).

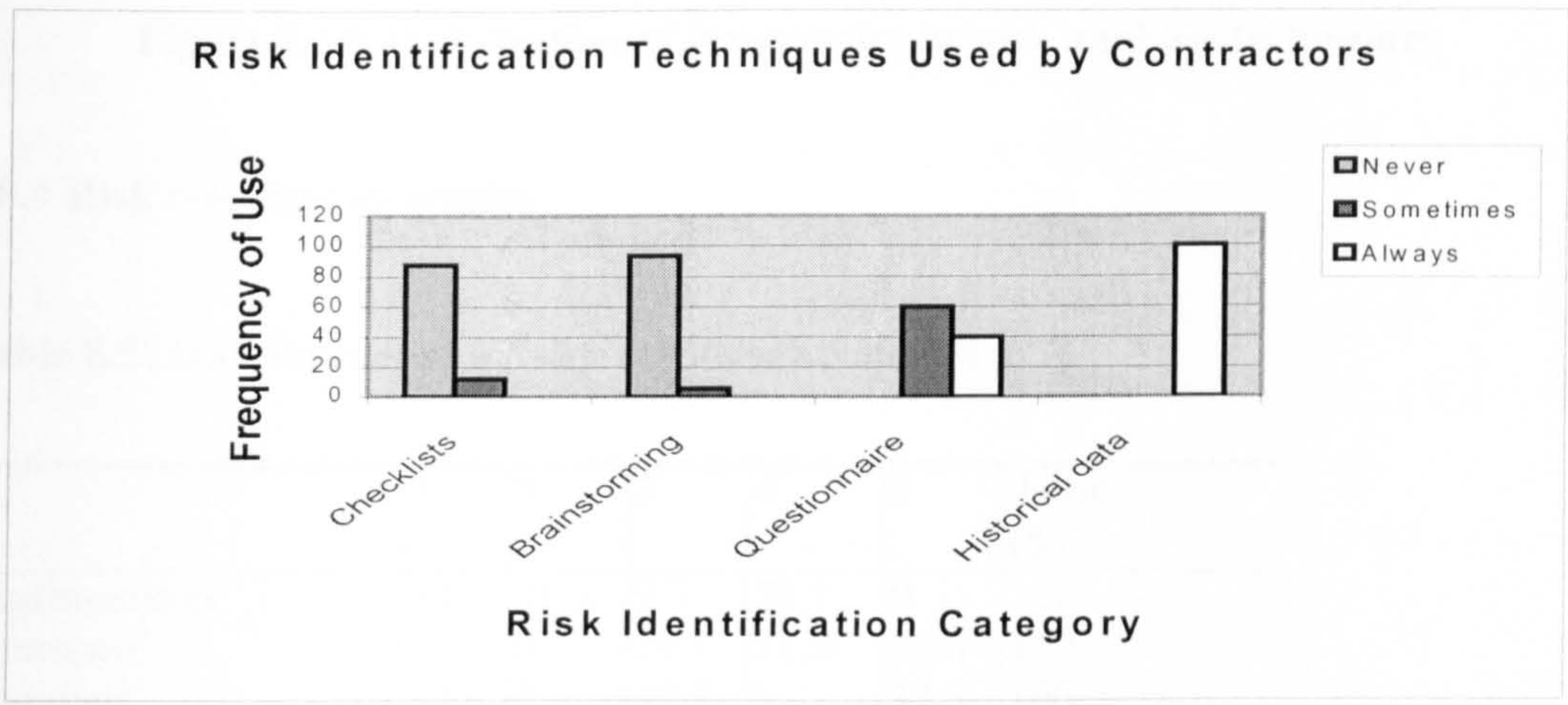

Figure 8.14: Distribution of frequencies by risk identification techniques

8.8.3 Risk analysis techniques

As with risk identification techniques, the survey revealed that most respondents favour experience and intuitive judgement in risk analysis exercise. Analytical models and stochastic approaches are almost never used. This is perhaps so due to the lack of appropriate skills and tools necessary to handle the elaborated risk management tools.

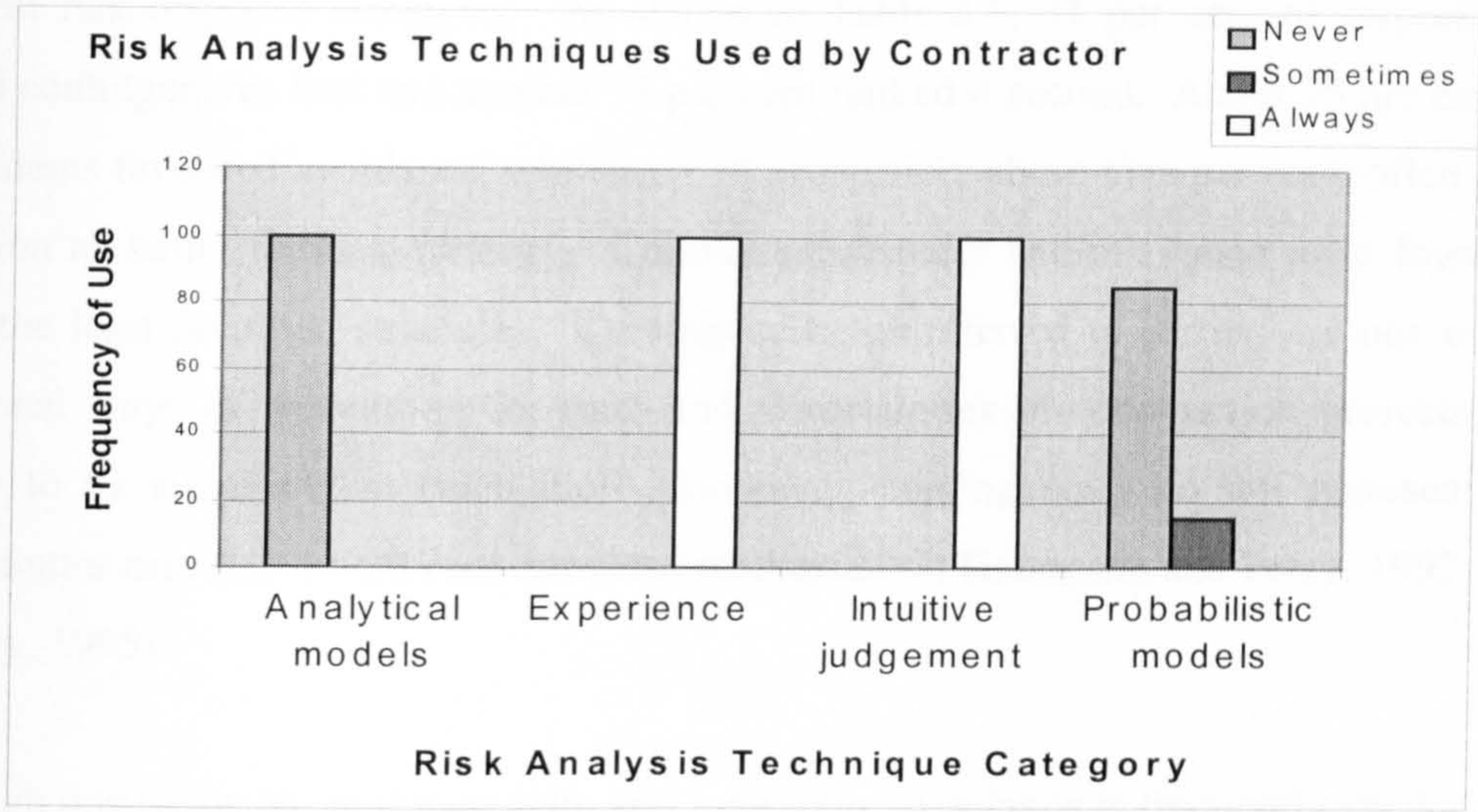

Figure 8.15: Distribution of frequencies by risk analysis techniques

8.8.4 Risk response strategies

Table 8.5: Distribution of by risk response strategies

	1	2	3	4	5	Total (%)
Contingencies	31.3	31.3	9.3	28.1	0	100
Insurance	0	0	28.1	31.3	40.6	100
Avoidanc e	25	0	37.5	0	37.5	100
Contractual transfer	0	0	21.8	46.9	31.3	100
Reductio n	9.3	12.5	31.3	18.8	28.1	100

Construction contractors were questioned about the frequency with which they use the different risk response strategies. As shown in Table 8.5, 31 per cent of respondents ranked contingencies first and another 31 per cent ranked it second. About 25 per cent of respondents favoured avoidance, while a small proportion, about nine per cent, often used reduction as being the best strategy. Contractual transfer and insurance were found as being the least favoured strategies. Contingencies, as referred to earlier, are one of the traditional ways of accounting for risks and uncertainties in construction projects due mainly to its simplicity in calculation. However, contingencies do not represent the uncertainties associated with cost estimates realistically, (Thompson and Perry, 1992; and Toakley, 1995).

Although unsustainable in the medium and long term, avoidance is frequently used as the simplest and comfortable way of getting rid of risks. Contractual transfer is a very difficult option for construction contractors since they are generally not in a good position to negotiate the terms of contract with the client. Clients use standard forms of contract that best protect their interests to the detriment of contractors. Some contractors pointed out that they often accept risky terms of contracts to keep their firms operational even in situations where the likelihood of loss is high. These findings are in line with conclusions by Aniekwu and Okpala, (1988b) who stated that construction contracts are seldom the subject of legal dispute and forms of contracts were inappropriate. Insurance is considered costly by many contractors and thus they are unwilling to purchase an insurance package. They argued that profit margins are extremely low and buying insurance would lead their proposals uncompetitive.

8.8.5 Benefits of risk management

Asked to give their opinion on the benefits of risk management all respondents considered it as being beneficial. They view risk management as a helpful approach in

anticipating risk and uncertainties inherent to construction projects instead of being reactive to the events.

Figure 8.16: Proportion of respondents as to the benefits of risk management

8.8.6 Obstacles to risk management

Table 8.6: Frequency ranking of obstacles to risk management

	1	2	3	4	5	Total
Lack of specific knowledge	28.1	12.5	15.6	21.9	21.9	100
Lack of awareness	0	6.3	0	65.6	28.1	100
Difficulty handling probabilities	12.5	31.3	28.1	18.6	9.5	100
Lack of effective tools	18.8	59.3	15.6	6.3	0	100
Time pressure	25	28.1	31.3	6.1	9.5	100

When required to express their opinion on the obstacles to the effective implementation of risk management within their organisations construction contractors mentioned lack of specific knowledge, difficulty in handling probabilities, lack of effective tools and time pressure as the main barriers. Most of all time pressure and lack of specific knowledge were found to be the most significant with 25 and 28 per cent of respondents,

respectively. It is important that respondents are very aware of risks permeating through construction projects, as awareness is a primary element in the whole process of risk management. Lack of awareness was ranked fourth by 65 per cent of respondents. Lack of effective tools explains partially the extensive use of intuitive judgement and experience. If these tools were available more practitioners would gradually make use of them in this task.

8.8.7 Respondents' knowledge of risk management

Construction contractors were asked to provide an assessment of their knowledge on risk management on a scale of 1 (very little knowledge) to 5 (very deep knowledge. The average score is 3.2, which represents average knowledge of the respondents.

8.9 Part IV - Global risk factors

This part of the questionnaire provided respondents with the opportunity to rate the variables previously identified from the literature, discussions with construction contractors and during the piloting stage. They were also asked to add any further factors that they felt had significant impact on cost performance. The rating served the purpose of contractors expressing their perceived significance of global risk factors as predictors of cost performance on a scale ranging from 1 (very low effect) to 5 (very high effect). The analysis of the data regarding global risk factors was performed with the use of both descriptive and inferential statistics. Descriptive statistics aim to provide description of data namely determination of averages, measures of dispersion and importance index. Inferential statistics are intended to make probability judgement concerning the population on the base of sample data. The process of data analysis comprises two main stages, namely measures of association and statistical description of the data and determination of the importance of global risk factors.

8.9.1 Measures of association

Measures of association are usually used to ascertain and describe the nature of any relationship between different variables. Measuring association is important in that the potential relationships among variables help to explain, describe, predict and control events. Uncovering relationships among variables adds much more knowledge than simply knowing about a single variable. Obviously, this assertion depends on the goals that have been set. The two main issues associated with the measuring association are the extent and direction of the association and cause-effect inferences. This study is devoted to the former issue, i.e., the extent and direction of the association.

Two techniques that measure association were considered: Spearman's rank coefficient of correlation; and Kendall coefficient of concordance. The Spearman's rank coefficient of correlation is used to measure the correlation between two sets of rankings. Kendall coefficient of concordance was considered the most appropriate since the study deals with more than two sets of data. The data was derived from the questionnaire so the considerations made for the descriptive statistics in terms of sample size apply to this analysis.

The literature revealed that there was no consensus on the influence of some factors affecting cost estimates among construction practitioners, particularly project size (McCaffer, 1976). Therefore, it was decided to test the degree to which construction contractors agreed in the rankings of risk factors affecting cost estimates namely estimator related factors, project/design related factors, and market conditions. For this purpose, the Kendall's coefficient of concordance (W) was determined. The Kendall coefficient of concordance **W** is a technique that can be used to compare the association among different sets of rankings by different respondents. A high or significant value of W suggests that the different raters are essentially applying the same standard in ranking the objects under study (Siegel and Castellan, 1988). Therefore, if there is a significant lack of agreement among the raters on the ranking of the variables under analysis **W** will tend to zero. On the contrary, full agreement lead to a **W** of one. The set of rankings is

designated **k** and the number of objects or individuals **N**. In this study **N** represents the number of global risk factors and **k** the number of respondents. The Kendall's coefficient of concordance is calculated as follows:

$$W = \frac{S}{(\frac{1}{12})\ K^{2}(N^{3} - N)}$$

(Equation 8.1)

$$S = \sum (R_j - \frac{\sum R_j}{N})^2$$

(Equation 8.2)

$$M = \frac{\sum R_j}{N}$$

(Equation 8.3)

where

R_j is the sum of the ranks attributed to each variable or object;

S is the sum of squares of the observed deviations from the mean R_j;

K is number of sets of rankings, that is, the number of respondents or judges;

N is number of entities ranked (the number of global risk factors); and

M is the mean value of the ranks.

When there are tied observations these are each assigned the average of the ranks that would have been assigned had no ties occurred. Then, the expression 8.1 needs to be adjusted for tied observations. The effect of tied observations is to depress the value of **W,** which is then determined by

$$W = \frac{S}{(\frac{1}{12})\ K^{2}(N^{3} - N) - K\sum T}$$

(Equation 8.4)

where

T is the correction factor for tied observations; and

t is the number of observations in any group tied that are tied for a given rank.

$$T = \frac{t^3 - t}{12}$$

(Equation 8.5)

When a small number of ties occur they have negligible effect on **W** and, therefore, the correction factor can be neglected.

8.9.2 Hypothesis testing and significance of W

Hypothesis testing is to do with comparing distributions. It involves accepting or rejecting explanations of differences or relationships among variables within known degrees of certainty. Hypothesis testing enables going from known to unknown distributions, that is, to make inferences about parent populations from which the known data are drawn. The null hypothesis is the hypothesis of "no difference", "no relationship" or "no agreement". Therefore, inferential statistics aims to estimate how far above or below zero a difference or relationship can be expected to lie due to sampling error. Then, the further a difference or a relationship is above or below zero, the less chance it has of occurring as a result of random sampling error and the greater chance it has of being statistically significant. The null and alternative hypothesis in this study are formulated as follows:

H_0 : There is no agreement on the rankings among contractors

H_1: There is an agreement on the rankings among contractors

8.9.3 Significance

The level of significance represents the probability of making a mistake by rejecting a null hypothesis due to sampling error, when it is in fact true. Working with sampling data is always subject to sampling error. The significance of test results in this study is set at p = 0.05 level, one-tailed test. This level of significance is chosen in order to keep the probability of making type I error as small as possible. That is, to avoid claiming that a significant difference between population distributions has been found when, in fact, it has not been found. In one-tailed test if the test score has a probability lower than the significance level, then it falls within the tail-end of the known distribution of interest.

This indicates that the score is unlikely to have come from the same distribution as the known distribution, but comes from a different distribution, that is, if a score falls beyond the significance level then it belongs to a different distribution to the known distribution, the unknown distribution. The significance level is, therefore, the decision criterion for accepting or rejecting the null hypothesis. If the probability is lower than the significance level the null hypothesis is rejected which means that the score comes from a different distribution to the known distribution. The overlap of distributions even when they are genuinely different make it difficult to avoid the risk of error. Ideally, it would be better to avoid both type I and type II errors at all, but that is almost impossible since the available information is based on samples and not populations. Additionally, it would be desirable to minimise both types of errors. Again, this is very difficult due to the limitations imposed by sample sizes. Very large sample sizes are impracticable or costly that can not be afforded.

Table 8.7 presents the rankings of estimator-related factors, project/design-related factors and market conditions factors provided by contractors. These rankings were adjusted for tied ranks. From the Table 8.7 S= N=7, K= and ΣT=. The values of Kendall coefficient of concordance W for each of three groups of risk factors are 0.32, 0.26 and 0.23, respectively. The significance of W is tested by measuring the probability of occurrence

of any value as large as the observed value of W using χ^2 statistics. Since the number of respondents is greater than 20 the expression for large samples was used, instead of small samples, to determine k(N-1)W, which is approximately distributed as χ^2 with N-1 degrees of freedom, (Siegel, 1956, p.269). The values of χ^2 are 28.83, 32.24 and 28.5 respectively. From the statistical tables (Siegel, 1956) the critical value of $\chi^2_{0.05}$ (df=31) is 43,7. The calculated values of χ^2 are below the critical value. Therefore, the null hypothesis, that there is no agreement on the contractors' rankings, is accepted and it can be concluded that there is no agreement among contractors significant at $p = 0.05$. Despite this disagreement on the rankings these factors were considered as being important predictors of cost performance by contractors. The disagreement means that the contractors apply different standards in ranking these factors.

Table 8.7 Estimator, project/design and market conditions risk factors rankings

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	#	17	18	19	20	21	22	23	#	25	26	27	28	29	30	31	32	Rj	M	(Rj - M)	(Rj - M)2
1	Motivational bias	2	1 5	3	3	1 5	3	3	1 5	2	3	3	3	2	2	2	1	2	3	1	2	2	2	1.5	3	3	2	1	3	1	1 5	3	3	70 5	64	6 5	42 25
2	Incentives	3	3	2	2	3	2	3	1 5	2	2	2	2	3	3	3	2	3	2	3	3	3	3	3	2	1	3	3	1	3	3	2	2	78 5	64	14 50	210 25
3	Adjustments and anc.	1	1 5	1	1	1 5	1	1	3	2	1	1	1	1	1	1	3	1	1	2	1	1	1	1.5	1	2	1	2	2	2	1 5	1	1	44	64	-20 00	400 00
																																		193			652 50
4	Project size	4	3	2 5	4	1	4	2	3	4	4	1	3	4	3 5	4	3	2	4	4	3 5	3 5	1	4	1	3 5	1	4	3 5	3	4	4	4	100	80	20	400
5	Design complexity	3	4	2 5	1 5	4	3	4	1 5	1	3	3	4	3	3 5	3	4	4	3	2	3 5	3 5	3	3	4	3 5	4	2	3 5	4	3	1	1	96	80	16	256
6	Vagueness in scope	2	1	4	1 5	2	2	1	1 5	3	2	4	2	1 5	2	1	1	3	1 5	1	2	2	2	1 5	3	2	2 5	3	2	2	1.5	3	2 5	66	80	-14	196
7	Project type	1	2	1	3	3	1	3	4	2	1	2	1	1 5	1	2	2	1	1.5	3	1	1	4	1.5	2	1	2 5	1	1	1	1 5	2	2 5	58	80	-22	484
																																		320			1336
8	Policies of the contractor	3 5	4	3	1	4	4	4	4	4	3	2	1	4	4	1 5	4	4	3	3 5	2	4	2 5	1	2	4	4	4	4	4	4	3	4	104	78 8	25 25	637 5625
9	Need for job	1 5	3	1	3	3	3	3	3	3	1	3	4	3	3	1 5	3	3	2	3 5	3	3	2 5	4	3	2 5	1	2 5	3	3	2 5	4	2 5	87	78 8	8 25	68 0625
10	Market conditions	3 5	1	2	2	1 5	2	1	2	1	1 5	1	2	2	1	3	2	2	1	1 5	4	1	1	2	4	2 5	2	2 5	1	2	1	2	1 5	59 5	78 5	-19	361
11	Number of bidders	1 5	2	1	4	1 5	1	2	1	2	1 5	4	3	1	2	4	1	1	4	1 5	1	2	4	3	1	1	3	1	2	1	2 5	1	3	64 5	78 5	-14	196
																																		315			1262 625

8.9.4 Degree of importance of global risk factors

The second stage involved the calculation of measures of central tendency and dispersion for each of the variables. These values are presented in Table 8.8. First, the average scores, which represent the weighted scores of the responses of construction contractors' were determined. Subsequently, for each variable the average score value of the respondents' importance rating was used to calculate the importance index I which denotes the relevance of each global risk factor as a driver of poor cost performance. Five index ranges groups were defined to measure the degree of importance of global risk factors as follows:

$1 \leq I \leq 100$;

where

Table 8.8 Index ranges of degree of importance

Range	Description
$01 \leq I \leq 20$	Denotes very low importance risk factor category
$20 < I \leq 40$	Denotes low importance risk factor category
$40 < I \leq 60$	Denotes average importance risk factor category
$60 < I \leq 80$	Denotes high importance risk factor category
$80 < I \leq 100$	Denotes very high importance risk factor category

The weighted average score is calculated by the following expression:

$R = C*X;$ **(Equation 8.6)**

where, R= the average score, C = constant expressing the weighting given to each response. The weighting ranges from 1 to 5 as defined above, X = n/N, n = frequency of

the responses and N = total number of responses. The importance range categories of the factors is determined by the importance index, which is calculated using the following expression:

$$I = \sum_{i=1}^{n} \frac{R \quad x \ 100}{5}$$

(Equation 8.7)

and the weighted average score R is calculated by the following expression:

$$R = \frac{(A_1.1 + A_2.2 + A_3.3 + A_4.4 + A_5.5)}{A_1 + A_2 + A_3 + A_4 + A_5}$$

(Equation 8.8)

Table 8.9 Descriptive statistics and importance of global risk factors

No.	Risk Factor	Mean	St. Dev	Index	Importance
I.	**Estimator related factors**				
1	Motivational biases	3.250	1.391	65.00	High importance
2	Incentives	2.750	1.270	55.00	Moderate importance
3	Adjustment/anchoring	3.906	1.422	78.12	High importance
II.	**Project related factors**				
4	Project size	3.000	1.136	60.00	Moderate importance
5	Project complexity	3.313	1.230	66.26	High importance
6	Vagueness	3.531	1.545	70.62	High importance
7	Project type	3.625	1.264	72.50	High importance
III.	**Competition related factors**				
8	Contractor policies	3.125	1.238	62.50	High importance
9	Need for job	3.313	1.176	66.26	High importance
10	Market conditions	3.563	1.366	71.26	High importance
11	Number of bids	3.613	1.407	72.26	High importance
IV.	**Fraudulent practices**				

12	Fraudulent practices	3.375	1.519	67.50	High importance
13	Collusion among contractors	3.125	1.338	62.50	High importance
14	Corrupt practices	3.344	1.405	66.88	High importance
15	Theft	3.156	1.019	63.12	High importance
V.	**Construction related factors**				
16	Geological conditions	3.125	1.338	62.50	High importance
17	Weather conditions	3.125	1.362	62.50	High importance
18	Site accessibility	3.125	1.100	62.50	High importance
19	Site location	3.500	1.136	70.00	High importance
20	Delay in payments	3.719	1.250	74.38	High importance
21	Lack of payment	3.719	1.326	74.38	High importance
22	Sub-contractor fault	3.531	1.344	70.62	High importance
VI.	**Economy related factors**				
23	Market conditions(supply/demand)	3.250	1.414	65.00	High importance
24	Price fluctuations	3.156	1.019	63.12	High importance
25	Exchange rate	3.281	1.276	65.62	High importance
26	Inflation	3.094	0.995	61.88	High importance
VII.	**Political related factors**				
27	Political instability	3.500	1.586	70.00	High importance
28	Political system	2.375	1.362	47.50	Moderate importance
29	Change in labour costs	3.125	1.129	62.50	High importance
30	Legislation	3.250	1.270	65.00	High importance
31	Strikes/disorder	3.625	1.476	72.50	High importance
32	Labour restrictions	3.281	1.250	65.62	High importance
33	Taxation policies	3.250	1.270	65.00	High importance
34	Change in import taxes	3.000	1.414	60.00	Moderate importance
35	Availability of local materials	3.468	1.162	69.36	High importance
36	Power group influences	2.781	1.307	55.62	Moderate importance
37	Project importance	2.813	1.355	56.26	Moderate importance
38	Government relations	3.156	1.289	63.12	High importance

8.10 Discussion

It has already been suggested that cost performance of a construction project is often taken as a function of both initial cost and final cost. Initial cost and final cost are thus the independent variables which are, in turn, influenced by many factors either within the project and surrounding environments. The initial cost is the initial contract award amount resulting from the tender price. Making accurate cost estimates is crucial to the

success of a construction project. However, striking the right balance between competitiveness and profitability is far from easy and often results in the final cost (at completion) differing from the initial cost. Furthermore, during the course of construction, changes, additions, deductions, alterations of project specifications, work quantities and input costs are very likely to occur thus resulting in change of the initial cost. The following is a brief discussion of the relevance of the different groups of global risk factors influencing both cost estimate and final cost in the light of the data analysis.

8.10.1 Estimator related factors

An estimator plays an important role in the production of accurate cost estimates. The respondents emphasised the role of experience and judgement in cost estimating. In general, estimator related factors were highly rated by respondents. It has been suggested that errors, motivational and cognitive biases form the main components of estimator related factors. Making errors can be considered as an inherent characteristic in humans and estimators are no exception. However, unlike management errors, technical errors can be significantly minimised as these can often be easily identified, (Wantanakorn et al, 1999). In this study, motivational bias, namely rewards to estimators was found somewhat important, whereas adjustment and anchoring, a form of cognitive bias, was particularly considered as having large impact on the accuracy of cost estimating and thus on the project cost performance. Contractors emphasised the widespread use of the "rules of thumb" and assumptions by many estimators. This is partly explained by the instability and volatility of the market in terms of prices. Being able to scan the market environment and accordingly making adjustments is key to successful bidding.

8.10.2 Project and design related factors

Overall, construction contractors considered this group of factors as being very important. Although project size and project complexity were considered to be very important, vagueness and project type were considered to have much more impact on the

quality of cost estimates and consequently on the project cost performance. Complexity has large influence on cost performance since the difficulty in cost estimating is high in complex projects, both in terms of multi-disciplinarity and technologies. Project type is linked to familiarity of contractor with some types of projects. Embarking on novel unfamiliar projects may pose significant obstacles to preparing good quality cost estimates. Vagueness in scope has largely been cited as being one of the most important causes of poor cost performance (Kaming et al, 1997). Indeed, very often claims and change-orders originate from poor scope definition.

8.10.3 Competition related factors

Within the context of this study, competition related factors were found to be very important predictors of cost performance. Among the four factors, contractor's policies and need for job scored lower than market conditions and number of bidders. Market conditions and number of bidders are interrelated factors. Policies are standing plans that guide thinking in decision-making within construction organisations. During previous recession periods, contractors were willing to undertake less attractive projects with an increase in the number of bidders. In the market economy, the number of suppliers is a prime determinant of the freedom of individual businesses to make decisions. The smaller the number of suppliers, the greater the choice they have in terms of prices. However, contractors tend to bid for most available jobs in order, at least, to keep their organisations running, consequently underestimating is common in times of recession.

8.10.4 Fraudulent practices

In this survey construction contractors perceived fraudulent practices as quite important. These factors should not be neglected by contractors when preparing their tenders since there is a wide occurrence of both fraudulent and corrupt practices in the construction industry (Enliwa and Buba, 1993; and Kangari and Lucas, 1997). Although some forms of contract, for example, the World Bank standard forms of contract provide some

warning clauses to discourage these practices, it seems that they have failed, at least, to minimise the situation. Fraudulent and corrupt practices are very subtle occurrences thus making them almost impossible to uncover. Corrupt practices, particularly in most developing countries, are regarded as unavoidable, (Elinwa and Buba, 1993; and Schuette and Liska, 1994; and Wang et al., 1999). Fraudulent and corrupt practices take various forms and can originate from different parties, for example theft on site is a very important factor to consider. Consultants may misrepresent project elements such as technical specifications in order to mislead bidders knowing that they will change these specifications at a later date. Contractors usually hire private security companies in the belief they will avoid materials and elements theft, however, this usually only minimises the problem. Corrupt and fraudulent practices can often lead construction contractors to spend more money than they had planned.

8.10.5 Construction related factors

Construction related factors were attributed high importance by construction contractors. Geological conditions, site accessibility and weather conditions have the importance index of 62, whereas site location, delay in payments, lack of payment and sub-contractor have importance index of 70, 74, 74 and 70 respectively. Geotechnical conditions were deemed important because most projects have not included soil investigations data in order to provide information for better cost estimating. The most cited geotechnical conditions are groundwater level and soil structure. Akinci and Fisher, (1998) asserted that although it is easy to reach an agreement on the change of dimensions, it is very difficult to agree on whether unexpected conditions warranted a contract modification. Weather conditions can greatly influence cost performance. Tropical regions, where most developing countries lie, are characterised by heavy rain, wind, extreme heat and humidity which affects negatively workers and equipment productivity. Site accessibility was referred to as a major obstacle in construction projects undertaken outside the main urban areas. Site location poses serious constraints to the realisation of projects within the planned cost and time framework due to logistic problems.

Construction contractors stressed that delay in payments was a common occurrence both in private and public projects, with the public sector being the worse defaulter. Most types of contracts provide compensation clauses for delay in payments, but clients will rarely agree to pay the interests due. In addition, contractors endeavour to avoid such conflicts with the public sector in order to develop and keep good relationships for future projects. Lack of payment is a situation where payment is due for a large extension of time, say more than six months. There are situations where contractors wait more than a year without getting paid. In this regard, Jaselskis and Talukhaba (1998) suggested that until they got paid, contractors needed a great deal of patience and sometimes lobbying, both of which increase their costs. Sub-contracting practice is in its infancy within construction industry. Traditionally, construction companies have in-built capacities covering a wide range of professions such as bricklayers, carpenters and plumbers. Contractors argued that subcontracting requires a higher degree of supervision in order to meet quality and time targets.

