Intelligent Selection of Concrete Bridge Superstructure Construction Methods in Egypt

by

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ABSTRACT

The selection process of bridge superstructure construction methods in Egypt currently depends on experts' knowledge, experience and intuition and is not supported by systematic procedures. This means that the decisions made can be sub-optimal, not taking account of all the necessary considerations. Invariably, these are cost, schedule and quality problems. This thesis is concerned with the development of a decision support system that provides a systematic and structured framework to improve the current selection process of bridge superstructure construction methods.

In order to fulfil this aim, the research methodology involved review of literature on bridge construction methods and multicriteria decision problems and knowledge acquisition using a variety of techniques. Knowledge was elicited from experts using interviews, card sorting, questionnaire survey, and process tracing. A rapid prototyping methodology was used to develop the prototype system. The system identifies the feasible alternatives, and then utilises the Analytic Hierarchy Process (AHP) to obtain the weighted benefit of each alternative. A cost model is used to calculate the cost of the alternatives. Finally, the system calculates the benefit/cost ratio for each alternative in order to prioritise them. The system was evaluated during, and after the development process and the feedback was integrated to the system to improve the prototype.

The research identified that the selection process is highly affected by cost, duration of construction, bridge physical characteristics and the surrounding environment and to a lesser extent by stakeholders' objectives and external constraints. It also identified eight main construction methods that are used in the construction of the superstructure of concrete bridges in Egypt.

The research concludes that the prototype system can improve the current selection process of concrete bridge superstructure construction methods in Egypt by providing sound technical guidance. Whilst the data sets and validation are based on an Egyptian context, it is argued that the findings have a wider application. The prototype system offers considerable benefit if used during the early stages of the bridge development life cycle. The collective effort of constructors, owners and designers is important in using and updating its knowledge base.

DEDICATION

To my late father for his wisdom, that instigated me to search for truth,

To my mother for her unequivocal relentless support,

To my wife for her Kind heart,

To my son Youssef and my daughter Malak for being around,

To my late grandmother Fatma for inspiring me,

And above all, Thanks to God All Mighty.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

One of the major determinants of any country's development is the scope of its transportation network (e.g. roads, railways, waterways, etc.). The maturity of the transportation network reveals the extent of development as well as the potential for any future investments. For example, the total length of highways in Egypt is 64,000 km, while in the United Kingdom it is 371,913 km (World Fact Book, 2004). If it is borne in mind that Egypt's area is four times that of the UK, and the population of Egypt is around 1.25 times the UK, the extent of development in each country can be comprehended. Bridges, as part of most road networks, are developed to cross obstacles such as waterways, valleys, roads, railway lines, etc. They require relatively high investments in terms of both cost and time in order to plan and build.

Egypt's terrain consists mainly of a vast desert plateau interrupted by the River Nile and bordered on two sides by the Mediterranean Sea and the Red Sea. The area along the Nile river, starting from the high dam on the south to the Mediterranean on the north, is agricultural land. Desert areas exist in the east desert, west desert and Sinai Peninsula. Long coastal lines exist along the Mediterranean and the Red Sea. Figure 1.1 illustrates the map of Egypt. Major cities in Egypt are densely populated with problems of congestion and high density traffic. The need for highways is emphasized in the Egyptian Government's five year plan running from 2002 to 2007, where the investment in bridges is around 53% of the budget assigned for the transportation sector, with an amount of around 1.44 Billion US$. The changing nature of environmental parameters and the amount of investments involved make it challenging for bridge engineers to choose a suitable construction method. For the purpose of this thesis, construction methods are defined as the selection of falsework, formwork and scaffold elements.

Figure 1.1: Map of Egypt (World Fact Book, 2004)

1.2 JUSTIFICATION FOR THE RESEARCH

Most of the explicit knowledge on bridge construction is captured in books, codes of practice, conference proceedings, journal papers, and regulations. However tacit knowledge, which is the implicit know-how built over years of experience, resides with bridge experts and may be lost over time for many reasons. It is geographically distributed, and difficult to access and utilise. As a consequence, the construction selection process is based mainly on intuition, skill, knowledge and judgement in a highly unstructured fashion. Moreover, the advancements in structural analysis and materials have introduced new techniques and necessitated the consideration of new influential criteria. Stone (1980) argues that, although the existence of a wide range of construction techniques has increased design flexibility, it has increased the difficulty in selecting appropriate alternatives. Such perquisites have complicated the selection process beyond the intuitive capability of most professionals.

During the early stages of bridge design, the decision on possible reliable structural configurations is dependant on many considerations such as maintenance, aesthetics, durability, environmental impact, and construction methods amongst others. Further, Tatum (1987) suggests that early design decisions that may exclude desirable construction methods, create constructability problems. They may increase construction effort and increase construction difficulty and the risk of problems. Such inappropriate decisions are caused by the lack of flow of knowledge and expertise from contractor to designer especially under traditional management systems where responsibility for design and construction is separated. This situation is unique to the construction industry as illustrated by Banwell (1964).

In addition, Basha and Gab-Allah (1991), in their evaluation of superstructure construction methods used in Egypt, considered eight criteria: construction cost, maintenance, durability, service life, resource availability, construction progress rate, and design efficiency. In six out of the fourteen cases examined, the chosen methods were not the best solution. They concluded that this situation is caused by several factors including the inadequate study of alternative construction systems. The reason for this is the nature of bridge projects in Egypt where speed is required for design and construction, thus limiting the time necessary to conduct proper studies. Furthermore, the nature of the Egyptian economy and increased competition constitute prime instigators for organizations to develop decision support systems as illustrated by Turban and Aronson (2001) based on surveys conducted during the 1980s and 1990s.

Bridges constitute major investment in most transportation networks. The activities associated with their design and construction represent the majority of the cost and time invested in most transportation networks. An example highlighted here is the bridge built to cross Suez Canal, the East portion of the project has a length of around 1 km, out of the total length of the associated road network of 5 Km. The cost for constructing this portion represented 90% of the costs of the associated road network. Zhao *et al* (2004) stated that "A highway system development involves huge irreversible investments, and requires rigorous modelling and analysis before the implementation decision is made". Although this fact may be less apparent in smaller bridges and longer road networks, bridge construction influences both cost and time of most road networks.

The foregoing discussion illustrates that bridge engineers, as decision makers, need to develop a resilient system where tacit knowledge is captured and represented in a sound and structured framework to help them in the decision-making process. It should establish common ground among relevant stakeholders when choosing construction methods and provide justification for investing in one alternative over another in a fast way. It is also useful to view such a system as part of a mechanism that evaluates different structural systems of concrete bridges. It could also serve as a useful training tool for engineers who are not familiar with the bridge construction industry.

1.3 AIM AND OBJECTIVES

The aim of the research is to investigate the factors involved in the selection of construction methods for the superstructure of concrete bridges in Egypt, and to develop an intelligent decision support system that is able effectively to evaluate and recommend a suitable construction method for a given bridge design. The specific objectives of the research are to:

- Review related work on the selection of alternative bridge construction methods for a given situation, as well as the application of intelligent decision making techniques to construction problems;
- Identify and investigate the criteria necessary for the evaluation of alternative superstructure construction methods in Egypt and investigate the situations under which different construction methods are used;
- Develop an intelligent decision support system to help bridge designers in Egypt to decide on the most appropriate superstructure construction method for a given bridge design; and
- Evaluate the developed system using real examples with industry experts.

The term "superstructure construction methods" refers to the formwork, falsework, and scaffold necessary for the construction of the superstructure of concrete bridges.

1.4 SUMMARY OF RESEARCH METHODOLOGY

Several methods have been adopted in order to achieve the research aim and objectives. The details of these methods are included in Chapter 2. However, a brief summary of the research methodology is provided here:

Literature review: An in-depth literature review has been performed on bridge construction methods as well as on the use of decision making tools to solve selection problems. The main reasons for the review were to understand the nature of bridge construction industry and its characteristics, and to explore the potential of using intelligent decision making in improving the selection of bridge construction techniques. The review provided the main theoretical framework for the research.

Semi-structured interviews: Sessions were conducted with selected experts in order to obtain general recognition of the problem, to investigate the criteria affecting the selection of construction methods, and to identify the construction methods used in Egypt. It also helped in building awareness of this study among professionals.

Card Sorting: Sessions were conducted with selected bridge professionals in order to organize the identified criteria in a hierarchical form.

Questionnaires: Questionnaires were sent out and received from different industry professionals in order to organize the identified criteria in order of importance.

Structured interviews: Sessions were conducted with industry professionals in order to understand the situations where the construction methods are used.

Process Tracing and Protocol Analysis: Sessions were conducted with a selected bridge estimator in order to construct a cost model that calculates the cost of each construction alternative.

Prototype development: The prototype system was developed using rapid prototyping where a prototype was developed early and improvements were made as early as possible to the system, based on feedback from experts and industry practitioners.

Evaluation: Sessions were conducted with selected industry experts in order to evaluate the system and assess its functionality and usability. The sessions included demonstrating system outlines and presenting a case study being tackled by the system. Each participant responded to an evaluation questionnaire that covered the various facets of the system. Figure 1.2 illustrates the methods used in order to fulfil research objectives.

1.5 GUIDE TO THESIS

The thesis is organized into eight chapters; the following represents a summary of the contents of each chapter:

Chapter 1, *Introduction*: it gives a background to the research and justifies the need for such research. It also contains a summary of the research methodology, and a guide to thesis.

Chapter 2, *Research Methodology*: it reviews research philosophies and approaches in general and emphasizes the methodology adopted for this research: literature review, interviews, card sorting, process tracing and questionnaire surveys. It also discusses the methodology adopted for the system development and the evaluation process.

Chapter 3, *Concrete Bridge Superstructure Construction Methods*: it discusses constructability issues, the characteristics of different stages of bridge projects, and concrete bridge construction methods (emphasizing the methods used in Egypt). The criteria for selecting construction methods are illustrated as well as the issues related to construction in Egypt.

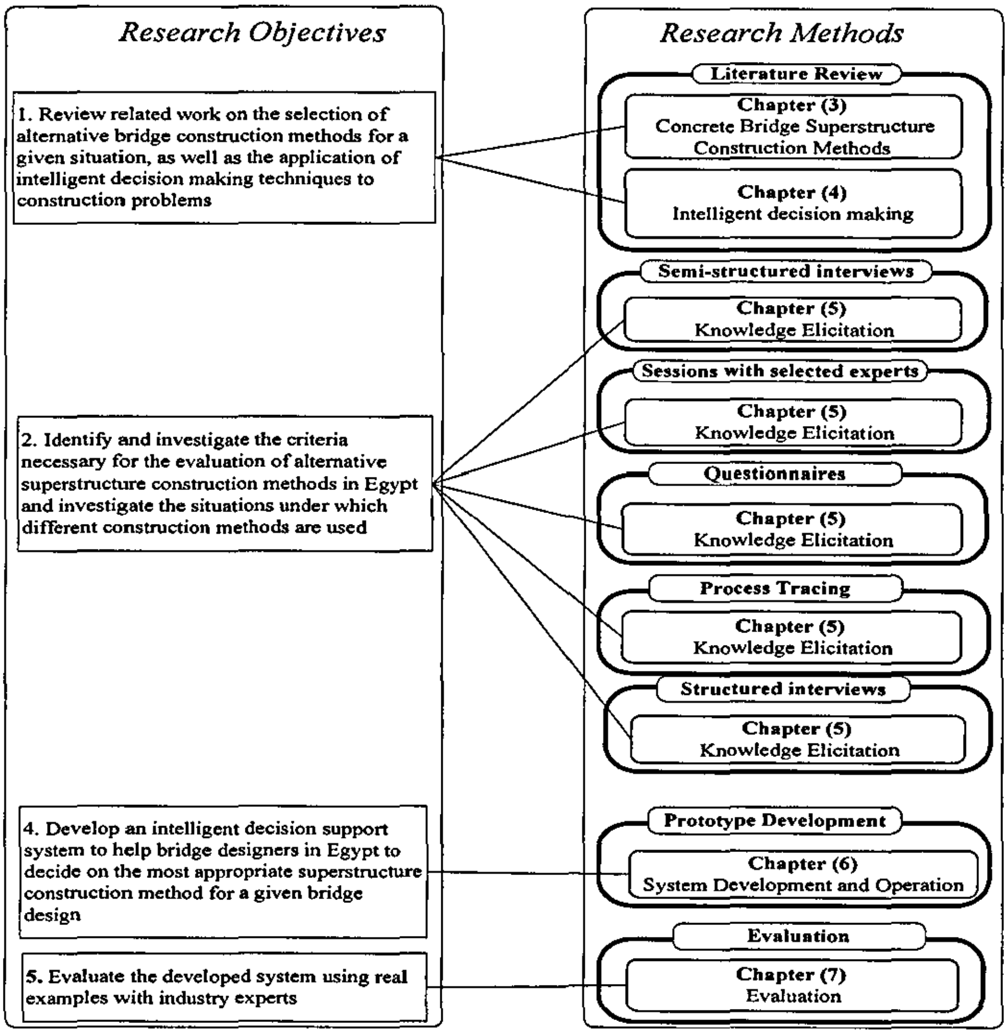


Figure 1.2: Research objectives and methods

Chapter 4, *Intelligent Decision Making*: this chapter reviews decision making as well as intelligent decision making techniques and the analytic hierarchy process. It also discusses the various applications of intelligent decision making systems in civil engineering.

Chapter 5, *Knowledge Elicitation*: this chapter presents and discusses the knowledge elicited using different techniques including semi-structured interviews, card sorting, questionnaires, structured interviews and process tracing.

Chapter 6, *System Development and Operation*: here, the objectives and targeted users are described as well as details of the system design, implementation, and operation.

Chapter 7, *Evaluation*: the procedure for the system evaluation is presented here as well as the analysis of the evaluation sessions.

Chapter 8, *Conclusions and Recommendations*: the outcomes are discussed here together with the limitations of the research. The chapter concludes with recommendations for further work.