8.10.6 Economy related factors

Economic factors impacting on construction cost performance were found to be very important, as shown by the importance indexes shown in Table 8.11. Typical developing countries exhibit severe discontinuities and fluctuations of construction demand and supply. The responding construction contractors considered price fluctuations, interest rates, exchange rates and inflation crucial variables to successful projects. These economic variables affect project costs and revenues. This situation is common in countries with unfavourable balance of payments and heavy debt servicing burdens. In Mozambique, where about 95 per cent of construction inputs are imported, the exchange rate depreciation has been substantial. For example, in January 2000 the exchange rate USD/MZM (Mozambique Metical) was 1:13 and in December, 1:17, a depreciation of about 30 per cent. Cumulative inflation from January to December 2000 was 15 per cent. What is more, commercial bank interest rates are prohibitive for any potential borrower (average rate 30 per cent) in construction business. As the profit margins are tight and

payment delays are common place, contractors have to be careful before applying for loans.

8.10.7 Political related factors

The responding construction contractors regarded political risks as very important. Indeed, government policies, decisions, attitudes and actions are very likely to endanger business environment and particularly construction projects. Evidence shows that politically motivated factors have significant influence upon construction projects in the country. Political events exert influence upon construction projects in the following sequence: influence at a macro level; influence at a market level; and influence at a project level. Political events that affect construction business in the country have two main dimensions: political actions initiated internally; and political actions instigated by foreign parties, mainly donors and lenders.

Some examples of recent adverse political events include, violent protests throughout the country in 2000 and recent alterations in construction regulations (2000). Most of political disputes are apparently purely based on ideological differences between political groups. However, the profound reasons are social and economic in nature. Unless these issues are solved and fair wealth distribution is achieved, political instability will remain a major concern. With regard to the latter dimension, external influence, it should be mentioned that Mozambique is extremely vulnerable and dependent on foreign aid which means that a large number of strategic decisions on political, social and economic issues are imposed by donors, lenders, and influence groups. These findings agree with views expressed in the literature (Ofori, 1991; Wolf, 1988; and Abdulkhalek, 1997).

Political system, power groups, and project importance were found to be less important than other factors. Surprisingly, political system was considered less important despite the significant differences between the former Marxist and current liberal democratic form of government. In the past, private initiatives were severely restricted to certain economic activities. Large state-owned companies, for example, dominated the

construction sector, with little opportunity for entrepreneurs. Power influence groups or pressure groups were not found very important. Project importance was not regarded as very important, perhaps due to the fact that it has been difficult to establish priorities clearly as the demand for infrastructures is high.

Labour restrictions, change in taxation, change in import tax are all part of substantial reform program aimed at updating and adapting law and regulations to meet current demands in terms of development, technologies, economy and international relations. It is worth stressing that much legislation dates back the 60s when the country was under Portuguese colonial rule. However, such improvement is a trial-and-error process that takes much time to become solid and effective as in the developed world. The reforming process is unstable and highly sensitive to change of government and affected by a change of government policy, (Smith, 1999). Changes in legislation include fiscal, treasury and monetary policies, methods of taxation, permits and construction regulations. The responding construction contractors stated that recent changes in the labour legislation package, the minimum wage rates and the introduction of VAT of 17 per cent as having brought serious problems to their operations and project plans.

Change in labour costs was found very important. The contractors considered that the government could reduce taxes in order to allow companies to rise the level of salaries. As a result of this state of affairs, relationships among unions, workers and employers are tense and strikes and disorders highly likely. Low wage rates are also believed to be the main reasons for dishonesty and theft. Apart from these it seems that culture is one of the most important factors behind criminal acts such as theft. Culture here means the inherent values, beliefs, principles, and behaviour of people.

The availability of local materials is regarded as very important. If there was local capacity, material related costs would be substantially reduced. Prices would be more stable and significant timesavings would be achieved in the construction process. Government relations have to with obtaining the necessary approvals from local planning authorities. Every project must comply with statutory requirements and regulations in

order to ensure standards of safety, suitability, comfort, stability, appearance and others. Government relations are deemed as a very important factor due to heavy paperwork and bureaucracy that can lead to extensive delays and unexpected costs. The responding contractors mentioned local planning authorities as barriers to good performance of projects. Often, unless bribes are paid to officials, approvals can take months and even years to obtain.

8.11 Summary

A survey of construction contractors was conducted in order to evaluate the level of importance of the main global risk factors affecting construction project costs. Global risk factors are those that originate from general and operational environment levels surrounding the organisation or project. The organisation may not be able to control these factors but they can tremendous impact on its operations and determine its success.

Overall, it was found that most of the factors identified at the outset of the study have had impact on cost performance. The construction contractors considered incentives for estimators, project size, political system, power groups influence and project importance factors as being not very important. The findings are useful as they raise the need for contractors and other parties increasing their awareness of global risk factors in order to be able to manage them effectively when engaging in contracts. Furthermore, it is important that new directions towards modelling, assessment, analysis and management of risks are taken.

The existing approaches to risk management have some shortcomings, namely: lack of objective data on which to base the analysis; they are predominantly quantitative and have failed to incorporate the human aspect of risk; they build on statistical decision theory which is largely prescriptive and does not take experience and judgement into account; and most decision-making problems in construction incorporate judgement and experience. Thus, new modelling approaches and tools are needed to complement the traditional ones.

Chapter Nine

Repertory grid interviews data analysis

9.1 Introduction

The preceding chapter presented an analysis and discussion of data collected through the questionnaire. This chapter presents the analysis and discussion of data collected through the repertory grid interviews. It explains how the repertory grids were designed and how the interviews were conducted. It also describes the process of elements and constructs elicitation. The different methods of grid analysis namely visual inspection, descriptive statistics, correlation and cluster analysis, are also thoroughly detailed.

9.2 Repertory grids data analysis objectives

The broad objective of the adopted repertory grids is to elicit relevant knowledge about global risk factors affecting cost performance. Data analysis of grids was undertaken to determine how constructs are used by construction contractors to handle risk, particularly the most important constructs used by construction contractors for the whole process of risk management. The specific objective is, therefore, to understand how construction contractors perceive and handle these risk factors in the management of their projects, that is, to ascertain the main criteria and sub-criteria used by construction contractors in the decision-making process within the context of risk management.

The data from the repertory grids enabled the researcher establishing similarities and differences among the most important constructs used by construction contractors in the reasoning process. There are many different and valid ways of analysing data from the grids and the choice of one or another technique depends upon the type of data, research questions and the problem under consideration. The main methods of data analysis are:

frequency count; content analysis; visual focusing; cluster analysis and principal component analysis. The first two focus on counting, whereas the remaining three are concerned with correlation.

The data analysis in the present research comprised both visual inspection and computer analysis. The following analysis was performed: visual inspection; descriptive statistics; correlation; and cluster analysis. Descriptive statistics provide summary information of the grids such as means, standard deviation, analysis of variance Root Mean-Square correlation (RMS), and Squared Multiple Correlation (SMC) and skewness. RMS is a standard way of averaging correlation that is defined as the square root of the average of the squared correlation.

However, the most used index for averaging correlation is SMC. Correlation analysis is at the core of the grid interpretation because it provides measures of association among elements, constructs and between elements and constructs thus providing information on discriminality.

Cluster analysis is a technique used to check similarities and differences among the elements and constructs. Cluster analysis allows the user to look for the patterns on the data, identify major groupings and thus building-up series of hierarchical groups based on the strongest associations in the matrices. The main advantages of cluster analysis over principal component analysis (Pricom) stem from its ability to keep a record of all details of relationships between elements and constructs, along with its simplicity.

Pricom condenses the information in the grid and loses some of the details in the process and it is concerned with determining all the independent dimensions (elements or constructs not significantly correlated at certain p) required to describe the relationships within a specific construing matrix (Stewart and Stewart, 1981). Due to the graphical representation of elements and constructs (axes at right angles) derived from Pricom analysis, the technique is also called spatial clustering. Easterby-Smith (1980) argued that the choice between cluster and Pricom analysis depends on the context within which the grid is being used. For the purpose of building a decision support system the information extracted from the cluster analysis is deemed good enough.

The basic information that can be derived from the grids is summarised as follows:

- information about specific elements (or constructs);
- information about relationship between elements (or constructs);
- information about relationships between elements and constructs;
- how each element is rated on each construct;
- how each construct is used;
- relationships between constructs;
- relationships between elements;
- lopsidedness (skewness index);
- constructs that have least differentiation (least standard deviation);
- most balanced constructs (least skewness index); and
- constructs that are used most similarly with respect to certain elements.

Since there were several grids it was necessary to perform the analysis in all of them in order to obtain a combined grid for each group of constructs. There are several programs that perform grid analysis but this study chose GRIDSCAL and GRIDSTAT (Bell, 1999) because there were the only available programs for the type of analysis required and they could perform the analysis of multiple and single grids. GRIDSCAL program can perform analysis of grids that have either the same elements or the same constructs and grids with both fixed elements and constructs. In this case both elements and constructs were fixed in each grid.

Several others on-line packages were evaluated and discarded because presented more disadvantages than GRIDSCAL and GRIDSTAT, which are practical, effective, moderately user-friendly and simple to use. GRIDSCAL assumes that the data are always read in rows where rows represent constructs and the columns represent elements. Each grid follows on from previous with no preceding information.

9.3 Design of the grid and knowledge elicitation

The grid was designed to elicit relevant knowledge related to the management of global risk factors identified in the literature and discussions with construction contractors and subsequently confirmed through the questionnaire survey. Therefore, the subject of the grid is "global risk factors affecting cost performance".

Twenty-five experts, from eight companies drawn randomly, from the list of those that participated in the questionnaire were identified and asked to participate in the interviews. All of them have extensive experience in construction projects ranging from fifteen to forty years. The professionals interviewed comprised planning directors, chief estimators and contract directors. Eighteen respondents hold a civil engineering degree, whereas the remaining seven possessed technical certificates in construction and business qualifications.

After the initial design, the grids were piloted using five per cent of the target sample. Piloting was deemed crucial to the final design of the grids since most respondents are not familiar with grids. Furthermore, it would provide useful information in order to refine and focus on the domain problem. The pilot stage included explaining the purpose and the subject of the interview. Then respondents were provided with elements and asked to describe how they thought the elements were different or alike. It was very difficult for the respondents to grasp the basics of the technique at first but with explanation and further conversation it was eventually possible to elicit deep constructs from the respondents.

Having given their descriptions of the elements, the respondents were asked to rate each one on every construct on one to five rating scale. The rating scale adopted was considered effective in that it provided reasonable discrimination among elements and constructs. Rating was favoured instead of ranking or dichotomising because it has greater flexibility of responses. Based on the trial run it was possible to refine the grids to

ascertain the respondents' understanding, time necessary to complete the grids, ensure the elements adequately covered the domain, and confirm the type of elements and if they were discrete enough. In addition, the piloting was very important to the researcher as enabled him gain confidence in the practical application of the repertory grid technique.

9.3.1 Elements elicitation

Elements are the focus of the grid. In this study, elements are global risk sources of which the respondents were asked to think about. Since elements should be homogeneous, specific and discrete there was a need to design several grids that grouped different risk categories. This was necessary because mixing different categories would lead to a situation where constructs generated from one category could not apply to constructs derived from a different category. It was decided that seven elements were enough to provide representative coverage of the domain area.

The grids thus comprise seven elements. Easterby-Smith (1980) suggested that an ideal number of elements should not be less than six or seven in industrial applications. Effort was made to keep the grids as small as possible to avoid lengthy elicitation sessions. Easterby-Smith also suggested that a grid comprising 10 elements and 10 constructs could take two hours to complete.

All elements were provided to the respondents instead of eliciting them. The main reasons for this procedure were: providing elements ensures adequate coverage of the domain area; and facilitates respondents' work since they need not recalling elements. There were designed eight grids in total comprising: estimators factors; fraudulent practices; sub-contractors factors; design and project factors; competition factors; construction factors; clients factors; and economy and political environment factors. The elements associated with each of the grids are estimators, past projects, past projects, past projects, project locations, past clients, past sub-contractors, years from 93 to 99.

9.3.2 Constructs elicitation

All constructs were elicited from the respondents through conversational approach. The total number of elicited constructs was 110 including repetitions that occurred in different groups of risk factors and it was observed that many respondents produced similar constructs. Most of the constructs (92 per cent) were obtained in the first five interviews and since the remaining twenty respondents could not produce additional constructs it was concluded that the list of constructs obtained provided good coverage of the domain. After interviewing all the respondents a second round of interviews with only three experts was conducted. The elicited constructs in the first round were provided to respondents and asked to rate the grids. The grids from the respondents were combined to produce a single grid for each group of risk factors. The whole elicitation process is summarised as follows:

- the interviewees were presented with the topic or subject under study (global risk factors affecting cost performance);
- they were shown the grid sheet with the elements already written in at the top;
- they were explained that it was important to express how they viewed the elements presented as well as to compare them. They were reminded that it was not important to provide correct answers but just how they saw the elements;
- they were asked to think of a particular risk factor that fitted the descriptions of each of the element prompts;
- the respondents were presented with three elements at a time, and asked which two of those were similar in some way and which one was different. They were asked to write down the characteristic that the two elements had in common on the left side of the grid (similar pole) and the opposite of this (the reason why the third element was different from the other two) on the right side of the grid sheet (different pole). The pair of words was selected to form and represent a contrast. Taking three elements and asking for two of them to be paired in contrast with the third was considered as the most suitable technique because it facilitated the emergence of construct poles

from the interviewees. This technique is called triadic elicitation. In order to minimise bias the selection of triads was made on a random basis.

- the latter two steps were repeated until all relevant constructs have been elicited by making comparisons between all the elements; and
- finally the respondents were asked to rate the grid using a five point scale, where 1 – indicates the element being described by the construct on the left and 5 – indicates the element being described by the construct on the right. It was assumed that points in the scale indicate equal gradations between the poles of the construct. Dichotomous "tick and cross" can be considered a particular case of rating where ticks indicate elements being described by construct on the left and crosses indicate elements being described by constructs on the right. Constructs are, therefore, not simply a pair of words but a scale on which respondents express their views about elements. A five-point scale was chosen because it was considered appropriate for discriminating elements and constructs. Stewart and Stewart, (1981) suggested that seven-point scale was close to most people's limits of discrimination. The rationale behind defining scales lies on the fact there are intermediate values between the two poles (left and right).

9.3.3 Laddering

Laddering was used in order to improve the relevance of the elicited constructs by questioning the respondents in order to provide greater understanding to what was being said. This technique enabled obtaining superordinate constructs from the more general and vague ones. Laddering was used to generate deeper constructs by asking "what" and "how" type of questions. Superodinate constructs are considered more relevant and factual rather than attitudinal. Laddering was repeated until the respondents could not identify any new constructs. At this stage, the refinement process was deemed adequate and thus, the constructs derived were considered as providing enough coverage of the domain and thus being the main criteria for risk decision-making by construction contractors.

9.4 Analysis of the grids data and discussion

9.4 1 Visual inspection of the grids

Visual inspection relies on looking for patterns and trends of ratings. In this sense, it is possible to work out the extent to which the ratings of elements are similar, that is, comparing each column with each other column of the grid and calculate the sum-of-differences down the column. A comparison between two columns is thus based on the sums-of-differences. With regard to constructs the sum-of-difference can be calculated twice reversing the directionality of one of each pair of constructs being compared and choosing which gives the lowest sum-of-difference because constructs are bipolar. In this process the sum-of-differences represent the distance between elements or constructs.

The lower the distance between two elements or two constructs, the more similar the elements or constructs are considered to be. The maximum distance on any one dimension on five-scale rating is 4 = (5-1). Using visual inspection it is also possible to detect the pattern of skewness and differentiation. Visual inspection is a general qualitative analysis and it was generally performed on all grids as the first stage of data analysis.

9.4.2 Estimator related constructs

Cost estimating in today's competitive environment is a key factor to the success of a construction project. According to Akintoye and Fitzgerald, (2000) the following factors affect the reliability or accuracy of cost estimates: estimator; project type; estimating technique; information available; method statement; buying power; and financial engineering. Estimating and bidding are two crucial functions performed by construction contractors but many of the decisions required in devising an appropriate strategy both in estimating and bidding tasks are based on experience and intuitive judgement.

The estimator related factors grid presented in the Tables 9.1-9.3 revealed a great deal of information with regard to the constructs used by construction contractors in handling global risk factors.

Table 9.1: Estimator-related factors: constructs

		E1	E2	E3	E4	E5	E6	E7	
C1	Good training	5	4	4	3	5	3	3	Poor training
C2	Good skills	5	1	4	1	4	4	2	Poor skills
C3	Good knowledge	5	3	5	2	4	3	5	Inadequate knowledge
C4	Good estimating practice	4	1	3	1	4	5	2	Bad estimating practices
C5	Very experienced	5	2	4	3	5	4	3	Inexperienced
C6	Very expensive	5	3	4	3	5	4	3	Inexpensive
C7	Effective in adjustment	2	4	5	2	4	5	2	Ineffective in adjustment
C8	Ability to recall	2	5	4	2	4	4	4	Inability to recall
C9	Ability in using past data	1	4	3	2	4	5	3	Inability in using past data
C10	High morale and motivation	4	1	3	1	3	4	3	Low morale and motivation

Table 9.2: Estimator-related factors: grid statistics

Construct	Mean	Std Dev.	Skewness	RMS	SMC
C1	3.86	0.90	-15.34	0.44	0.98
C2	3.0	1.63	-2.73	0.67	0.99
C3	3.86	1.21	-9.85	0.41	0.98
C4	2.86	1.57	-2.38	0.62	0.99
C5	3.71	1.11	-9.87	0.65	0.98
C6	3.86	0.90	-15.34	0.65	0.99
C7	3.43	1.4	-5.34	0.39	0.97
C8	3.57	1.13	-8.47	0.39	0.98
C9	3.14	1.35	-4.24	0.41	0.98
C10	2.71	1.25	-2.87	0.60	0.98
Average of statistics	**3.40**	**1.25**	**7.64**	**0.52**	**0.98**
St.Dev of statistics	**0.42**	**0.24**	**4.70**	**0.12**	**0.01**

Table 9.3: Constructs correlation (clustering by complete linkage)

Cluster stage	Lower cluster	Upper cluster	Level of Similarity	Preceding clusters	Next cluster
1	5	6	0.951	0-0	5
2	2	4	0.908	0-0	3
3	2	10	0.896	2-0	5
4	8	9	0.812	0-0	6
5	2	5	0.697	3-1	8
6	7	8	0.661	0-4	9
7	1	3	0.434	0-0	8
8	1	2	0.253	7-5	9
9	1	7	-0.377	8-6	0

A visual inspection of rows and columns shows that the observed mean scores of the respondents on element E1 on constructs C1, C2, C3, C4, C5, C6 and C7 are very high (rating 4 and 5 out of 5), which means that they characterise element E1 using the constructs mentioned on the right. On examining construct C1 it is possible to see that is highly rated along all elements with 3 as the minimum rating.

Construct s C1 and C6 have the least differentiation since they exhibit the lowest standard deviation whereas construct C2 has the greatest differentiation (largest standard deviation). The most balanced construct, with the least skewness, is C2 whereas the most lopsided constructs (with high skewness index) are C1, C6 and C8.

It can also be seen from the values of Squared Multiple Correlation (SMC), Table 9.2, that each construct has a strong relationship with all others. The SMC expresses the relationship of each constructs with all others, that is, the proportion of variance each constructs has with the set of other constructs.

These values are within the range of 0.97 to 0.99, which represent strong relationship. Table 9.2 also presents the averages of the statistics and standard deviation of the statistics that can be used to evaluate the whole statistics and detect any potential

unexpected trends or patterns. Constructs C1 and C6 possess negative and high skewness values, which indicates that the ratings are skewed to high values as it can be seen from the grid ratings. Construct correlation are presented in Table 9.3. The levels of similarity are generally high which indicates strong correlation among clustered constructs. The most correlated constructs are C5 and C6 with a level of similarity of 0.951. Constructs C1 and C2 show very low similarity and constructs C1 and C7 have a negative correlation. The following is the characterisation of the constructs elicited.

a) Good training

The respondents regarded good training as an essential ingredient for the estimating profession. It is believed that many estimators lack good training because there are no formal and specific courses in this area and a vast majority of estimators learn by experience. As such, they lack theoretical background on which to build their skills. Although learning from examples is an important way of learning, it should be regarded as a complement to formal training rather than a self-contained method of learning. In this regard Akintoye and Fitzgerald (2000) argued that most contractors relied on their own methods of estimating but these methods were inaccurate and solely based on experience.

b) Good skills

Estimating is considered both an art and science. Among other factors, the accuracy of estimates depends largely on skills. Ideally estimators should possess specific and general skills. Specific skills relate to the specific estimating work, while general skills relate to the broad are of construction. The latter skills form the foundation for the development of specific skills.

c) Good knowledge and experience

Professional estimating competency is acquired by the combination of knowledge attained during training and skills developed through experience and the application of the attained knowledge. Therefore, a good estimator is supposed to possess extensive experience and large body of knowledge.

d) Cost of hiring an estimator

The respondents considered that competent estimators are costly. This is so because the local supply of good estimators is extremely low and many companies have to seek estimators abroad. The respondents asserted that hiring an expatriate estimator increased companies' overheads and thus reducing their competitiveness, but it was a necessary measure to ensure the company produced good quality cost estimates.

e) Adjustment and anchoring

The adjustment and anchoring, has to do with the subjective facet of estimating. The respondents argued that adjustment and anchoring skills were important and necessary in order to improve the chance of wining contracts since price fluctuations were systematic. There was no confidence on the available bidding models developed so far. Furthermore, estimators work under heavy pressure and time constraints and thus very difficult to operate on the base of analytical models.

f) Reliance on historical data

The respondents confirmed that estimators are often attempted to use past data in order to simplify their work and thus making estimates on current practices. The accuracy of such estimates is dictated by the estimators' ability to recall past project details. Since projects are rarely similar or equal such practice can lead to incorrect assessments and thus

increasing the likelihood of making errors (underestimates or overestimates). In order to minimise or avoid such procedures some contractors have used rules of thumb and set up guidelines so as to help estimators in their job.

g) Morale and motivation

It is assumed that all individuals possess a range of motives awaiting gratification. Individuals are supposed to behave in a particular manner if they expect that a gratification will occur. Morale and motivation were considered by respondents as playing an important role in the way estimators work. Well-motivated estimators are generally in a better position to produce high quality estimates that unmotivated ones. However, there is no consensus as to what constitute the main driving forces within estimators. Construction contractors initially thought monetary incentives was the main motivating factor but, it was found that motivation was a complex matter that could not be explained by a single variable.

9.4.3 Fraudulent practices-related constructs

Fraudulent practices related factors grid and statistics are presented in the Tables 9.4 - 9.6. A visual inspection of rows and columns shows that the observed mean scores of the respondents on the majority of elements on the different constructs are generally balanced. That is the reason why the values of skewness shown on Table 9.5 are low. The only exception, however, is the construct C7 which presents very high skewness index. All constructs possess negative skewnesses, which indicates that the ratings are skewed to high values as it can be seen from the grid ratings.

Table 9.4: Fraudulent practices-related factors: constructs

		E1	E2	E3	E4	E5	E6	E7	
C1	Misrepresentation of project elements	1	2	4	4	3	3	4	Transparency in design
C2	Collusion practices	2	1	5	4	2	3	1	Fair competition practices
C3	Fair bid evaluation	3	3	4	1	2	5	2	Unfair bid evaluation
C4	Objective evaluation criteria	2	2	4	3	2	3	2	Unclear evaluation criteria
C5	Good reputation of client	4	4	3	3	2	2	2	Bad reputation of client
C6	Transparent bidding process	1	1	4	3	3	2	2	Inadequate bidding process
C7	Local competitive bidding	3	3	4	4	4	4	3	International competitive bidding
C8	Good security	1	2	2	2	2	3	3	Poor security

Table 9.5: Fraudulent practices-related factors: grid statistics

	Mean	Std Dev.	Skewness	RMS	SMC
C1	3.0	1.15	-4.58	0.57	0.99
C2	2.57	1.51	-1.62	0.58	0.98
C3	2.86	1.35	-2.95	0.21	0.97
C4	2.57	0.79	-4.52	0.58	0.99
C5	2.86	0.90	-5.45	0.46	0.95
C6	2.29	1.11	-1.74	0.61	0.98
C7	3.57	0.53	-25.91	0.57	0.95
C8	2.14	0.69	-2.83	0.40	0.98
Average of statistics	**2.73**	**1.0**	**6.20**	**0.50**	**0.97**
St.Dev of statistics	**0.42**	**0.31**	**7.56**	**0.13**	**0.01**

Table 9.6: Constructs correlation (clustering by complete linkage)

Cluster stage	Lower cluster	Upper cluster	Level of similarity	Preceding clusters	Next cluster
1	2	4	0.941	0-0	3
2	6	7	0.801	0-0	3
3	2	6	0.679	1-2	6
4	1	8	0.627	0-0	6
5	3	5	-0.020	0-0	7
6	1	2	-0.091	4-3	7
7	1	3	-0.767	6-5	0

Constructs C4, C7 and C8 have the least differentiation since they exhibit the lowest standard deviation whereas construct C2 has the greatest differentiation.

It can also be seen from the values of Squared Multiple Correlation (SMC), Table 9.5, that each construct has a strong relationship with all others. These values are within the range of 0.95 to 0.99, which represent strong relationship.

Table 9.6 shows the results of cluster analysis. Cluster analysis groups constructs according to their similarities and produces a dendogram from which the table is drawn. From the Table 9.6 it can be observed that the constructs C2, C4, C6, C7, C2, C6, C1 and C8 are the most correlated, whereas the constructs C3, C5, C1, C2, C1 and C3 are the least correlated. The following is a brief characterisation of elicited constructs.

a) Misrepresentation of project elements

One form of fraudulent practices is the misrepresentation of project elements by design teams. The respondents argued that very often design teams manipulate technical specifications and/or work quantities in order to mislead the vast majority of bidders and

favour a specific bidder with which they have close relationships. Then they disclose the actual information to that bidder in order to make a realistic estimate and increase the chance of winning the contract while the remaining bidders submit higher tenders. This happens because the design team is also the same in charge of supervision on behalf of the client. To minimise this effect, it is important for contractors to examine carefully the project elements and ask questions to the design team should they arise. These findings confirm work by Schuette and Liska, (1994) who mentioned that architects have used weasel clauses in the specifications with the intent of placing inequitable risks to contractors.

b) Collusion among contractors

Collusion among contractors is also a frequent occurrence. It materialises when a group or groups of contractors agree to conspire, undermine or distort the essence of competitive bidding and thus influence the results of bid. This illegal approach tends to push the prices up to the detriment of the client. Projects with few bidders are much more prone to collusion practices with contractors pushing prices up than projects with many bidders. The reason behind collusion was explained as a practice aimed to secure a large share of the market for the group of colluding contractors.

c) Fair bid evaluation

The objective of competitive bidding is to maximise competition and to ensure the most competitive contractual terms for the client. Fair bid evaluation is an important ingredient to a successful bidding process and credibility of the client. Although the process of evaluating tenders is considered to be largely dependent on subjective judgement where the cost is not the only evaluation criterion, it is possible to establish pre-determined criteria. The respondents also observed the lowest bid does not necessarily win the contract. The fact that there has not been consistency in the criteria used to evaluate tenders gives room to various interpretations.

d) Good reputation of client

The way a specific client has managed the bidding processes determines to a large extent his/her credibility. Unfortunately there are various cases where the evaluation criteria were not clear. These included situations where contracts were awarded to non-licensed contractors or contractors with evident technical and financial debilities or dishonest practices.

e) Transparent bidding process

Trasnparent bidding has to do with compliance with the bidding requirements suitable to the type and size of contract as well as regulations. For example, a small contract can be awarded based on a short-list, while a medium-sized one requires an open tendering. The Public Sector in Mozambique has established a set of guidelines and regulations related to procurement of services, works and goods. However, these procedures have rarely been followed by public officers.

f) Local competitive bidding

Local competitive bidding is considered as the most problematic bidding procedure with regard to seriousness and fairness. Since it depends on the local authority, usually client organisation, the level of accountability is low compared to international competitive bidding in which the funding agencies demand strict compliance with the guidelines and thus reducing the likelihood of malpractice.

g) Good security

All respondents stated that theft, particularly on site, was a serious problem since was systematic and has led to additional costs. Material theft was considered a major factor leading to poor quality and many complaints for repair during liability defect period are

related to material theft. Materials like paints, cement, steel bars, pipes, and electrical fittings are the most targeted because they can be easily sold anywhere.

9.4.4 Project and design-related constructs

According to Choy and Sidwell (1991) design and documentation errors are the major sources of contract variations. In addition for the contracts that are based on drawings and specifications, the design should be developed thoroughly before tender stage so as to avoid claims and disputes at a late stage and improve the quality of works.

Design and project factors constructs grid and statistics are presented in the Tables 9.7 - 9.9. A visual inspection of rows and columns indicates that the observed mean scores of the respondents on the majority of elements on the different constructs are not balanced, that is, they are lopsided. Table 9.8 shows the values of skewness index. Fifty per cent of the values are low, whereas the remaining fifty per cent are rather high.

Table 9.7: Design and project-related factors: constructs

		E1	E2	E3	E4	E5	E6	E7	
C1	Large project	3	3	4	3	2	3	3	Small project
C2	Innovative technologies	3	4	4	4	2	3	3	Traditional technologies
C3	Attractive project	5	5	4	3	4	3	3	Unattractive project
C4	Long construction period	4	4	3	4	3	3	3	Short construction period
C5	Effective co-operation among parties	4	2	2	3	2	3	2	Ineffective cooperation
C6	Detailed design	3	3	2	3	2	2	2	Lack of details
C7	Good specifications	2	2	3	2	4	5	5	Poor specs.
C8	Government project	5	5	5	2	5	2	4	Private project

Table 9.8: Design and project-related factors: grid statistics

	Mean	Std Dev.	Skewness	RMS	SMC
C1	3.0	0.58	-12.66	0.3	0.98
C2	3.29	0.76	-11.62	0.44	0.99
C3	3.86	0.90	-15.34	0.47	0.90
C4	3.43	0.53	-22.53	0.60	0.99
C5	2.57	0.79	-4.52	0.32	0.97
C6	2.43	0.53	-6.64	0.60	0.99
C7	3.29	1.38	-4.64	0.59	0.91
C8	4.0	1.41	-8.97	0.34	0.97
Average of statistics	**3.23**	**0.86**	**10.87**	**0.47**	**0.94**
St.Dev of statistics	**0.57**	**0.33**	**5.70**	**0.05**	**0.14**

Table 9.9: Constructs correlation (clustering by complete linkage)

Cluster stage	Lower cluster	Upper cluster	Level of similarity	Preceding clusters	Next cluster
1	4	6	1.0	0-0	4
2	3	8	0.786	0-0	6
3	1	2	0.764	0-0	5
4	4	5	0.510	1-0	5
5	1	4	-0.040	3-4	6
6	1	3	-0.30	5-2	7
7	1	7	-0.871	6-0	0

All constructs possess negative skewnesses, which indicates that the ratings are skewed to high values as it can be seen from the grid ratings.