CHAPTER 2: RESEARCH METHODOLOGY

2.1 INTRODUCTION

The Oxford English dictionary defines research as "The study of materials and sources in order to establish facts and reach new conclusions". The Chambers English dictionary employs a scientific approach when defining research as "Systematic investigation towards increasing the sum of knowledge". This chapter aims to be an orientation chapter where existing research methodologies and those employed are addressed. Creswell (2003) suggests that researchers need to embark on two main issues before conducting their research; firstly the research philosophy, where the questions of how to capture knowledge and what to capture are answered; secondly the research approach, where the specific directions for procedures are identified as well as the techniques used for knowledge acquisition. Whilst these issues are discussed in the first part of this chapter, the second part explains the methodologies adopted in this research.

2.2 RESEARCH PHILOSOPHIES

Philosophical ideas or knowledge claims, according to Creswell (2003), remain hidden in research as illustrated by Slife and Williams (1995). However, they should be understood as they enable researchers to construct a comprehensive view of their research methodology.

Scientific knowledge has evolved along three main themes: intellectual, dialectical, and empirical. Intellectuals, led by Des Cartes, adopt pure reasoning to develop scientific knowledge. Dialectics led by Plato, adopt trial and error in the form of thesis, antithesis and synthesis. Empiricists such as Kant adopt observation and experimentation (Fellows and Liu, 1997).

More recently, four main schools of thoughts regarding research philosophy have emerged as illustrated by Creswell (2003): postpositivism, constructivism, advocacy or participatory, and pragmatism.

In postpositivism the notion of absolute truth is abandoned to search for truer knowledge as indicated by Myrdal (1969) especially in the sphere of the behaviour and actions of humans. Konsowa (1998) poses an example of this notion in science, as identified by the renowned physicist Heisenberg whilst studying velocity and position of electrons, where he illustrated that our interpretation of truth is constrained by our capabilities to comprehend it and absolute truth can never be identified. In this approach data, evidence, objectivity and rational considerations shape knowledge. The use of empirical observations and measurements is evident in this philosophy. A quantitative approach is used predominantly in this philosophy.

Constructivism refers to instances where individuals seek to understand the world in which they live by developing subjective meanings of their experiences. Ultimately, the aim of this philosophy is to understand and interpret the meanings others have about the world in view of history and culture. The advocacy philosophy started when it was understood that both postpositivism and constructivism cannot adequately address the issues of social justice for marginalised groups while advocacy can provide more help to researchers in this field. Qualitative approach is used predominantly in these two philosophies.

Pragmatism or paradigm of choices, as indicated by Patton (1990), refers to instances where knowledge arises out of actions, situations, and consequences rather than being constrained by theories and principles, as is the case in postpositivism. This approach is triggered by the fact that research always occurs in social, economical, political and other contexts.

The next section will discuss research methodologies including qualitative, quantitative and mixed methods and some of the associated methods of inquiry.

2.3 RESEARCH METHODOLOGIES

Research methodology is defined as "the application of scientific procedures towards acquiring answers to a wide variety of research questions" (Adams and Schvaneveldt, 1985). It can also be defined as "The principles and procedures of logical thought processes which are applied to a scientific investigation" (Fellows and Liu, 1997). It appears that this term is characterised by investigation, procedural framework, and systematic, with the aim of increasing knowledge (Remenyi *et al*, 1998) and (Amaratunga *et al*, 2002).

2.3.1 Knowledge Acquisition

Knowledge acquisition is defined as "the process of extracting, structuring, and organizing knowledge from one or more sources" as indicated by Turban and Aronson (2001). Knowledge elicitation is part of knowledge acquisition and refers to the process of eliciting and interpreting knowledge from experts (Diaper, 1989). McGraw and Harbison-Briggs (1989) identify five main stages of knowledge acquisition in the continuum of developing decision support systems: identification, conceptualization, formalization, implementation and testing. During the identification stage the problem is identified, and the aim and objectives are formulated. This stage is mainly concerned with identifying the problem characteristics. Throughout the conceptualization stage, the sources of knowledge including literature and domain experts are investigated and the main concepts are depicted and related. The Formalization stage involves organising the recognized concepts and relations into a model that represents the problem. The implementation stage involves developing the prototype decision support system using the acquired knowledge. The final stage, evaluation, involves testing and validating the prototype to determine its effectiveness in achieving the aim and objectives identified in the first stage using an appropriate problem set. The results are then used to revise the prototype.

2.3.2 Overview of Research Methodologies

There are three main research methodologies, or strategies of enquiry as illustrated by Creswell (2003): qualitative, quantitative and mixed (sometimes called hybrid). Each has its scope of applicability and characteristics.

From examining the continuum of scientific studies, it can be seen that natural sciences reside at one end while social sciences reside at the other. Natural science studies are interested in studying events and sequences of facts that are considered as independent objective criteria by which the validity of scientific statements are judged. Quantitative approaches are normally used in natural science studies. At the other end of the scale, social sciences have ‘thinking participants’ where the study is not constrained to facts but includes the participants’ perceptions. In social sciences, qualitative approaches are normally used. The separation between thoughts and events is a main characteristic in social sciences (Love *et al*, 2002). However, along the continuum of scientific knowledge there is a wide variety of problems that have elements of both natural sciences and social sciences such as problems associated with construction management.

Love *et al* (2002) illustrate that construction management (CM) problems have a multidisciplinary nature and their research builds on theories that have been developed in other disciplines besides engineering such as economy, sociology, psychology and law. The inadequacy of qualitative and quantitative approaches to deal with this kind of research has triggered a debate between CM academics where it was suggested that CM research requires a mixed approach (Blackwood *et al*, 1997) and (Holt and Faniran, 2000).

Amaratunga *et al* (2002) illustrate that, generally, the qualitative approach recognizes the presence or absence of a given feature in a problem or situation while the quantitative approach measures the extent to which this feature exists. Mixed approaches combine both features. The next subsections will discuss qualitative, quantitative and mixed approaches.

2.3.3 Qualitative Approach

This approach is predominantly used in the constructuvism research philosophy. The qualitative approach enables the researcher to explore the problem without being constrained by previously determined categories of analysis (Patton, 1990) or framework (Fellows and Liu, 1997). It allows an in-depth and detailed investigation of the problem by understanding and gathering data and information. It concentrates on words and observations to express reality and attempts to describe people in natural situations (Amaratunga *et al*, 2002). Qualitative research is considered as a forerunner to the quantitative approach in instances where no theory or applicable framework exists (Fellows and Liu, 1997).

The emphasis of qualitative research on studying ordinary events in natural settings enables it to provide a rich and holistic interpretation and great potential to reveal complexities in contrast with the quantitative approach which may be considered artificial, as it starts from a predetermined framework (Patton, 1990). The qualitative approach emphasizes the role of the individuals' experiences to reveal meanings placed on occurrences and procedures. It can also describe and explain situations and events in their local contexts. Furthermore, it can be used to complement, validate or re-interpret quantitative data gathered from the same settings (Amaratunga *et al*, 2002). Despite the fact that it is relatively easy for researchers to start qualitative research, the analysis of the output is more difficult when compared to the quantitative approach.

The qualitative approach employs certain strategies (Creswell, 2003) or styles as defined by Fellows and Liu (1997). These include: ethnographic research, action research and case studies, which are discussed in turn below.

2.3.3.1 Ethnographic research

Patton (1990) indicates that the principal question to be answered in this style is to answer the question "what is the culture of this group of people?". This style has its roots in anthropology where the researcher normally constitutes part of a cultural group being examined over a period of time with the aim of observing their behaviour with central attention to the idea of culture (Fellows and Liu, 1997). Spradley (1979) illustrates that this approach normally utilises interviews, documents and observations to collect data and results in a narrative descriptive output that includes charts, diagrams and other illustrations that help in presenting and analysing data. The research process is resilient and evolves in response to field realities. It offers a comprehensive in-depth understanding of the underlying issues (Creswell, 2003). However the results are likely to be affected by the researcher's involvement in the group and the group is likely to be influenced by his/her presence. Furthermore, Myers (1999) illustrates that it takes considerable time to conduct when compared to other research approaches.

2.3.3.2 Action Research

Denzin and Lincoln (2000) define action research as a process in which action, in the form of improvement, and research in the form of understanding, are executed at the same time. In this style, the researcher is actively participating in the research problem in order to suggest and test solutions to certain problems (Fellows and Liu, 1997). This method is practiced in real life by practitioners as well as politicians embarking on the implementation of social changes (O'Brien, 1998). A notable example is when a consultant, due to his knowledge in the problem area and his research expertise, is invited by a construction organisation to solve a problem that requires his active participation.

This style provides flexibility and quick adaptation to rapid changes that characterise real life problems. Action research provides the researcher with hands-on experience and the ability to produce new hypothesis or to strengthen existing ones. It can also diversify the research problem when used with other methods (Patton, 1990). However, the researcher is often faced by the lack of control over variables. The fact that this research is conducted to solve a particular problem limits its scope of applicability.

2.3.3.3 Case studies research

Amaratunga and Baldry (2000) define this style as "a research strategy that focuses on understanding the dynamics present within single settings where a relatively intensive analysis is conducted of this single instance of the phenomenon under investigation". This analysis may involve a programme, an event, an activity, a process or one or more individuals according to Creswell (2003). Others, such as Yin (1994), emphasise that it takes place in the real life context where the boundaries between phenomenon and context are not clearly recognized. The information gathered using this style is rich and may sometimes be used to prove the validity of certain conclusions resulting from other styles.

Despite the scepticism expressed by Shavelson and Townes (2002) of the ability of this style to go beyond being used as a preliminary research strategy for exploratory reasons, and by Fellows and Liu (1997) who consider it merely as a means of obtaining data rather than a particular methodological approach in itself, others have debated these conclusions. Yin (2003) explains that it can be used beyond being an exploratory technique to be both descriptive and explanatory when it represents a unique or extreme circumstance, or when it represents a typical sample of the population. Furthermore, Patton (1990) is of the view that one major reason for using case studies is to evaluate outcomes. Case studies offer rich and in-depth information and may be utilised as an introduction to a subject of study that cannot be defined accurately or where no other information exists upon which to base other forms of research methodology.

The limited breadth of the case study usually poses doubts on its scope of application. The number of case studies utilised depends on availability, cost and time. Thus the information gathered cannot be generalized without due consideration.

2.3.4 Quantitative Approach

This approach is predominantly used by the postpositivism philosophy. The quantitative approach follows the academic tradition in the natural sciences that assumes that numbers can represent concepts and facts (Amaratunga *et al*, 2002). It is used when it is possible to yield specific aim, objectives and hypotheses through the study of theory (Fellows and Liu, 1997). Standardized measures are utilised to include the different experiences of people in a limited predetermined number of groups to which numbers are assigned (Patton, 1990). Procedures employed in the quantitative approach usually search for distinguishing characteristics, elemental properties and empirical boundaries and seek the answers to the questions of "how much and how often" as expressed by Nau (1995).

The main advantages of the quantitative approach in the view of Amaratunga *et al* (2002) are that it ensures the independence of the observer from the research, and it uses objective methods to infer conclusions rather than inferring conclusions subjectively. However, it does not cater for the need to explore new subjects that do not fall into any prior framework or theory. Creswell (2003) identifies two main strategies of inquiry associated with quantitative research: surveys and experiments.

2.3.4.1 Surveys

This technique relies on statistical sampling whereby the selected sample is considered to represent the population under study. This style is usually conducted in instances when it is required to answer the questions of "who, what, where, how many and how much" with a focus on the contemporary events without control over behavioural variables (Amaratunga *et al,* 2002).

This style has three main advantages; it produces a quantitative description of the required aspects of the study; it identifies the relationships between the study variables, information is gathered mainly through asking respondents questions followed by analysis of the responses (Pinsonneault and Kraeme, 1993). However, this technique is not particularly cost or time effective and requires considerable effort from the researcher and respondents especially when using interviews. A low response rate is usually expected when using postal questionnaires. There is also inherited bias and distortion in the answers given by the respondents. Nevertheless, if this approach is used properly, it can prove to be an excellent tool to elicit knowledge especially in the field of construction management as suggested by Fellows and Liu (1997).

2.3.4.2 Experimental Research

Hicks (1982) defines this style as "A study in which certain independent variables are manipulated, their effect on one or more dependent variables is determined and the levels of these independent variables are assigned at random to the experimental units in the study". This style suits bounded problems or issues in which the variables involved are known or at least can be assumed with some confidence. The experiment is designed so as to isolate variables whereby the values of the independent variables are changed and their effect on the isolated variables is monitored. This procedure is normally difficult when applied to social sciences as rationalising behaviour through experimentation does not cater for the process of thought (Fellows and Liu, 1997).

The major strength of this approach lies in its ability to determine precisely the individual effect of each variable through controlling the other variables involved. One major weakness is that the experiment may not represent the population hence limiting the scope of its applicability.

2.3.5 Mixed Approach

Miles and Huberman (1994) describe this approach as "A way to achieve findings by using different research methods and by squaring the findings with others to be squared with". Amaratunga *et al* (2002) define it as "the combination of methodologies in the study of the same phenomenon where it is assumed that the weakness in each method will be compensated by the counter balance of strengths of another". The inherited weaknesses and strengths involved in quantitative and qualitative techniques are summarised in Table 2.1.

Creswell (2003) states that there are three main strategies in this research approach: sequential procedures, concurrent procedures and transformative procedures. In sequential procedures the research starts with a qualitative approach followed by a quantitative approach or vice versa. The first sequence is normally used for exploratory reasons when it is required to gain an understanding of the people's views of the problem or where the problem has no definite framework that can be inferred from literature. It is then followed by a quantitative approach with a representative sample in order to generalize results.