Most construct s have the least differentiation since they exhibit low standard deviation, whereas constructs C7 and C8 have the greatest differentiation.

It can also be seen from the values of Squared Multiple Correlation (SMC), Figure 9.8, that each construct has a strong relationship with all others. These values are within the range of 0.91 to 0.99, which represent strong relationship.

Table 9.9 shows the results of cluster analysis. Cluster analysis groups constructs according to their similarities and produces a dendogram from which the table is drawn. From the Table 9.9 it can be observed that the constructs C4, C6, C3, C8, C1, C2, C4 and C5 are the most correlated whereas the constructs C1, C4, C1, C3, C1 and C7 are the least correlated. The following is a brief characterisation of the elicited constructs.

a) Large project

The size of a project is an important factor to consider when deciding to bid since the amount of uncertainty increases as the project size increases. The respondents revealed they faced much more difficulties with large than small projects due the large number of variables and the resources they have to handle. The contractor size also plays a significant role in this regard as small firms lack technical/financial capabilities to undertake large projects, for example.

b) Innovative technologies

The respondents related innovative technologies mainly to new construction methods and materials that are not traditional by local standards. Although innovative technologies are generally associated with large projects, the diversity of materials and new design requirements in recent years have increased the difficulties in handling even small building projects, particularly finishings. The technological complexity is considered as a significant obstacle to forecasting cost with good accuracy.

c) Extensive construction period

By their nature construction projects tend to be prolonged when compared to other types of projects. This is so because they involve a large amount of complex work and disciplines that can not be finished quickly. Projects that take longer are much prone to be affected by uncertain events that short period projects because the external environment is very likely to change (for example price fluctuations). In addition design changes are more likely as the project duration increases.

d) Effective co-operation among parties

An effective co-operation among client, contractor and supervision team is crucial to the successful completion. The flow of information within this chain has large effects on the progress of works since many decisions have to be taken on a daily basis by all the parties. The respondents argued that very often there are delays due to late decisions by client even when the supervision and contractor strive to keep the project on schedule.

e) Detailed design and adequate specifications

The respondents measure the quality of design by the extent to which it is detailed. The lack of details and poor tender documentation allied to insufficient time for cost estimating are also responsible for poor quality cost estimating. They argued that lack of important details invariably lead to alterations, additions that are difficult to accept by clients. Then contractors are placed in a bad position to negotiate the changes and the cost implications. This has been the main source of conflicts between clients and contractors.

f) Public project

The public sector is the largest market for construction projects but has poor reputation for failure to meet the terms of the contract. Bidding for public projects requires contractors to be prepared to face various problems that can undermine works progress. Such problems include delay in site commission, late payments, poor contract documents, etc.

9.4.5 Competition related constructs

Competition related factors constructs grid and statistics are presented in the Tables 9.10 - 9.12. A visual inspection of rows and columns shows that the observed mean scores of the respondents on the majority of elements on the different constructs are not balanced. Table 9.11 shows that the values of skewness index are very high and all constructs possess negative skewnesses which indicates that the ratings are skewed to high values as it can be seen from the grid ratings. The average skewness of 25.55 is clearly an expression of high rating values on most of the constructs.

Table 9.10: Competition-related factors: constructs

		E1	E2	E3	E4	E5	E6	E7	
C1	Favourable market conditions	3	2	2	1	2	1	1	Unfav. market conditions
C2	Large number of bidders	5	5	5	4	4	5	2	Small number of bidders
C3	Attractive project	5	5	4	4	4	4	4	Unattractive project
C4	High need for job	5	5	4	4	5	5	4	Low need for job
C5	Large project	3	3	3	4	2	2	2	Small project
C6	Heavy competition	4	4	4	4	3	4	4	Low competition
C7	High construction supply	3	4	2	2	3	2	3	Low construction supply
C8	Empowerment	4	4	2	2	3	2	4	No empowerment

Table 9.11: Competition-related factors: grid statistics

	Mean	Std Dev.	Skewness	RMS	SMC
C1	1.71	0.76	-0.95	0.45	0.97
C2	4.29	1.11	-16.07	0.36	0.98
C3	4.29	0.49	-54.60	0.55	0.99
C4	4.57	0.53	-58.95	0.44	0.97
C5	2.71	0.76	-5.89	0.28	0.96
C6	3.86	0.38	-56.51	0.25	0.97
C7	2.71	0.76	-5.89	0.50	0.97
C8	3.0	1.0	-5.55	0.49	0.99
Average of statistics	**3.39**	**0.72**	**25.55**	**0.41**	**0.98**
St.Dev of statistics	**0.94**	**0.23**	**24.46**	**0.10**	**0.01**

Table 9.12: Constructs correlation (clustering by complete linkage)

Cluster stage	Lower cluster	Upper cluster	Level of Similarity	Preceding clusters	Next cluster
1	7	8	0.882	0-0	6
2	1	3	0.710	0-0	4
3	2	4	0.520	0-0	4
4	1	2	0.439	2-3	7
5	5	6	0.417	0-0	6
6	5	7	-0.220	5-1	7
7	1	5	-0.354	4-6	0

Most constructs have the least differentiation since they exhibit low standard deviation whereas constructs C2 and C8 have the greatest differentiation.

It can also be seen from the values of Squared Multiple Correlation (SMC), Table 9.11, that each construct has a strong relationship with all others. These values are within the range of 0.96 to 0.99, which represent strong relationship.

Table 9.12 shows the results of cluster analysis where it can be observed that the constructs C7, C8, C1, C3, C2, C4, C1, C2, C5 and C6 are the most correlated, whereas the constructs C5, C7, C1, C5, are the least correlated. The following is a brief characterisation of the elicited constructs.

a) Favourable market conditions and competition

Market conditions refer to the environment within which construction contractors operate and include factors such as supply and demand, purchasing power, commercial legislation, rules and regulations, competition and availability of finance. Market conditions are said to be favourable when they offer potential business opportunities for contractors to win contracts and make profits. During periods of high demand contractors can often operate at full capacity realising large profit margins. The respondents revealed that in recent years market conditions tend to become very unfavourable due to several factors of which interest rates, devaluation and inflation are of paramount importance.

b) Large number of bidders and high need for job

Projects with many bidders are expected to provide wider variability between tenders. The respondents confirmed that the number of bidders determines to a large extent their approach to estimating. If there are few bidders they can qualitatively assess the likely range of bid price and thus adjust their price with relative ease. However, when the number of bidders is high and there is low supply this task becomes quite complex and often they have to place tight margins in order to increase the chance of winning to the detriment of profit. Many respondents said they preferred to operate at a loss to closing the doors when the need for job is high. They argued that empowerment policies would help native contractors building their capacity as it occurs in other countries.

c) Attractiveness and impact of project

The attractiveness of a project has mainly to do with the type of project, project size, project impact, and potential margin that can be achieved. Large projects are more attractive than small ones particularly in recession periods due to the duration and the contract amount involved. The amount of money increases the annual business volume and minimises cash-flow problems. Project with large impact on the communities, for example new roads or sewage system, are highly attractive since beside the financial goal, they are important marketing assets. Projects with high rate of return are very attractive as well. An example of these are rural road maintenance projects which are labour-intensive based projects and thus with minimum labour costs. In addition, well-located projects have also huge impact than others in remote areas.

9.4.6 Construction-related constructs

Construction related factors constructs grid and statistics are presented in the Tables 9.13 - 9.15.

Table 9.13: Construction-related factors: constructs

		E1	E2	E3	E4	E5	E6	E7	
C1	Adequate site investigation	5	4	4	4	5	4	4	Inadequate SI
C2	Extreme heat	5	5	5	4	4	4	4	Mild temperatures
C3	High humidity	4	4	4	5	3	3	2	Low humidity
C4	Heavy rain	4	4	4	5	3	3	4	Moderate rain
C5	Right season	3	2	2	3	4	2	2	Inappropriate season
C6	Good road network	2	2	2	1	2	1	1	Poor road network
C7	Paved roads	2	1	1	1	1	2	2	Unpaved roads
C8	Good level of road maintenance	1	1	1	1	1	2	2	Poor maintainance levels
C9	Remote site	2	2	3	3	4	4	5	Well located site
C10	Good communication links	3	3	3	2	2	2	4	Poor communication links

Table 9.14: Construction-related factors: grid statistics

	Mean	Std Dev.	Skewness	RMS	SMC
C1	4.29	0.49	-54.60	0.45	0.99
C2	4.43	0.53	-53.09	0.47	0.99
C3	3.57	0.98	-10.52	0.48	0.99
C4	3.86	0.69	-22.87	0.40	0.98
C5	2.57	0.79	-4.52	0.43	0.99
C6	1.57	0.53	-1.13	0.47	0.99
C7	1.43	0.53	-0.68	0.43	0.98
C8	1.29	0.49	-0.39	0.53	0.99
C9	3.29	1.11	-6.46	0.51	0.74
C10	2.71	0.76	-5.89	0.33	0.98
Average of statistics	**2.90**	**0.69**	**16.02**	**0.45**	**0.96**
St.Dev of statistics	**1.12**	**0.21**	**19.92**	**0.06**	**0.07**

Table 9.15: Constructs correlation (clustering by complete linkage)

Cluster stage	Lower cluster	Upper cluster	Level of similarity	Preceding clusters	Next cluster
1	1	5	0.806	0-0	5
2	2	6	0.750	0-0	7
3	8	9	0.745	0-0	6
4	3	4	0.636	0-0	7
5	1	7	0.510	1-0	8
6	8	10	0.113	3-0	8
7	2	3	-0.194	2-4	9
8	1	8	-0.520	5-6	9
9	1	2	-0.801	8-7	0

The constructs C5, C6, C7, C8, C9 and C10 are the most balanced whereas the remaining constructs exhibit high values of skewness which indicates that the ratings are skewed to high values as it can be seen from the grid ratings.

Most construct s have the least differentiation since they exhibit low standard deviation. It can also be seen from the values of Squared Multiple Correlation (SMC), Table 9.14, that each construct has a strong relationship with all others except construct C9 that is most unique with a SMC of 0.74. Table 9.15 shows the results of cluster analysis where it can be observed that the constructs C1, C5, C2, C6, C8, C9, C3, C4, C1 and C7 are the most correlated whereas the constructs C8, C10, C2, C3, C1, C8 C1 and C2 are the least correlated. The following is a brief characterisation of the elicited constructs.

a) Adequate site investigation

Knowledge of geotechnical conditions plays an important role in the estimating of earthmoving works but this information is rarely provided in the projects. According to Chan (1998) most clients often do not appreciate the importance of a detailed site investigation and consider the cost associated with it as wasteful since it does not produce visible results. Ashton and Gidado (2001) argued that despite the wealth of knowledge available there is a significant problem with the adequacy of site investigation procedure. In an examination of 8000 commercial buildings it was found that 50 of the sample had suffered unforeseen ground conditions (NEDO, 1988). Many respondents have faced problems with differing site conditions, namely different soil conditions and level of water table, but it has been difficult to reach an agreement on the issue between the contractor and the client. For example, digging sandy soil has different cost implication from escavating a rocky soil.

b) Extreme heat, high humidity, right season and heavy rains

The weather conditions pose serious constraints to construction projects in Mozambique. The ideal construction period is between April to September, dry season, where temperatures, rain and humidity are not as extreme as in the remaining period of the year, but as it is evident, it is almost impossible to confine construction works within this period. The effects of extreme heat and humidity on the workforce productivity can not be neglected as they affect both mental and physical ability of humans. In addition, in

both warm and dry seasons several tropical diseases of which malaria is the most endemic prevail. Apart from the heat and humidity impact on labour, works can not progress smoothly due to frequent torrential rain particularly in the centre and north of the country.

c) Good road network, paved road and road maintenance

Good road network is a crucial asset in communications among different parts of the country. There have been many construction projects, particularly schools, hospitals, water and supply systems, located in remote regions but undertaking such projects has been a daunting task for contractors. With the exception of Maputo City and the surrounding areas there are severe logistic problems in Mozambique. The road network is poor and the conditions of the existing roads are bad. In most regions of the country, namely Niassa, Tete, Nampula and Zambezia, contractors have to travel to Zimbabwe and

Malawi to have access to the site since there is no links from within the country. Obviously, these operations increase the construction costs. One of the major causes of inaccurate estimating is the unfamiliarity with the area where the project is to implement.

9.4.7 Client-related factors constructs

Construction related factors constructs grid statistics are presented in the Tables 9.16 - 9.18. The constructs C1, C3, C4, C8, and C5 are the most balanced, whereas the remaining constructs exhibit high values of skewness which indicates that the ratings are skewed to high values as it can be seen from the grid ratings.

The values of Squared Multiple Correlation (SMC), Table 9.17, show strong relationships for each construct with all others except construct C5 that is most unique.

Table 9.18 shows the results of cluster analysis where it can be observed that the constructs C6, C7, C2, C6, C1, C4, C1, and C3 are the most correlated whereas the constructs C1, C5, C1 and C2 are the least correlated. The following is a brief characterisation of the elicited constructs.

Table 9.16: Client-related factors: constructs

		E1	E2	E3	E4	E5	E6	E7	
C1	Public client	3	4	4	4	3	2	2	Private client
C2	Experienced client	3	2	4	4	3	3	3	Inexperience client
C3	Bad fund management	2	2	2	1	1	1	1	Good fund management
C4	Delayed payments	2	2	2	2	2	1	2	Timely payments
C5	Reliable	3	3	3	2	2	2	5	Unreliable
C6	Relies on foreign grants	3	2	4	4	4	3	3	Own sources of finance
C7	Co-operative	3	2	3	4	4	3	3	Uncooperative

Table 9.17: Client-related factors: grid statisctics

	Mean	Std. Dev.	Skewness	RMS	SMC
C1	3.14	0.90	-7.68	0.74	0.99
C2	3.14	0.69	-11.40	0.24	0.97
C3	1.43	0.53	-0.68	0.69	0.68
C4	1.86	0.38	-3.98	0.71	0.91
C5	2.86	1.07	-4.07	0.68	0.74
C6	3.29	0.76	-11.62	0.72	0.98
C7	3.14	0.69	-11.40	0.39	0.90
Average of statistics	**2.69**	**0.72**	**7.26**	**0.60**	**0.88**
St.Dev. of statistics	**0.68**	**0.21**	**4.10**	**0.18**	**0.11**

Table 9.18: Constructs correlation (clustering by complete linkage)

Cluster stage	Lower cluster	Upper cluster	Level of similarity	Preceding clusters	Next cluster
1	6	7	0.867	0-0	2
2	2	6	0.650	0-1	6
3	1	4	0.560	0-0	4
4	1	3	0.354	3-0	5
5	1	5	-0.322	4-0	6
6	1	2	-0.645	5-2	0

a) Experience with the client

The client has been cited as one of the major causes of business failure (Dun and Bradstreet, 1986). If the contractor has some experience with the client it is relatively easier to assess the risk associated with engaging in a contract and then adopt appropriate strategies to deal with that risk. This is the case of maintenance contracts that are drawn on repetitive basis, but it will certainly not be for the vast majority of construction projects. The issue of experience with the client can be well illustrated by the following quotation from Golzen, (1984): "there are quite a lot of clients around who try to get firms to do something for nothing and who are best avoided even if you are short of work at the time". Furthermore, a co-operative client can help to avoid poor relationship between the parties and thus reduce or minimise the number of claims and disputes.

b) Inadequate management of funds

The public sector is well known for its failure to manage funds effectively. There are several cases where public departments awarded contracts without any provision in the budgets resulting in the failure to pay contracts and cancellation of contracts. In some

circumstances money budgeted for works are used for different purposes leading to delay or failure to pay contractors.

c) Timely payments and client reliability

It is rare for public clients to make timely payments in accordance with the terms of the contract. Furthermore, poor financial management often means that funds are not available to pay the contractor, (Wells, 1986). As the largest client, the public sector has shown little concern in meeting the conditions of the contract. Even though contractors suffer from client's faulty, they will not challenge its attitude because they avoid spoiling relationships with the client. Aniekwu and Okpala (1988) asserted that in many developing countries construction contracts are seldom the subject of legal dispute and goodwill between the client and contractor is important. As a result, many of existing forms of contracts with emphasis on legal rights, obligations, procedures and sanctions are inappropriate in these countries.

d) Source of funds

The government has typically had insufficient resources to allocate to public investment then most of the financial resources originate from both bi-lateral and multilateral agreements. Some of this money is managed by the government, which includes in the public budget, whereas some other lenders prefer to manager their funds. Projects managed by public sector are frequently problematic. However, funding agency projects are not problem free. The most concerning aspects are that they impose their own requirements with regard to forms of payment and contract documents. For example, most lenders offer a very limited or no advance payment at all.

9.4.8 Sub-contractor related constructs

According to Kwakye (1994), contractor selection is one of the most crucial decisions for successful projects. Murdoch and Hughes (1992) suggested that there is a very strong tradition in the construction industry that best price can be gained by making tendering contractors bid for work, so that the lowest price gets the jobs. There is, however, increasing dissatisfaction amongst clients regarding this type of competitive tendering because all it guarantees is the lowest price. Furthermore, nomination of sub-contractors should be avoided as much as possible since it can potentially brings problems of co-ordination and conflicts in personality. Inappropriate nomination of sub-contractors is often considered as one of the causes of claims by contractors.

Construction related factors constructs grid statistics are presented in the Tables 9.19 - 9.21.

Table 9.19: Sub-contractors-related factors: constructs

		E1	E2	E3	E4	E5	E6	E7	
C1	Project type experience	4	2	2	4	4	3	2	No project type experience
C2	Competitive bid	4	3	4	4	4	3	4	Uncompetitive bid
C3	Consistency of priced rates	3	3	4	4	5	3	4	Inconsistency of priced rates
C4	Geographical area experience	3	3	2	3	5	3	4	No area experience
C5	Good management skills	3	3	2	2	2	5	4	Bad management skills
C6	Good financial capability	2	2	2	3	4	4	4	Poor financial capabilities
C7	Good technical capability	3	3	2	4	4	4	4	Poor technical capabilities
C8	Good safety records	4	4	4	5	5	5	4	Poor safety records
C9	Good performance record	3	2	2	4	4	4	4	Poor performance records
C10	Good workmanship	3	3	3	4	2	2	2	Poor workmanship

Table 9.20: Sub-contractor-related factors: grid statistics

	Mean	Std Dev.	Skewness	RMS	SMC
C1	3.0	1.0	-5.55	0.38	0.98
C2	3.71	0.49	-33.94	0.34	0.98
C3	3.71	0.76	-17.55	0.43	0.99
C4	3.29	0.95	-8.13	0.51	0.98
C5	3.0	1.15	-4.37	0.41	0.99
C6	3.0	1.0	-5.55	0.60	0.99
C7	3.43	0.79	-12.70	0.58	0.99
C8	4.43	0.53	-53.09	0.47	0.98
C9	3.29	0.95	-8.28	0.59	0.99
C10	2.71	0.76	-5.89	0.40	0.98
Average of statistics	**3.36**	**0.84**	**15.51**	**0.47**	**0.98**
St.Dev of statistics	**0.47**	**0.20**	**15.12**	**0.09**	**0.00**

Table 9.21: Constructs correlation (clustering by complete linkage)

Cluster stage	Lower cluster	Upper cluster	Level of Similarity	Preceding clusters	Next cluster
1	7	9	0.923	0-0	2
2	6	7	0.847	0-1	4
3	2	3	0.645	0-0	7
4	4	6	0.632	0-2	6
5	1	8	0.624	0-0	6
6	1	4	0.167	5-4	7
7	1	2	-0.091	6-3	9
8	5	10	-0.573	0-0	9
9	1	5	-0.661	7-8	0

The constructs C1, C4, C5, C6, C9 and C10 are the most balanced whereas the remaining constructs exhibit high values of skewness which indicates that the ratings are skewed to high values as it can be seen from the grid ratings.

Most of the constructs have the least differentiation since they exhibit low standard deviation. The exceptions to this pattern are constructs C1, C5 and C6.

It can be seen from the values of Squared Multiple Correlation (SMC), Table 9.20, that each construct has a strong relationship with all others. These values are within the range of 0.98 to 0.99, which represent strong relationship.

Table 9.21 shows the results of cluster analysis where it can be observed that the constructs C7, C9, C6, C7, C2, C3, C4, C6, C1 and C8 are the most correlated whereas the constructs C1, C4, C1, C2, C5, C20, C1 and C5 are the least correlated. The following is a brief characterisation of the elicited constructs.

a) Experience with specific types of projects

Familiarity with the type of project facilitates the task of the contractor in the estimating and management process. When a sub-contractor is familiar with a specific type of project it may be possible to measure the individual elements with a reasonable degree of accuracy and plan the allocation of resources effectively and optimally. Conversely it will be almost impossible or very difficult to handle the project.

b) Competitive bid

A bid is competitive when the price estimate is in accordance with project elements such as plans and project specifications. Very often sub-contractors with high need for job underestimate prices in the hope of winning contracts. This attitude can seriously endanger project success if the contractor does not pay attention and bases his evaluation on price.

c) Consistency of priced rates

Consistency of priced rates is essential as it reveals sub-contractor's ability to estimate construction costs with competency, honesty and following sound principles. Sub-contractors work under extreme pressure because the time constraints are always tight. Main contractors have worked on the limit in bidding preparation and thus the action of sub-contractors is fundamental for them to perform subsequent job.

d) Geographical area experience

Geographical area experience is important in that different regions possess distinct characteristics in terms of logistics, physical conditions, services, sub-contractors, labour and culture which should be born in mind when estimating and during project execution. For example, in some regions in the north of country it is extremely difficult to hire labourer since most people prefer farming and fishing to working in construction projects. Convincing these people to work in construction requires much effort and very good pay.

e) Good management, financial, technical skills

It is desirable that sub-contractors have good management practices, financial and technical capabilities in order to ensure the contract is successful. In addition, sub-contractors with these attributes relieve the main contractors' close supervison. Sub-contractors with strong financial position are able to cope with clients' payment default that is commonplace in the country.

f) Good Safety record

It is essential that a sub-contractor has well established safety plans for a specific project so as to minimise the risk of accidents. The safety management must be carefully

controlled by the main contractor, who is the ultimate responsible before the client, and it must ensured that all regulatory requirements in place.

g) Good workmanship and performance record

Construction quality is one of the key performance indicators for most projects and, besides other factors such as design, depends largely on the good workmanship. Most workers lack formal training and have learnt from experience. While this method has worked, it is not as effective as submitting them to training sessions. As result, skilled artisans are scarce in the market and most of those that benefited from training in the past are retiring. Poor quality of projects is commonplace and as clients have become aware of the situation they impose strict control on the quality. Claims by clients on poor quality not only cost money but also damages firms' reputation and it is thus desirable to avoid such problems.

9.4.9 Economy and political environment constructs

Economy and political environment related factors grid and statistics are presented in the Tables 9.22 - 9.24. A visual inspection of rows and columns shows that the observed mean scores of the respondents on the majority of elements on the different constructs are generally balanced. That is the reason why the values of skewness shown on Table 9.23 are low. The only exception however is the construct C8 that presents a high skewness index of 15.34. All constructs possess negative skewness which indicates that the ratings are skewed to high values as it can be seen from the grid ratings.

The values of Squared Multiple Correlation (SMC), Table 9.23, shows that each construct has a strong relationship with all others. These values are within the range of 0.98 to 0.99, which represent very strong relationship.

Table 9.24 shows the results of cluster analysis. Cluster analysis groups constructs according to their similarities and produces a dendogram from which the table is drawn.

Table 9.22: Economy and political-related factors: constructs

		E1	E2	E3	E4	E5	E6	E7	
C1	Favourable market conditions	3	2	2	3	3	2	2	Unfavourable market conditions
C2	High construction supply	2	2	3	1	4	5	4	Low construction demand
C3	High interest rates	2	2	1	2	5	4	5	Low interest rates
C4	High currency devaluation	2	2	4	5	5	4	4	Low currency devaluation
C5	Unpredictable change in exchange rates	4	4	5	4	2	2	2	Stable exchange rates
C6	Unconvertible currency	2	1	1	1	2	1	2	Convertible currency
C7	High inflation	4	4	5	2	1	2	3	Low inflation
C8	Proneness to political instability	3	4	3	5	4	5	3	Political stability
C9	Good government policies	2	2	1	2	4	3	3	Wrong policies
C10	Free market system	1	1	1	5	5	4	4	Centrally planned economy
C11	Unreliable judicial system	1	1	2	3	2	2	1	Credible judicial system
C12	Effective commercial law	3	2	1	2	3	4	1	Ineffective commercial law
C13	Frequent disorder/strikes	3	3	2	2	3	4	5	Rare strikes/disorders
C14	Severe restrictions on expatriate labour	2	1	2	3	2	5	5	No restrictions on expatriate labour
C15	Stable taxation system	2	3	3	2	2	3	2	Unstable taxation system
C16	Stable import taxes	2	3	2	2	3	3	2	Unstable import taxes
C17	High level of bureaucracy	1	2	2	2	2	2	2	Efficient public services
C18	Corrupt practices	5	4	5	4	3	2	2	Low rate of corruption
C19	Delay in approval process	4	4	5	4	2	2	1	Prompt approval

Table 9.23: Economy and political-related factors: grid statistics

	Mean	Std Dev.	Skewness	RMS	SMC
C1	2.43	0.53	-6.64	0.35	0.99
C2	3.0	1.41	-3.30	0.49	0.98
C3	3.0	1.63	-2.60	0.62	0.99
C4	3.71	1.25	-8.32	0.43	0.99
C5	3.29	1.25	-5.43	0.63	0.99
C6	1.43	0.53	-0.68	0.41	0.99
C7	3.0	1.41	-3.30	0.57	0.99
C8	3.86	0.90	-15.34	0.39	0.99
C9	2.43	0.98	-2.67	0.60	0.99
C10	3.0	1.91	-2.15	0.56	0.99
C11	1.71	0.76	-0.95	0.38	0.99
C12	2.29	1.11	-1.75	0.33	0.99
C13	3.14	1.07	-5.83	0.51	0.99
C14	2.86	1.57	-2.24	0.46	0.99
C15	2.43	0.53	-6.64	0.38	0.99
C16	2.43	0.53	-6.64	0.36	0.99
C17	1.86	0.38	-3.98	0.37	0.99
C18	3.57	1.27	-7.08	0.61	0.99
C19	3.14	1.46	-3.74	0.62	0.99
Average of statistics	**2.77**	**1.08**	**4.70**	**0.48**	**0.99**
St.Dev of statistics	**0.65**	**0.43**	**3.33**	**0.11**	**0.00**

Table 9.24: Constructs correlation (clustering by complete linkage)

Cluster stage	Lower cluster	Upper cluster	Level of similarity	Preceding clusters	Next cluster
1	5	19	0.973	0-0	3
2	3	9	0.941	0-0	8
3	5	18	0.925	1-0	7
4	4	10	0.833	0-0	10
5	13	14	0.708	0-0	13
6	8	11	0.665	0-0	12
7	5	7	0.644	3-0	14
8	2	3	0.600	0-2	13
9	12	16	0.604	0-0	15
10	4	17	0.461	4-0	12
11	1	6	0.417	0-0	16
12	4	8	0.401	10-6	17
13	2	13	0.372	8-5	15
14	5	15	0.070	87-0	18
15	2	12	-0.113	13-9	16
16	1	2	-0.441	11-15	17
17	1	4	-0.560	16-12	18
18	1	5	-0.977	17-14	0

The constructs C5, C15, C2, C12, C1, C2, C1, C4, C1 and C5 are the least correlated, whereas the remaining are the most correlated whereas. The following is a brief characterisation of the elicited constructs.

a) Economic and political factors

The economic and political factors that impact on construction companies can be seen at three interlaced levels: macro; market; and project level. The most important economic

variables that have had significant impact on cost performance are high interest rates, high inflation and highly fluctuating exchange rates. These economic variables were consistently stable in the period 1975-1987, but for political reasons and not due to good economic performance. In addition, private initiatives were severely restricted and the significant construction companies were state-owned.

The devaluation of the local currency in 2000 alone was of about 30 per cent with an average 2.5 per cent a month. The dependency on imported construction materials make it extremely difficult to make accurate cost estimates. In parallel, the instability of taxation system, import taxes, high levels of corruption and bureaucracy cause serious constraints to the import chain. The process of globalisation and the dependency of the country on foreign aid make it impossible the government to formulate effective policies aimed at helping the industrial sector and the construction industry in particular.

The free market system has been invoked to limit government interference. For example, local contractors can hardly compete with foreign firms because of several requirements imposed by foreign donors or creditors. Native firms have been forced to engage in Joint-Ventures with foreign firms in order to undertake major works. Delay in approval was considered by contractors as a chronic problem that frequently leads to additional costs. Although there are timeframe for the regulatory agents to issue the required permits these are hardly respected. Public officials frequently delay approval until they receive bribes. The current commercial law and regulations have been in place for some decades now and has not been change to account for new developments and dynamism of social and economic environments. The judicial system is definitely unreliable and almost nobody trusts it.

A recent report on the administration of justice in the country revealed that the judicial system was inefficient and ineffective and thus was unable to back political, economic and social systems. Scarcity of resources, corruption, negligence, incompetence and lack of motivation were among the problems identified. As result, most contractors believe trying to put cases in court is waste of time and money. Political instability proved to be

a crucial factor on the whole economy and construction industry in particular. In the year 2000 political instability was among the main drivers of the rise in interest rates, inflation and currency devaluation. The fear for political motivated disturbances led most businessmen to transfer their financial resources to other countries causing shortage in hard currency that create severe imbalances.

9.5 Summary

This chapter was devoted to the analysis of data elicited through repertory grid interviews and subsequent discussion. The objective of the grid analysis was to identify the natural structure and pattern between elements and constructs. This was necessary in order to understand construction contractors' psychological processes and to identify how they perceive and handle risk factors in the management of their projects. The data elicited from multiple grids helped to ascertain the main criteria and sub-criteria, that is decision variables, used by construction contractors in the decision-making process within the context of risk management. The knowledge elicited from the repertory grid interviews was intended to build the knowledge base. A total of eighty constructs excluding repetitions were elicited.