Table 2.1: Strengths and weaknesses of quantitative and qualitative approaches

(Amaratunga *et al*, 2002)

	Strengths	Weaknesses
Quantitative Approach	• Covers wide range of situations • Fast and economical • May be generalized when analyzing representative sample using statistics • Generally objective	• Inflexible and artificial • Limited effectiveness in understanding processes • Limited effectiveness in understanding significance people attach to actions • Less effective in generating theories • Less effective in understanding new problems that can not be viewed within prior framework or theory • Requires use of standardized measures
Qualitative Approach	• More natural and flexible • Effective in understanding change processes over time • Effective in understanding meanings people attach to actions • Effective in adjusting to new issues and ideas as they emerge • More effective in theory generation • Offers an in-depth and detailed analysis • Approaches field work without being constrained by predetermined categories of analysis	• Data collection may require more resources • Analysis of data is generally more difficult • Harder to control the research process • Generally subjective

Alternatively, the study may start with a quantitative approach to test a hypothesis or theory followed by a qualitative approach for detailed exploration. In the concurrent procedures, both qualitative and quantitative approaches are used simultaneously where the results complement each other. The researcher may nest one approach inside another involving larger data collection to search for answers to specific research questions. Finally, the transformative procedure is used when the researcher utilises the theoretical perspective as a means of providing a framework for the research that contains both quantitative and qualitative data gathering techniques.

A mixed approach may also be used as a mean of validating (i.e. triangulating) research findings. Denzin (1978) distinguishes between four types of triangulation; data triangulation, investigator triangulation, methodological triangulation, and interdisciplinary triangulation. Data triangulation refers to instances where data is gathered at different times or from different sources; investigator triangulation refers to instances where different researchers independently gather data on the same study and compare results; interdisciplinary triangulation occurs where the research process is informed by many disciplines; and methodological triangulation, where multiple methods of data collection and analysis are used.

In the mixed approach, the researcher bases his/her knowledge claim on pragmatic grounds where the problem in hand possesses central attention. The nature of this approach is exploratory and is useful in instances when the researcher does not know the important variables to examine (Creswell, 2003).

2.3.6 Choice of a research approach

Creswell (2003) identifies three main considerations affecting the choice of a research approach: the research problem, the personal experience of the researcher, and the audience to which the research is addressed. Furthermore, Neuman (2000) states that it also depends on the purpose of the study, and the type and availability of the information required.

Perhaps a more practical approach is identified by Patton (1990) who suggests that it involves answering the following questions: "who is the information for and who will use the findings?"; "what kinds of information are needed?"; "how is the information to be used?", "for what purposes is the research being done?", "when is the information needed?", 'what resources are available to conduct the research?". Upon answering these questions and taking into consideration the characteristics of each approach a research methodology can be constructed. Patton (1990) states that there is no right or wrong in choosing the research methodology and it is considered as "the art of the possible".

Amaratunga *et al* (2002) are of the view that the quality of any research is determined by three main criteria: the extent to which research adds to the body of knowledge, its reliability and validity. If the research is narrow with limited applicability or the problem has limited direct bearing on the field, it is likely to be less contributing to the body of knowledge in this field. Reliability is achieved if the study procedures are free from errors and bias or, ultimately, if the same procedures for the same problem are repeated, it will produce the same results. Validity generally refers to the extent to which the model represents reality. Yin (2003) divides validity into three types: construct validity, internal validity and external validity. Construct validity is concerned with setting up the right operations for the concepts under study. External validity refers to establishing the area to which this study can be applied. Internal validity is concerned with the ability to deduct causal relationships where certain conditions lead to others and is generally used in explanatory studies. The choice of a research approach is coupled with studying the techniques that will be used in eliciting the required knowledge.

2.3.7 Knowledge Elicitation Techniques

There are a number of knowledge elicitation techniques that can be used. However, the following discussion will be limited to four relevant techniques, which are: interviews, card sorting, questionnaire survey and process tracing.

2.3.7.1 Interviews

Gillham (2000b) defines an interview as a conversation where one person, the interviewer, is seeking responses for a particular purpose from another person, the interviewee. The knowledge is elicited through verbal interaction. Interviews are convenient elicitation techniques when it is required to obtain conceptual knowledge of the study area without being constrained to a predefined framework or when an in-depth knowledge of some aspects of the study area is required (Diaper, 1989). Although it is relatively easy for the researcher to start his/her study by conducting interviews their analysis and reporting is difficult. There are two main determinants that directly affect the successful elicitation of knowledge using this technique; the interviewee should possess the relevant knowledge or have access to it; and the required knowledge can be verbalised. It is also important that the knowledge engineer (i.e. researcher) has good communication skills (Mcgraw and Harbison-Briggs, 1989). The interview sessions are normally recorded using tape recorders or video cameras and transcribed and analysed later.

The interview process consists normally of three main stages, development and piloting, setting up and travelling to and from interview location, transcribing and analysing interviews. Although, the process is generally cost and time-consuming, the researcher may adopt a few strategies to decrease cost including: using telephones to conduct sessions although the process loses some quality due to the absence of face-to-face interaction and/or the impatience of interviewees especially in long phone calls; decreasing the number of interviewees to a minimum; decreasing the length of the interview questions which decreases the time consumed in conducting research and makes the interview process more focused (Gillham, 2000b).

Diaper (1989) illustrates that there are three types of interviews; structured interviews, semi-structured interviews and unstructured interviews. Structured interviews are interviews in which the interviewer asks some questions in the same words and in the same order in each session. The nature of questioning in this type is closed questioning. It is also considered as a "systematic goal-oriented process" as expressed by Wright and Ayton (1987). Semi-structured interviews are used when there is a list of questions to be asked, but the order in which they are covered and the words used to express them may vary from session to session. They mostly make use of open-ended questions while seeking for specific information. This type helps in maintaining both focus and breadth of the information gathered. Unstructured interviews are designed to allow interviewees to cover the required topics in their own way. It has the advantage of being fast but is limited by the vagueness of the obtained information. In the latter type the use of probes, to encourage interviewee to elaborate on the information, and prompts, to change course of interview, is essential.

There are two types of questions closed ended and open-ended. Closed ended questions refer to those questions where the interviewee is offered answers to choose from. They limit the ability of the interviewee to explain and are more suitable in questionnaire surveys (Fowler, 1993). In open-ended questions, the interviewee is totally free to answer and elaborate.

As questions are the main tool in communicating with the interviewee, their successful compilation is paramount. (Moser and Kalton, 1978) illustrate a few guidelines in compiling good questions including how to avoid the following; negative phrasing of questions; making questions ambiguous; using terms that are not normally used by the interviewee; over exaggerated forms; phrasing questions in a threatening or embarrassing manner; questions leading to a specific response; complex questions; and long questions.

There are other important aspects to the interview session of psychological nature that should be considered by interviewer and are important to the successful elicitation of knowledge including; facial expression, which should be appropriate and responsive; eye contacts, where too much use of eye contact may make interviewees feel embarrassed; head nods, when overdone may seem unnatural; gestures, the use of suitable gestures may be appropriate in order to express interest; physical proximity and contact, not being too close or too far while conducting session; verbal dimension should be considered especially in the use of voice tones and in listening rather than talking from the part of the interviewer (Gillham, 2000b).

2.3.7.2 Card Sorting

Diaper (1989) defines sorting tasks as "Utilising elements of the domain to understand how the knowledge provider conceptualises the study area". The required knowledge may be elicited from the experts or taken after analysing the domain area. According to Chi *et al* (1981) concept sorting, is a psychological technique that is useful in organising conceptual knowledge characterising problems and enables the researcher to comprehend the expert's personal domain organisation and abstract it into items that are organised in a tree-like or hierarchical fashion (Gammack and Young, 1985).

McGraw and Harbison-Briggs (1989) consider the main stages involved in this technique as: identifying the main criteria affecting the problem and the top level main headings; each of the criteria contributing to the problem are written on cards or on magnetic backed strips (if working with a magnetic board); the expert is asked to organise cards under the main headings of the top level; they are then asked to put them into further groups according to those that belong together until the whole hierarchy is constructed. During the session the researcher summarises the findings to stimulate discussions and further refinement. This process is normally conducted over several sessions so as to allow the expert to shuffle and combine concepts.

2.3.7.3 Questionnaire Survey

Adams and Schvaneveldt (1985) define questionnaires as "a list or grouping of written questions which a respondent answers". As questionnaires may be used as an approach to generalize other findings, it is important that the responses represent population. Adams and Schvaneveldt (1985) define sampling as the process which enables a researcher from making estimates or generalizations based on the knowledge elicited from part of the population. In essence, the process involves selecting the number of respondents that are thought to represent the population.

According to Fellows and Liu (1997), the researcher should normally expect a low response rate, around 25-35%, when using questionnaires. Thus, the questionnaires should be designed to ensure a high response rate as well as to conduct a meaningful analysis. There are some guidelines recommended by Creswell (2003), Fellows and Liu (1997) and Fowler (1993) which include; the questions must be clear and easy to answer; they should be as short and concise as possible and concise; simplicity is a key factor in phrasing questions; questionnaires should be developed in a way that enables easy analysis of the results.

Normally a pilot survey is conducted first with one or two respondents in order to ensure that the questionnaires are understandable. A pilot survey is a process whereby the questionnaire design is tested with the purpose of fulfilling the following; ensure that the questions are ordered correctly; check that the questions are understandable; check the need to add or eliminate any questions; and finally check that the correct language has been used in the questions.

According to Gillham (2000a) and Suskie (1992) there are many advantages to using questionnaires. These include: they are relatively of low cost and less time consuming compared to interviews; information can be obtained from many people relatively quickly; it is considered more flexible for the respondents who can complete questionnaires at a time suitable to them or distribute it over time after consulting other sources; the analysis of the results is easier and more presentable; it sustains respondents anonymity; and is less biased due to the absence of the researcher. The disadvantages of questionnaires are; the quality of data may sometimes be questionable for many reasons including incompleteness of questionnaires and misunderstanding of the questions by some respondents; the structure of the questions and the wording used may affect answers; experts are normally more comfortable when expressing knowledge by talking rather than writing; a low response rate; questionnaires may be handed to others to complete especially with busy professionals; the lack of face-to-face contact; and less flexible for the respondents to express their answers. The latter disadvantage can be overcome by providing space for comments in order to obtain insight information. There are two main ways to send questionnaires (to respondents) either by post or by e-mail to respondents.

2.3.7.4 Process Tracing

McGraw and Harbison-Briggs (1989) define process tracing and protocol analysis as "paired techniques that are used to allow the researcher to trace or study the expert decision making process for a particular problem". It is also defined by Turban and Aronson (2001) as "a technique to track the reasoning process of the expert". They enable the researcher to focus on the important decision making elements of the task and to compile decision heuristics and attributes. The effectiveness of using these techniques depend on two main factors: completing the process of domain familiarisation and conceptualisation prior to the start; and having follow-up interviews to clarify and refine results. This technique is considered less interactive when compared to other techniques such as interviews as the information generally flows from the expert to the researcher. The decision making process is observed while the expert is presented with a specific problem. The information is generally recorded and transcribed in the form of protocols or notes and then analysed.

This technique involves verbal interaction where two main approaches can be used: concurrent verbalisation and retrospective verbalisation. In concurrent verbalisation, the expert is required to finish the task and to explain the process at the same time or to think aloud. The expert will talk while the researcher is listening and recording. Discussions may take place whenever necessary thus enabling accurate results. In retrospective verbalisation, the expert finishes the task prior to discussing the activities involved. It is used when it is thought that concurrent verbalisation will drastically affect the experts' train of thoughts. There are many approaches that can be adopted to conduct this technique including environmental observation, constrained information, constrained solutions, simulated and episodic scenarios. In environmental observation, the researcher is required to observe the expert in the course of normal working, noting major tasks, interaction with other personnel, primary decision constraints, and required processing time. However, observation alone cannot reveal the required information with regard to processes and decisions. The constrained scenario is another technique where the expert is required to work with a limited set of information whereby some of the important information may be missing or with a restricted scenario. It is helpful to identify the most important aspects of the process but may prove uncomfortable to the expert as illustrated by Hoffman (1987). In constrained solutions, the expert is required to remove or manipulate a pivotal variable. In simulated scenarios, the actual data is used to form a task or a problem that has already been solved. In episodic scenarios the tendency of an expert to use analogies to other problems or situations when confronted with a new problem is recorded. After finishing sessions of process tracing, the recordings are transcribed and translated into notes or protocols where the researcher traces the domain experts' decision process from problem presentation to problem solution (McGraw and Harbison-Briggs, 1989).

2.4 THE METHODOLOGY ADOPTED FOR THE RESEARCH

The knowledge required to fulfil the aim and objectives of this research has two main sources: literature and bridge experts. These sources correspond to the two main types of knowledge identified by Laudon and Laudon (1998), explicit and implicit. Explicit knowledge is codified in books, journals, and other tangent sources where literature review plays the main role. On the other hand, tacit knowledge resides in the minds of experts and describes their perception of the processes and procedures and offers contextual knowledge for the problem so as to enable modelling of the decision process involved in selecting bridge construction methods. The process of eliciting knowledge is not an easy task as experts tend to be important and busy people, hence, it is vital that the methods used minimise the time each expert spends off the job taking part in knowledge elicitation sessions, and that it is efficient. The experts involved in this research had many years of experience in the bridge industry and represent construction, estimation, design and top management as will be indicated in Chapter 5.

According to Gammack and Young (1985) the nature of the elicited knowledge is an important determinate in the selection of the suitable knowledge elicitation technique. McGraw and Harbison-Briggs (1989) state that knowledge can be divided in terms of its nature into four main types: declarative, procedural, semantic and episodic. Declarative knowledge represents the conscious information that can be verbalised by the expert such as general heuristics. It normally characterises the first stages of research and an interview is an efficient technique in eliciting this knowledge. Procedural knowledge represents the know how of procedures and routine tasks. Structured interviews, process tracing and simulations can be used to elicit this knowledge. Semantic knowledge is used to identify and organise major concepts and to identify decision making procedures and heuristics that are unconsciously present, in the experts' mind. Examples of the techniques used are repertory grids, concept sorting, task analysis, and process tracing. Episodic knowledge is organized by time and place of occurrence and is generally experiential information. Examples of the techniques used to elicit this type of knowledge are simulations and process tracing (McGraw and Harbison-Briggs, 1989).

Diaper (1989) developed a matrix whereby the techniques are plotted against knowledge type as mentioned in Table 2.2.