Several techniques were used for data analysis namely visual inspection, descriptive statistics and cluster analysis. Visual inspection enabled the establishment of data patterns and rating trends. Descriptive statistics comprised the calculation of measure of central tendency (means), measures of dispersion of the ratings, skewness and SMC. The SMC expresses the relationship of each construct with all others and it was concluded that there is a strong relationship of each constructs with all others in different groups of risk factors.

The Cluster Analysis method was used to establish the relationships among constructs. Through data collection and analysis it was possible to establish the most important constructs used by construction contractors during the process of risk management

decision-making. Particularly, it was also possible to identify the most important constructs for each professional and determine the way they are associated.

The repertory grid interviews enabled the translation of mental models into knowledge models and the combination of knowledge from multiple sources. Combined grids were obtained by aligning planning directors', estimating directors' and contract directors' grids. All grids had the same elements and constructs and consequently the number of elements in the combined grids remained the same, whereas the number of constructs tripled. The main condition for comparing grids is that either the elements or constructs are identical in all grids. According to McKnight (1976), to adequately compare multiple grids it is necessary that the elements and/or constructs are identical. In general elements are more easily shared between a group of individuals than constructs.

The comparison of grids is made through the observation of the rating pattern. Most constructs satisfied either literal similarity or conceptual similarity. Literal similarity is considered satisfied when individuals use exactly the same verbal labels. Conceptual similarity is considered satisfied when individuals use distinct verbal labels to convey the same idea (Duck, 1975). It was observed that most constructs were elicited in the first five interviews and the remaining respondents prominently provided the same constructs. This means that construction contractors used similar criteria when managing risk.

Although the Personal Construct Theory recognises that different individuals may construe events or experiences in different ways (individuality corollary), this does not mean that individuals' construct systems are mutually exclusive. Furthermore, the commonality corollary, from Personal Construct Theory, states that individuals may construe events or experiences in similar ways. Therefore, the comparison of grids from different individuals helped to identify the level of shared understanding (Shaw, 1981) between individuals and, thus validate constructs' commonality.

Repertory grid technique is best suited to domains characterised by a high degree of subjectivity (Stewart and Stewart, 1981) such as risk management decision-making that is

a poorly structured problem. The repertory grid technique has, however, severe limitations when it comes to synthesis type of problems and elicitation of deep knowledge (Blanning, 1984).

The analysis did not concentrate on elements since the main purpose of the grids was the elicitation of the construct system. Finally, it is worth mentioning that the laddering technique was very useful in the process of knowledge elicitation since it facilitated obtaining deep constructs from the more general ones.

Chapter Ten

Development of risk decision framework

10.1 Introduction

The two preceding chapters were devoted to data analysis and discussion in order to obtain relevant information. This chapter explains how the fuzzy decision framework KBS for analysis and management of global risk factors was developed. The framework was developed from the literature review, findings of the research and interactive discussions with construction experts.

One of the most important components of the framework is the Fuzzy Risk Decision Framework FRIDEF that is a fuzzy knowledge-based system. A fuzzy KBS is a knowledge-based system that uses fuzzy logic, an application of fuzzy set theory, instead of classical Boolean logic. The process of system conception, knowledge elicitation, analysis and representation is explained. The chapter also describes the main features of the system namely the user interface, inference engine and working memory and the important process of verification and validation. The knowledge-based system aims to help construction contractors analyse and manage global risk factors affecting construction cost performance at a project level.

10.2 Objectives of the framework

The risk decision framework is designed to provide a framework for construction contractors to analyse and manage global risk factors affecting construction cost performance. The framework should be viewed as an important component within the holistic and proactive project management. By no means is this the definitive framework for global risk factors analysis and management. It does, however, cover the most relevant categories of global risk factors deemed crucial for the success of construction projects by both contractors and clients. It is expected that the framework will increase

construction contractors awareness and capability in managing project risks. By doing so they will be able to understand the uncertainty permeating through construction projects and thus make improved and informed decisions.

10.3 Background for developing a KBS

Before embarking on the development of KBS a careful analysis of the problem was carried out to ascertain whether a KBS would be appropriate and if was an effective technology. As outlined in Chapter 6 there are some main features that make certain and specific construction industry problems suitable for KBSs. In this regard, the following issues were addressed: was the problem mainly algorithmic or heuristic; did the knowledge change over time or remained constant; was the input data correct and complete; were approximate solutions acceptable; and could the problem be solved by other means.

The analysis was carried out at different levels namely the nature of risk in construction, the current state of risk analysis and management, the current techniques and tools used by construction contractors. Alternative and complementary approaches for risk assessment and management were also addressed in order to see which routes could be taken in order to improve and complement the current state of art.

It was, therefore, concluded that alternative approaches that clearly incorporate subjectivity and empirical knowledge, have to be addressed for an effective modelling and analysis of risk factors in general, and global risk factors in particular. Risk management is a humanistic system rather than mechanistic.

10.4 Risk decision framework

The scope of risk management is the systematic identification of the sources of risk, measurement of the impact and likelihood of risks and the development of the most appropriate response strategies to the risks that may damage the performance of the project. It is concerned with the outcome of future events whose exact outcome is

unknown and with how to deal with these uncertainties. Risk management is conceptualised as a component of the whole project management exercise.

The framework provides a perspective for structuring risk decision-making and incorporates processes concepts, methods, techniques and tools aimed at implementing the chosen approach. The decision framework comprises the FRIDEF system which is a fuzzy knowledge-based system and following steps: risk planning; risk identification; risk analysis; risk response; risk monitoring and control; and risk report. These components are explained below.

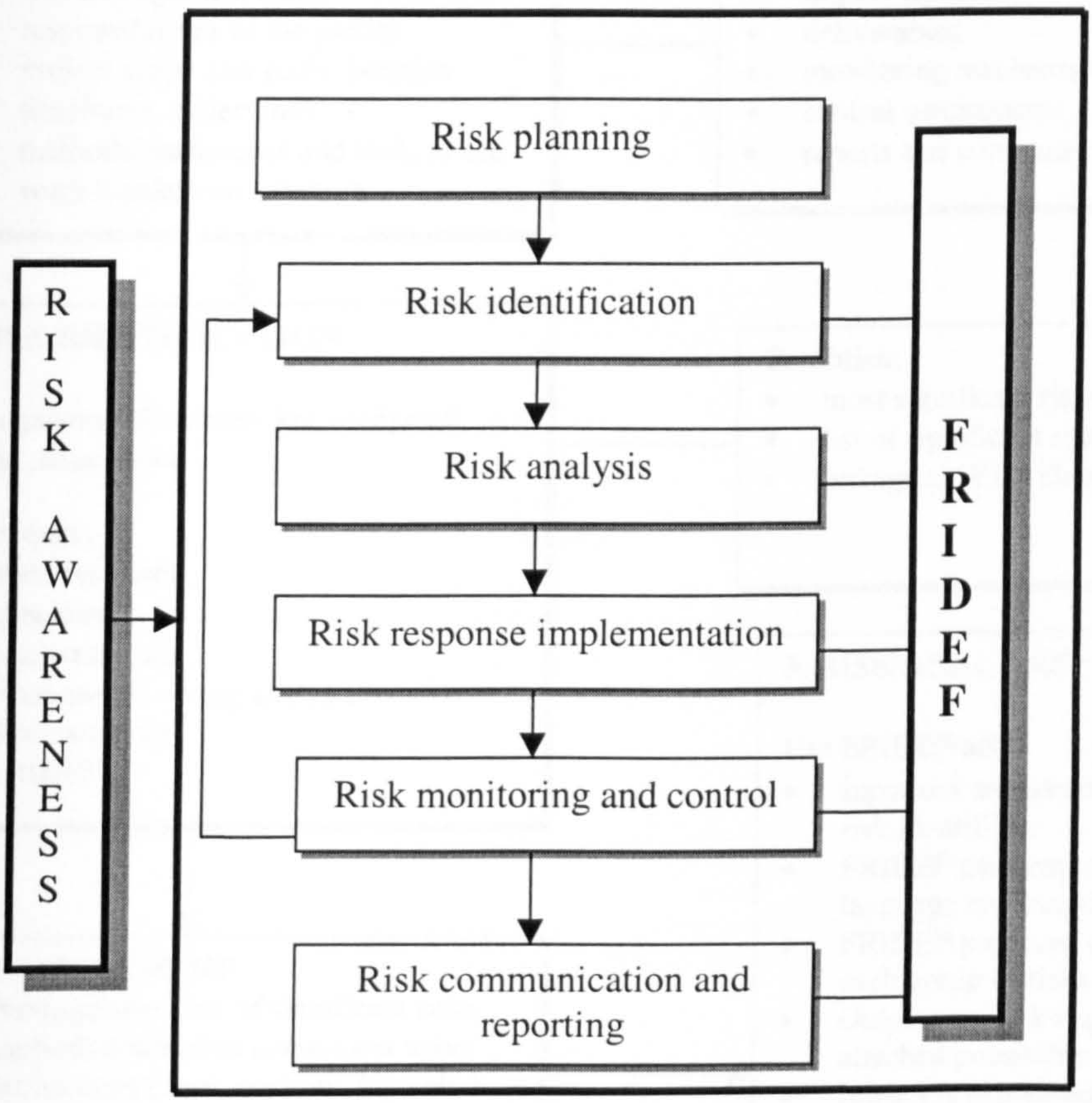

Figure 10.1 Risk decision framework

INGREDIENTS:
Corporate culture
Organisational structure
Risk management strategy
Risk management policies/procedures

1. RISK PLANNING:
Define:
- risk management team
- responsibilities of the parties
- project scope and goals, benefits
- timeframe, milestones
- methods, techniques and tools to use
- work breakdown structure

Establish:
- risk thresholds
- impact measures
- deliverables
- monitoring mechanisms
- control mechanisms
- reports and communication forms

2. RISK IDENTIFICATION

Pre-requisites: Risk plan, knowledge of project, experience

Techniques:
- historical data
- checklists
- brainstorming
- what can go wrong analysis
- Swot analysis
- FRIDEF

Establish:
- most significant risks
- list of significant risks
- linkage to WBS elements

RISK ASSESSMENT
- Pre-requisites: list of significant risks
- method: qualitative assessment using expressions (low, medium, high etc.)
- alternatively, using numbers ranging from 1 to 10.
- each risk should be assessed

3. RISK ANALYSIS

Use FRIDEF and:
- input risk assessments for each risk identified
- FRIDEF performs natural language computations
- FRIDEF produces outputs for each group of risks
- Outputs are risk impact and attached possibility
- Impact is expressed in natural language and in numbers between 1 and 10
- FRIDEF produces graphical reports showing inputs and outputs (linear, 2 D and 3 D)

From risk analysis

RISK ANALYSIS RESULTS

- list potentially severe risks
- link risks to WBS
- determine possibility x impact rating IPR
- team classify risks and discusses results
- team determine likely impact on cost
- team decides which risks deserve further consideration

4. RISK RESPONSE STRATEGY AND IMPLEMENTATION

Pre-requisites: results of risk analysis and risk plan

- response strategies: avoidance, reduction, absorption, insurance and contractual transfer.
- there is no best strategy. Appropriate strategy depends specific project, likely impact, cost-effectiveness, feasibility, timing, consensus, ownership.
- as a recommendation, first course of action is avoidance, then reduction, contractual transfer, insurance and absorption.
- select strategies and assess potential consequences prior to implementation

5. RISK MONITOING AND CONTROL

Pre-requisites: risk plan

- Assess project progress
- Identify any changes in risks
- Check emergence of new risks
- Check in risk exposure
- Check compliance with policies and procedures
- Take corrective measures if required (for example assess, analyse and formulate responses to new risks)

6. RISK COMMUNICATION AND REPORTING

Pre-requisites: all previous steps

- produce risk management reports (tsources of risk, significant risks, most impacted WBS elements, responses adopted, control mechanisms, costs and benefits)
- reports from FRIDEF can be attached
- inform project stakeholders of risk management process

Figure 10.2 Risk management process map

10.4.1 Risk management planning

Risk planning entails the determination of the approach, objectives and activity plan for the implementation of risk management process. It specifically involves establishing and clarifying the following aspects: project goals; scope; WBS; benefits; steps involved; definition of measures of impact; risk tolerable thresholds; timeframe; milestones; responsibilities; resources; deliverables (risk register, risk response strategies, reports etc.); monitoring and control mechanisms; methods; techniques; and tools to be employed in the whole process from risk identification to risk communication and reporting. Risk planning exercise aims thus to ensure that risk management is conducted efficiently and effectively and in operational terms it can be considered as if it was a project in its own right.

The basis upon which risk planning is conducted comprises the organisation culture, organisation structure, risk management policies and procedures, and the project itself.

The risk management plan is a very important document, as it will be used as a benchmark against which the deliverables will be compared. It should be born in mind that risk management is not a linear but a cyclical process (continuous loop) performed throughout project life cycle. The most significant participants in the risk management exercise should be identified and their roles clearly defined. In this regard it should be noted that risk management is better performed collectively rather than individually, since groups can be helpful in creating synergies. Furthermore, both top-down and bottom-up approaches should be encouraged.

The risk management group should be headed by a facilitator that is responsible for leading the process from the beginning through completion and it is important that all group members are actively involved. The project manager or the risk manager is the ideal facilitator. Risk management group should ideally include project managers, estimating and planning personnel, senior executives and anyone who can provide crucial information on the process. While senior executives are concerned with corporate

strategies they can provide valuable contribution to the risk management process at the operational project level due to their wider vision. Once the issues mentioned in this section have been considered the next step of systematic risk management can be initiated.

10.4.2 Risk identification

Risk identification and analysis aim to improve decision-making by uncovering the most significant risks relating to the implementation of the project. It is important that the risk management group perform risk identification systematically since it ensures a better understanding of project risks. The starting point for dealing with risks is to identify them because unless the risks are identified they can not be managed. Because of this risk identification has been regarded as the most important step in risk management.

Each risk factor should be linked to the element of the WBS or work package WP that can potentially affect. The level of detail of the element is determined in accordance with project specificity and clarity. As an indication, two or three levels below the project as a whole would suffice. For example, elements could be grouped into work types.
There are many different ways of identifying risks and the choice of one or another depends upon several factors such as the project scope, project type, project size, experience of risk management group etc.

The most important ingredients to risk identification are the understanding of the project objectives, project scope, construction knowledge, construction experience, project knowledge including the main activities, and the understanding of potential threats confronting the achievement of those objectives. Although it is impracticable and impossible to identify all risks the present framework provides exhaustive, relevant and key risk sources as well as the main risk factors that relate to both operational and general environments in order to facilitate the identification process. In this regard Wirba et. al citing Flanagan and Norman suggested that the consideration of the eight largest risks typically covers up to 90 per cent of the risks to a project. Further potential risks can

however be identified using techniques such as checklists, brainstorming, fishbone diagrams, historical data, "what can wrong" analysis and SWOT analysis. These risks can further be incorporated into the operational system.

10.4.3 Risk analysis

Risk analysis uses qualitative techniques and tools to evaluate the two most important dimensions of risk, namely risk impact or severity and risk likelihood. There are several different ways to measure the impact and likelihood of a risk event. The impact represents the severity or effect on the project objectives if the risk occurs. Statistical decision models often use probability to measure the likelihood and quantitative units (for example sum of money and time - days, weeks etc.) to measure the impact.

A different approach is to use "probability x impact" (P-I) matrix, where probability and impact are multiplied to rank risks into classes. Using this approach, risks can be categorised into high, moderate or low depending on their position on the matrix. For example, a risk score of 0.64 = (0.80x0.80) represents a very high risk requiring thus a close attention. Another approach is to develop scales for both dimensions namely impact rating and likelihood rating. The impact scales may also be rank-ordered values. The objective of impact scale is to assign a relative value to the impact on project objectives. The definitions and meaning of the scales were elicited through interactive discussions with organisations and practitioners.

The risk likelihood in the present framework is assessed through possibility measures (see Section 7.5) and the impact through simultaneously linguistic terms and crisp values (impact scale). The combination of impact versus possibility through the "impact x possibility" matrix produces the Impact-Possibility-Rating IPR that is used to place risks into different classes and thus concentrating greater attention on the most significant.

Any risk can be described as low, medium or high according to its position in the IPR matrix. All risks with IPRs located in the grey area in Table 10.1 deserve thorough examination by management. The possibility and impact measure is an important evaluation technique because it does not consider risk dimensions in isolation. The impact scale and possibility-impact matrix are depicted in Tables 10.1 and 10.2.

After the different risks have been identified there is a need for the risk management team to express its perception on the magnitude (risk assessment) of each of the risks using linguistic expressions such as low, medium, high or alternatively crisp values. These assessments have the corresponding membership functions representing uncertainty that are fed into the FRIDEF for further natural language computation. The system processes these inputs and produces the severity of risk associated with each group of risk factors namely estimator-related, . design/project-related, fraudulent practices-related, competition-related, client-related, construction-related, sub-contractor-related and economy/political-related, as well as the overall global risk resulting from the combination of the former, if required.

The output is expressed both in linguistic (for example very low, low, medium, high and very high) and in numeric terms (from 1 - lowest risk level to 10 - highest risk level). In addition, each output value has its associated possibility measure ranging from 0 to 1. The possibility measure is different from probability measure. Possibility reflects the degree of ease with which a variable may take a value, that is, it describes whether an outcome can occur, whereas a probability describes whether it will happen.

Risks that are likely to cause severe damages to the project objectives are listed together with the elements of WBS that may be impacted. At this stage the risk management team may raise the following important questions: "what is the possibility that each of these risks will really materialise?"; and "which of these risks are extremely harmful and which are tolerable?". The results from risk analysis namely risk impact, risk likelihood and risk ranking using IPRs must be discussed, understood and agreed upon by the risk management group before the following stage of the process.

Table 10.1 Possibility-Impact matrix

Possibility ↓							
1.0	1	2	4	6	8	10	
0.8	0.8	1.6	3.2	4.8	6.4	8	
0.6	0.6	1.2	2.4	3.6	4.8	6	
0.4	0.4	.08	1.6	2.4	3.2	4	
0.2	0.2	0.4	0.8	1.2	1.6	2.0	
0.1	0.1	0.2	0.4	0.6	0.8	1.0	
Impact ⟶	**1**	**2**	**4**	**6**	**8**	**10**	

Table 10.2 Risk impact on cost performance

Risk level	**Meaning**	**Impact scale**	**Mean**	**Percentage (%)**
Very low	Negligible effect on cost	1.0 - 4.0	1.5	< 3.0
Low	Marginal effect on cost	2.5 - 5.5	4.0	3.1 < P < 8
Medium	Serious effect on cost	4.0 - 7.0	5.5	8.1 < P < 20
High	Critical effect on cost	5.5 - 8.5	7.0	20.1 < P < 30
Very high	Catastrophic effect on cost	7.0 -10	8.5	> 30

10.4.4 Risk response strategies and implementation

Unless responses are developed and effectively implemented the preceding stages of risk management can be worthless. Successful implementation of risk response strategies depends on the following: project team motivation; project team understanding of the value of risk management; project team commitment to their roles; project team skills; availability of resources; and time availability. It is the effectiveness of risk response that determines whether the risk exposure is reduced or it increases. Risk response involves generating alternative options for managing risks, evaluating and comparing the different alternative options, selecting one or more alternative options, and implementing the

selected alternative options. The risk management plan should be called upon at this stage as a base upon which risk response relies. For example it is important that the risk threshold value is determined. In principle there is no best risk response strategy and the appropriateness of a specific risk response depends on its merit. Often a combination of risk responses can be much more effective than a single response.

Two main response strategies are available, namely risk control comprising avoidance, reduction, absorption; and risk transfer comprising insurance and contractual transfer. Each of these strategies can have several tactics that are used for its implementation so after selecting a response strategy the analysts should devise the most appropriate tactical responses to the risks under consideration.

Since the selection of one or another response strategy is a typical management problem and there is a large number of factors that influence such selection it can not be guaranteed that response strategies that work for certain circumstances will be effective in other circumstances. What can be provided are general guidelines to help risk analysts improve the decision-making process. To ensure an effective risk response strategy the following issues deserve due consideration before any course of action or risk response strategy is taken:

- feasibility (ensure the selected strategies are realistic, achievable and work);
- cost-effectiveness (the cost involved in mitigating a specific risk and the benefits);
- timing of risk response implementation (immediate or not immediate);
- appropriateness to the level of risk;
- the extent to which a particular risk is controllable;
- consensus (there should be an agreement and commitment of the project stakeholders in implementing risk response strategies); and
- ownership (each response strategy should be owned to ensure responsibility and accountability).

In addition, it is important to evaluate the consequences of each course of action prior to the implementation. The Table 10.3 displays the different risk levels, their meanings and the recommended risk response strategies whereas the sections below describe what each strategy involves as well as the associated tactics. As a general guideline it is recommended that risk avoidance be considered as the first course of action, reduction the second, contractual transfer the third, insurance the fourth, and absorption the fifth.

Table 10.3 Risk response strategies according to risk impact

Risk level	Meaning	Recommended response strategy
Very low	Negligible effect on cost	Absorption/reduction
Low	Marginal effect on cost	Reduction/absorption/transfer
Medium	Serious effect on cost	Avoidance/reduction/contractual transfer/Insurance
High	Critical effect on cost	Avoidance/reduction/insurance/
Very high	Catastrophic effect on cost	Avoidance/reduction/Insurance

a) Risk avoidance

The main purpose of risk avoidance is to eliminate uncertainty and thus reducing the likelihood of a risk event to zero. It is however worth stressing that it is impossible to eliminate all project risks. The tactics that can used for that purpose include changing the project plan to eliminate the risk (for example, changing the scope to eliminate the cause of risk), obtaining additional information, avoiding specific partners such as suppliers, promoting training, allocating additional resources, changing complex technologies and adopting familiar methodologies. In circumstances where the risk impact is considered unacceptable since it would turn out to be catastrophic to the project objectives should the risk event materialise risk avoidance may imply the abandonment of the project.

b) Risk reduction

Some project risks can be eliminated through reduction strategy. Risk reduction is necessary whenever the level of risk is so significant to be easily retained or absorbed. Reduction aims to reduce the degree of risk impact to below an established acceptable threshold level. This threshold is established in advance and serves as criteria against which comparison is made. The threshold level is stated in linguistic terms such as very low, or low.

Reduction is very specific and targets specific and individual causes of risks to reduce their likelihood or their impact on project objectives. The following tactics can be used in order to reduce risks: gathering additional information on project elements or activities; proposing changes to the original design; proposing changes to construction methods; changing the supplier; changing the sub-contractor; thorough examination of contract documents and contract clauses; and enhancing communication between the parties.

c) Contractual transfer

Often risks can not be retained or reduced effectively and the contractual transfer is the most appropriate option. Contractual transfer involves transferring risks from one party to another through contractual documents namely the contract, general conditions of contract and particular conditions of contract. The party to which risks are transferred is deemed best positioned to manage or control the risks and unless this is so project objectives can be in jeopardy and conflicts between the parties are likely to arise. The parties include contractor, sub-contractor, designer and client. If risks are not fully transferred from one party to another they should at least be fairly shared between the parties.

The most important actions that can be taken in transferring risks are: thorough examination of contractual documents; changing contract clauses (for example, cost escalation, currency etc); adding contract clauses; and modifying general conditions of contract. The contractor should therefore examine tender documents thoroughly in order

to detect any potential risk and propose to the client the most appropriate allocation strategy during tendering and contract negotiation.

d) Insurance

Insurance can be an alternative course of action when absorption, reduction and contractual transfer are not feasible. It involves transferring risk between one party and an insurer. Theoretically it is possible to ensure all sort of risks. In practice, however, many risks are not insurable at an acceptable price and insurers are not willing to accept some types of risks. As a general guideline, if the cost of insurance package is greater than the potential impact of the specific risks it is wise not purchasing the insurance.

e) Risk absorption or retention

Risk retention is a feasible course of action in situations where the level of risk is negligible or there are residual risks (those remaining after risk reduction and risk transfer). In such circumstances there is no change to project plan and the organisation accepts taking the risk. Residual risks include those negligible risks that have not been tackled for cost-effectiveness reasons.

Risk absorption can be materialised in the form of contingency allowances aimed to ensure the planned return in the event of risks materialising. The amount of contingency allowance is determined in accordance with the level of risk. The contingency plan tactic is only implemented if the predicted risks materialise. The usual contingency amounts are of the order of 5 to 15 per cent of the final cost estimate depending on the project size, project type, complexity, level of competition and type of contract. In adopting risk absorption the benefits of taking the risk should be evaluated and compared to the costs.

10.4.5 Risk monitoring and control

Monitoring and control are crucial functions in risk management and they aim to check whether the actual risk management performance is satisfactory, that is, if the desired results are being achieved or not. Since risk is dynamic throughout the project implementation it is necessary to assess how the project is progressing in reality as opposed to what has been predicted. Monitoring aims to check the effective implementation of risk response strategies, identification of changes in project risks, reduction of risks, emergence of new risks, change in risk exposure and compliance with policies and procedures.

The control process comprises the following steps: establishing performance standards; measuring performance; comparing the performance to the standard; and taking corrective action the actual performance does not meet the required performance. Corrective actions can include reformulation of risk plan, risk identification, risk analysis and response strategies. The standard performance is the target against which subsequent performance is measured and established in accordance with project objectives, for risk threshold level. The deviation between the actual and standard performances can either favourable or unfavourable but the latter causes greater concerns since it can threaten project objectives.

10.4.6 Risk communication and reporting

Effective communication of risks is crucial for successful risk management and it requires certain skills. It is essential that all stakeholders have a common understanding of risks so that they can play their roles actively. Risk communication is the process of exchange of information among interested parties about the nature, magnitude, significance and management of risk so that the process is understood and validated.

This interchange of information should be fluid and dynamic. The interested parties include project team members, project managers, senior management and other stakeholders. The communication of risk can be through various channels of which oral presentation and written reports are the commonest.

The risk report is the memory of risk management process and should contain information on the whole risk management process. It should contain risk database including the main sources of risk, significant risks, most impacted WBS elements, most sensitive project elements, costs and benefits of risk management. The report is an important document that can be used as reference of learned lessons in future projects. The information contained in the reports can be used to boost organisational learning by creating risk management knowledge bases.

The report files generated by FRIDEF include a list of all variables, rules, performance results, inference results as well as plots and graphical elements of inputs and outputs that can be used to enhance the understanding, comprehensiveness and clarity of the risk report.

10.5 General description of the FRIDEF system

A knowledge-based system is an interactive computer program that perform specialised complex tasks requiring knowledge, experience, intuition, heuristics and judgement in a narrow domain. The risk decision model aims to reduce uncertainty and improve the quality of construction decisions.

The FRIDEF has the following main components: knowledge base, inference engine, working memory and user interface. The knowledge base comprises both factual and heuristic rules. Heuristics are rules of thumb that are usually empirical in nature, based on experience and intuition with no scientific grounds. The inference engine examines and applies the rules contained in the knowledge base. The inference mechanism begins with a set of data and after an initial examination it moves towards a solution or recommendation.

The FRIDEF uses production rules and rule-based inference. A rule comprises a set of conditions and a set of actions. If all of the conditions in a rule are true, then the actions are executed. The working memory is the part of FRIDEF that keeps track of the problem domain by storing data such as user's answers to questions, facts obtained from external sources, intermediate results of reasoning process and conclusions arrived at. The user interface is the communication channel between the user and the system. It enables the user to exchange information with the system.

10.5.1 Knowledge, databases and algorithmic models

The importance of database model and analytical model, in addition to knowledge model, was thoroughly examined in the process of framework development. It is always necessary to decide whether database access is necessary as well as on the function of analytical models in the system. The importance of both databases and analytical models depends upon the role they play in the system.

The FRIDEF relies prominently upon the knowledge base model. Although it incorporates databases and analytical models, which play a significant role, at this stage of the development of the system these modules are not as substantially important to the functioning of the system as the knowledge model is. The databases contained in the system include financial database, economic database, contractors database and project database. The models module include fuzzy set algorithms namely, fuzzification, composition, defuzzification and linguistic approximation. Further expansion of the system may incorporate large databases and additional analytical models if necessary.

10.5.2 How the FRIDEF system works

The system needs to first obtain initial data to get started and it acquires information through the user interface. The user enters, through selection in the menu, values for each of the different variables displayed on the screen. The model has 50 variables and 1600

rules in total. The values can be expressed both in linguistic terms and numbers and they represent the assessment of the variables by the user. Some examples of values assumed by the variables are very high, high, moderate, low and very low.

Apart from the data entered from the screen there are several databases that are manipulated through an in-built DBMS. The databases comprise questionnaire data, cost database, financial database, project database, economy database and contractors database. There are also some analytical models aimed at performing some algorithmic operations that are not provided in the shell, which include linguistic approximation through Euclidean distance and FRIDEF recommendation.

After obtaining the initial data the system gets started and performs matching, resolution and aggregation. Matching is the process whereby the system compares input data to antecedents terms of the appropriate rules. Resolution combines the assessments using modus ponens and produces partial outputs. Aggregation combines the different partial outputs, from several rules, into a cumulative membership function or total risk output.

The main advantages of the FRIDEF are:

- it allows distribution of specialised expertise to a vast array of non-experts;
- a great deal of consistency can be achieved and maintained;
- the expertise can be made available all the time eliminating the need for a full-time expert and thus reducing costs of labour; and
- the combination of heuristics and, sometimes, algorithms can produce quick and inexpensive solutions to difficult problems;

In addition, the KBS has the advantages of enabling better decisions, faster decisions and disseminating expertise and the ability to encode knowledge directly in a form that is very close to the way experts themselves think about the decision process. The system has been designed to run on any IBM compatible PC's supporting MS-DOS.

10.6 How the FRIDEF system was developed

One of the most important tasks at earlier stages of the development of a KBS is to define the structure of the problem and its solutions. The problem under study and the purpose of the system were clearly defined. For this purpose it was important to understand the problem, the issues the experts consider and how they use the available information to produce solutions.

The development of the FRIDEF was an iterative process and involved first obtaining a small amount of knowledge from the experts, encoding it into the system and testing the model. The testing results were subsequently used to improve and expand the system. The development process comprised several stages that required several testing and modifications before a KBS was effectively implemented. The stages followed can be summarised as follows: initial specification (problem: analysis and management of global risk factors); knowledge acquisition (questionnaire, repertory grids, books, journals articles); design (knowledge analysis and representation); implementation (variables, membership functions, rule base, relationships); and validation, verification and maintenance.

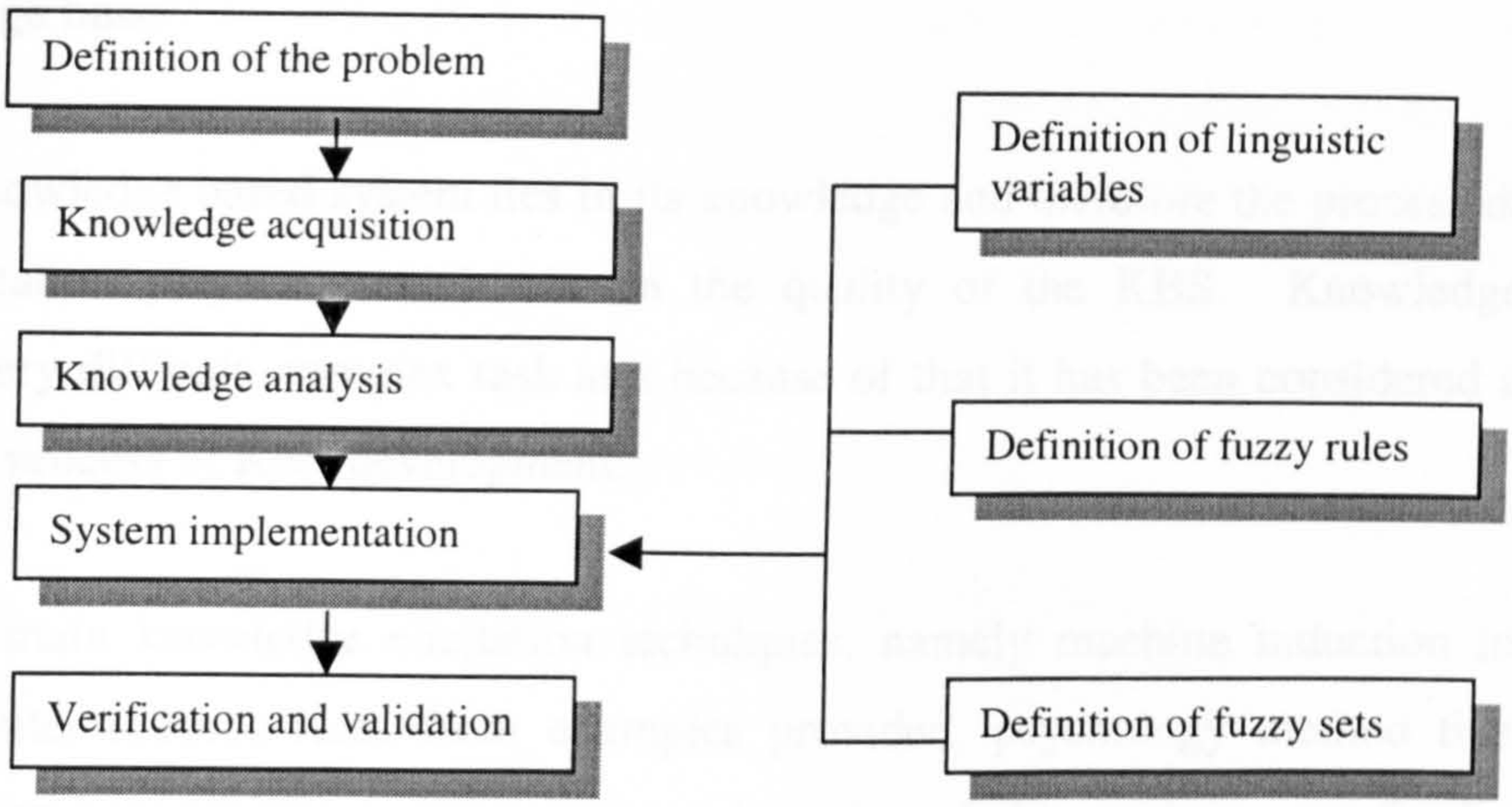

Figure 10.3: Steps followed for developing the FRIDEF

10.6.1 Problem definition and system requirements

The role of requirement specification of KBS is to provide a clear description of the problem as well as to explain how it will be solved including the inputs and outputs of the system. It determines the different development steps and project goals, evaluation methods, hardware constraints, inference techniques, knowledge representation, needs, desires and concerns of the users. All these issues were properly addressed at earlier stage.

With regard to the goal, that system is designed to be correct at least 75 - 80 per cent of the cases which is an acceptable level as suggested by Harmon et. al. (1990). Knowledge based systems can be classified according to the problem or domain areas and the type of solution they provide. The FRIDEF is a predictive system that is designed to predict future events through processing available information. The main objective of FRIDEF is, therefore, to assess the likely degree of global risk given a set of circumstances or situation and then providing recommendations on the appropriate response strategy. The set of circumstances in this case refers to the input variables that the user feeds into the system.

10.6.2 Knowledge base

The power of knowledge based system lies in its knowledge and therefore the process of knowledge elicitation plays a crucial role on the quality of the KBS. Knowledge elicitation is a very difficult, complex task and because of that it has been considered a bottleneck in the process of KBS development.

There are three main knowledge elicitation techniques, namely machine induction in which the computer induces rules from examples provided, psychology method that involves interaction between the domain expert and the knowledge engineer and finally the technique in which the knowledge engineer plays the role of the domain expert. Machine induction and the technique where the knowledge engineer plays the role of the expert were discarded because they were considered inappropriate for this study. First, there is lack of objective and reliable data concerning global risk factors that could be fed into the computer to form examples as the induction technique requires. Second, the knowledge engineer will usually lack sufficient domain and knowledge base development techniques. As a result, the psychological process, namely repertory grid interviews was adopted.

The knowledge base in this study was elicited mainly from experienced construction contractors through informal discussions, interviews, questionnaires and repertory grid interviews. The repertory grid technique was chosen because is very a flexible technique for obtaining mental maps of individuals and involved 25 construction contractors from who the most important constructs were elicited. The respondents were also asked several questions including the decision criteria for assessing and managing risks.

Although the experts were the main sources of knowledge others sources such as books, journals articles, reports, guidelines, magazines, regulations, and institutions were searched to collect additional important information related to global risk factors and construction knowledge. The latter sources possess excellent information that is easier to retrieve than the knowledge elicitation from experts. The author's experience in

construction projects was also partially useful in deriving, organising, compiling and formalising the knowledge contained in the knowledge base. Heuristics are rules of thumb that are usually empirical in nature, based on experience and intuition with no scientific grounds.

Table 10.4 Variables and membership functions of FRIDEF

Group of risk	Variable (constructs)	Values (membership functions)
Estimator factors	Training	Very poor, poor, average, good, very good
	Skills	Very poor, poor, average, good, very good
	Knowledge	Very poor, poor, average, good, very good
	Experience	Very little, little, average, large, very large
	Morale and motivation	Very low, low, moderate, high, very high
	Hiring cost	Very low, low, moderate, high, very high
Fraudulent practices	Misrepresentation	Very low, low, moderate, high, very high
	Collusion among bidders	Very low, low, moderate, high, very high
	Bid evaluation	Very unfair, unfair, moderate, fair, very fair
	Security	Very poor, poor, moderate, good, very good
	Theft rate	Very low, low, moderate, high, very high
Design/Project	Innovation	Very low, low, moderate, high, very high
	Attractiveness	Very low, low, moderate, high, very high
	Construction period	Very short, short, moderate, long, very long
	Cooperation	Very poor, poor, moderate, good, very good
	Details level	Very poor, poor, moderate, good, very good
	Specifications	Very poor, poor, moderate, good, very good
Client		
	Experience with client	Poor, moderate, good
	Fund management	Poor, moderate, good
	Source of funds	Donated, loan, public budget

	Co-operation	Poor, moderate, good
	Payment record	Very poor, poor, moderate, good, very good
Sub-contractor		
	Price consistency	Very low, low, moderate, high, very high
	Area experience	Very little, little, moderate, large, very large
	Management skills	Very poor, poor, moderate, good, very good
	Financial strenght	Very poor, poor, moderate, good, very good
	Technical strenght	Very poor, poor, moderate, good, very good
	Safety records	Very little, little, moderate, large, very large
	Performance record	Very poor, poor, moderate, good, very good
	Workmanship	Very poor, poor, moderate, good, very good
Group of risk	**Variable (constructs)**	**Values (membership functions)**
Competition	Market conditions	Very poor, poor, moderate, good, very good
	Number of bidders	Very low, low, moderate, high, very high
	Need for job	Very low, low, moderate, high, very high
	Project size	Very small, small, moderate, large, very large
	Supply	Very low, low, moderate, high, very high
Construction factors	Temperature	Minimum, mild,extreme
	Rain	Low , moderate, heavy
	Humidity	Low, moderate, extreme
	Road network	Very poor, poor, moderate, good, very good
	Road type	Unpaved, semi-paved, paved
	Site location	Remote, moderate, good
	Communications	Poor, moderate, good

Economic-political		
	Supply	Very low, low, moderate, high, very high
	Exchange rate	Very unstable, stable, very stable
	Inflation	Very low, low, moderate, high, very high
	Interest rate	Very low, low, moderate, high, very high
	Market conditions	Very poor, poor, moderate, good, very high
	Instability	Low, moderate, High
	Policies	Bad, moderate, good
	Judicial system	Very unreliable, unreliable, reliable, very reliable
	Commercial law	Obsolete, ineffective, effective
	Disorders-strikes	Very rare, rare, frequent, very frequent
	Expatriate labour restrictions	Low, medium, high
	Taxation system	Unstable, moderate, stable
	Import taxes	Unstable, moderate, stable
	Bureacracy	Little, moderate heavy
	Corruption practices	Very rare, rare, frequent, very frequent
	Approval	Very delayed, delayed, timely

10.6.3 Development tool

Having examined the most important tools for the development of KBSs it was decided to use a shell rather than building a system from scratch. Building a system from scratch or using programming environment is costly, lengthy and very demanding and thus these options were discarded. Shells are easier to use, enable quick implementation, most use production rules and have different inference mechanisms to cater for different requirements.

According to Edwards (1991) shells account for 56 per cent of KBSs development software. A shell is basically a KBS without a knowledge base which is usually built by the knowledge engineer. Despite these advantages they are less flexible compared to programming languages. For example, it is difficult to find a shell that fit all specific

problem requirements and thus in most circumstances there is a need to complement the facilities provided by them. A shell provides the knowledge engineer with the following: an inference engine, user interface, facilities for building knowledge base – editor, display and browsing facilities and rule validator and debugging.

In this research a shell called TILshell from ORTECH ENGINEERING INC of Texas, was chosen as the most appropriate tool due to its flexibility, portability, inference mechanisms, windows, graphics that simplify input and output information and mathematical routines. TILshell has an open architecture that enables the system to access and supply information to external programs. In addition, it has a powerful debugging utilities which can be used during the development process. However, the shell did not offer all the features needed and thus external programs had to be written for performing linguistic approximation.

TILShell is a windows-based object-oriented development tool that provides a way to describe fuzzy systems, test the systems through simulation, compile the system for further online testing or compile finished system into the output code necessary for the final implementation on the target processor. It can be easily extended by adding new objects via Windows-DLL linkages. The TILShell comes with complete editors for each part of fuzzy logic namely variables, membership functions and rules. These editors allow entering and modifying descriptions of variables, membership functions, rules and connections between variables and rulebases in graphical point-and-click environment.

The description of the system in TILshell is represented in the Fuzzy Programming Language FPL that comprises fifteen different objects. These objects provide ease and flexibility in designing fuzzy systems. FPL uses hierarchical object structure where specific rules apply to where certain objects can be defined. For example, Rule objects can only be defined in Rulebase objects while Rulebase objects can only be defined in Project or package objects.

Project object is the top level object of FPL and there can be only one project object per file. The name of the project is the name the user uses to call the fuzzy system. Chart objects are used to define charts for viewing data during debugging.

Chart objects are contained in Debug objects. Connect objects serve the purpose of defining the input and output variables (VAR objects).

Debug objects store information about the debugging process set up of TILShell. Emit objects are used to embed text or source code in the output code when a FPL source file is compiled. External objects are used to embed an external reference and call to a user-defined function implemented in the target environment's language. Member objects are used to define membership functions for variables. Model objects define the model that runs during simulation. Procunit objects are used to perform non-fuzzy processing on variables using the FPL script language. Rule objects are used to define the production rules of a fuzzy system. Simulate objects contain all options and objects necessary to support a simulation.

10.6.4 Knowledge encoding

Knowledge encoding or representation is concerned with how knowledge is organised and represented in the knowledge base. There are several ways of representing knowledge in KBSs but most of these are highly complex and inadequate for most practical applications. The suitability of a representation method can be measured by the ability to accurately represent the expert knowledge in the form that is clear and accessible both to experts, non-experts and the inference mechanism.

The most common representation forms are semantic networks, frames and, production rules. The choice of any one depends on the specific nature of KBSs. In this research production rules were adopted because they seem to capture the knowledge related to global risk factors better than other forms of representation. It was found that a great deal of knowledge and heuristics used by construction contractors in solving risk decision problems is in the form of rules, for example (**IF** sub-contractor A is very experienced **THEN** performance is good).

The main advantages are that they are easy to understand, provide modularity in design, which enables addition, deletion and changes of rules independently, uniformity of

knowledge, and naturalness and rules can represent both procedural and declarative knowledge. In addition, the simple IF-THEN format facilitates the formulation of questions. Production rules are the most popular technique of knowledge representation in KBSs because they have the ability to encapsulate heuristics well. Furthermore, since FRIDEF is a prediction type of KBS rules seem to be the most appropriate way of representing knowledge, (Durkin, 1994). An example of rules is as follows:

IF inflation is medium AND exchange rate is medium THEN economic risk is medium

IF need for job is low AND number of bids is low THEN competition is low

10.6.5 Inference engine

The inference engine is a software designed to control the reasoning operations of the FRIDEF. Its main function is to manipulate and examine domain knowledge encoded in the knowledge base together with the input information from the user about the current problem and databases. In the light of these information it derives additional data and conclusions. Therefore, the inference engine can be considered a general purpose thinking machine or interpreter of the knowledge contained in the knowledge base.

10.6.6 Fuzzy sets and membership functions in FRIDEF

Membership functions in fuzzy set theory play a similar role that of probability distribution functions in probability theory, that is, membership functions are used to represent uncertainty. The concept of membership is key to the representation of objects within a universe by sets defined on the universe. A membership function is a function that map a universe of objects, X, onto the unit interval [0, 1]. The universe of objects represents the elements of the set and the interval corresponds to the set of grades. The grades of membership in fuzzy sets may fall anywhere in the interval [0, 1]. A degree of 0 (zero) means that an element is not a member of the set at all. A degree of 1(one) represents full membership.

There are several methods for deriving membership functions and the choice of any one method depends on the problem under consideration. Membership functions are selected to describe the behaviour of the variables and thus experience and judgement are important features in the process. In this research the standard membership **S** and π functions (Zadeh, 1975) were tried in the first stage of model development. The **S** function is the mirror image of π function. It was assumed that **S** and π functions, non-linear functions, were more effective in describing global risk variables than the commonly used linear functions such as triangular and trapezoidal. Then triangular functions were developed through data elicited from construction contractors during repertory grid interviews.

They were asked to provide ranges of numeric values that according to their perception best represented the different adjectives or fuzzy sets used to describe fuzzy variables, namely very low, low, medium, high and very high on a scale from 1 to 10. The adjectives or fuzzy sets correspond to respondents' intuitive meaning for the terms as used to describe risk. In this context the values 1 through 10 correspond to the level of risk where 1 is the lowest level and 10 the highest level. The responding construction contractors have enough knowledge and experience in handling natural language since they deal with project risk frequently using subjective judgement.

The concepts of fuzzy logic are already a part of these professionals and they are familiar with word descriptors. The triangular functions elicited in this way were fed into the inference engine and the results from the two types of functions (triangular and non-linear functions) compared. It was concluded the difference in terms of performance and results were insignificant and eventually the triangular functions were incorporated in the model. It is believed that linear functions are practical and help simplifying the analysis. Furthermore, it should be mentioned that membership functions are a function of context.

As suggested by Ross (1995) the most important features of the functions for use in fuzzy operations is that they overlap and the precise shapes are not determinant in their utility.

The process of editing membership functions graphically and observing their behaviour during simulation and debugging was performed through "Var/Member" object of the shell.

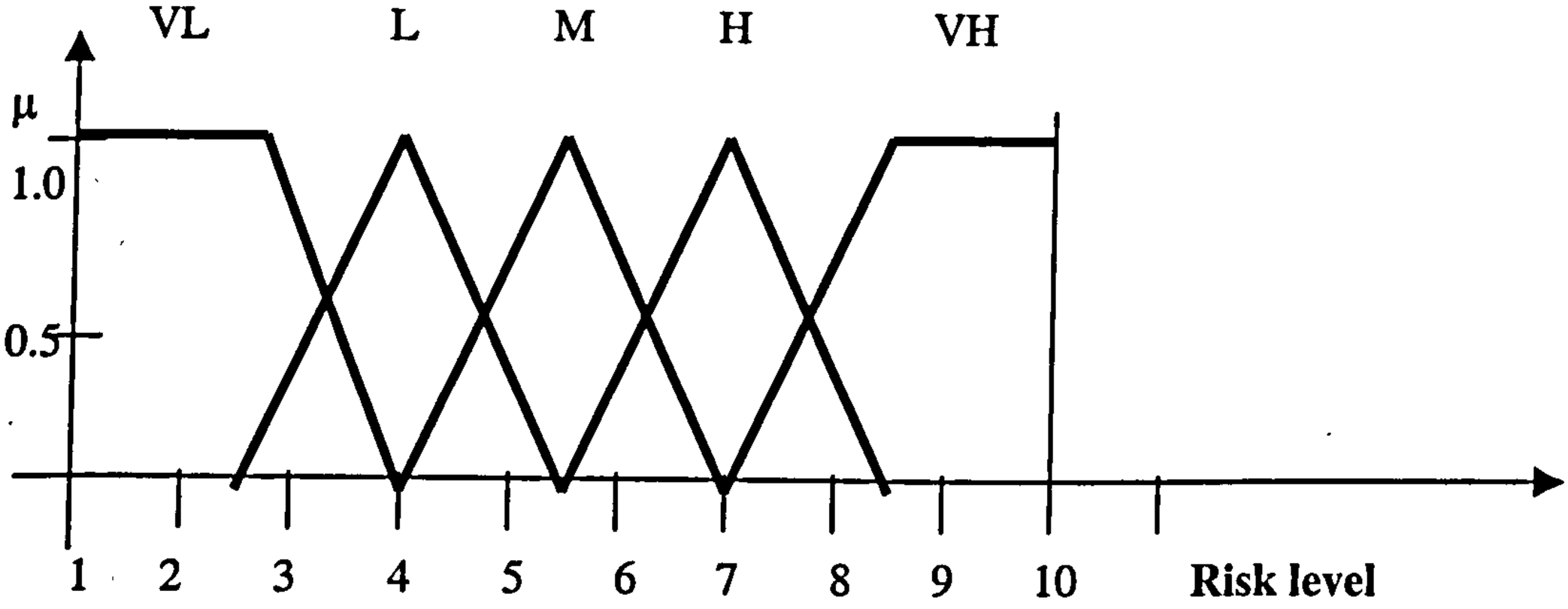

Figure 10.4 Membership functions for: very low - VL, low - L, medium - M, high - H and very high - VH.

10.6.7 Forward-chaining

FRIDEF uses forward chaining because analysing and managing global risk factors implies first collecting information and then reaching a conclusion through processing this information. Construction contractors provided an important insight on how they solved risk problems. They start from an initial set of data to reach a conclusion or assessment of risk. The reasoning process is therefore driven by data and implies that the program has no a-priori knowledge of the possible solutions. The starting point is the data collected through observation and then the system uses such data to reach a conclusion.

Rules are scanned one after another in a certain order until one is found whose antecedents match the information for the problem entered into the working memory.

Subsequently, the rule is applied and the working memory is updated. The process is repeated until the goal-state is achieved or no usable rule is found.

10.6.8 Working memory

The working memory is the part of FRIDEF that keeps track of the problem domain by storing data such as user's answers to questions, facts obtained from external sources, intermediate results of reasoning process and conclusions arrived at. The system matches this information with knowledge in the knowledge base to infer new facts. The working memory can thus be considered as the fuel of the system. These new facts are added to the working memory and the matching process proceeds. In addition, the working memory receives information from external databases, spreadsheets and other external sources to be used during a working session. This information can be accessed either at the beginning of the session or at any appropriate time during the session. Working memory is a working space, which is wiped clean after each session.

10.6.9 User interface, inputs and outputs

The interface is the communication channel between the user and the knowledge-based system - FRIDEF. Its main objective is to guide and control the dialogue between the user and the system so that the information, facts, explanations and conclusions can be exchanged. It enables the user to enter instructions and information into the FRIDEF and receives information from it.

a) Inputs

The instructions specify the parameters that guide the FRIDEF through its reasoning process. There are 50 variables or risk factors in all and the number of values of each variable varies between three and five, which are considered enough to provide enough description of risk levels.

The main inputs to the FRIDEF are the values assigned to the variables of the system resulting from risk assessment exercise performed by the risk management team. These values are linguistic expressions such as "very low, low, medium, high and very high". For example, the variable inflation, which is part of the economic risk can be described as "high, medium or low" in linguistic terms.

Alternatively the user can enter a numerical or crisp term where the degree of risk varies between 1 (lowest) and 10 (highest). In order to generate a large number of data sets representing different cases the user can enter up to 100 sets of data each time. This feature is important when there is a need to evaluate the response of the system for different project contexts (sensitivity analysis). There is also an alternative option for input data, which is to use an input data file. This file is then read by the system when it starts the consultation process. The use of linguistic terms enhances the friendliness of the system while allowing the inference mechanism to analyse the project within a contextual basis. The system was organised into several segments corresponding to the different groups of risk factors namely estimator, fraudulent practices, project/design, client, construction, sub-contractor, economic and political. The outputs of each of these groups of risk factors are combined to produce the overall risk.

b) Outputs

The outputs from the FRIDEF are the impact and the possibility measure (possibility is explained in Section 7.5). The system provides the severity of loss of the different groups of risk factors as well as the associated possibility values. In addition it provides the overall risk as a result of the combination of various risk factors with its possibility value. The possibility value can be multiplied by the crisp output to obtain the IPR of each risk. It is however argued that the strategy response to risk is a management problem and the manager or decision-maker has to evaluate different factors surrounding the project and accordingly make his/her judgement. The results of risk analysis given to different individuals may be interpreted in different ways and distinct strategies may be pursued.

The outputs produced by FRIDEF are expressed in both linguistic and crisp terms. Linguistic terms comprise expressions such as "very low, low, medium, high and very high". The possibility value varies between 0 (zero) and 1 (one) where 1 represents highest degree of ease of a risk level occurring and whereas 0 the opposite. For example, if the output of "competition-related risk is high" with possibility 0.5, then it is less certain than the output "competition risk is high" with possibility 0.9. In other words, a high possibility value means the result (linguistic term or crisp value) is a good description of risk level, whereas low possibility represents poor description.

In order to enhance the friendliness of the system and to facilitate the interpretation of the results the system also provides full graphical plots and reports. The inputs and outputs can be plotted one after another by selecting the variables from the boxes. There are three plot options namely linear, bi-dimensional and tri-dimensional. The report module includes input variables, output variables, rules and inference results.

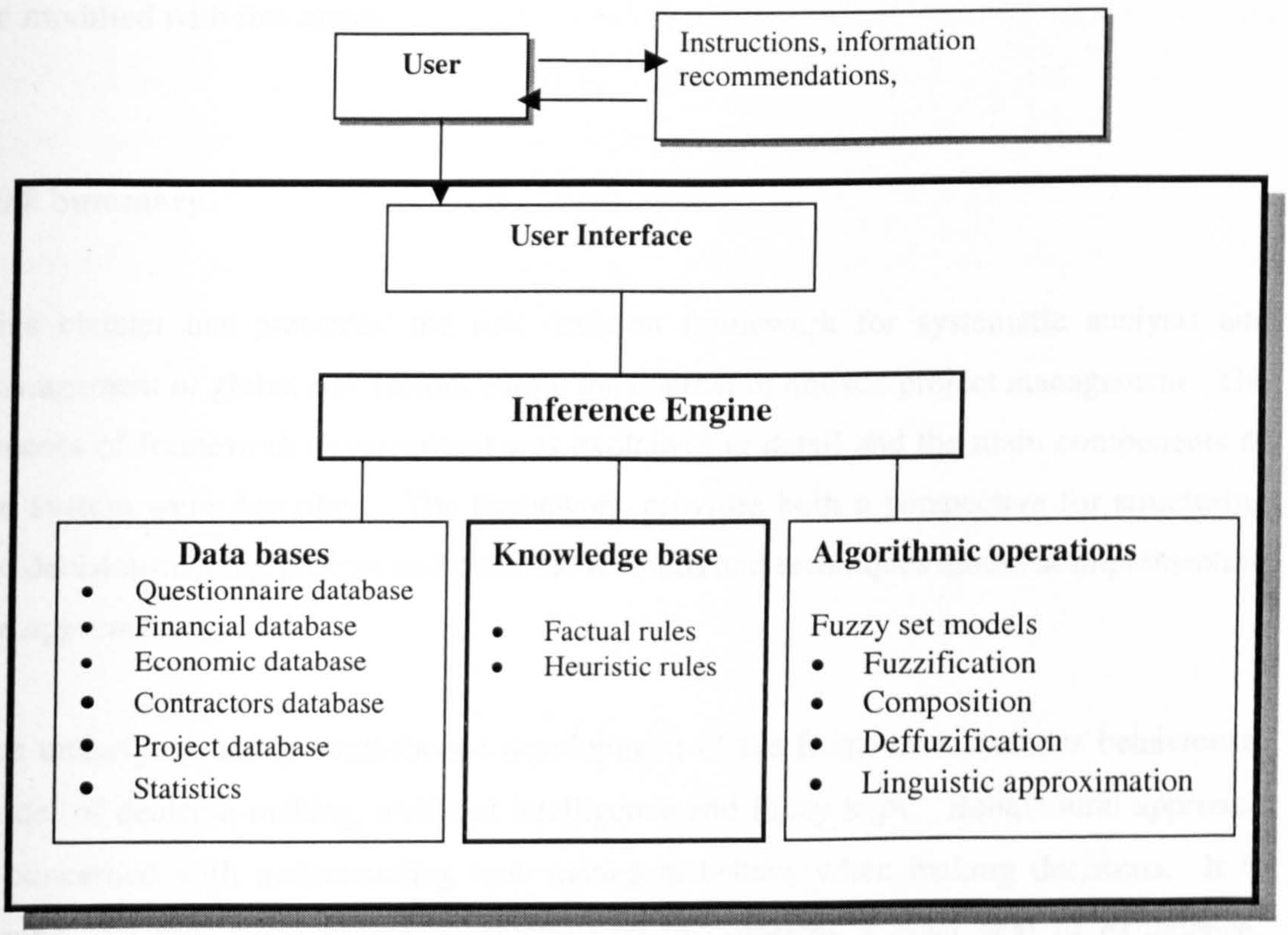

Figure 10.5: General architecture of FRIDEF

10.7 Handling uncertainty in FRIDEF

Rules and conditions of the FRIDEF contain uncertainty. Consequently, the reasoning process carried out by the inference engine on the knowledge is approximate and as a result, solutions or recommendations given by a KBS are not a hundred per cent certain. In the light of this fact, there is a need to take into account the uncertainty intrinsic to knowledge in the knowledge base. The strategy used in this research to handle uncertainty is fuzzy logic. Other strategies such as Bayesian, Certainty Factor and Evidence Theory were, however, considered and discarded because there were not effective to handle the type of uncertainty encountered in global risk factors, which is vagueness. These techniques are fully explained in chapter 7. In addition, fuzzy models require fewer rules than conventional KBSs and this brings benefits since the models can be modified with few errors.

10.8 Summary

This chapter has presented the risk decision framework for systematic analysis and management of global risk factors within the context of holistic project management. The process of framework development was explained in detail and the main components of the system were described. The framework provides both a perspective for structuring the decision-making process and practical methods and techniques aimed at implementing the approach.

The underlying background for the development of the framework includes behavioural model of decision-making, artificial intelligence and fuzzy logic. Behavioural approach is concerned with understanding how managers behave when making decisions. It is argued that risk management in construction incorporates a great deal of experience, judgement, assumptions and rules of thumb. As such, it can be considered a humanistic system rather than a mechanistic system that is governed by normative models. Fuzzy

logic provides approximate model for evaluation of a project's risk by linguistic approach since uncertainty intrinsic in risk is fuzzy in nature.

The framework emphasises the main decision criteria and sub-criteria that construction contractors use when dealing with global risk factors affecting construction cost performance. Then, it uses risk assessment provided by the analyst to process natural language computations in order to produce risk analysis results based upon knowledge base, databases and inference mechanism.

The results of risk analysis are given in qualitative approximate terms in contrast with statistical models. The latter models provide accurate but not precise results and the approach presented in this research sacrifices accuracy to gain significance. Furthermore it provides greater insight into the key strategies that may adopted to manage risk. The main risk attributes were elicited from several sources of which repertory grid interviews were the most important. Construction contractors provided valuable information through an interactive process in the development of the framework. It was demonstrated that fuzzy logic can be used for modelling global risk factors since its main features correlate well with the mental concepts such as facts, rules and inference mechanisms employed by construction contractors in decision-making.

Chapter Eleven

Verification and validation of the framework

11.1 Introduction

The preceding chapter explained how the risk decision framework for analysis and management of global risk factors was developed. The risk decision framework includes a fuzzy knowledge-based system FRIDEF, and aims to help construction contractors analyse and manage global risk factors affecting construction cost performance at a project level.

Chapter eleven addresses the crucial process of verification and validation of the developed framework in order to ascertain the logical soundness, completeness, accuracy, acceptability, practicality and effectiveness. Logical soundness is concerned with the degree to which the underlying philosophy can be justified. Completeness is concerned with the extent to which the proposed framework ignores certain considerations and information because they are hard to accommodate. It relates to the effective coverage of the domain knowledge. Accuracy relates to the confidence level that can be associated with the results, bias, and sensitivity to assumptions. Acceptability relates to user confidence, belief, familiarity and understanding of the methods. Practicality relates to the level of expertise required to use the method, computational resources required to operate the method, time required, availability of input data, and flexibility in using different types of data. Effectiveness relates to the usefulness of results, that is, if the method can accomplish its intended objectives. The verification and validation are performed through the use of panel of experts and two cross-sectional case studies.

11.2 Objective

The objective of verification and validation of the risk decision framework is to assess the performance, functionality and practicality in order to ensure its applicability in solving real problems. A valid framework would be one that has proven to be effective in performing the tasks for which it was designed. The minimum requirements for the validation process are:

- the availability of human experts; and
- a test population (cases studies in the present research).