As stated in Chapter 1, the aim of this research is to investigate the factors involved in the selection of construction methods for the superstructure of concrete bridges in Egypt and to develop an intelligent decision support system that is able to effectively evaluate and recommend a suitable construction method for a given bridge design. In this research, the knowledge acquisition process involved capturing and transforming knowledge from bridge experts into a manageable form in order to develop a decision support system. It fulfils the requirements of the second objective of this research, which was to identify and investigate the criteria necessary for the evaluation of alternative superstructure construction methods in Egypt and to investigate the situations under which the different construction methods are used.

Table 2.2: Characteristics of knowledge acquisition methods (Diaper, 1989)

Technique	Facts	Conceptual Structure	Causal Knowledge	Rules	Weight of Evidence	Procedures	Context of Rules	Explanation	Justification
Interview	√	√	√	?	?		?		√
Talking through case studies	√	×	√	√	×	√		√	
Protocol Analysis						√			
Card Sorting		√							
Repertory grids		√	×	√	√	×			
Questionnaires	√								
Key: √, Good; ×, Bad; ?, possible but difficult									

2.4.1 Overview of Research Process

The research process has been divided into five main stages (see Figure 2.1). The first stage was to identify the problem and to determine the aim and objectives. The conceptualization stage involved reviewing relevant literature and conducting semi-structured interviews in order to identify the criteria affecting the choice of construction methods and to identify the construction methods used in Egypt. The main characteristics of knowledge at this stage are: declarative, factual and highly conceptual.

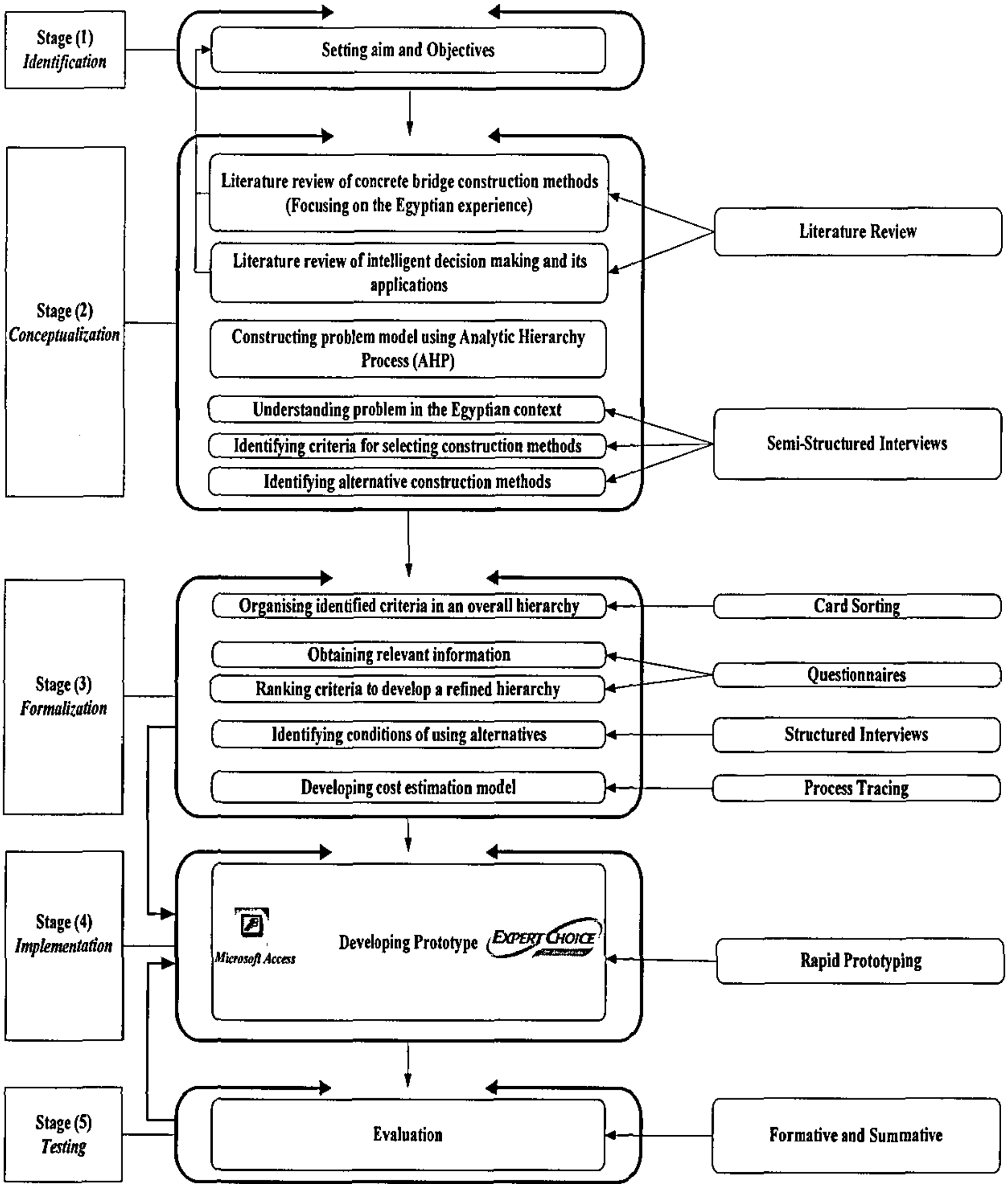


Figure 2.1: Adopted research process

In the formalization stage, the card sorting technique was used to organize the identified criteria into a hierarchical form; questionnaires were sent mainly to generalise problem and to refine the identified hierarchy in a more concise and usable form; structured interviews with practitioners were used afterwards in order to explore the experts' perceptions of the conditions for using the various construction methods.

The process tracing technique was used in order to construct the cost estimation model for each of the construction methods where the knowledge is mainly factual and highly procedural. In the implementation stage the decision support system has been developed using rapid prototyping. Finally, the prototype was evaluated during the development stage (i.e. formative evaluation) and at the end of the development stage (i.e. summative evaluation). During the latter stage a real life case study was presented to experts using the prototype to obtain their opinions of the system, and the possible ways of improving it.

The research has adopted a mixed approach where both qualitative and quantitative techniques were used interchangeably. A qualitative approach was used at the beginning (e.g. using semi-structured interviews) in order to identify criteria without being constrained to a specific framework, understand the problem in the Egyptian context, and identify the construction methods used. The qualitative approach was also used in later stages in order to obtain an in-depth understanding of the conditions limiting use of the construction methods (e.g. using structured interviews). On the other hand, the quantitative approach (e.g. questionnaire survey) was used afterwards in order to generalise the problem and to refine the identified hierarchy. The following sections will explain in detail the different methods used in the knowledge acquisition in the research including literature review, interviews, card sorting, questionnaires, and process tracing. It will also illustrate the system development and evaluation stages.

It can be seen that the research methodology adopted both the constructivism and postpositivism philosophies where the qualitative approach used at the beginning was a reflection of the first philosophy whilst the quantitative approach used in later stages was a reflection of the second one.

2.4.2 **Specific Research Methods Adopted**

2.4.2.1 Literature Review

The literature review involved a thorough review of all the relevant material that had a direct bearing on the topic. Greenfield (2001) specifies the reasons for conducting a literature review as; to identify gaps in literature; to avoid tackling a problem that has been solved successfully before; to build on other research conclusions; to identify key authors and others working in the field; and to identify methods relevant to the research. Furthermore, the literature review enriches the researcher's knowledge by introducing new information, ideas and prospects. It also helps the researcher to put the research problem into prospective (Rudestam and Newton, 2001). The review should start from the more general and then focus on the specifics.

The literature review process adopted in this research was conducted along three main dimensions which were to: identify research topic components, identify sources of information; take notes and prepare a working bibliography. These elements are going to be discussed in the following subsections.

2.4.2.2 Research Topic Components

There are three main components comprising the research problem: bridge construction methods, decision making and research methodologies. The research required an identification of bridge construction methods used in the superstructure, their characteristics, their technical aspects, and finally criteria affecting their choice. The second component involved an understanding of decision making by investigating the different techniques that can be used to deal with the research problem, including their characteristics and limitations. The different software that can be used to develop decision support systems have also been reviewed. The third component was to investigate different research methodologies so as to choose a suitable methodology for this research.

2.4.2.3 Sources of Information

Having determined the main components of the research, each component provided an area to search for information. According to Anderson and Poole (1998), there are three main sources of information: primary, secondary and tertiary. Primary sources include articles in professional journals, thesis and specialised books, which constitute a first hand account of the original work. Secondary sources include abstracts and reviews of other research works, while tertiary sources generally provide an overview or limited information of the study area such as textbooks. In searching for information, leading textbooks have provided the framework while research papers provided in-depth updated knowledge.

The starting point in this research was to search for abstracts in the relevant databases such as Civil Engineering Abstracts and COMPENDEX using appropriate keywords. Many of these databases offer weekly e-mail alerts for new publications relevant to the keywords selected. Leading journals related to bridges, construction, artificial intelligence, decision making and management were also consulted. The publications of leading organisations such as IABSE (International Association of Bridges and Structural Engineers), American Society of Civil Engineers (ASCE), and British Standards Institution (BSI) amongst others were searched for documents related to subject area. Documents produced by leading Egyptian companies such as The Arab Contractors (Osman Ahmed Osman & Co.), General Nile Company for Roads and Bridges, Nasr General Contracting Company (Hassan Allam), provided an overview of bridge construction methods used in Egypt, as well as their construction procedures. Acknowledged experts in the field were also asked to provide a list of recommended readings.

In general, tertiary sources offered a good starting point that provided an overview of the relevant fields together and a source for primary information which were then critically reviewed. Methods or techniques of potential applicability were sieved and scrutinized to determine the most appropriate ones. Tertiary sources were consulted to provide an overall framework and to provide a starting point in areas lacking primary or secondary sources of information.

2.4.2.4 Taking Notes and Preparing a Working Bibliography

Two main methods were used in taking notes; computers and index cards. RefWorks software was used to record important information from books, journals, internet and other sources. It enabled the researcher to include all the publication details so as to produce a working bibliography. RefWorks includes fields to record an abstract as well as notes extracted from information sources. The data is stored in a central server where it can be accessed via the Internet. The software also offers another component (Write-N-Cite) whereby all references are made available to extract the required information during the writing up of a thesis. All references may be attributed a chapter number so that relevant publications can only be cited during the writing of the corresponding chapter.

Ideas and thoughts as they emerge were recorded on index cards and then coded to the chapter number or research component. It was also used to take notes from information sources when it was not possible to access the Internet during note-taking. A working bibliography was prepared and presented in alphabetical order and the final version is included at the end of the thesis.

2.4.3 Interviews

In this research semi-structured interviews and structured interviews were used. Semi-structured interviews were used as the first stage in knowledge elicitation for many reasons including:

1. To allow interviewees to express their views freely without being constrained to any prior framework. Prompts were used to instigate interviewees to elaborate on the elicited knowledge when necessary;
2. To obtain the knowledge related to criteria affecting choice of construction methods in Egypt;
3. To identify the superstructure construction methods used in Egypt;
4. To understand the problem in the context of the bridge development process;
5. To increase awareness of bridge practitioners of the research project; and
6. To explore the willingness of industry practitioners to participate in later

stages of the research.

At a later stage in the research, structured interviews were conducted to obtain the conditions limiting the use of the construction techniques. The questions were in a tabulated format and the respondents were asked to complete the table during the interview session.

Prior to the interviews, the information required was identified based on the aim, objectives and process of the research. The interview questions were prepared and reviewed in order to ensure that they were free from any language errors and that they covered the areas that needed to be studied. The interviewees were contacted by phone and informed of the research aim and a general outline of the issues that were to be discussed. The session time and place were then confirmed. Prior to starting sessions the interviewees were asked to give permission to record the sessions on a tape recorder and they were assured of the confidentiality of the recordings.

The interview sessions consisted of three main phases: introductory phase, during which the aim and objectives of the research were explained together with an outline of the information required from the session; core stage, where the main questions concerning criteria affecting choice of bridge construction methods were explored; and closure, where the contents of the session were summarized and the interviewees asked if they were willing to take part in further stages of the research. The social element was obvious in the first and last stages.

After analysing the semi-structured interviews, the card sorting technique was used as discussed in the next section.

2.4.4 Card Sorting

In this research, the criteria affecting choice of construction methods have been elicited from the experts during the semi-structured interview sessions and complemented with findings from literature. The card sorting sessions were conducted in order to organise criteria in a hierarchical fashion that reflects the inter-relationships between them. Each criterion was written on a small magnetic backed strip and the participants were asked to organize the criteria under seven main headings to start with. A magnetic board was used to organise the cards so as to facilitate the sorting process. The result of this stage was the overall hierarchy that represents the problem as shown in Figure 5.1.

2.4.5 Questionnaire Survey

In this research, a questionnaire survey was used to generalise the problem and to establish a wide industry perspective on the research problem. The respondents were asked some questions related to their expertise and other questions to express their views about certain aspects of the bridge industry. They were also presented with the developed hierarchy resulting from the previous stage (i.e. card sorting) and were asked to rank elements at each level in order of importance.

As most of the respondents are based in Cairo, the questionnaires were delivered by hand by the researcher himself or by a special messenger. In this way, the respondents felt the importance of their answers to the questionnaires. Most of the respondents were contacted by phone before sending the questionnaires. The questionnaires were accompanied by a covering letter indicating the aim of the research and at what university and ensuring utmost confidentiality of the responses. The respondents were selected carefully to represent the various stakeholders in the industry, consultants, clients and general contractors. The questionnaires were prepared in both English and Arabic languages to overcome any language problems that may exist among some practitioners. The main result of this stage was the refined hierarchy, which is shown in Figure 5.5.

2.4.6 Process Tracing

The protocol analysis technique was conducted in this research by asking an experienced estimator, who had more than 15 years of experience in bridges, to think aloud while tackling the problem of estimating the cost of a bridge using each construction method. He was constrained to think in the continuum of the final objective which is to compare these alternatives together as part of their evaluation process. Many sessions were conducted where the results were written in notes and were analysed by highlighting all concepts that were relevant to the cost estimation process involved for each construction method and presented in an MS Excel spreadsheet format. The results were then compiled and presented to the estimator to validate and comment on. The results are presented in Appendix E.