The validation process involved the validation of the whole framework comprising processes, methods, techniques and tools. The first part of the validation focuses on the validation and verification of the techniques and tool (FRIDEF) as an important part of the decision framework. The second part is concerned with the validation of the overall framework.

11.3 Evaluation of FRIDEF

Evaluation is the process of measuring the performance of a KBS to ascertain the extent to which the system meets its predicted performance targets and it comprises the sub-processes of verification and validation. The reliability of a KBS is crucial and that is the reason why the evaluation must be performed before the system is available for use. Unlike conventional programs that are only subject to verification, a KBS evaluation process requires not only verification but also and mainly validation (Preece, 1990).

Conventional programs usually have well defined specifications that can be measured in accordance with pre-determined standards. The evaluation of conventional software relies on verification and involves invariably the execution of a set of cases as

benchmarks whose results are known with precision. In this way the calculations of a mathematical program can often be verified through hand calculations. This approach however can not be successfully applied to KBS due to the differences between KBSs and conventional DSSs. First, KBSs are not objective in nature; second, they employ approximate reasoning, which means uncertainty is tolerated and, finally, KBSs are not suitable for laboratory experiments.

Therefore, evaluating the extent to which a KBS is correct is far from easy. Several leading experts on testing have estimated that KBSs are at least five times more difficult to test than conventional systems (Gonzalez and Dankel, 1993). This is so because the number of logical paths in KBSs tends to be much larger than in conventional systems due to the complexity of human reasoning.

Knowledge engineers rarely keep records or documentation of the changes occurred in the prototyping process. It can thus be difficult to determine whether rules in the knowledge base conflict with each other or produce undesirable effects. In addition, many experts disagree on what is the criterion for the correctness of the system. O'Keefe et. al. (1987) asserted that, with few exceptions, validation of the existing knowledge-based systems has been done in ad hoc and informal manner. He added that if the problem of reliability was not properly addressed, future growth of KBSs would be seriously hampered. The issue of reliability is particularly critical in sensitive areas such as medical diagnosis, air traffic control and nuclear power plants, for example.

The main reasons for errors and inadequacies in KBSs are lack of specifications, semantic and syntactic errors and incorrect knowledge representation. No single evaluation method or technique has gained universal acceptance and, in practice, the evaluation process tends to combine several techniques. In this regard, Harmon et al., (1990) asserted that many people are working on testing and validation but no one has yet advanced a good proposal for solving it.

11.3.1 Verification

According to O'Keefe et. al. (1987) verification refers to building the KBS right and validation refers to building the right KBS. Verification has, therefore, to do with checking if the system meets the initial requirement specifications and to ensure that the system is free from semantic and syntactic errors introduced during the development stage. These errors can affect negatively the completeness and consistency of the knowledge base and the inference engine of the system. It is thus the main objective of verification checking whether specific inputs give the expected results. If this is so the system can be considered properly designed and subsequently implemented.

The main issues addressed in the verification of FRIDEF included the following: addition of rules; addition of fuzzy sets on defined linguistic variables; modification of fuzzy sets shapes, number, and overlap; checking redundancies of rules; adding premises for existing rules; checking conflicts of rules; checking missing rules; and subsumed rules. Both static, "quick test window" and "control surface window", and "dynamic debugging and tuning" of "TILshell" tool were used for this purpose.

11.3.2 Validation

Validation refers to the determination of the correctness of the final system with respect to user needs and requirements. Apart from addressing the issues under the verification process, validation mainly aims to ensure the correctness of the knowledge base as well as whether the system solves the problems within the domain correctly and accurately. According to Nguyen, (1987) validation is intended to ensure that the system developed is that the users want and need, that is, the knowledge the system contains correctly represents and simulates the domain knowledge and is acceptable to the users.

Since a KBS attempts to model the human expert decision-making, if correctly designed it is expected to perform in the same way in terms of results as the expert. Validation should, therefore, assess the results and validate the system's reasoning process. It is recommendable that the evaluators are the people who are going to use the system.

The design of the validation process focused on the following issues: the subject of validation; validation methodology; validation criteria; user acceptance; completeness; speed of responses; cost/benefits; and correctness of conclusions.

The evaluation process was considered an evolutionary process and was performed throughout the development process and it started with initial prototypes and gradually increased in the following steps. This is the most appropriate approach since evaluating the whole system after final design is very complex due to the size of the model.

11.3.3 Validation methodology

There are several methodologies for validating knowledge-based systems but the most common are informal validation, validation by testing, field tests, subsystem validation and sensitivity analysis, (Gonzalez and Dankel, 1993).

Informal validation is superficial and qualitative and involves the knowledge engineer meeting several experts and using them to ascertain the validity of each conclusion reached by the system. Validation by testing is formal and quantitative. It requires prepared test cases, which are processed by the system and the results compared to those of the panel of experts that try to solve the same problem.

If a KBS produces "correct" results for a given set of inputs then it is considered to have solved the test case. If this is so for the entire set of test cases then the system is considered valid. Field tests involve experiments in the operational environment. Subsystem validation requires partitioning the knowledge base into modules, which are validated separately using others methods described in this section. Its main disadvantage is that not all systems can be easily partitioned and, therefore, the validation of portions

not guaranteeing the validation of the entire system. Sensitivity analysis is similar to simulation and involves changing the inputs and observing the pattern of outputs. Sensitivity analysis is a powerful technique in systems relying on uncertainty management.

The methodology adopted in this study includes test cases, sensitivity analysis and questionnaire. Test cases and sensitivity analysis were adopted because they enable real-world testing of the framework. They enable determining the accuracy, correctness and completeness of the system. Questionnaire was adopted to determine the degree of practicality, effectiveness, friendliness, user acceptability, speed of responses, and cost/benefits.

Informal validation was not used because it was considered less effective than other methods. Field tests were discarded since they implied being at the site monitoring the ongoing operations which is difficult due to time constraints and sensitivity of the work. Subsystem method was not used because it lacks consistency when it comes to the validation of the whole system.

11.3.4 Test cases

There are some points to ponder when designing a test case, namely selection of the test cases and selection of test criterion of the evaluators. Test cases represent past problems that were successfully solved and include specific problem information and the corresponding results. The selection of test cases considered typical problems from the domain.

During the testing the problem information was given to the KBS and the recommendations from it were compared with the results given in the test case by the evaluators. Five construction experts, three of which did not take part in the development stage, and the remaining two that participated in the development stage were selected to run the validation exercise. The level of agreement of the experts was assessed through a "Likert scale" – strongly agree, agree, acceptable, disagree, strongly disagree.

11.3.5 Validation criteria

The criterion against which a KBS is valid is of paramount importance. A KBS can be valid against some determined criteria and can be invalid against different criteria. The determination of criteria depends upon the specific purposes of KBS. The validation criteria include comparison against known results, comparison against expert performance and comparison against theoretical possibility (Gonzalez and Dankel, 1993).

Comparison against known results involves comparing system's results against historical cases. Comparison against expert performance criterion compares system's results against expert predictions of final results. Although being less strict, this approach is more realistic since it allows for likely errors by the expert due to the fact that the comparison is made against historical existing cases. Comparison against theoretical possibility is commonly used to model physical processes and the performance of the system is then compared to the theoretical behaviour of the physical model.

The main criteria adopted in the validation of FRIDEF is the comparison against expert performance because the system is built to mimic the reasoning of a human expert and thus can not be expected to be a hundred per cent accurate. This approach was adopted because it provides a meaningful answer to the question of what criteria should be used to judge whether the system recommendations are similar to the one made by the domain experts.

The degree of agreement between the recommendations of the system and the experts is used to check for any need to improve some parts of system. To minimise the problem of selection bias it was decided to use both intra-experts and inter-experts. Intra-experts are those from whom knowledge base was elicited whereas inter-experts are those who did not take part in the knowledge acquisition process (O'Leary, 1987).

11.4 Case studies

Two groups of project types namely building and civil engineering were considered. The reason for considering two types was to ensure different types of projects that are representative of typical projects in the country are covered. Afterwards the selection of cases within the groups was performed randomly. The cases were selected from past projects with the co-operation of construction contractors.

11.4.1 Case study A - construction of education building

The objective of this study was to ascertain how project risk management had been being conducted in the past and show how the decision framework can be used to identify, evaluate and manage risk factors that contribute to poor cost performance. The study does not provide a detailed description of the process but it shows how the framework can be used in a proactive manner to enhance cost performance.

Case study A is education building project located in the city of Maputo and the client is the Ministry of Education. The project was organised and managed along conventional lines where the design is separated from construction and was procured through local competitive bidding. The project contract data are as follows:

- type of contract - price-fixed contract;
- contract amount - USD 4.116.000;
- advance payment - 20 per cent of contract amount against bank guarantee;
- price adjustment - not applicable according to the contract;
- area of building - 11.200 square meters;
- site possession date - 15 May 1995;
- contractual completion date - 10 January 1997; and
- actual project cost performance (cost performance index) - 120.9 per cent.

a) Risk management performed by the company

The contractor conducted risk management using its own procedures and techniques. The company performed a thorough examination of the bidding documents in order to understand the project, assess potential risks and prepare a realistic tender price. The relevant risks identified, through "what can go wrong analysis" and experience, at this stage were the exchange rate, the proportion of local and convertible currency, inflation, import procedures, scope change, effect of competition on cost estimates, delayed payment, collusion and theft.

The proportion of contract paid in convertible currency was important because most materials were to be purchased abroad. In addition it would be used to pay expatriate staff and some local staff. The analysis of these risks was performed informally. The contractor responded to these risks through acceptance, reduction and contractual transfer strategies. As a result it got 80 per cent of the contract paid in USD. It negotiated with the client the increase of the proportion of convertible currency and tried to include a clause to account for inflation but the client did not accept. The exchange rate, delayed payment, theft, import procedures, competition, and collusion related risks had to be assumed by the contractor. Thereafter, the management of risk was performed throughout the construction process using the same methodology.

The final cost at completion was USD 4.976.000, which indicates a total cost overrun of USD 860.000. The total amount of change-orders was USD 460.000 and included the increase in quantities of concrete on foundations and flat slabs, painting and air ducts. The remaining portion of overrun of USD 400.000 was a result of both organisation-specific and global risks. The estimated amount of loss due to import procedures (duties, taxes, delays), inflation, exchange rate, theft on site, delayed payment and the effects of underestimating is USD 307.000 which represents 7.4 per cent of the contract price.

b) Risk management workshop using framework

A risk management team was created within the company in order to conduct the whole process of risk management in accordance with the risk decision framework. The team comprised the head of procurement, project manager, the contracts' director, a senior estimator and a planner. The project manager played the role of facilitator.

The company has a commercial policy in place that accommodates risk management but lacks specific risk management policy. Risk management has been approached in informal and ad-hoc manner with no formalised processes, methods, techniques and tools from the initial tendering stages through project completion. The basis for risk management was mainly experience and professional judgement.

The team was presented with the risk decision framework and given a thorough explanation of its purpose, and functioning. The team went through all stages of risk planning and then performed risk identification using historical data, checklists, fishbone diagram and brainstorming. The risk identification exercise included the indication of the project elements (WBS) that could be affected. The main identified risks are briefly described in the following sections.

- Fraudulent practices-related risks

The major fears from this category of risk were related to corruption, collusion among bidders as a frequent practice, and theft rate on site.

- Level of competition

Market conditions were not good and consequently the supply of construction projects was low. The size of the project and the unfavourable market conditions led to high need for job and strong competition. The company made an effort in order to optimise costs

and thus increase the chance of winning the contract. As an illustration the difference in tender prices between the company and the second lowest was of about 20 per cent which is a very large gap. This decision had however very bad consequences to the company in terms of costs because it was unable to cover most of the project costs.

- Project/design-related risks

The team considered the design as somewhat innovative in terms of technology as the company had not been involved in similar works in the recent past particularly the fluid networks within the laboratories. In addition, the project was attractive due to the work volume involved but the most significant concern was with scope change, specifications and the level of details. There was a significant change in the design of foundations after appropriate soil investigations were conducted.

- Client-related risks

The company had some experience with the client as it had executed several works in the past for the Ministry of Education. However, payment record and sources of fund were the main concern since delay in payment would require borrowing money in order to ensure works progressed satisfactorily. Delay in payments is usual in contracts funded by a foreign agency. The co-operation between the contractor and the client was not bad. Important decisions were taken promptly by the client and the progress of works was not significantly affected.

- Construction-related risks

Differing site conditions was the major concern since the project did not include site investigation results and as the foundations were very important elements due to the amount of loads involved. The bearing capacity of the soil was unknown and this factor could lead to important changes in the structural design of foundations and consequently

on the quantities of work. Climate conditions were deemed as a threat to good productivity since the construction period meant exposure to different seasons.

- Sub-contractor related factors

There were few sub-contracted works because the company decided to undertake the largest portion of works. The only works that were sub-contracted were external paving, fluid networks and roof waterproofing. The risk associated with sub-contractors was thus reduced to a minimum level.

- Economy and political related risks

The issue of exchange rate was raised because most of construction materials had to be imported and the terms of payment stipulated that 20 per cent of the amount of contract would be in local currency that is not convertible. The company decided to import some materials and equipment because they were not available locally and even they were would be more expensive.

The interest rates were so high that borrowing money was almost prohibitive. This factor leads the company to avoid borrowing as much as possible. The rate of inflation was also a major concern because no price adjustments were provided in the contract despite the rising inflation. During construction period there were observed three strikes with the labourer demanding a pay increase.

- Risk assessment and analysis

After all the most significant risks have been identified, the risk management team assessed the risks using linguistic terms such as "low, medium and high". These assessments were fed into the FRIDEF system and the outputs produced were compared to the assessments provided by experienced construction professionals. The results are depicted in Table 11.1.

The impact of design/project risk is "Low" in linguistic terms, which corresponds to the crisp value of 3.85. The degree of compatibility of 3.85 with the function "Low" derived from the possibility distribution is 0.90. The impact-possibility rating IPR is then 3.46, which means that the risk is not negligible (See Table 10.1). Figure.11.1 shows the value of risk impact where it can be seen that "Low" with possibility 0.90 is also "Very Low" with possibility 0.2, and close to "Medium". This is so because the output is not precise, it is fuzzy, as well. The criterion is to choose the higher possibility value. The experts assessed this as "Low" which means that there is some degree of agreement between the results from the system and those from the experts.

Competition related risk output is "Medium" (with crisp value 5.0) with possibility 0.7. The IPR is thus 4.0, which means the risk deserves further examination. The assessment by experts is "Low", which indicates some degree of agreement.

Fraudulent practices related risk has an output of "Medium" (crisp value 5.5) with possibility 1.0. The IPR is thus 5.5, which means it is a risk deserving a thorough examination. The assessment by experts is "Medium", which reveals good agreement with the result from the system.

Client related risk output is "Medium" (crisp value 5.85) with possibility 0.8, which gives an IPR of 4.68. The experts' assessment for this risk is "Low", which compared to the result from the system reveals some disagreement.

The output for economy/political related risk is "High" (crisp value 6.9) with possibility 1.0 which gives an IPR of 6.9. The assessment from experts is "High", which shows an agreement with the result from the system.

The overall risk impact (aggregation of the several risks) is "Medium" (crisp value 5.2) with possibility 0.6 and IPR of 3.12. The impact is considered over the total contract amount since the risks under consideration are not specific to certain work packages.

According to its position in the impact-possibility matrix (Table 10.1) this risk is "Medium." The possibility value of 0.6 indicates that the impact is not totally "Medium" but "Low-Medium" (see Figure 11.1). Suggestions on risk response strategies presented in Table 10.3 indicate that reduction/absorption/transfer sequence would be appropriate in this case. If the selected course of action were absorption a contingency amount of 8 to 10 per cent would be reasonable.

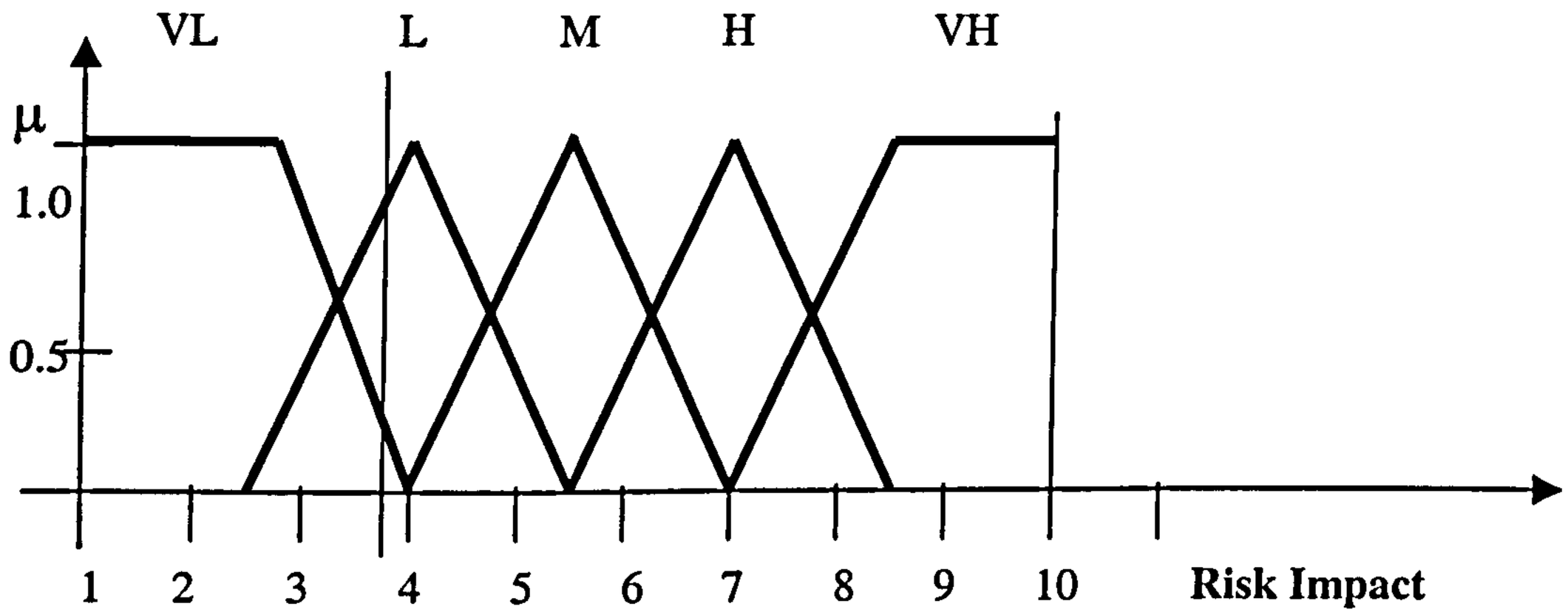

Figure: 11.1 Graphical representation of risk impact

Table 11.1 Comparison of risk evaluation

RISK FACTOR	PANEL ASSESSMENT	FRIDEF OUTPUT	EXPERTS EVALUATION
1. Design/project		Low /4.025/0.9	Low
1.1 Duration	Medium		
1.2 Attractiveness	Large		
2. Competition		Medium/5.5/0.7	Low
2.1 Number of bidders	Medium		
2.2 Need for job	Medium		
3. Fraudulent practices		High/6.9/1.0	Medium
3.1. Collusion	Medium		
3.2. Theft	High		
4. Client		Low/4.038/0.7	Low
4.1. Source of funds	Public		
4.2. Experience client	Good		
4.3. Payment record	Bad		
5. Economic/political		Medium/5.5/0.8	High
5.1 Import	Medium		
5.2 Inflation	High		
5.3 Interest rate	High		
5.4 Exchange rate	High		
Overall risk		**Medium/5.2/0.6**	

11.4.2 Case Study B -road construction and rehabilitation

Case Study B is a road construction project located in Tete province, about 2000 km away from Maputo, and the client is the Ministry of Public Works. The project was organised and managed along conventional lines where the design is separated from construction and was procured through local competitive bidding. The paved road consisted of one carriageway without shoulders and it had about 30 years of age. It was necessary to re-gravel a significant extension of the road. The project contract data are as follows:

- type of contract - price-fixed contract;
- contract amount - USD 4.371.428;
- advance payment - 20 per cent of contract amount against bank guarantee;
- price adjustment - not applicable according to the contract;
- scope - rehabilitation of 173 km and construction of 27 km of paved road;
- commencement data - November 1999;
- contractual completion date - September 2000; and
- actual cost performance index - 133.9 per cent.

a) Risk management performed by the company

The contractor conducted risk management using its own procedures and techniques. The company performed a thorough examination of the bidding documents in order to understand the project, assess potential risks and prepare a realistic tender price. The relevant risks identified, through a "what can go wrong analysis" and experience. At this stage, the identified risks, were the competition, exchange rate, interest rate, inflation, import procedures, delayed payment, and accessibility. The contract was 100 per cent paid in local currency despite the fact that most materials and equipment were to be purchased abroad (South Africa). In addition it would used to pay expatriate staff and some local staff.

The analysis of these risks was performed informally. The contractor responded to these risks through acceptance and reduction strategies. Thereafter, the management of risk was performed throughout the construction process using the same methodology.

The final cost at completion was USD 4.785.714 which indicates a total cost overrun of USD 414.286. The total amount of agreed change-orders was USD 414.286.

However, the contractor is claiming an additional amount of USD 1.069.275 but the client does not accept to pay any further money. The contractor argued that incurred

additional costs due to delays caused by rain, inflation, exchange rate, accessibility and import process.

b) Risk management workshop using framework

A risk management team was created within the company in order to conduct the whole process of risk management in accordance with the risk decision framework. The team comprised the Head of Procurement, Project Manager, the Contracts' Director, a senior estimator and a planner. The Project Manager played the role of facilitator. The company lacked specific risk management policy. Risk management was approached in informal and ad-hoc manner with no formalised processes. The basis for risk management was mainly experience and professional judgement. The identified risks were briefly described in the following sections.

- Estimator-related risks

The team considered the accuracy of cost estimates would not be as good as desirable despite the company employing well trained, experienced, and well paid estimators. The problem lies in the fact that the project was located at a remote site making it difficult to estimate the costs of the different components. However, the application of labour-intensive methods in some sections was helpful since reduced the costs significantly. The cost of labour in Mozambique is extremely low compared to developed world whereas the cost of equipment is very high.

- Fraudulent practices-related risks

The major fears from this category of risks were related to collusion among bidders as a frequent practice and the fairness in bid evaluation. Theft on site was negligible since the type of work did not involve portable or easily sellable materials.

- Level of competition

The size of the project and unfavourable market conditions had led to high need for job and strong competition. Although the area of road construction is limited to few companies, competition is still strong. There was a need for the contractor devising a strategy to optimise costs and thus increase the chance of winning the contract. This decision had however very bad consequences to the company in terms of costs because it was unable to cover most of the project costs.

- Client-related risks

The company had extensive experience with the client as it had executed several similar works in the past for the same client. Despite the client being known, delayed payment and the source of fund were the main concerns. The contractor was not would not be interested in borrowing money in order to ensure works progressed satisfactorily. The co-operation between the contractor and the client was acceptable.

- Construction-related risks

Since the large portion of the work involved rehabilitation of the existing road there were no site investigations and the risk of differing site conditions was considered negligible. Climatic conditions were deemed as a great threat because Tete has the highest temperatures in the country, average 35 degrees, with the accompanying humidity. Further, the project would be exposed to rain due its execution period.

Accessibility was another major problem since the site was remote and most bridges had been destroyed. The contractor has to pass through Zimbabwe and enter again the country to access the site.

- Economy and political related risks

The issue of exchange rate was raised because most of construction materials had to be imported and the terms of payment stipulated that 100 per cent of the amount of contract would be in local currency that is not convertible. The company had to import most of the materials and equipment because they were not available locally and even they were would be much more expensive. The interest rates were so high, about 30 per cent, that borrowing money was almost prohibitive. This factor leads the company to avoid borrowing as much as possible. The rate of inflation was also a major concern because no price adjustments were provided in the contract despite the rising inflation.

- Risk assessment and analysis

After all the most significant risks have been identified, the risk management team assessed the risks using linguistic terms such as low, medium and high. These assessments were fed into the FRIDEF system. The results are depicted in Table 11.2. The interpretation of the results is similar to the Case Study A. The impact of competition risk, fraudulent practices risk and client risk is low. The first four risks affect the whole cost estimate whereas the economy/political risk is linked to cost of materials and equipment that represent 65 per cent of the total cost. The IPR for this risk (see Figure 10.1) is 5.44, which is a significant score, and the impact is 6.8 (see Figure11.1). The prominent response strategy adopted for the majority of risks was acceptance that resulted in critical effects on cost.

Table 11.2 Comparison of risk evaluation

RISK FACTOR	PANEL ASSESSMENT	FRIDEF OUTPUT	EXPERTS EVALUATION
1. Competition		Low /3.8/0.8	Low
1.1 Number of bidders	Low		
1.2 Need for job	Medium		
2. Fraudulent practices		Low/3.8/0.8	Medium
2.1. Collusion	Medium		
2.2. Theft	Low		
3. Client		Low/4.04/0.7	Low
3.1. Source of funds	Public		
3.2. Experience client	Good		
3.3. Payment record	Bad		
4. Construction		High/7.5/0.7	High
4.1 Climate	Extreme		
4.2 Accessibility	Poor		
4.3 Location	Remote		
5. Economic/political		High /6.8/0.8	High
5.1 Import procedures	High		
5.2 Inflation	Medium		
5.3 Interest rate	High		
5.4 Exchange rate	High		
Overall risk		**Medium/5.3/0.8**	

11.4.3 Conclusions

Two case studies were designed to validate the risk decision framework. The main criterion used to validate the framework was comparing the output from the system and the judgement of the experts. The level of agreement was found to be significant. Although the two case studies are far from comprehensive for a detailed process of validation, preliminary results suggest that the performance of the system is reasonable. It is important to ensure that the system deals with fuzziness from the inputs and passes it

to the outputs and therefore the results are not expected to be precise, that is, the solutions are approximate. It is worth recalling that the hallmark of a fuzzy system is a smooth transition between the cases governed by different rules. Despite this fact decision-makers are able to understand and use the results. That is why variables overlap.

The studies revealed that most risk is passed into the contractor, through the contract, who often is not able to control it. Contractors have been forced to increase their tender margins by unacceptable amount. This is the main reason why construction costs in Mozambique are very high and the quality is generally poor. For example, the average cost of building per m^2 in Mozambique is USD 500 -600 whereas in South Africa or Zimbabwe the average is about USD 200 -300.

In the opinion of the construction experts that participated in the validation process the framework can be used to enhance the current management of risks but is should be expanded to provide an overall assistance rather than being limited to a strict group of risks.

11.5 Validation of the whole framework

The questionnaire was adopted to determine the degree of practicality, functionality, effectiveness, friendliness, user acceptability, speed of responses, and cost/benefits.

The questionnaire designed to validate the framework comprises Yes and No type of questions. The method of analysis used to validate the findings is the one-tailed binomial probability test.

The binomial distribution is discrete and is used in situations where only two outcomes are possible from each question, that is, each observation sampled from the population may only take one of two values depending on the value sampled. The application of binomial distribution implies thus the definition of the two possible outcomes

namely

success S and failure F. The probability of success is denoted p and the probability of failure F is denoted q and the two are mutually exclusive which leads to the expression

$$p + q = 1 \qquad \textbf{(Equation 11.1)}$$

The binomial distribution function is given as:

$$P(x) = \binom{n}{x} p^x q^{n-x} \qquad \textbf{(Equation 11.2)}$$

$$\binom{n}{x} = \frac{n(n-1)(n-1)(n-2)(n-3).....(n-x+1)}{x(x-1)(x-2)(x-3)..... 3x2x1} \qquad \textbf{(Equation 11.3)}$$

n is the number of observations or samples

x is the random variable, x = 1, 2, 3, 4 ..... n

p is the probability of the number of successes or the number of "**Yes**"

q is the probability of the number of failures or the number of "**No**"

This equation enables the determination of the number of successes or failures occurring in n trials with the probability of successes and failures at each trial equal to p and q. The formula can also be used to calculate the probability that the number of success is greater or less than some value k, that is $P(x \leq K)$ and $P(x \geq k)$.

The solution to this type of problem involves summing the relevant probabilities given in the appropriate binomial tables over the appropriate range of the values of x (Flemming and Nellis, 1994). Due to the symmetry of the binomial distribution when p=0.5, $P(x \geq k) = P(x \leq n-k)$. The mean of a binomial distribution is given by "np". The significance level for testing the null and alternative hypothesis was set at 0.05. The assumption made for the response ratio is equal and it is represented by p = 0.5. The hypothesis were established as follows:

H_0: p = q = 0.5

There is no difference between the probability of yes responses and the probability of no responses related to questions aimed to validate the framework. The value of p represents the expected proportion of successes.

H_1: p > q

The probability of Yes responses is greater than the probability of no responses.

The decision criterion consists in rejecting all values of x that are so small that the probability associated with their occurrence under H_0 is equal to or less than $\alpha = 0.05$. The random variable x represents the number of No responses. The value of $n = 10 \leq 35$ and thus the probabilities can be derived from the standard tables.

11.5.1 Results from the validation questionnaire

The results from the validation questionnaire are displayed in Table 11.3. The validation questionnaire is included in the Appendices of this thesis. Questions four and six aim to ascertain familiarity with the proposed framework and question five seeks to find out if the organisation has a structured risk management framework. Questions seven and eight aim to check the acceptability and practicality. Question nine is used to evaluate correctness of the results and question ten the acceptability of the framework. Question twelve aims to assess effectiveness. Question thirteen evaluates cost/benefit and question fourteen assesses the implementation speed.

Table 11.3 Responses frequencies and binomial statistical test

Question		Yes	No	Test
1. Company				
2. Organisation				
3. Type of work				
4.Have you seen a similar RM framework?		6	4	0.377
5.Structured RM framework		4	6	0.828
6. Is your RM process similar to the framework presented?		3	7	0.945
7. Framework easy to implement?		9	1	0.017
8. Inputs/outputs easy to understand?		8	2	0.055
9. Outputs useful to decision-making?		9	1	0.017
10. Willingness to implement framework		8	2	0.055
11. Capability to implement framework		10	0	0.001
12. Can framework enhance performance?		9	1	0.017
13. Is framework cost-effective?		7	3	0.172
14.Does it take long to implement?		7	3	0.172

- Familiarity

Question four asked construction contractors whether they had seen a risk management framework similar to the one presented to them. The results indicate that three respondents had seen similar framework. The test indicates that the probability of six saying *Yes* out 10, that is $P(x \leq 4)$, for this question is $0.377 > 0.05$ which is significant at 95%. This result shows that the difference in responses between the two groups of responses did occur by chance, that is, it is not statistically significant and the null hypothesis that the probability of *Yes* and *No* responses is thus accepted. It can be suggested that although the framework is unfamiliar to some of the responding contractors it can be adopted by a significant number of them. The respondents who responded that had not come across a similar framework said the main difference lies in the risk analysis methods.