2.4.7 System Development

The knowledge acquired through various stages of the research was represented hierarchically where criteria affecting choice of construction methods, the construction methods used, as well as cost elements for each method have been identified, in order to develop a decision support system. The system was developed using rapid prototyping. Rapid prototyping is intended to save both the cost and time required in the development process. It recognises that design guidelines alone cannot provide a good system from the very beginning. If the implementation stage is left late in the development life cycle, more difficulty and costs are imposed on the developer. There are three major stages involved in rapid prototyping: design/redesign, prototyping, and evaluation. The prototype is produced early and is subject to enhancement until the final usable product is reached (Hix and Hartson, 1993).

In this research, after acquiring the required conceptual knowledge and organising them, it was possible to start developing a simple prototype system using MS Excel, MS Access and Expert Choice. A series of refinements took place with the prototype being continually improved. Chapter 6 explains the process of system development.

2.4.8 Evaluation

Hix and Hartson (1993) state that there are two kinds of evaluation: formative evaluation and summative evaluation. In formative evaluation, the system is evaluated during the development process. Summative evaluation is conducted after the system has already been developed. The purpose of the evaluation process is to ensure that the system is reliable (i.e. free from errors, and is consistent), valid (i.e. produces meaningful results), and that it is user-friendly.

This research has adopted both evaluation approaches. The formative approach was used to enhance user-interaction with the system and to ensure its reliability and was performed in an iterative way during the system development process. After finishing system implementation, a summative evaluation was performed. During the summative evaluation, the system was demonstrated to several experts using a real life case study. The experts were required to evaluate the system by completing an evaluation questionnaire. Chapter 7 is devoted to explaining the evaluation process.

2.5 SUMMARY

This chapter has discussed basic philosophies, strategies of inquiry and knowledge elicitation techniques. A constructivist stance was taken at the beginning of the research methodology, where the qualitative approach was used to elicit knowledge from experts so as not to constrain them to a predefined framework in order to enrich the outcomes. Subsequently, a postpositivist stance was taken where the quantitative approach was used to measure the intensity of the knowledge elicited in the previous stage (construction methods criteria). The research methodology adopted several methods to elicit knowledge including interviews, card sorting, questionnaire survey and process tracing. A rapid prototyping methodology was adopted for system development. The prototype was evaluated in a summative and formative ways and the comments were integrated to the prototype as will be discussed in Chapter 7. The next chapter discusses the bridge development process in the context of bridge construction and discusses the construction techniques used in the superstructure of concrete bridges in Egypt.

CHAPTER 3: CONCRETE BRIDGE SUPERSTRUCTURE CONSTRUCTION METHODS

3.1 INTRODUCTION

This chapter seeks to examine the stages involved in bridge development. Preliminary design is discussed and some of the methods used to evaluate designs are illustrated. The criteria affecting the evaluation process are highlighted with special emphasis on buildability. Methods used in the construction of bridges are classified and outlined. The specific methods used in bridge construction in Egypt are explained including: stationary systems supported on the ground and on elevated platforms; cantilever construction using one or two form travellers; advancing shoring system; using launching trusses to erect precast beams; using cranes or heavy lifting to erect beams using incremental launching system; and finally custom systems. The criteria affecting construction methods are examined as well as some of the important issues related to the construction industry in Egypt. The chapter concludes with a summary.

3.2 DEFINITIONS

The following terms will be used in this chapter and their explanation is presented hereafter in accordance with BS 6100: 1999 as follows:

1. Substructure: Part of a structure wholly or mainly below the level of the adjoining ground or a given level. For the purposes of this research this

"given level" is defined as the level of the bridge pier, abutment or pylon supporting superstructure

2. Superstructure: Part of a structure above the substructure;
3. Formwork: A structure, either temporary or permanent, provided to contain fresh concrete and support it in the required shape and size until it has hardened;
4. Falsework: Any temporary structure used to support a permanent structure while it is not self-supporting during construction work, modification or demolition;
5. Scaffold: Temporary structure that provides access for operatives to construction works and support for materials and equipment.

The term "Superstructure Construction Methods or Systems" refers to the formwork, falsework and scaffold necessary for the construction of the superstructure using precast, cast in-situ, prestressed or reinforced concrete or any combinations between them.

3.3 BRIDGE DEVELOPMENT STAGES

The traditional life cycle of construction projects normally consists of five main phases: concept and feasibility studies (conceptual phase), detailed engineering, procurement, construction, and start up and operation (Barrie and Paulson, 1992). Ryall (2001), in describing the bridge life cycle, divides detailed engineering into analysis and design where the detailed calculations, shop drawings and specifications, and other documents required for construction are produced. He also elaborates on operation and defines it as including operation, maintenance, and possible strengthening or widening of the bridge, and eventually demolition or collapse. The synthesis of both views is illustrated in Figure 3.1. These phases are not discrete but overlapping, and flow into one another organically (Khan, 1991 and Heisler, 1994).

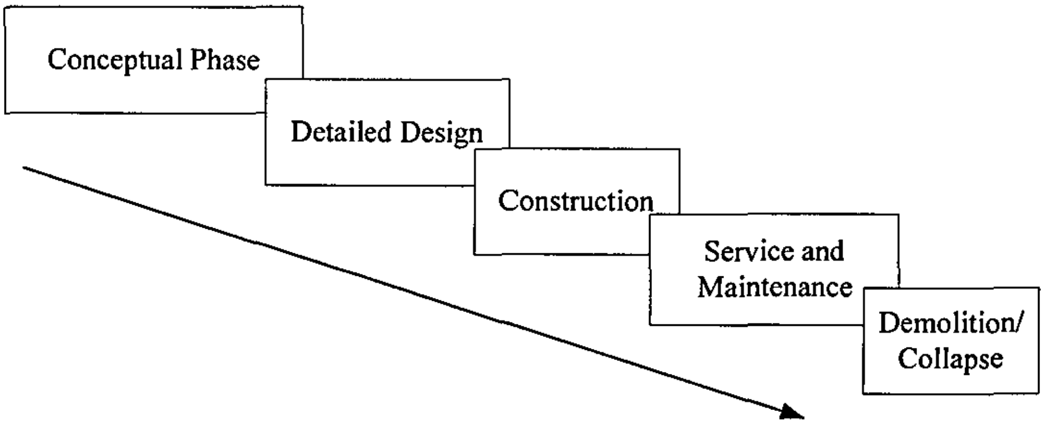


Figure 3.1: Bridge life cycle stages (Barrie and Paulson, 1992) and (Ryall, 2001)

Abdul Kadir (1996) synthesised the views of Signore (1985), Tatum (1987), Khan (1991), Heisler (1994) and others, and expounded on the elements of the conceptual phase as follows: conceptual design, outline design and preliminary design; cost, finance and economics; statutory requirements; construction methods; project needs; establishing project team; project general programme; procurement of main items; and contractual relations with the parties involved. The requirements for detail in the conceptual phase are more pronounced in civil engineering projects when compared with buildings as illustrated by Latham (1994).

Design starts early in the bridge life cycle. Troitsky (1994) illustrates that bridge design can be divided into three main stages: scheme design, preliminary design, and detailed design. Abdul Kadir (1996) adds one more stage at the beginning and calls it conceptual design. Accordingly, it can be said that the bridge design process consists of four stages: conceptual design, scheme design (outline design), preliminary design, and detailed design. The first three stages are normally performed in the conceptual phase while the last one is normally a stage on its own. These stages can be described as follows:

1. Conceptual design: the design reflects the owners' broad requirements of the bridge such as location, tentative length, number and width of traffic lanes and sidewalks, utility requirements, required clearances for navigation or traffic (Gab-allah, 1983).
2. Scheme design: a number of schemes are generated based on the imagination and experience of the designer. Normally one or two schemes are selected. Computers are of limited help at this stage due to the nature of this stage (Troitsky, 1994).
3. Preliminary design: the selected schemes are subject to further study to comprise competitive proposals. These proposals should be compared taking into consideration relevant criteria to arrive at the best proposal (Troitsky, 1994).
4. Detailed design: the chosen alternative is studied in detail in order to produce detailed drawings, specifications and other documents required for construction, operation and maintenance of the bridge (Troitsky, 1994).

During preliminary design, many influential decisions, including the choice of the appropriate construction method, are made and it is considered pivotal in the bridge life cycle (Troitsky, 1994). Accordingly, the preliminary design stage will be examined in the following section due to its relevance to the research problem.

3.4 PRELIMINARY DESIGN

During this stage, the selected scheme or schemes are investigated in a way that permits the compilation of a number of detailed alternatives for each scheme. The details of each alternative include: material, foundation type and size, span size and number, type and size of supports and construction method (Liebenberg, 1992).

The decision maker compares alternative designs in order to arrive at the most appropriate solution. Walter and Scalzi (1976) suggest three main criteria to evaluate design alternatives: economy, functional requirements, construction requirements and design requirements. Bindra and Bindra (1976) extend this list to include: nature of obstacle to be crossed, foundation conditions, climatic conditions, availability of construction materials and any other strategic considerations. However, Pritchard (1992) highlights the significance of the other phases in the bridge life drawing particular attention to the escalating cost of maintenance noted in the USA and UK over the last two decades.

Liebenberg (1992) and Troitsky (1994) argue that the evaluation problem may be solved by integrating criteria together into an objective function and optimizing it. The parameters of this function should be determined and agreed upon by the project team. This view is discussed further in the following sections.

3.4.1 Quality Index

Troitsky (1994) attempted to rationalize the selection process by arguing that it is possible to construct a quality index for any bridge U as a function of the parameters $x, y, z,..$, which represent the criteria involved, such as span size, type of foundation, span construction, etc. The quality function can be defined as:

$$U = u(x, y, z,...)$$

Mathematically, it is necessary to find the limits of this function. It is possible to find corresponding values of parameters x, y, z, from the equations:

$$\frac{\partial u}{\partial x} = 0, \frac{\partial u}{\partial y} = 0, \frac{\partial u}{\partial z} = 0$$

However, pure mathematics cannot yield a solution because quality indexes cannot be expressed algebraically as the majority of parameters change in quality from one alternative to another. The rationale of these equations is in the influence of each parameter to change quality indexes of the structure. Accordingly, in order to construct the first equation, an increase in the parameter $x = \pm\Delta x$ is made several times (at least three times) whilst maintaining the same values of $y \,\&\, z$ and monitoring the change in Δu until it changes in sign. This should correspond to the limit of the function U. The same procedure should be repeated for $\frac{\partial u}{\partial y} = 0$ and $\frac{\partial u}{\partial z} = 0$. These equations will have to be solved together to obtain the solution.

Practically, this rationale can be adopted in the following example (Troitsky, 1994):

1. A bridge system and material from the scheme design is chosen;
2. The remaining parameters, (such as foundation type, supports and span construction) are considered unknown and should be determined;

3. The parameter with the highest impact on the quality index, such as type of foundation (i.e. if not already defined by geological perquisites), should be chosen and changed whilst fixing the other parameters to obtain the first alternative;
4. The type of foundation is changed to obtain a second alternative and the two alternatives are compared. If the second alternative is better then a third one is investigated and compared to the second alternative. If the third alternative is worse then the second alternative is chosen;
5. The resulting alternative from point 4 is chosen and used to change another influential parameter such as span size by assuming a suitable size of the span whilst fixing other parameters to obtain the first alternative. The span is changed to obtain a second alternative and the two should be compared. If the second alternative is better a third alternative should be investigated as described in point (4);
6. The resulting alternative in point (5) is chosen and it is now required to determine a suitable construction system. Whilst changing the construction system the results are observed until the best construction system is reached in the manner explained before;
7. These stages are repeated for another scheme design (if available). Finally, the outcomes of both schemes are compared to arrive at the best one. The process is illustrated schematically in Figure 3.2.

The alternatives are compared considering technical and economical parameters in order to find the optimum solution for the local site conditions (Troitsky, 1999).