Question five asked construction contractors if they had a structured framework for risk management. The result indicates that the probability of four respondents out of ten saying *Yes*, that is P ($x \leq 6$), is $0.828 > 0.05$ which is significant at a confidence level of 95%. This result leads to the acceptance of null hypothesis that there is no difference between the probabilities of *Yes* and *No* responses and that the difference observed occurred by chance. Consequently the alternative hypothesis that the probability of *Yes* is greater than the probability of *No* responses is thus rejected. Two of the contractors that responded *No* argued they have a semi-structured approach to manage risk and every project passes through this process. The contractors who responded *Yes* confirmed that although not sophisticated they have established in-house policies and procedures for risk management.

Question six asked contractors whether they used risk management process similar to the process presented or not. The result shows that three contractors responded they had a similar process whereas the remaining one used different processes. The result indicates that the probability of *No* responses being less or equal to 7 ($P\ x \leq 7$) is 0.945 which is greater than 0.05 significant at 95%. Therefore it can be concluded that the probability of responding contractors using a similar processes to the proposed framework and the probability of those using different methods are the same.

The difference in the observed values may be due to mere chance. It is important to notice here that having a similar process does not imply necessarily using similar techniques and tools. The contractors responding *Yes* considered the process used by them and the framework presented as emerging from the same philosophy. Furthermore they argued that the downstream techniques and tools are built upon the prevailing philosophy.

- Acceptability and practicality

Question seven served to ascertain the degree of ease with which the users could implement the framework. The responses lead to the probability $P(x \leq 1)$ equal to 0.011 which in turn lead to the rejection of the null hypothesis at 95 per cent and consequently the acceptance of the alternative hypothesis that the probability that contractors could effectively implement the framework is higher than that of non-implementation.

Question eight aimed to ask contractors if they were able to understand the meaning of both inputs and outputs incorporated in the framework. Nine respondents out of ten responded *Yes* while the remaining one responded No. This response pattern leads to the $P(x \leq 1) = 0.011 < 0.05$. From this result the null hypothesis is rejected and the alternative hypothesis accepted. It can be concluded that the probability that contractors could clearly understand and interpret the meaning of the inputs and outputs is greater than the probability of non-understanding.

Question ten attempted to ascertain the willingness of contractors to implement the framework within their organisations. Eight respondents confirmed they are interested and two showed no willingness. This result leads to $P(x \leq 2) = 0.055$ which is slightly greater than 0.05 and thus to the acceptance of the null hypothesis that there is no difference between *Yes* and *No* responses. The result suggests that the observed difference of the values of the probabilities could have been occurred by chance which means that the probability of respondents willing to incorporate the framework within their organisations and of those unwilling to do so are the same.

- Correctness

Question nine seeks to establish whether the results from the risk analysis process could be effectively used to make informed decisions by contractors. This response pattern

leads to the $P(x \leq 1) = 0.017 < 0.05$. From this result the null hypothesis is rejected and the alternative hypothesis accepted. It can be concluded that the probability that contractors regard the results from risk analysis as useful to decision-making is greater than the probability of uselessness.

- Effectiveness

Question twelve asked contractors if they could see any enhancement of cost performance through the implementation of the framework. All but one responded *Yes* to the question. The probability $P(x \leq 1) = 0.011$ is less than 0.05, which leads to the conclusion that the majority of contractors believe that the framework can be helpful in the improvement of cost performance. The responding contractors suggested that the framework increases their awareness of risks and thus their ability to take appropriate measures to mitigate them both during bid preparation and construction period. They added that the results of risk management could be useful for pre-contract negotiation with the client.

- Cost effectiveness

Question thirteen asked if the contractors thought the implementation of the framework was cost-effective. Nine contractors responded *Yes* and the remaining one responded *No* which leads to $P(x \leq 0.017) < 0.05$. In the light of this result, the null hypothesis is rejected and the alternative hypothesis that the probability of contractors that feel the framework is cost-effective is greater than the probability of those that think it is not cost-effective, is accepted. The responding contractors suggested that the costs involved in the installation and use of the framework are not significant compared to the benefits gained with the process.

- Implementation speed

Question fourteen asked the contractors if they felt the implementation of the framework was time-consuming. Seven respondents suggested the implementation did not take

much time while the remaining three said the opposite, that it was time-consuming. This result leads to $P(x \leq 3) = 0.172$ which is greater than 0.05. The null hypothesis is thus accepted which means that there is no difference between the probabilities of those feeling that the framework is time-consuming and of that thinking it is not. Some respondents argued that the time spent on the implementation of the process depends upon the size and type of project and therefore this need to be monitored and evaluated.

Implementation capability

Question eleven asked contractors whether they were capable of incorporating the proposed risk management framework into their companies. All of them confirmed that had capability to do so. This result leads to $P(x \leq 0) = 0.001 < 0.05$ and to the rejection of the null hypothesis that there were no differences in *Yes* and *No* responses. The conclusion is that the likelihood that contractors are capable of incorporating the framework is greater than the probability of lack of capacity. This means that they have the required resources to do so.

11. 6 Summary

This chapter presented the results obtained from a preliminary validation exercise of the framework for risk analysis and management of global risk factors affecting construction cost performance. The objective of validation was to assess the extent to which the framework is effective, complete, practical, acceptable, user-friendly, correct, and cost-effective.

The evaluation process involved the consideration of various aspects such as verification, validation methodology and validation criteria. Test cases, sensitivity analysis and questionnaire were deemed the most appropriated methods whereas comparison against comparison against the experts' performance comprised the validation criteria. There is an open debate on the validation process and thus it can not be considered a definite subject.

O'keefe et. al. (1987) for example, suggests that when the system's performance is measured against an absolute standard of "correctness" the system's level of performance may be underestimated. In addition, it is suggested that evidence shows that it is unreasonable to measure the performance of a KBS against known or correct results when its human counterparts, from whom its knowledge base was derived, can not perform at levels close to known results. Another issue of concern is that decisions made by experts may influence the results themselves and as a result the system's level of performance measured during validation is not the same as it would be in "live" use. It can be concluded therefore that there may not be a correct result to measure performance of the KBS against. The points of view presented here suggest that in many situations it is more feasible and appropriate to measure the performance of the system against the performance of experts. But the validation of the system's performance against experts' performance is no without problems as discussed previously. To minimise the problem of selection bias, both inter-experts and intra-experts were used to form the validation panel. Despite the prevailing shortcomings it was still possible to conduct the evaluation process.

The framework comprising the processes, methods, techniques and tools can be considered valid at an acceptable level. In most practical applications a KBS is considered good if it can solve 75 to 80 of cases that are presented. The results from the case studies suggest a reasonable level of agreement between the performance of the system and expert's assessment. The results also suggest that the correctness and completeness of the system are acceptable. The results from the questionnaire suggest that the framework is applicable, acceptable, practical, user-friendly and cost-effective.

The responding contractors expressed substantial willingness and capability to incorporate the framework into their project management decision-making system. All experts agreed that the assessment and recommendations given by FRIDEF were acceptable. The differences between the system and the panel of experts were marginal with only a small deviation, which is understandable when dealing with fuzzy systems.

Despite these indications further work is required in the validation process because the number of analysed cases is limited.

Chapter Twelve

Discussion of the results

12.1 Introduction

The aim of the research is to formulate a decision support framework for modelling, assessing and managing global risk factors that affect cost performance from the contractor's perspective and at a project level. The study is concerned with financial risk rather than hazard.

The previous chapters presented the rationale for the research, research aim and objectives, literature review, research methodology, data collection and analysis and the development of risk decision framework. This chapter briefly summarises the content of the previous chapters and outlines the most important results in line with the research objectives. The results of the research are subsequently discussed within the context of the research questions, theory and literature. The chapter also outlines the strengths and weaknesses of the research process including the methodology adopted, and techniques and tools employed.

12.2 Research problem

The theory and the literature review coupled with discussions with construction contractors enabled the formulation of the research problem and research questions. The review presented in chapter 3 revealed that poor cost performance was a widespread occurrence in construction projects. The reason behind such poor cost performance record is the ineffective risk management due to many causes. Several quantitative probability-based approaches have been used to analyse and manage risk.

Unfortunately, evidence shows that there are theoretical and practical problems associated with such approaches and that there is gap between existing models and their practical application. Some of the limitations of the existing approaches to risk management are that they emphasise quantitative aspects and play down the significance

of many qualitative issues yet they play a major role in risk management, particularly of global risk factors, which are poorly structured.

The aim of the research is to develop a decision framework for modelling, assessing and managing global risk factors affecting cost performance from contractor's perspective. The research problem is "risk factors affecting construction cost performance - focus on Mozambique". The research questions are summarised as follows:

- what is the extent and significance of poor cost performance in construction projects and what are the most critical factors affecting construction cost performance?

- are construction contractors aware of the obstacles posed by risk factors in general and global risk factors in particular to project success?

- to what extent is risk management influenced by project strategy variables such as procurement routes, contract types and conditions of contracts?

- how do construction contractors currently deal with risk analysis and management as an intrinsic part of a holistic project management, in view of a large number of techniques and tools that seem inappropriate or ineffective?

- are construction contractors sufficiently equipped with appropriate knowledge, techniques and tools to face risk that permeate through construction projects?

- are the current underlying theories behind risk management decision-making the most appropriate background to the development of processes, techniques and tools for tackling risk?

- how can risk management be enhanced in order to help construction contractors make better and informed decisions?

A questionnaire survey was designed and administered to construction contractors in order to find to these questions. In addition, repertory grid interviews were conducted to elicit risk management knowledge.

12.3 Review of the research methodology

The research was conducted in order to find the answers to these questions. The main philosophical views namely positivism and phenomenology were evaluated with the objective of devising the most appropriate research strategy. It was concluded that both positivism and phenomenology could be blended in search for the answers to the research questions. The delineation of the most appropriate research strategy included the analysis of research perspective, research type, data collection methods and techniques.

As explained in Chapter 2 the data was collected through questionnaire survey and repertory grid interviews. The first stage of the research comprised: an extensive review of the theory, literature review on risk management and related disciplines, and discussions with construction contractors in order to ascertain the extent of risk factors affecting the cost performance of construction projects. The insights from this stage enabled the formulation of research problem, research questions and the conceptual framework. The research perspective adopted for the research is a mixture of quantitative and qualitative approaches, being the quantitative perspective the first and the qualitative the primary. The validation of the results was made through case studies.

The rationale behind the adoption of this strategy lies on the approach of risk management that is taken in the study. It is argued that to be effective risk management should incorporate explicitly incorporate experience, intuition, feelings, opinions, judgement and perceptions of decision-makers because decision-making in construction rarely follows prescriptive models. Furthermore, decision-making is not often in numerical or discrete terms. Decisions are often made in complex and dynamic

environments where the available information is rarely perfect and complete. As such, the phenomenological view that stresses the need for appreciating the different constructions and meanings that managers place upon their experience seems to be a primary approach.

12.4 Discussion

The following discussion of the results aims to present the main issues arising from the research and is conducted considering the relevance to the aim and objectives of the research and taking into account the following aspects: relationship to research questions and existing research; implications for practice and implications for theory. Relationship to existing research discusses findings in relation to research questions and literature. Implications for practice discusses the findings in relation to practical applications by construction professionals of the concepts and ideas developed. Implications for theory discusses the implications of the findings to both the immediate body of knowledge as well as to the parent disciplines and fields of knowledge. The placement of the research findings within the context of theory and literature is important because ensures making the contribution to the body of knowledge clear and explicit.

12.4.1 Relationship to research questions and literature

This study proposed to develop a risk decision framework for construction contractors to model, analyse and manage global risk factors affecting the cost performance of construction projects. The relationship between global risk factors and cost performance was expounded in Chapter 4. The main supposition was therefore that there was a problem with cost performance of construction projects. It was emphasised that poor cost performance was a common occurrence that affected construction projects and if not dealt with effectively could put company existence in jeopardy.

Poor cost performance can often lead to significant financial looses and since the competition has increased and margins have become tight companies can not afford even

marginal losses. These marginal losses can often wipe-off profit margins thus affecting company financial stability. The following sections present discussion of the results in line with the research questions and literature.

- a) The evidence, as presented in Sections 8.7.6 and 8.7.7, has shown support for this supposition. It was observed that all types of projects examined had experienced cost overruns and nearly 50 per cent of building projects, that are most representative in the country, had poor cost performance. The issue is even worse in case of developing countries since the market conditions tend to deteriorate progressively due to economic problems. These findings corroborate views of the literature (Flanagan and Norman, 1993; and Raftery, 1994) that regard poor cost performance of construction projects, particularly excessive time and cost overruns, as a common and widespread occurrence.

- b) Construction contractors are aware of problems posed by risk and they understand the relationship between risk and project success. The findings suggest that many construction contractors are risk takers and have incorporated risk management into corporate culture. The risk attitude of contractors was not formally determined. It was rather informally measured on the basis of their intuitive perception of whether they were prepared to accept the degree of risk indicated by the risk profile. If they were adverse to risks they would frequently avoid projects due the degree of risk that many of them carry. What they seem to lack are formalised and structured approaches to risk management. This result echoes the results from (Kartam and Kartam, 2001) who found that the application of formal risk management techniques in Kuwaitian construction industry was limited. It should be mentioned however that there are several companies for whom it is urgent to activate the cultural shift towards the adoption of risk management in particular and modern construction management in general. The literature interprets the lack of appreciation in the construction industry in comparison to other industries as cultural gap (Thompson and Perry,

1992). Furthermore, the construction industry has been characterised as very slow to embrace changes.

- c) Risk management was found to be highly influenced by project strategy namely procurement routes, conditions of contract and contract types. These are the main instruments for risk apportionment between the parties but the fact that clients have had the greater power than contractors has led them to protect their own interest and allocate the majority of risks towards the contractors. Gergeas et. al., (1998) analysed the influence of procurement route and contracts on cost overruns and found that lump-sum, unit-price and cost-plus in descending order had significant impact. There are two main views of risk allocation within the construction industry: one suggests that there should be a balanced allocation of risk in the contracts; and the other suggest the allocation of risk to the party best positioned to manage them. It seems, however, that fairness and equity are far from being reality. These findings support Charoenngam and Yeh's (1999) suggestions that contractors in developing countries have been unable to influence the fairness of the contract conditions or clauses.

- d) The findings show that the prominent procurement method is the traditional combined with price-based contracts. The selection of project strategies is not based on the specific characteristics of a project such as project complexity, competition, project size but depends upon the desires of the client. This problem has given rise to adversarial relationship between the parties with clients trying to avoid paying additional money and contractors to minimise their costs in order to guarantee the profit margins.

- e) Most contractors deal with management through experience, intuition and subjective judgement. The evidence suggests that "soft data" plays and important role on reasoning and decision-making in contrast with "hard data". The evidence shows that qualitative reasoning is often sufficient to lie the ground for informed decision-making. For example, it is important for a construction contractor to know whether some risk factors such as interest rates, inflation and exchange rate, are likely to

increase or decrease and whether the consequences of these events are likely to be large or small. Therefore, it is often enough to know the direction and the level of magnitude of changes. These results also concur with Kartam and Kartam's (2001) survey findings that the use of analysis techniques for managing and controlling construction risk is generally low with exception of subjective judgement and practical experience. Al-Bahar and Crandall (1990) also advanced that contractors rarely quantify uncertainty and relied upon series of rules of thumb derived from experience and judgement to handle risk.

- f) The elicited constructs form the criteria that construction contractors use when managing risk. They are used together with other qualitative measures of risk impact and risk likelihood. It was found that they rarely apply formal methodologies and sophisticated techniques and tools such as probabilistic simulation. The reasons behind this approach seem to be lack of specific knowledge particularly on probability, lack of appropriate tools, tight schedules, lack of adequate and reliable data, and lack of confidence in quantitative methods.

- g) Handling risk in arbitrary and informal way can often be ineffective. An alternative way would be to gather a vast amount of expertise and experience within the industry in order to make them available to a vast audience of professionals particularly for non-experts. It seems the knowledge-based system could be an appropriate technology for consolidating these multiple sources of knowledge. The application of knowledge-based systems for managing risk is not advanced as substitute for the traditional probability-based approaches, but rather as a complementary strategy. There is no question in that distinct methodologies for analysing risk will inevitably produce different answers. The relative degree of risk associated with a specific project is however independent from the methodology in use. For this reason the effectiveness of any valid methodology can not be questioned on the grounds of the outputs alone.

- h) There is no question that the implementation of risk management improves project performance as the results show in Section 8.8.5. Construction contractors agree that systematic application of risk management as an integral part of a proactive, holistic project management would bring benefits and enhance the success of projects. These findings suggest that construction contractors perceive crisis management as having detrimental effects on projects in contrast with adequate planning for adverse events. Maughan (1999) reported on an in-depth study undertaken to benchmark 150 projects with the following conclusions: risk management improves schedule and cost performance against plan; without risk management projects outturn approximately 60 per cent over target; and with full and mature risk management projects outturn 5-10 per cent under target.

- i) The idea of probability arises when there is no certainty about an event due to scarcity or imprecision of information. The underlying principles behind the current risk management approaches are rooted in probability theory as a means of handling uncertainty. Before the entry of fuzzy set theory into the mathematical repertory the only well established approach for dealing with uncertainty had been probability theory. Probability has several assumptions such as randomness, repeatability, knowledge of probable future states. Randomness requires that each event is independent from all other events. This assumption does not always hold true because projects deal with consciously planned human actions that are not generally random. Secondly, projects are unique by definition and the assumption of repeatability is not always valid. Thirdly, knowledge of the future states is very limited due the uncertainty involved in human actions.

Poorly structured problems such as management of global risk factors involve multiple variables with complex and strong interrelationships that can not be defined clearly. As such, the conformance with the above mentioned conditions can not be guaranteed.

12.4.2 Implications for theory

A theory can be defined as a set of interrelated propositions and statements organised into a deductive (move from general to particular statements) system that serves the purpose of explaining a phenomenon. Established principles and laws are examples of theories. The most relevant theories upon which the study is based are the systems theory and the behavioural or administrative decision model. Further theories include classical decision models, decision-making under uncertainty, knowledge management, and fuzzy set theory. From the theoretical point of view, this study is exploratory. The findings support the systems theory and the empirical evidence shows that organisations and projects are open systems interacting and being influenced by the environment. The way in which the decision-makers and managers adapt to the influences of the environment determines the likelihood of success.

The findings also seem to adhere to administrative decision model because it was revealed that construction contractors use simplifying strategies in the management of risk. They tend to select acceptable course of actions instead of looking for the best ones. The best alternatives are difficult to obtain due to the imprecision and lack of reliable data. Furthermore, they work under severe time pressure that limits their capability in processing information.

The findings also suggest that fuzzy set theory can make significant contributions in the understanding and modelling complex systems. This is so because humans have capability to understand and analyse imprecise concepts. Construction professionals reason in terms of fuzzy sets and not in terms of discrete symbols and numbers. Global risk factors were modelled and analysed with recourse to fuzzy sets, possibility measures and natural language instead of probability. Fuzzy sets and possibility complete statistics when they are poor. The process favours significance and accuracy instead of precision. In summary it can be suggested that the evidence corroborates the theory underlying the research process. Furthermore, the approach adopted in this study represents a paradigm shift from traditional towards innovative methodologies in order to take account of changes that are taking place in the industry.

12.4.3 Implications for practice

Much of previous research on risk management has focused on statistical decision model where the likelihood of risk events was measured through probabilities. Most of these studies are presented and discussed in Chapter 3. Examples include Al-Bahar and Crandall, (1990) who developed a model entitled construction risk management system (CRMS) for quantitative risk management with the use of objective statistical (historical records) and subjective (elicited from experts) data.

The probability here is defined as a subjective judgement, opinion or degree of belief that a risk event will occur. Perry and Hayes, (1985); Perry and Thompson, (1992); ICE, (1998) all proposed similar frameworks for managing risks with emphasis on quantitative models based on probability. The exceptions to this approach are Kangari and Boyer (1989) and Wirba et. al. (1996) who attempted to formulate new methods for handling uncertainty namely fuzzy logic.

Few researches embraced a different perspective namely a distinct approach to decision and different methods of measuring uncertainty and the methodologies pursued in these works differs from the methodology employed in the present study.

The main implications for practice relate to the extent to which the results can be useful to construction practitioners. The validation process involved two case studies and the results suggest that the ideas advanced in this study have a great potential. If properly performed the risk management strategy proposed could increase the ability of construction contractors planning, identifying, analysing, managing, communicating and reporting risk and thus enhancing the prospect of good project cost performance.

The process of risk management is being documented and a set of toolboxes will be produced. Case studies conducted to validate the framework. Several seminars and workshops with construction professionals are planned to disseminate the findings of the research and as an attempt to increase the awareness of risks in the construction industry. Many construction professionals are receptive to the suggestion.

12.5 Limitations of the research

The research has explored the theory of fuzzy sets as a mechanism for handling uncertainty instead of probability. Although being around for more than thirty-five years and being used in vast areas of knowledge, the theory of fuzzy sets is still open to debate and there is no consensus on the philosophy around it. Further, there is a debate on the pragmatic meaning, interpretation and definition of membership functions including their ranges. It has been argued that the theory of fuzzy set applied to management decision-making lacks the clarity provided by the classical approaches. It might be because the theory violates the laws of non-contradiction and the law of excluded mean in contrast with scientific tradition.

It seems however that the establishment and acceptance of the theory depend upon its ability to enhance the decision-making effectiveness. Other fields such as operations research and financial management for example, have successfully expanded the management of uncertainty beyond probability theory to account for the aspects that can not be effectively tackled by this technique. Furthermore, it seems that the problems associated with fuzzy systems can be significantly reduced as experience is gained through the learning process. According to Rosen (1992) theory develops through the dialect triad: thesis; antithesis and synthesis. The first stage of theory development is the thesis, which often leads to debate, discussion, and opposition. Advantages and disadvantages can be identified in this process. A theory is only rejected or falsified in favour of a more accurate one if a significant number of serious anomalies are detected.
The research was conducted in Mozambique and therefore the generalisation aspects to different contexts can not be guaranteed. It seems, however, that the results apply to most developing countries that share similar characteristics.

12.6 Summary

This chapter has briefly summarised the content of the previous chapters and outlined the most important results and findings of the research. It has discussed the results of the research within the context of the research questions, literature and theory. The chapter has also outlined the strengths and weaknesses of the research process including the methodology adopted, and techniques and tools employed.

Chapter Thirteen

Conclusions, recommendations and further work

13.1 Introduction

The aim of the research is to formulate a decision support framework for modelling, assessing and managing global risk factors that affect cost performance from the contractor's perspective and at a project level. The preceding chapter discussed the results of the study within the context of the research questions, literature, and theory. This chapter briefly outlines the most important findings, and draws conclusions from these findings. Finally, the chapter makes recommendations to the industry and suggests areas for further research based upon the results, discussion, conclusions and limitations.

13.2 Conclusions

The overall aim of this research is to evaluate and develop an effective decision framework for a systematic modelling, analysis and management of global risk factors that significantly influence contractors' cost performance at the project level. The findings determined from the research are explained within the context of the data analysis reported in Chapters 8 and 9 and are linked to the conclusions and recommendations. Findings, conclusions and recommendations are closely related and sometimes they overlap. As the first step towards the improvement of risk management of global risk factors the research set out to:

- review literature on risk management process, particularly contractors' current risk analysis and management practices;
- evaluate the main issues on construction management namely pre-project planning, contract strategies, bidding procedures, cost estimating and control, contractor's policies and the associated decision-making process;

- evaluate how risks have been allocated in contracts and the adequacy of the available contract strategies;
- identify and assess the main global risk factors that impact construction projects costs;
- examine the potential application of knowledge-based systems and decision support systems in risk management decision making;
- evaluate the applicability of complementary technologies, namely fuzzy set theory for modelling and analysing global risk factors;
- development of a knowledge based decision support system for an effective management of global risk factors based on fuzzy logic approach; and
- verify and validate the decision system with the participation of construction professionals.

The conclusions derived from this study are summarised under the following headings: construction contractors attributes, contracting strategies and cost performance, risk analysis and management, global risk factors, repertory grid interviews and the application of fuzzy set theory to build a KBS. The significance of these conclusions is that any construction organisation in Mozambique can adopt the proposals or recommendations in order to improve risk management and thus enhancing project cost performance.

13.2.1 Construction contractors attributes

The evidence relating to construction contractors attributes was presented and discussed in Section 8.6. The research revealed that most construction contractors focus their attention on construction works and few extend their activities to embrace other activities such as consultancy because construction works absorb much effort. Policies governing the management of human resources are directly linked to the fluctuating market conditions.

Companies tend therefore to rationalise the employment of labour force through several tactics such as hiring workers on project-by-project basis in order to minimise costs.

Most companies, about 75 per cent, have less than 20 years in business. This is so because the restrictive government policies that prevailed in the past hampered seriously the emergence of private sector. Furthermore, many companies that existed in the past were nationalised and eventually went bankrupt. Despite the significant experience of most players, construction contracting sector can be considered an emergent sector that need strengthening in terms of technical, financial and management capabilities.

The financial turnover pattern of construction companies reflects the state of economy of the country that is still incipient. In the developed world the construction sector contributes significantly to the GDP with percentages of the order of 7 to 9 per cent. Most companies, about 75 per cent, had financial turnovers below USD 1.000 million in 1997, 1998 and 1999 which reflects the pyramid structure of the sector.

With regards to project types the study revealed that building construction and building maintenance are the largest sectors. This pattern shows that the demand for housing, education, commercial and industrial building is high first due to a long period of stagnation of construction activity and second due to low amount of money involved in building compared to capital projects.

Finally, the evidence shows an extremely unbalanced distribution of construction activity throughout the country. The Maputo region, the capital of the country, occupies a privileged position in terms of investment in construction with about 80 per cent of the total volume in recent years. This aspect reflects the economic strength of the region that has historical roots on one hand, and is a typical problem of developing countries, on the other hand.

13.2.2 Contracting strategy and cost performance

With regards to the contracting strategy and cost performance of construction projects it was found that the traditional method where the design is separated from construction is the most predominant and 95 per cent of projects were implemented following this path. Design and build is the second relevant option and it is often chosen by clients to shorten the delivery period and avoid complex organisational and management problems associated with the traditional method. The research concluded that the choice of contract strategy is largely influenced by legislation, source of finance and project size.

The procurement of public projects follows a particular set of guidelines that can not be omitted. The source of finance refers to the funding agency or entity that often determines how a project should be procured. As the project size increases the amount of accountability and responsibility is greater and there is a need to ensure transparency in the process that often means being too much formal or using proven processes such as the traditional method. The Local Competitive Bidding is the most used bidding procedure compared to International Competitive Bidding, negotiated and selective procedures.

The reasons for this lie on the need for providing equal opportunities to competitors, ensuring the implementation of empowerment policy formulated by the government, and ensuring the most advantageous tender is obtained. Unit-rate-fixed price-followed by unit-rate variable-price contracts are the commonest types of contract in use in construction projects. The main reason is that these types of contract are associated with the traditional method where design and construction are apart and tenders are invited on the base of bill of quantities. It is also a method of clients protecting their interest particularly the risk of cost overrun.

Cost performance, quality performance, schedule performance and safety in order of priority were found to be the main project performance indicators used by construction contractors. Although there are trade-offs between these indicators and the prime indicators depend on the specific project it can be said that these indicators constitute the significant measures of success.

Building projects and building maintenance are the type of projects that experienced the highest levels of cost overruns. This result is not statistically surprising since these sectors comprise the largest share of construction projects. The cost overruns sizes are widely spread with "less than 10 per cent", "11-20 per cent" and "21-30 per cent" being the most relevant categories. The relevance of these sizes stem from the fact that as the margins have become tight even a marginal overrun can wipe-off the profit and lead to financial difficulties.

The results revealed that construction contractors almost use single value estimates and never probabilistic estimates. It might be that they are unfamiliar with probabilistic estimating and they work under pressure. The results indicate that contingency is the most uncertain component of cost estimating followed by indirect costs. Materials and equipment are less uncertain while labour costs can be determined with high relatively accuracy.

13.2.3 Risk analysis and management

With regards to the responsibility for risk management it was found that estimating departments and senior management were the only responsible. Planning personnel were ranked second by the majority of respondents, while project team members were positioned in third and fourth place. These results revealed that these two groups have also been involved in the process of managing risk.

Risk identification is mainly performed through historical data and questionnaires and the other methods are not used due to time constraints. Risks are assessed and analysed

through experience and subjective judgement and the main response strategies are contingencies, avoidance and reduction in descending order.

Existing techniques and tools for risk management built upon statistical decision approach are rarely used by construction contractors because they are generally unfamiliar. Furthermore, since projects have been perceived as being unique, it has been difficult or impossible to gather sufficient and reliable historical data on which to elicit objective probabilities. In summary, there is gap between the existing techniques and tools and their practical application.

The construction contractors are aware of risk and view many tangible benefits in the effective implementation of risk management. They mentioned lack of knowledge, lack of effective tools, difficulty in handling probability and time pressure as the main obstacles to an effective implementation of risk management.

13.2.4 Global risk factors

Global risk factors affecting construction cost performance were identified from the literature, discussions with construction practitioners and questionnaire survey. The respondents were asked to express their perceived significance of global risk factors as predictors of cost performance and to add any further factors they felt had significant impact. The most important groups of risk factors are: estimator related factors; project and design related factors; competition related factors; fraudulent and corruption related factors; construction related factors; economy related factors; and political related factors. These factors and their relevance are briefly summarised in the following sections.

- Estimator related factors

Making errors can be considered as an inherent characteristic in humans and estimators are no exception. Motivational bias, namely rewards to estimators was found somewhat important whereas adjustment and anchoring, a form of cognitive bias, was particularly

considered as having huge impact on the accuracy of cost estimating and thus on the project cost performance. Contractors emphasised the widespread use of the "rules of thumb" and assumptions by many estimators. This is partly explained by the instability and volatility of the market in terms of prices. Being able to scan the market environment and accordingly making adjustments is key to successful bidding.

- Project and design related factors

Overall, the construction contractors considered this group of factors as being very important. Although project size and project complexity were considered to be very important, vagueness and project type were considered to have much more impact on the quality of cost estimates and consequently on the project cost performance. Complexity has large influence on cost performance since the difficulty in cost estimating is high in complex projects both in terms of multi-disciplinarity or technologies. Project type is linked to familiarity of contractor with some types of projects. Vagueness in scope has largely been cited as being one of the most important causes of poor cost performance. Indeed, very often claims and change orders originate from poor scope definition.

- Competition related factors

Within the context of this study, competition related factors were found to be very important predictors of cost performance. Among the four factors, "contractor's policies" and "need for job" scored lower than "market conditions" and "number of bidders", however, "market conditions" and "number of bidders" are interrelated factors. During previous recession periods contractors were willing to undertake less attractive projects with an increase in the number of bidders. In the supply and demand economy, the number of suppliers is a prime determinant of the freedom of individual businesses to make decisions. The smaller the number of suppliers, the greater the choice they have in terms of prices. However, contractors tend to bid for most available jobs in order, at least, to keep their organisations running, consequently underestimating is common in times of recession.

- Fraudulent and corruption related factors

Contractors should not neglect these factors when preparing their tenders since there is a wide occurrence of both fraudulent and corrupt practices in the construction industry. Although some forms of contract, for example, the World Bank standard forms of contract provide some warning clauses to discourage these practices it seems that they have failed, at least, to minimise the situation. Fraudulent and corrupt practices are very subtle occurrences thus making them almost impossible to uncover. Corrupt practices, particularly in most developing countries, are regarded as unavoidable. Fraudulent and corrupt practices take various forms and can originate from different parties, for example theft on site is a very important factor to consider. Contractors usually hire private security companies in the belief they will avoid materials and elements theft, however, this usually only minimises the problem. Corrupt and fraudulent practices can often lead construction contractors to spend more money than they had planned.

- Construction related factors

Construction related factors were generally attributed high importance by construction contractors. Geological conditions, site accessibility and weather conditions have the importance index of 62, whereas site location, delay in payments, lack of payment and sub-contractor have higher importance indexes.

- Economy related factors

Economic factors impacting on construction cost performance were found to be very important. Typical developing country exhibits severe discontinuities and fluctuations of construction demand and supply. The responding construction contractors considered price fluctuations, interest rates, exchange rates and inflation crucial variables to successful projects. These economic variables affect project costs and revenues. This

situation is common in countries with unfavourable balance of payments and heavy debt servicing burdens.

- Political related factors

The responding construction contractors regarded political risks as very important. Indeed, government policies, decisions, attitudes and actions are very likely to endanger business environment and particularly construction projects. Evidence shows that politically motivated factors have a large influence upon construction projects in the country. Political events exert influence at macro, market and project levels. Political events that affect construction business in the country have two main dimensions: political actions initiated internally; and political actions instigated by foreign parties, mainly donors and lenders. With regard to the latter dimension, external influence, it should be mentioned that Mozambique is extremely vulnerable and dependent on foreign aid which means that a large number of strategic decisions on political, social and economic issues are imposed by donors, lenders, and influence groups.

13.2.5 Repertory grid interviews

The repertory grid technique allows the interviewer to address the respondent's assumptions and personal understanding of the subject under study directly. The objective of repertory grid interviews was to elicit relevant knowledge about global risk factors affecting construction cost performance. Construction contractors revealed that they rarely used probabilistic methods for managing risk and instead they preferred their experience and professional judgement.

The analysis of data from repertory grid interviews enabled the researcher to understand how construction contractors perceived and handled risk inherent in construction projects with particular incidence to the main risk management criteria and sub-criteria, constructs used to manage risk, and scales used to measure risk impact and likelihood. The main criteria, sub-criteria and constructs elicited from construction contractors serve the purpose of building the knowledge base of the decision support system

(FRIDEF) whereas the measures of risk are used in the process of risk management to establish membership functions, risk response strategies, and acceptable risk thresholds. The most important constructs elicited from construction contractors without repetition are presented in the appendices.

13.2.6 Application of Fuzzy Set Theory to Build a Knowledge-based system.

Fuzzy logic has been used to develop a knowledge-based system that integrates risk decision framework. The framework has been validated with construction contractors and can be considered reasonably acceptable. The KBS developed using fuzzy logic is a still a prototype and therefore it can not be claimed to perform at the desirable level. The research has shown that fuzzy set theory can be a powerful technology for handling poorly-defined and complex problems due to incomplete and imprecise information that characterise real-world systems. Risk management of global risk factors belongs to this group of problems.

13.3 Contributions of the research

Management research is the systematic and objective process of gathering, recording and analysing data for improving managerial decision-making. The discussion of the results in the light of the theory and practice has enabled to determine the implications of the research to the body of knowledge. The issues arising from the research emerge through comparison of two instances: the instance prior and the instance after the research.
The research has thus established important findings and suggestions on risk management that will be valuable to the decision-making in the construction industry. The most important contribution was to establish the framework comprising the process, techniques and tools for structuring, assessing, analysing and managing global risk factors that affect cost performance of construction projects. The findings and suggestions of the research can be summarised as follows:

1. The research has identified risk management as an important function of construction project management within the construction management discipline. Furthermore, construction contractors use project management philosophy in managing construction projects. Risk can affect the cost, time, quality and productivity of a construction project and therefore it must managed effectively and efficiently. Risk can have a high financial impact on both contractors and clients and according to Dun and Bradstreet (1986) the most significant causes of construction failures are directly associated with management problems.

2. The research has established that construction organisations operate within an environment and not a vacuum. They are inevitably influenced by and constantly interacting with their environment. As such, construction organisations and projects are open rather than closed systems, which are rigid and do not adapt to changing environments. Construction organisations' efficiency and effectiveness largely depend upon how managers scan the external project environment, identify the critical factors and adapt their organisations accordingly.

3. The research has established that the environment surrounding construction organisations and projects is nowadays very dynamic and highly complex. The dynamism is represented by the degree of change of the domains. For example, it is not easy to determine the economic environment the will prevail in the course of a project to be undertaken in the future. The complexity is largely due the large number of variables involved and the level of knowledge required in the operation of the organisations. The amount of uncertainty in the internal, operating and general environment and the approach taken to its evaluation are important factors to the success of a project. Furthermore, global risk factors seem to pose more challenges to construction contractors than other categories of risk.

4. The research has established that poor cost performance of construction projects is widespread and it is particularly acute in Mozambique where construction contractors

face far more severe constraints in terms of human, material, and financial resources than their counterparts in developing world. These constraints include an unbalanced distribution of the industry throughout the regions, management skills, shortage of skilled labour, low productivity, shortage of supplies, bad quality of supplies, inadequate contract strategies and shortage of equipment. Furthermore, most of the time the political and legal frameworks are not conducive to good business.

5. Existing techniques and tools for risk management built upon statistical decision approach are rarely used by construction contractors because they do not have enough knowledge to handle them. Furthermore, since projects have been perceived as being unique, it has been difficult to gather sufficient and reliable historical data on which to elicit objective probabilities. Instead, most construction contractors have relied upon experience, intuition and professional judgement in the process of risk management. Current techniques and tools do not fully recognise and incorporate rules of thumb, professional judgement and experience of construction professionals. Many risk management systems fail due to the lack of expert support to inexperienced or novice model users. In summary, there is gap between the existing techniques and tools and their practical application.

6. There is a need for pursuing new directions in risk management since risk has become more complex than ever before. Particular attention should be concentrated on innovative technologies that are able to effectively take into account the features of the actual practices of risk management by construction professionals. Expertise from various sources can help to reduce bias in the process of decision-making. The technology of KBS is a viable alternative in that purpose.

7. The research has made a synthesis of the different global risk factors that were treated separately and using different approaches in the past. Furthermore, the research provided a new mechanism for conceptualising and measuring risks originating from the general environment. Knowledge-based decision support systems can a play a significant role in

the process of improving decision making among construction organisations particularly risk decision-making.

8. Most of the current risk management systems are developed on the base of mathematical models derived from management science and from the point of view of rational decision model. Although some of these models work effectively for certain types of problems they fall short in modelling risk management problem which, to a large extent, is an humanistic system rather than mechanistic. Humanistic systems involve a great deal of human perception and reasoning. Although the conceptualisation of the external environment is available, its formal measurement has received little attention by researchers due to the complexity of the environments.

9. The research has shown that fuzzy set theory can be a powerful technology for handling poorly-defined and complex problems due to incomplete and imprecise information that characterise real-world systems. Risk management belongs to this group of problems. According to Zadeh, as the complexity of a system increases human ability to make precise yet significant statements about is behaviour diminishes until a threshold is reached beyond which precision and significance become mutually exclusive. Using fuzzy logic to model risk means sacrificing precision while gaining significance. The technology is intended to complement rather than to replace other approaches such as those based on statistical decision theory.

10. The research has enabled the development of a fuzzy decision framework for analysis and management of global risk factors affecting construction cost performance. The framework evolved from processes of best practices in risk management that derived from the literature, questionnaires, interviews and case studies with construction contractors. The framework includes a KBS that employs the technology of fuzzy logic and uses linguistic variables to express risk instead of numeric expressions thus enhancing the interaction between the system and the user. The framework model can be taken as an aid to strategic thinking and it can be viewed as playing two important roles. First, it offers a perspective for structuring the process of risk decision making by

providing the overall process; secondly, it offers techniques and tools for evaluating and analysing a problem in terms of the different elements of risk.

13.4 Recommendations to industry

The successful completion of a project depends on many factors of which risk management is one of the most important. The following recommendations, resulting from the conclusions of the study, to industry are therefore deemed fundamental in order to enhance the effective management of risk:

- The business environment has become highly dynamic and complex and the need for continuous change within oganisations is crucial than ever before. Organisations must be able to manage change effectively. Construction organisations should therefore instill good project management culture (with emphasis on risk management), as part of corporate culture, to ensure the stakeholders are aware of risks that permeate through construction projects and can proactively manage them. Promoting risk management culture within organisation is important because stakeholders do not work in a value-free vacuum and their activities are governed by values, attitudes, behaviours, beliefs, customs, and norms that are unique to a specific organisation. Cultures are coherent systems necessary for the stability and smooth functioning of organisations and create shared understanding concerning attitudes and ways of thinking. In addition, there is a strong relationship between cultures and corporate strategies. Any strategy has its own unique underlying culture and a change in strategy may require a change in culture (values and behaviours). There are several ways of instilling culture but the most important is to ensure that stakeholders understand organisation's goals, objectives and values and effective dissemination of information. The main producers of corporate cultures are therefore senior managers although a bottom-up approach can be useful. Furthermore, benchmarking of risk management should be encouraged to allow the

implementation of best practices either from within the construction industry or from other industries such as banking, manufacturing and insurance.

- Construction contractors should devise risk knowledge management practices in order to enhance individual and organisational learning as a mean of sharing the intellectual asset. Knowledge management involves knowledge identification, acquisition, structuring, and dissemination. Knowledge includes skills, competencies, experience, ideas, talents and commitments, whereas the repository of knowledge comprises best practices, people, reports and documents. Successful organisations build competitive advantage and enhance performance through less controlling and more learning, that is, through continually creating and sharing knowledge.

- Construction contractors should think strategically and establish realistic risk management strategies, policies and procedures. Strategic thinking is necessary to account for the dynamism and complexity of the business environment. The policies and procedures are important tools in the process of project risk management as they set up the standing guidelines for risk decision-making.

- Construction contractors should always perform systematic risk management regardless the size of the project. The framework presented in this study can be used for a systematic risk management comprising risk planning, risk identification, risk analysis, risk response, risk monitoring and control, risk reporting and communication. The decision on which techniques and tools to use should be governed by the risks that are thought to be significant and project characteristics. Purely qualitative assessment can sometimes be effective, but different circumstances can lead to the use of distinct approaches.

- Construction contractors should also pay attention to the global risk factors because they seem to pose much challenge to project success than other category of risks. The awareness, recognition and knowledge of these risks could enhance contractors'

negotiation ability with clients for a fair and effective contractual risk allocation. Knowledge of risks can also be helpful in deciding whether or not to bid for a project.

13.5 Suggestions for further research

The research has achieved its aim of developing a framework for managing global risk factors affecting construction cost performance at a project level and from contractors perspective. Although it is not claimed to be a definitive framework it can play a valuable role as a methodology for addressing risk. Several important issues were raised both at the beginning and throughout the research process. Some of these have been analysed, described, and incorporated into the study. Others, however, could not be incorporated due to scope, time constraints and because the research has prominently been exploratory and experimental. The aspects that were not covered in-depth are part of recommendations for further work that should be pursued. In this respect additional research seems therefore to be needed on the following aspects:

- The system could be extended to incorporate other categories of risk such as organisation-specific risks that were not included in the present study. Furthermore, in extending the system it would be desirable to consider the main phases of construction project namely identification, definition, feasibility, design, implementation and operation and maintenance. Such a system would be useful to a wider audience of construction players including clients and designers. Furthermore, it would be important to investigate risk management practices from clients and designers' perspective.

- It would also be useful to develop larger financial, economic, cost, contractors, suppliers and clients' databases and incorporate them into the system so as to enhance the performance of the database module.

- The difficulty associated with generating membership functions has been considered a major drawback in developing fuzzy systems. The development and experiments of membership functions using different methods such as Artificial Neural Networks and Genetic Algorithms should be encouraged. These technologies seem to be effective in generating much more reliable membership functions than ad-hoc methods and would help in firming up a family of these functions.

The system developed in the present study can be integrated with other risk management such as probabilistic models in order to create synergies and thus improving risk decision making.

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APPENDIX A - Contractors main questionnaire

Covering letter **10.05.2000**

Construction projects are fraught with risks. Although many of these risks can not be eliminated they can be appropriately identified, assessed and managed. Risks encountered in construction projects can generally be classified into three major groups. **Organisation specific, global** and **Acts of God. Organisation-specific** risks are those considered to be under contractor's responsibility and control. These risks factors are associated with material delivery and quality, labour skills and availability, equipment performance and availability and management efficiency. Contractors are solely responsible for controlling these risk factors. **Global risk factors** refer to the general project risks and uncertain variables of the surrounding environment within which construction organisations operate. These risks comprise mainly socio-cultural, economic and political factors. Although these risk factors significantly affect construction projects, particularly in developing countries, contractors are unfamiliar with them. Acts of God are risks caused by natural forces such as earthquake, hurricanes and heavy floods.

The purpose of this questionnaire is to investigate global risk factors affecting construction cost performance within construction companies in Mozambique so as to develop an effective decision framework to assess and manage them properly. This questionnaire focuses upon the following risk related issues: general information of the firm; cost performance; contracting strategies; risk analysis and management; global risk factors and linguistic expressions used to describe risks. Please, respond to the questions with regard your company. The data collected in the survey will be treated as strictly confidential.

Yours faithfully,

Address: Daniel Baloi, UEM – GIU, tel: 491938, Campus Universitário. E-mail: Baloi@Zebra.Uem.mz

Part I - General information related to the company

The objective of Part I is to collect information related to construction organisations identification, type, size and type of projects.

1. Company identification

Company name _____

Company address _____

Company contact: Name position
phone

For the following questions please tick the appropriate response (s).

2. Do you want to receive a summary of the research findings ☐ Yes ☐ No

3. To whom should results be sent? _____

Please, state an alternative name, if not above _____

4. How many direct employees does the company have in Maputo now (tick as appropriate)

	Tick
a. Less than 50 employees	☐
b. 50 – 150	☐
c. 151 – 250	☐
d. 251 – 350	☐
e. More than 350	

5. How long has the company been in business (tick as appropriate)

	Tick
a. Less than 5 years	
b. 6 – 10 years	
c. 11 – 15 years	
d. 16 – 20 years	
e. More than 20 years	

6. Type of organisation (tick the main activity)

	Tick
a. Contractor	
b.Consultant	
c. Both	
d. Other, please state _____	

7. For each of the following categories, please state the number of projects the company has been involved in the last three years .

	1997	1998	1999
a. Building Construction			
b. Building Services			
c. Civil Engineering			
d. Heavy Construction			
e. Building Maintenance			
f. Civil Engineering Maintenance			
g. Others, please state _____			

8. Please, state the company annual turnover in the last three years (tick as appropriate).

	1997	1998	1999
Less than USD$ 1.0m	☐	☐	☐
USD$1.0 m – $3.0m	☐	☐	☐
USD$ 3.0m – 6.0m	☐	☐	☐
USD$ 6.0m – $9.0m	☐	☐	☐
More than USD$ 10.0m	☐	☐	☐

9. Please, indicate the number of projects start-ups in each of the following regions in the last three years

	Number of projects		
	1997	**1998**	**1999**
a. Maputo	☐	☐	☐
b. Sofala	☐	☐	☐
c. Zambezia	☐	☐	☐
d. Nampula	☐	☐	☐
e. Cabo Delgado	☐	☐	☐
f. Tete	☐	☐	☐
g. Manica	☐	☐	☐
h. Gaza	☐	☐	☐
i. Inhambane	☐	☐	☐
j. Niassa	☐	☐	☐

Part II. Cost performance and contracting strategies

The objective of Part II is to investigate project performance indicators, incidence of cost overruns, contracting strategies, tendering procedures and type of contracts in construction projects.

10. Please, state the percentage of contracts awarded under each of the following contracting strategies in the last three years

Percentage of contracts

	1997	1998	1999
a.Traditional (design, tendering and construction)			
b.Design/build			
c.Construction management			
d.Management contracting			
e.BOT (Build, Operate, Transfer)			
f.BOOT (Build, Own, Operate, Transfer)			
g.Turnkey (Finance, design, build and Comm)			
h.Project management			
i.Partnering			
j. Others, please state _____			

11. Please, rank in order of importance the following factors as they influence the choice of contract strategy

Ranking: 1 – Most influencing

Rank

a. Source of finance

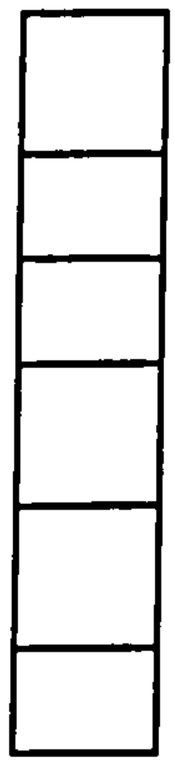
b. Legislation

c. Practicality

d. Project size

e. Project type

f. Others (Please mention) _____



12. Please, state the percentage of contracts awarded through the following bidding procedures in the last three years

Percentage of contracts

1997 1998 1999

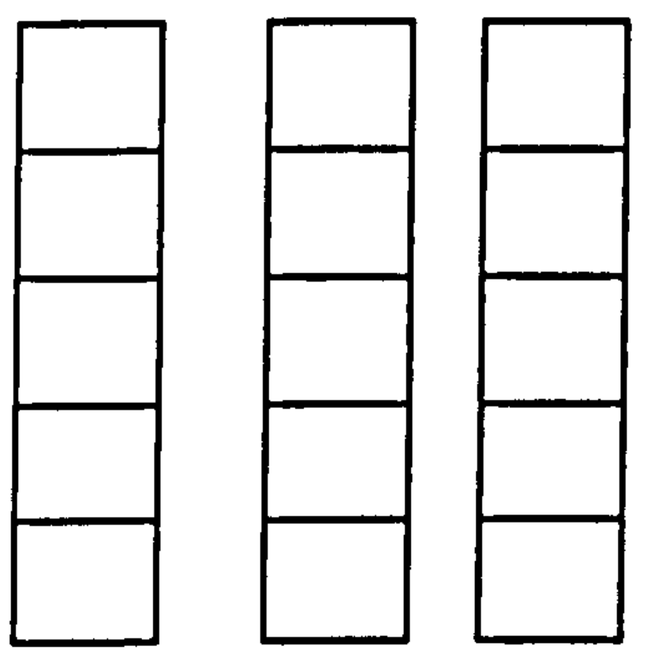
a.International Competitive Bidding

b.Local Competitive Bidding

c.Negotiated

d.Selectivee.

e.Others (Please mention)



13. Please, state the percentage of each of the following contract types in the last three years

Percentage of contracts

	1997	1998	1999
a.Lump-sum fixed price			
b.Lump - sum variable price			
c.Unit rate fixed price			
d.Unit rate variable price			
e.Cost plus fixed fee			
f.Cost plus percentage			
g.Cost plus overhead plus fee			
h. Others (Please mention)			

14. Please, rank in order of importance each of the following project performance indicators

Ranking: 1 – Most important

	Rank
a.Cost performance	
b.Schedule performance	
c.Quality performance	
d. Safety	
e. Profit	
f. Client satisfaction	
g.Others, please state _____	

15. Please state the percentage of cost overruns experienced by the following types of projects in the last three years.

	Cost overruns		
	1997	1998	1999
a. Building			
b. Building services			
c. Civil Engineering			
d. Heavy Construction			
e. Building maintenance			
f. Civil Engineering maintenance			
g. Others, please state			

16. Please, state the percentage of projects that experienced the following cost overruns average sizes in the last three years

	Percentage of projects		
	1997	1998	1999
a. Less than 10% cost overrun			
b. 11 – 20%			
c. 21 – 30%			
d. 31 – 40%			
e. More than 40%			

17. How often do you use each of the following cost estimating approaches in cost estimation (please tick as appropriate).

	Never	Sometimes	Always
a.Single value estimates			
b.Probabilistic estimating			
c. Others (please mention) _____			

18. How often do you use each of the following cost estimating methods (please tick as approriate)

	Never	sometimes	Always
a.Operational cost			
b. Past unit cost			
c. Output rate cost			
d. Sub-contract rate			
e. Others (please mention)			

Part III. Risk analysis and management practices

The objective of Part III is to investigate uncertainty introduced by the cost estimates elements, risk identification, analysis and management approaches and risk communication procedures

19. Which of the following cost components are the most uncertain (please rank) ?

Ranking: 1 – Most uncertain

Rank

a. Labour

b. Equipment

c. Materials

d. Indirect costs

e. Others, please state

20.Please, rank in order of responsibility who performs project risk identification within the company

Rank

a. Estimating department personnel

b. Planning and estimating department personnel

c. Senior executives

d. Project personnel

e. Others (please mention)

21. Please, rank the frequency of use of each of the following risk identification techniques

Ranking: 1 – Most used

Ranks

a. Checklists

b. Brainstorming sessions

c. Questionnaire

d. Historical data

e. Others, please state

22. How often do you use each of the following risk assessment techniques (tick as appropriate) ?

	Never	Sometimes	Always
a. Deterministic methods			
b. Experience			
c. Intuitive judgement			
d. Probabilistic analysis			
e. Combination, please state			

23. Please rank in order of importance each of the following risk response strategies

Ranking: 1 – Most used

Rank

Contingencies

a. Insurance

b. Avoidance

c. Contractual transfer

d. Reduction

e. Others, please state

24. How would you rate your knowledge of risk analysis and management in construction project? Please rate on a 1 to 5 scale, where 1 means very little knowledge and 5 very good knowledge.

1 2 3 4 5

25. Do you think there would be benefits in applying risk management in construction projects?

a. Yes

b. Do not know

c. No

26. Please rank the following factors that may pose difficulties to an effective and efficient implementation of risk management in construction projects.

	Ranks
a. Lack of specific knowledge	
b. Lack of awareness	
c. Difficulty working with statistics and probabilities	
d. Lack of effective tools	
e. Time pressure	
f. Others, please mention	

Part IV. Global risk factors affecting cost performance

The objective of Part IV is to investigate the significance of global risk factors affecting cost estimates and final costs. Global risk factores are those related to the surrounding environment within which the organisation operates. These include socio-cultural economic and political variables.

27. Please rate each of the following global risk factors as they affect project cost performance

Rate	Meaning
1	Very low effect
2	Low effect
3	Average effect
4	High effect
5	Very high effect

Estimator related factors

Factor	Rating
a. Motivational bias	
c. Estimating assumptions	
d. Adjustment and anchoring	

Design related factors

Factor	Rating
a. Project size	
b. Design complexity	
c. Vagueness in scope	
d. Project type	

Level of competition related factors

Factor	Rating
a. Policies of the contractor	
b. Need for job	
c. Market conditions	
d. Number of bidders	

Fraudulent practices related factors

Factor	Rating
a. Corrupt practices	
b. Collusion among contractors	
c. Collusion between consultant and contractor (s)	
d. Theft of materials and equipment	

Construction related factors

Factor	Rating
a. geological conditions	
b. Weather conditions	
c. Site accessibility	
d. Site location	
e. Client generated factors	
f. Sub-contractor generated factors	

Economy related factors

Factor	Rating
a. Market conditions	
b. Price fluctuations	
d. Inflation	
e. Exchange rate	

Political related factors

Factor	Rating
a. Political instability	
b. Political system	
b. Change in per unit labor cost	
c. Change in regulation	
d. Change in labour rates	
e. Strikes	
f. Labour restrictions	
g. Taxation changes on imported materials	
h. Supply of local materials	
i. Importance of project	
j. Exchange rates stability	
k. Influence of power groups	
l. Project desirability	
m. Bureaucracy	

28. Please state other risk factor that influence cost performance of construction projects

APPENDIX B - Repertory Grid Interviews

15.10.2000

Covering letter

Following our telephone conversation, I enclose the outline format of the proposed interview. The interview is part of the research to investigate the management of Global Risk Factors Affecting Project Cost Performance and is a sequence of the questionnaire that you were asked to complete. The main objective of the interview is to elicit risk management constructs and the way your company has used them to managed project risk. Constructs represent your descriptions of the different elements that are considered in the management of risk.

All information you provide will be treated as strictly confidential. I would like to express my gratitude for your offer to take part in these interviews and for the time you have made available for the present exercise.

Yours Faithfully,

Daniel Baloi

Address: Daniel Baloi, UEM – GIU, tel: 491938, Campus Universitário. E-mail: Baloi@Zebra.Uem.Mz

Table B.1: Construction contractors repertory grid sample

	E1	E2	E3	E4	E5	E6	E7	
C1								
C2								
C3								
C4								
C5								
C6								
C7								
C8								
C9								
C10								
C11								
C12								
C13								
C14								
C15								
C16								
C17								
C18								

Table B.2: Elicited construction contractors constructs

Group of risk	Variable (constructs)
Estimator factors	Training
	Skills
	Knowledge
	Experience
	Morale and motivation
	Hiring cost
Fraudulent practices	Misrepresentation
	Collusion among bidders
	Bid evaluation
	Security

	Theft rate
Design/Project	Innovation
	Attractiveness
	Construction period
	Cooperation
	Details level
	Specifications
Client	
	Experience with client
	Fund management
	Source of funds
	Co-operation
	Payment record
Sub-contractor	
	Price consistency
	Area experience
	Management skills
	Financial strenght
	Technical strenght
	Safety records
	Performance record
	Workmanship

	Variable (constructs)
Competition	Market conditions
	Number of bidders
	Need for job
	Project size
	Supply

Construction factors	Temperature
	Rain
	Humidity
	Road network
	Road type
	Site location
	Communications
Economic-political	
	Supply
	Exchange rate
	Inflation
	Interest rate
	Market conditions
	Instability
	Policies
	Judicial system
	Commercial law
	Disorders-strikes
	Expatriate labour restrictions
	Taxation system
	Import taxes
	Bureacracy
	Corruption practices
	Approval

Please give your opinion on the range of quantitative values that best describe the following expressions as used to assess the magnitude of risk associated with projects:

Note: The scale of values is 0 - 10, where 0 represent the lowest risk level and 10 the highest risk level.

a) Very low risk (VL) from to

b) Low risk (L) from to

c) Medium risk (M) from to

d) High risk (H) from to

e) Very high risk (VH) from to

APPENDIX C - Questionnaire - Framework validation

Covering letter

This questionnaire represents the end of the research project into Global Risk Factors Affecting Construction Cost Performance. The enclosed framework that includes a schematic diagram, the explanatory text and the software package is the final output of the early discussions, workshop, questionnaire survey and repertory grid interviews conducted with your kind co-operation. The aim of the framework is enhance the effective management of global risk factors affecting cost performance. The purpose of writing to you is to give feedback on the information that you provided and ask your assistance in the validation of the framework. Please, evaluate the framework including the software package before completing the questionnaire. Please, provide more details on answering "yes" or "no" questions. Should any question arise do not hesitate to contact-me at any time.

Yours faithfully,

Daniel Baloi

1. Company identification

Company name _____

Company address _____

Company contact: Name position phone

2. Type of organisation (tick the main activity)

	Tick
a. Contractor	
b.Consultant	
c. Both	

3. What type of work does your company undertake

a. Building Construction	
b. Building Services	
c. Civil Engineering	
d. Heavy Construction	
e. Building Maintenance	

4. Have your organisation been using a risk management framework similar to the one presented to you?

a) Yes	
b) No	

5. **Does your company have a structured framework for risk management?**

a) Yes ☐

b) No ☐

6. **Are your risk management process similar to the present framework?**

a) Yes ☐

b) No ☐

7. **Are the steps and procedures comprising the present framework easy to implement?**

a) Yes ☐

b) No ☐

8. **Are the inputs and outputs are easily understandable?**

a) Yes ☐

b) No ☐

9. **Are the results produced by FRIDEF useful for decision-making?**

a) Yes ☐

b) No ☐

10. **Would you implement the present framework to improve risk management in your company?**

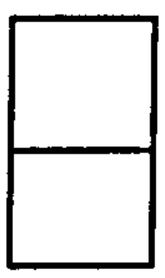
a) Yes ☐

b) No ☐

11. Could you implement the present framework in your company?

a) Yes

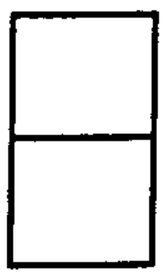
b) No



12. Dou you think the present framework could enhance cost performance in your company?

a) Yes

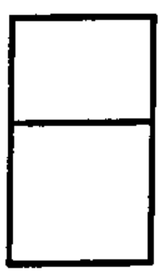
b) No



13. Dou you think the present framewrok is cost-effective?

a) Yes

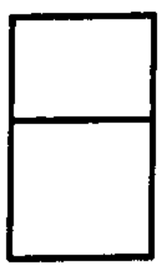
b) No



14. Dou you need much time to implement the framework?

a) Yes

b) No



15. Have you any suggestion, comment or recommendations?

APPENDIX D - Economic indicators (Mozambique)

Table D.1. GDP, Inflation rates and Exchange rates

Year	GDP per capita	Inflation	Exchange
	USD	%	USD/MZM
1985	98	47.5	43.2
1986	87	12.2	39.7
1987	94	175.8	404
1988	96	55	626
1989	97	40	820
1990	108	47.1	1038
1991	107	35.2	1845
1992	97	54.5	2742
1993	95	43.6	5238
1994	94	70.1	6552
1995	91	54.9	11000
1996			
1997			
1998			
1999		6.2	13170
2000		11.5	16985
2001		20.4	23000

Table D.2 GDP Growth rate

Year	Rate (%)
1996	7.1
1997	11.1
1998	11.9
1999	7.3
2000	2.1

Source: National Human Development Report 2000, UNDP Maputo