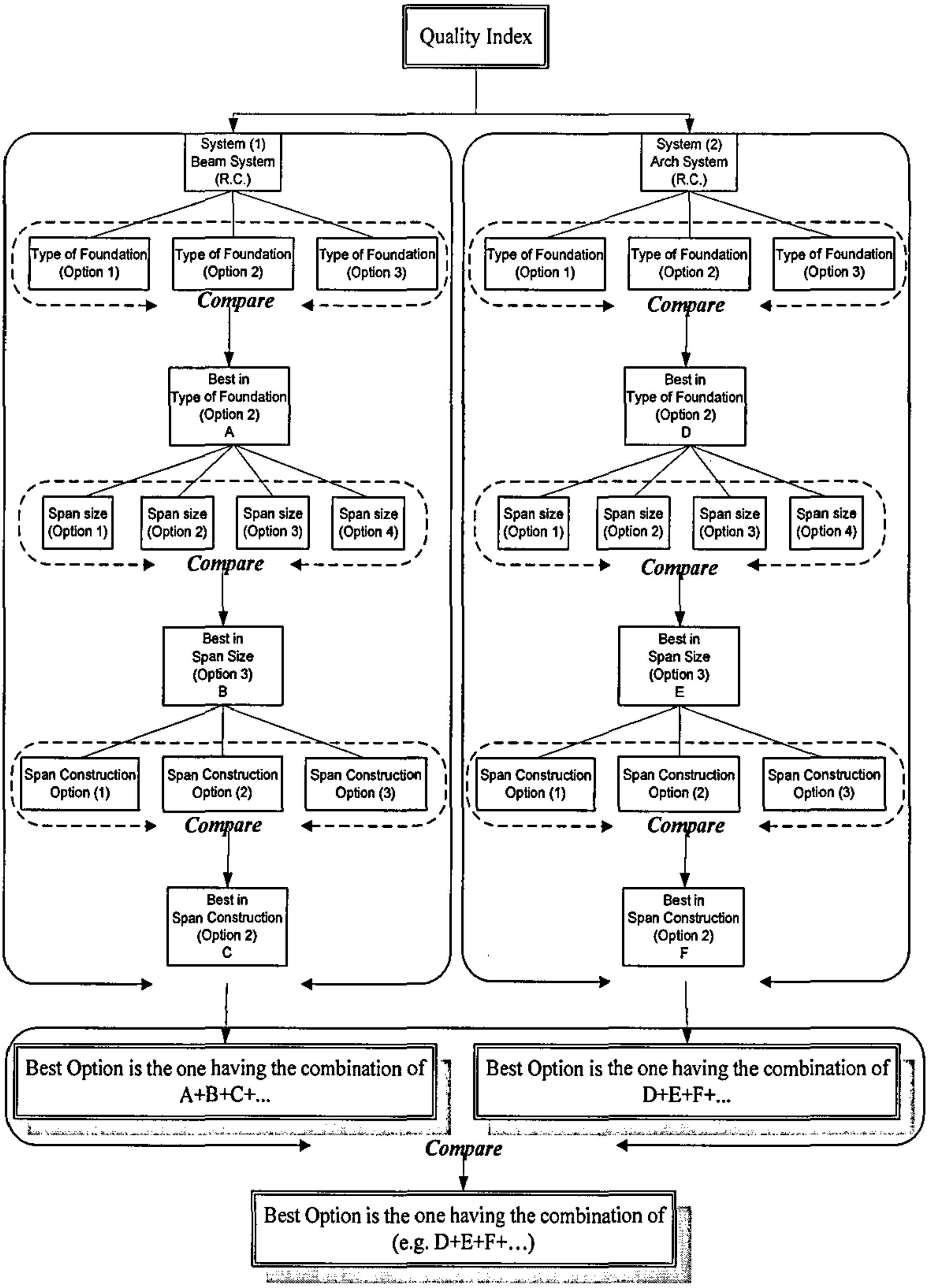


Figure 3.2: Methodology of preliminary design (Troitsky, 1994)

3.4.2 Structural Utility

The concept of structural utility can be traced back to Freudenthal (1961) and others. The main aim is to achieve optimal structural reliability by maximizing effectiveness expressed in terms of an objective function (utility function linear with money). The attempt to create such a function is illustrated by Liebenberg (1992) as follows:

$$
\begin{aligned}
\text{Structural Utility} &= B - C_t \\
&= B - (C_p + E_d) \\
&= B - (C_i + C_m) - \sum(S_m \times P_m) - \sum(U_n \times P_{n)})
\end{aligned}
$$

Where:

B = expected present value of the benefits resulting from the bridge existence

C_t = total capitalized costs

C_p = capitalized prime costs

E_d = expectation of damage

C_i = initial cost (including construction cost)

C_m = capitalized normal maintenance costs

S_m = capitalized cost of damage due to noncompliance with serviceability criteria

p_m = probability of exceeding a serviceability limit state

$\sum p_m s_m$ = risk of exceeding a serviceability limit state

U_n = captialised cost of reaching an ultimate limit state

P_n = probability of reaching an ultimate limit state

$\sum p_n U_n$ = risk of reaching an ultimate limit state

The preliminary design process starts by studying the brief and compiling few schemes. These schemes are compared together in order to select one scheme. This is followed by selecting the construction material and assuming member sizes. If the design fulfils the requirements of serviceability and strength, the material is changed to obtain m number of alternatives. The structural system is also changed to obtain n number of alternatives. If the alternative does not fulfil the requirements of serviceability and strength then member sizes should be changed. The structural utility for $m \times n$ alternatives is assessed in order to arrive at the optimal design. This process is illustrated in Figure 3.3.

3.4.3 Discussion

There are some shortcomings in the quality index and utility function. Troitsky (1994), states that theoretically changing one parameter in the quality index may change the others as well. For example, if the type of construction of the span raises doubts about the correct choice of the span size, it is necessary to determine span size again using the new type of construction. Accordingly, checking should be continued by the method of successive approximations. This error is possible because the initial values of the parameters are not arbitrary but based on practice. In that sense the order of investigating parameters should go from the most important to the least important in order to decrease chances of error.

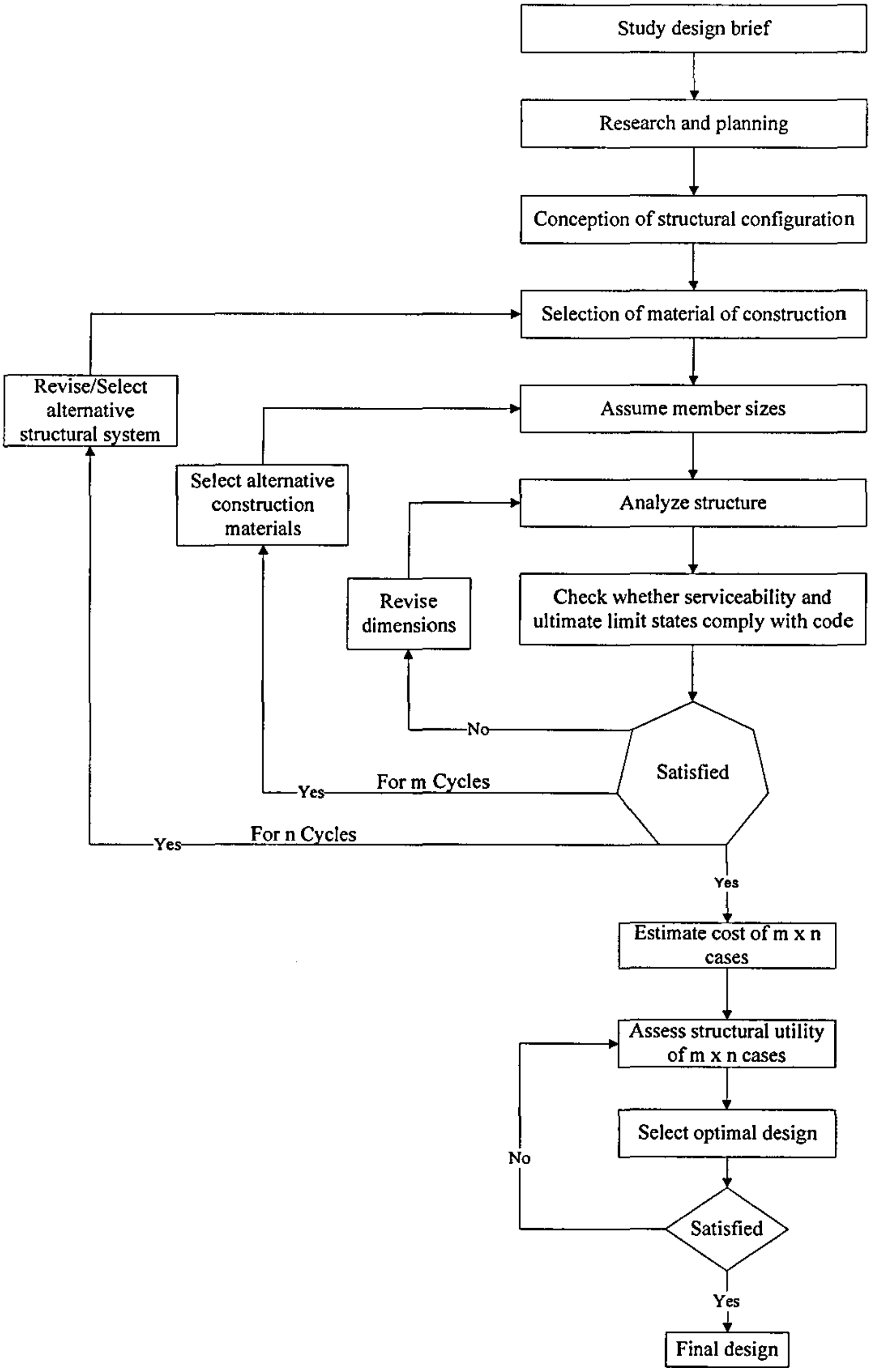


Figure 3.3: Bridge structural design process (Liebenberg, 1992)

On the other hand, Liebenberg (1992) states that the utility equation contains values that are difficult to quantify due to their subjective nature. Furthermore, both methods do not provide an integrative view in choosing alternatives. Accordingly it is extremely difficult to investigate the sensitivity of the alternatives to the criteria. Liebenberg (1992) highlighted that it is important to develop tools that would rationalize this decision making process and help in assessing both subjective and objective criteria. Traditionally, the inability to quantify and integrate both subjective and objective criteria has led practitioners to emphasize quantifiable criteria with less attention to subjective criteria (Lopes and Flavell, 1998).

Acknowledging this problem, Raina (1991) and Pritchard (1992), proposed using a weighted average method to evaluate design proposals. The mulicriteria approach is promising although this particular method has inherited problems and may produce misleading results, as indicated by Vincke (1992).

The preliminary design problem may be decomposed as illustrated in Figure 3.4. The extent to which a proposed design is buildable, durable, maintainable, aesthetically pleasing and cost effective are considered part of the measures that determine its effectiveness. Buildability examines some of the issues related to the bridge development process including the choice of the construction method and will be discussed in the next section.

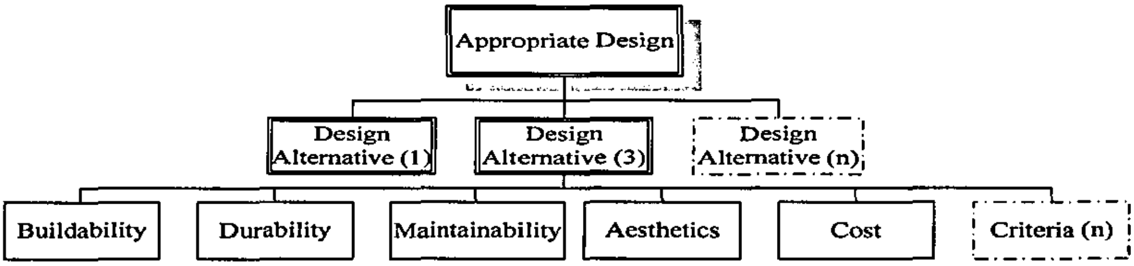


Figure 3.4: Proposed decomposition of preliminary design

3.5 BUILDABILITY

The importance of the early phases in project development is widely recognised. Kolltveit and Gr0nhaug (2004) illustrate that this importance stems from the fact that most of the technical concepts are developed during this phase. In terms of functionality, any mistakes will be present for the life of the project and possibly for the life of the structure (Jump, 1992). In terms of cost, it has the highest impact on the total cost as indicated by Evbuomwan and Anumba (1996), Bishop (1996) and Paulson (1995). Figure 3.5 illustrates that the ability to influence project cost diminishes as one goes along a project's life cycle.

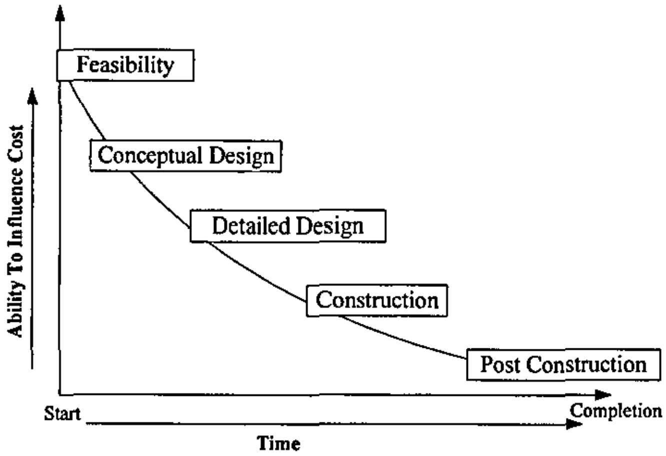


Figure 3.5: Ability to influence cost with time during different phases of bridge projects (Griffith and Sidwell, 1997)

The impact of integrating both design and construction as early as possible can be traced back to Banwell (1964) who acknowledged that under traditional contracts the contractor is normally absent from the design stage whereas his/her expertise and knowledge are valuable. This view has been further asserted by Tatum (1987), Eldin (1988), and CIRIA (1996) who illustrate that the early consideration of construction knowledge is undoubtedly crucial to achieve bridge projects objectives, such as cost minimization, timely completion and ease of construction. The process of integrating construction knowledge in the design process is referred to as "Buildability" and can be defined as "the extent to which the design of a project facilitates ease of construction, allowing the most efficient and economic use of resources, subject to the overall requirements for the completed project" (CIRIA, 1996) and (ICE, 1995). In the USA another term is used: "Constructability", which addresses wider issues during conceptual planning, engineering and procurement, and field operation (Tatum, 1987).

CIRIA (1996) identifies a number of issues that affect buildability in bridges, which should be taken into consideration during early design: health and safety, site investigation, integral construction, bridge geometry, standardisation of details, aesthetics, innovation, existing structures, traffic management, tolerances, and applications and method of construction. Designers must address safety issues resulting from the construction process such as the provision of safe accesses. The accuracy of geotechnical information is important to minimize changes in design, as well as construction, after starting the construction process. The integration of the structure decreases the number of joints thus improving durability and maintainability of the bridge. Simplicity is of essence in bridge geometry where unnecessary curves, skews, variations in super-elevation and non-uniform concrete shapes should be avoided. Despite apparent savings in material due to the latter reason, the cost of construction may increase. Standardisation of details and preassembly of structural elements are important aspects in decreasing cost and improving quality. Aesthetics is an important factor and emphasis is placed on the importance of incorporating any architectural features with the structure. Constraints dictated by neighbouring structures must be catered for during design. Traffic management requirements are important as they affect the public and they may impose constraints on the construction methods used. Tolerances in construction should be reasonably set and clearly defined in order to eliminate possible conflicts between the constructor and the Engineer. A viable construction method is an integral part of any bridge design. The designer should assume the construction method, as well as its sequence and illustrate them on drawings. He/she should also state any special constraints that would be imposed on the use of any alternative construction method.

Unlike many structures, bridges cannot be designed until the construction system has been selected (Gab-Allah, 1983). This is especially true for the foundations and superstructure. In bridge projects, design normally proceeds on the basis of a particular construction method. The need for cohesion between construction method and design of the superstructure is reflected in the following facts:

1. There are a number of instances, as in the case of free cantilever method, where the design is radically affected by construction stages. For example, the arrangement of prestressed cables is designed to cater for the cantilever behaviour of the structure during construction as well as continuity under service load.
2. Construction methods may apply temporary loads on the bridge superstructure due to their constituent components and any construction equipment. These loads are normally considerable (i.e. around 200 metric tons in the case of advancing shoring system) and this needs to be taken into consideration during design.

3. Construction methods affect the initial bridge cost; in some instances it was observed that the cost of procuring some of these systems in Egypt (i.e. excluding manpower and operation) was around 13% of the total bridge construction cost.
4. Some of the systems may require modification of the permanent structure. In the advancing shoring system where support brackets are necessary, two recesses in bridge columns of considerable size have to be incorporated and the design should take account of that. Some types of launching girder system require enough area above the piers to support trusses. CIRIA (1996) illustrates an example where permanent foundations are extended to accommodate temporary falsework. Tatum (1987) highlights that its effect on the project plans and site layout is significant.
5. Anderson *et al* (1999) state that under the traditional contract procedures, the design is usually completely finished by the time the contractor enters the project.

The importance of fusing construction methods to the design process of bridges is also emphasized by many including: Liebenberg (1992), Troitsky (1994), Raina (1991), Duan (2003) and Pritchard (1992). The cohesion between design and construction is important and in many cases, as seen above, is mandatory. The next section discusses methods used in the construction of the superstructure of concrete bridges.

3.6 CONCRETE BRIDGE SUPERSTRUCTURE CONSTRUCTION METHODS

3.6.1 Introduction

Liebenberg (1992) suggests that concrete bridges can be classified in terms of the materials used in construction, functional purposes, primary structural system, and method of construction. The materials used in construction are reinforced concrete, prestressed concrete, or composite. The functional purposes of bridges can be classified in terms of type of traffic (e.g. class of highway, railway, airport runway and cycle or pedestrian), the type of pipeline or conveyor and the nature of obstacle to be crossed (e.g. rivers, roadways, railway lines and deep gorges). Despite numerous variations in bridge structural systems they can be broadly classified into four main groups in terms of their primary structural system as follows:

A- Slabs, grids, beams, girders, cantilevers and frames at which bending, torsion and shear forces predominate;

B- Trusses and related types at which either compressive or tensile forces predominate;

C- Arches and related types where compressive forces predominate;

D- Cable-suspended structures, cable stayed and suspended bridges at which the tensile cables (i.e. linked to pylons) work together with the deck structural system to form the main supporting system.

Another type of classification is according to the construction method used and is explained in the following sections.

3.6.2 Classification of Concrete Bridge Superstructure Construction Systems

There is a wide range of methods used for the construction of the superstructure of concrete bridges. As new materials, equipment and ideas are developed, construction techniques become more and more varied. Tang (1984) illustrates that these methods include: using falsework in construction, free cantilever construction, span wise construction, and incremental launching. Raina (1988) adds crane erection, jacking or counter weighting and cable erection. However, Liebenberg (1992) adopts a comprehensive generic classification in which these systems are classified into four broad categories: on centering systems, horizontal incremental launching, cantilevering from previous sections, and vertical hoisting, lifting, and jacking. However, it is important to add another category to cater for other combinations (i.e. custom systems). Cast in-situ concrete, precast concrete, or a combination may be used depending on the system used. Reinforced concrete, prestressed concrete or composite concrete may also be used depending on the technique utilised. The synthesis of these views is illustrated in Figure 3.6.

On centering systems are mainly composed of stationary systems and travelling systems. In stationary systems the system is dismantled after finishing and transported to the next span. Proprietary standardized steel or aluminium sections are generally used. On the other hand, travelling systems roll over on the ground or over brackets fixed to bridge piers where no or limited dismantling is required. Both systems are either supported directly on the ground, bridge piers or brackets. Examples of these systems are advancing shoring system for cast in-situ concrete and launching girders systems. In the incremental launching method the bridge is constructed in segments and then pushed forward into position. In the free cantilever method the bridge is constructed in segments where every segment is supported on the previously finished one. This method is used for prestressed concrete, either cast in-situ or precast. In hoisting or lifting, cranes are used to place the superstructure in position. Heavy lifting using hydraulic jacks is also a possible solution. Custom systems refer to instances where combinations of the aforementioned methods are used. These include other innovative techniques that cannot be categorized under any of the conventional methods.

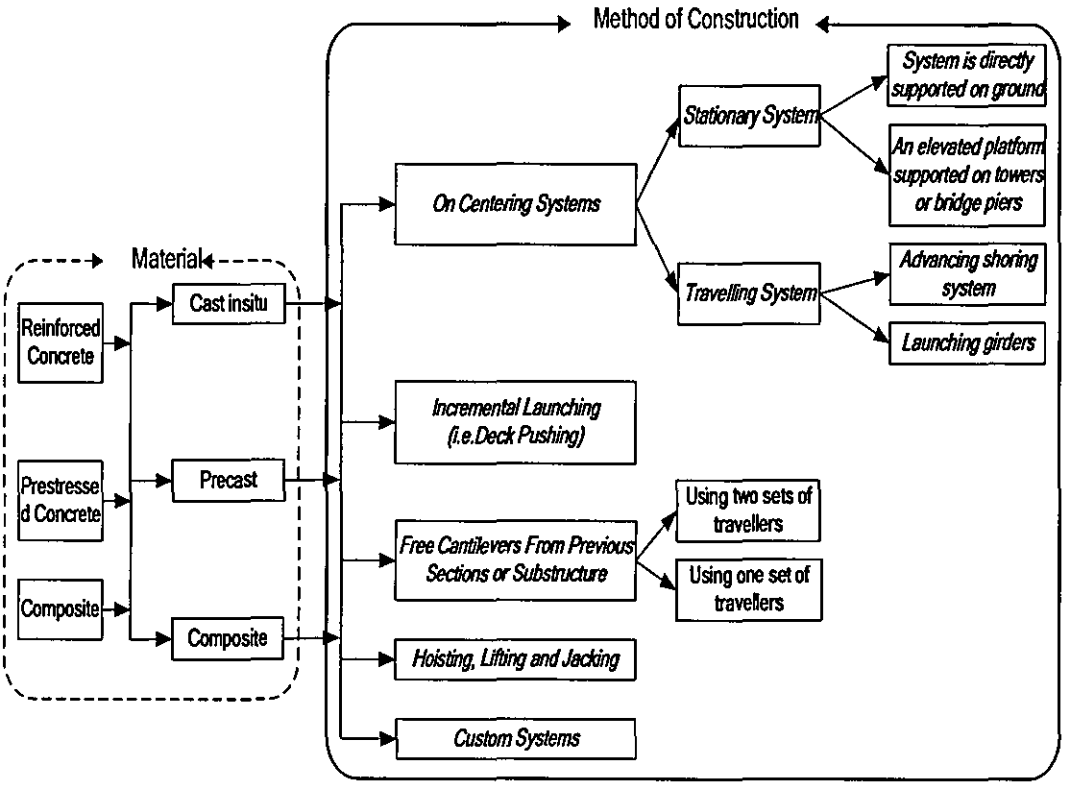


Figure 3.6: Classification of bridge construction methods

Basha and Gab-Allah (1991) state that the construction methods used in Egypt are: precast concrete girders erected using launching girders, incremental launching, cast in place free cantilever, precast segmental free cantilever, precast segmental on falsework, cast-in-place reinforced or prestressed concrete on falsework.

The knowledge acquired in this research suggests that precast segmental free cantilever and precast segmental on falsework have yet to be used in Egypt. The authors may have included the first because of the New Benha Bridge that was intended to be constructed using this technique but was finally constructed using cast in-situ cantilever construction.

Based on the findings of this research, construction methods used in Egypt can be summarized as follows: stationary systems either directly supported on the ground with full occupancy of the ground or by creating an elevated platform with no or limited occupancy of the ground; advancing shoring system; erecting precast prestressed beams using launching trusses, heavy lifting or cranes; horizontal incremental launching; cast in-situ free cantilever construction using two travellers; cast in-situ free cantilever construction using one traveller and stationary formwork on the other side. These methods are also illustrated in Figure 3.6. It should be noted that some of these methods may have been used slightly differently in Egypt. However, this variation occurs in some of the details and does not affect the overall concept. The mentioned details are the most commonly used in Egypt.

The choice of a suitable system among those mentioned above for a given design is the focus of this research, hence they are discussed below. Each method is described with respect to three main dimensions: main components, scope of application and characteristics, and construction sequence.

3.6.3 Stationary System Supported on Ground

This system normally requires full occupancy of the ground. It is the most commonly used method in Egypt and throughout the world. In the early days, timber was the main material used in construction. Nowadays, it is used for formwork only, whilst rarely, as in the case of very small bridges as illustrated by Gaballah (1983), as falsework for bridges' superstructure.

3.6.3.1 Main Components

The trend now is to use proprietary standardized elements for falsework, formwork and scaffolds. Although many systems have been used including, PERI and ACROW, the latter remains the most commonly used in Egypt. The main components of which are shorebraces, bracings, props, tilt up shores, U-Forms, wedges, steel angles, etc. It may be possible to combine one system of falsework with another of formwork as in Suez Canal Bridge, East Portion where the ACROW system was used for falsework while the Peri system was used for formwork. Figure 3.7 illustrates some of the elements used in falsework while Figure 3.8 illustrates it in use.

3.6.3.2 Scope of application and characteristics

Bridge physical characteristics

This method can accommodate any deck curvature and most cross sectional shapes including box section, slabs, slab and beams. It can be used for any type of concrete and fits well with complicated configurations (Tang, 1984). It is preferred in moderate heights above ground of around 10m (Liebenberg, 1992). It has been used for span lengths of up to 300m according to Liebenberg (1992), although it is more effective for short spans (Tang, 1984).

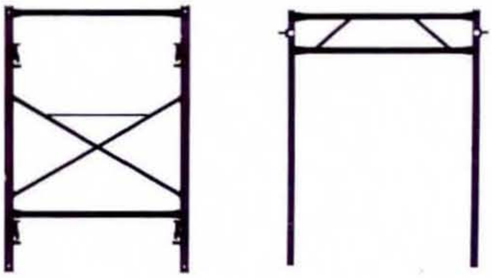


Figure 3.7: Main Shorebrace elements used in ACROW system (ACROW Misr, 1995)

Figure 3.8: ACROW system used in Construction (ACROW Misr, 1995)

Surrounding environment and site conditions

This method requires full accessibility to ground to allow system erection and dismantling. There should not be any obstacles on the ground to hinder system erection, and the ground should be able to sustain loads transmitted by falsework and without much variation in level. Cranes are generally used to help during erection. This method may not be preferred in crowded areas.

Construction method characteristics

It takes relatively more time per span when compared with other methods due to its dependence on labour although it does not require skilled labourers (Liebenberg, 1992). There are almost no loads generated by this method that would affect the design of the permanent structure. It is durable and suitable for reuse, if made of steel or aluminium. Deflection occurs due to strains in system elements and soil settlement and this should be calculated with sufficient accuracy to prevent cracks resulting in the fresh concrete. The cost is relatively small, especially if used in many projects.

3.6.3.3 Construction Sequence

Firstly, the ground should be prepared to accommodate loads, usually using concrete blinding or by simply placing timber under shorebraces legs. Some clearing, grubbing and levelling may be required as well. Falsework is normally constructed in small towers constituted by the proprietary system elements and connected together using pipes, connectors and cross bracings. Normally the final element in the falsework is used to adjust the levels of the formwork. The levels should be adjusted to cater for the deflections that will occur due to the soil and falsework (i.e. by creating camber). Normally timber is placed over shorebrace elements so as to provide support for the formwork. After erecting formwork, steel reinforcement and prestressed cables (if used) are fixed. In the case of box sections which are commonly used in Egypt, it is normally concreted in two stages, bottom slab and webs then top slab. After striking the inner formwork for webs, the falsework and formwork for the top slab are erected and steel reinforcement and prestressed cables (i.e. if used) are fixed before concreting takes place. After concrete gains the required strength, the system is dismantled and transported to another span and the same cycle is repeated, as illustrated in Figure 3.9.

Figure 3.9: Falsework components during striking (The Arab Contractors, 2000)

3.6.4 Stationary System Using An Elevated Platform

In this method an elevated platform is created and supported either on Bailey towers, with limited occupancy of the ground, or on brackets attached to bridge piers. The platform may be totally assembled on the ground and then lifted into position or assembled in position.

3.6.4.1 Main Components

The main components used in this method are pier brackets or Bailey units, steel beams, falsework, and formwork. Bailey units were developed by Sir. Donald Bailey during World War II and were used successfully to construct temporary bridges in order to enable machinery and troops to cross obstacles (Harpur, 1991). This system is widely used in Egypt, and the elementary unit used is illustrated in Figure 3.10.

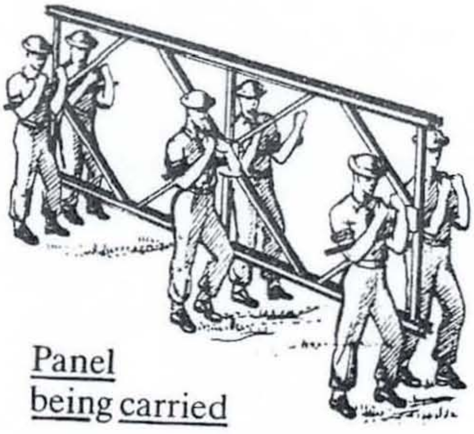


Figure 3.10: Typical Bailey panel being carried (Harpur, 1991)

3.6.4.2 Scope of application and characteristics

Bridge Physical Characteristics

This method is used for any deck cross section and for any curvature. It can be used for any span length provided that intermediate Bailey towers are provided every 20-25m, and can be used for heights of up to 25m and for any type of concrete.

Surrounding environment and site conditions

This method requires access so as to allow system erection and dismantling. It can be used to cross obstacles of limited width such as railway lines, roads, small canals, etc. Ground conditions should be able to sustain loads transmitted by Bailey units, otherwise temporary footings may be required. It can accommodate variations in the ground topography. This method generally results in less interference with the public compared with the previous one.

Construction method characteristics

This method does not create considerable loads that would affect the permanent structure, except in the case of brackets. It requires skilled labourers for assembly on the ground and cranes to erect them. Their low cost enables most contractors to adopt them in different projects, although brackets may be expensive due to the cost of manufacturing. They are generally durable and suitable for reuse several times. The time required for construction is less compared with the previous method.

3.6.4.3 Construction Sequence

The construction sequence depends on the method used. In the case where Bailey panels are used to create an elevated platform, the units are assembled in a horizontal or vertical fashion, as required. There are special pins and angles to connect panels together, and the arrangement of the assembled panels depends on the straining actions resulting from loads transmitted by the falsework and formwork. The analysis of the loads is done in conjunction with the design manual offered by Sir Donald Bailey, which illustrates the proper arrangement of units to resist applied loads. Figure 3.11 shows a horizontal application of the Bailey panels. They were used to cross a small waterway. Two small strip footings were constructed to support the Bailey panels. The formwork and falsework are supported on the Bailey panels.

Figure 3.12 illustrates the Bailey panels arranged in a vertical manner at which they are supported on the foundations of the permanent structure.

Figure 3.11: Horizontal application of Bailey panels (The Arab Contractors, 2004)

Figure 3.12: Vertical application of Bailey panels (The Arab Contractors, 1991)

3.6.5 Cantilever Construction by In-situ Concreting Using Two Form Travellers (Concreting Carriages)

In this method the superstructure is constructed in segments using two form travellers one at each end of the bridge superstructure.

3.6.5.1 Main Components

The form travellers consist of formwork suspended from a steel frame and carried by the portion of the deck already built (Mathivat, 1979). The steel frames are connected together using two transversal beams (i.e. front and rear mirrors). They may be located under or over the bridge top flange, although the latter is more commonly used in Egypt. The formwork of top slab, bottom slab and access platforms are suspended by the transversal beams using high strength tensile bars, as illustrated in Figure 3.13. Auxiliary bridges may also be used to provide access between cantilevers and temporary intermediate supports may also be used to limit cantilever moments. The travellers are fixed at the rear by means of high strength tensile bars. The main components of the most commonly used form travellers in Egypt are illustrated in Figures 3.13, 3.14 and 3.15.

3.6.5.2 Scope of application and characteristics

Bridge physical characteristics

The box section is used widely in cantilever construction, except in rare circumstances, as indicated by (Mathivat, 1979). This method may accommodate limited horizontal curvature depending on the deck's radius of curvature and segment length. It can be used for any height of the superstructure above ground provided that it satisfies the minimum clearance required for erecting form travellers.

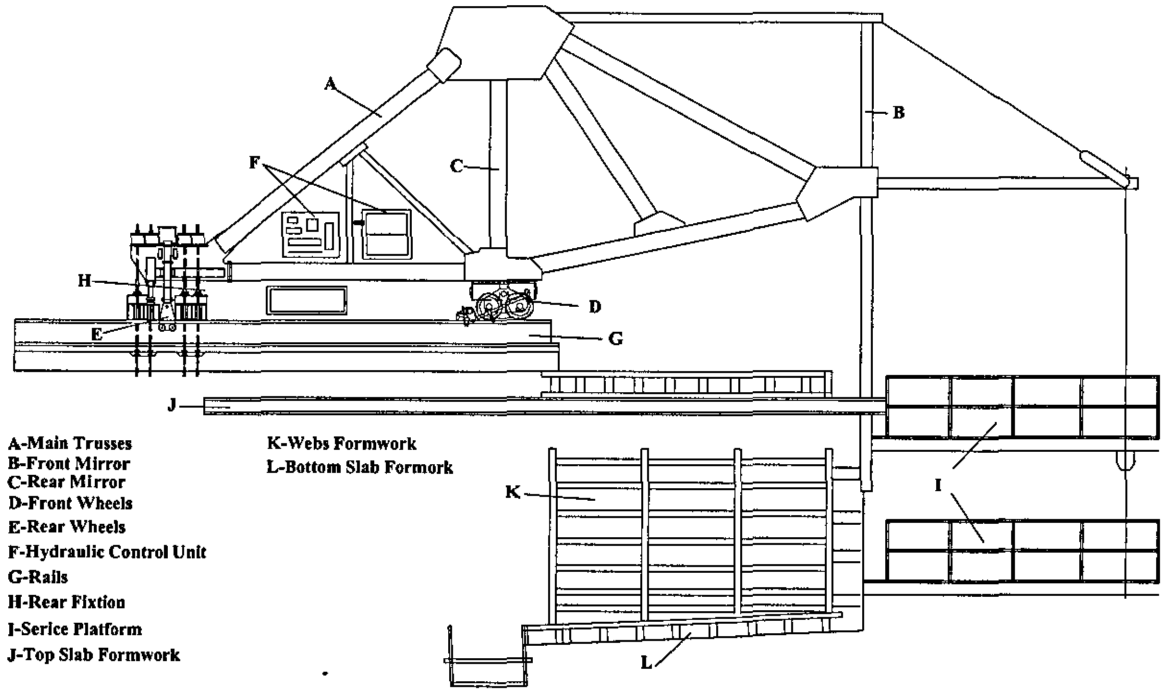


Figure 3.13: Longitudinal section showing components of form traveller (The Arab Contractors Bridge Manual, 1996a)

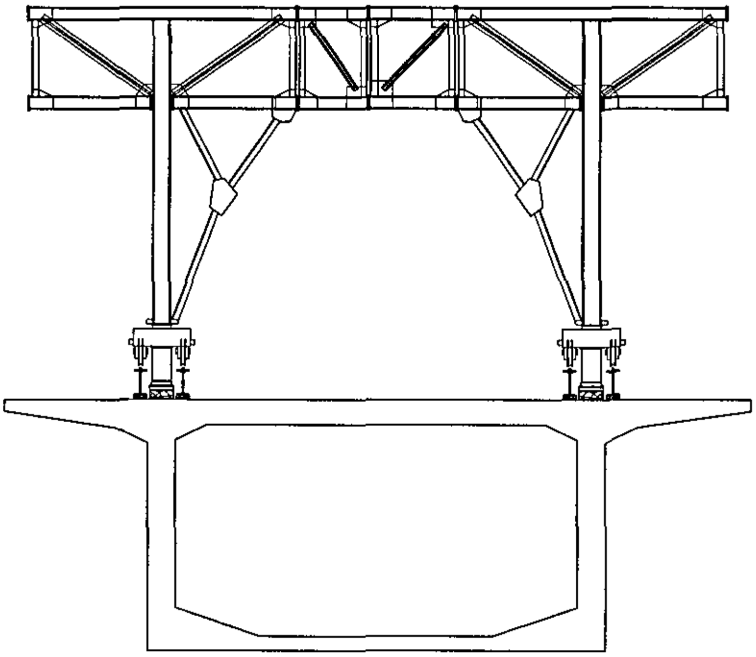


Figure 3.14: Front Mirror (The Arab Contractors Bridge Manual, 1996a)

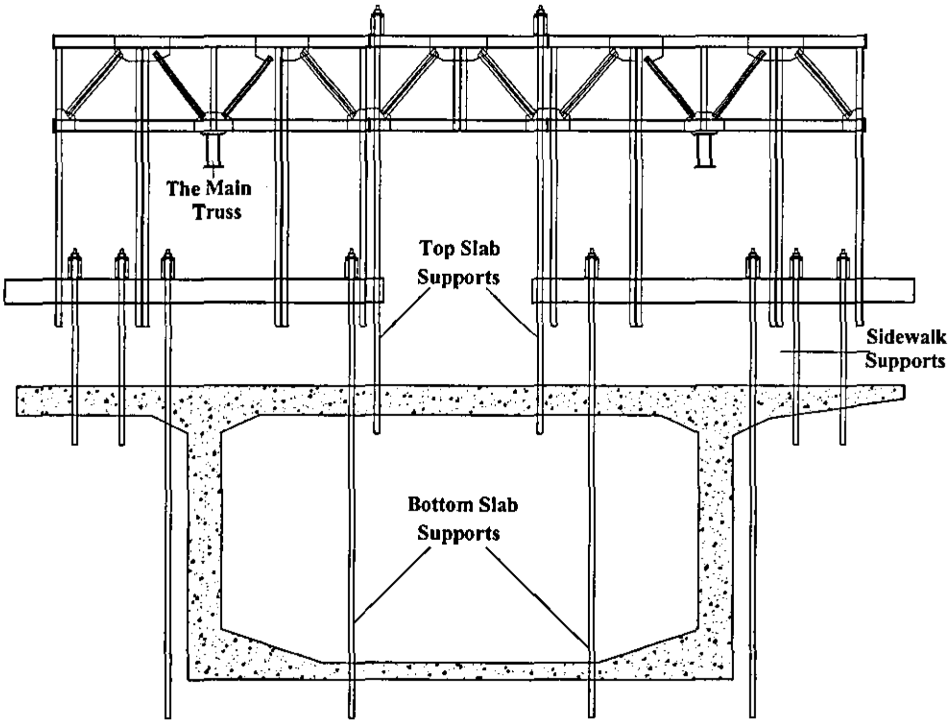


Figure 3.15: Rear mirror (The Arab Contractors Bridge manual, 1996a)

The span length can be up to 240m and it is optimally used for spans ranging between 50-150m as indicated by Mathivat (1979). It is used for prestressed concrete precast or cast in-situ and the latter type has been used in Egypt.

Surrounding environment and site conditions

This method is used mainly when there are obstacles on the ground. It has been used successfully in many bridges over the Nile in Egypt. It can be used regardless of the ground condition. Cranes are required to erect and dismantle form travellers and during operation.

Construction method characteristics

The bridge is executed in segments, as illustrated earlier. The length of each segment usually ranges between 3-5m (Liebnberg, 1992). The system is integral, in the sense that it requires limited help from other equipment except for handling construction material, erection and dismantling. This method can be classified as machine intensive, thus it is relatively expensive and requires high initial investment. The travellers can be used several times for similar jobs after modification. The precision required in this method mandates using highly skilled labour. It is obvious that the construction stages have a direct bearing on design.

3.6.5.3 Common Construction Sequence

Construction starts from bridge piers to the cantilever ends as follows:

1. Stage (1); the first section of the bridge superstructure is constructed, usually called stump or springing according to Mathivat (1979), denoted by 0 as illustrated in Figure 3.16. The length of the stump usually ranges between 10m and 15m and there are a number of methods used in constructing stump such as:

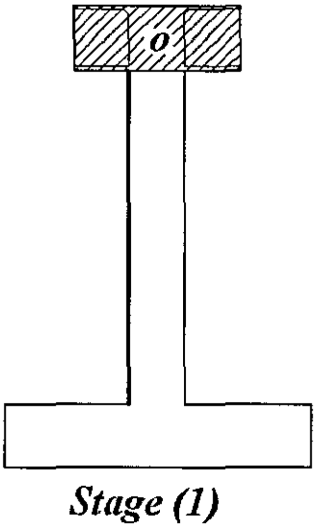


Figure 3.16: Constructing the stump (Mathivat, 1979)

A- Using stationary falsework and formwork as illustrated in Section 3.6.3

B- Bailey panels may be used to support falsework and formwork. They are supported on the pilecap as illustrated earlier in Figures 3.12 and now in Figure 3.17.

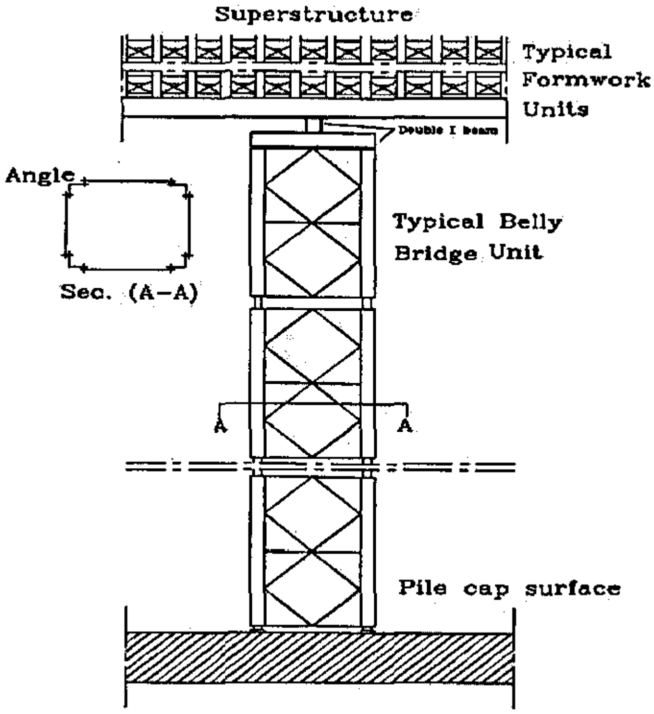


Figure 3.17: Bailey Panels Used in the Construction of the Stump (The Arab Contractors, 1991)

C- Steel brackets may be fixed to bridge piers to provide support to the falsework and formwork of the stump as illustrated in Figure 3.18

D- In some instances temporary foundations on a limited number of piles may be used so as to act as supports to Bailey panels.

Figure 3.18: Finished Stump Using Steel Brackets (The Arab Contractors, 1996a)

2. The form travellers are erected on both sides of the stump and moved progressively. Steel reinforcement and prestressing ducts are installed for each segment. The segment is concreted and after concrete gains the required strength prestressing cables are stressed and the form travellers move to stage (3). As construction proceeds, the continuity cables are inserted progressively and stressed across segments. The work proceeds symmetrically from both ends of the cantilever to ensure balance as illustrated in Figure 3.19. In instances where the superstructure is not symmetrical, segment lengths may vary to control balancing moments, otherwise temporary supports are used. The process is repeated until both cantilevers finish.

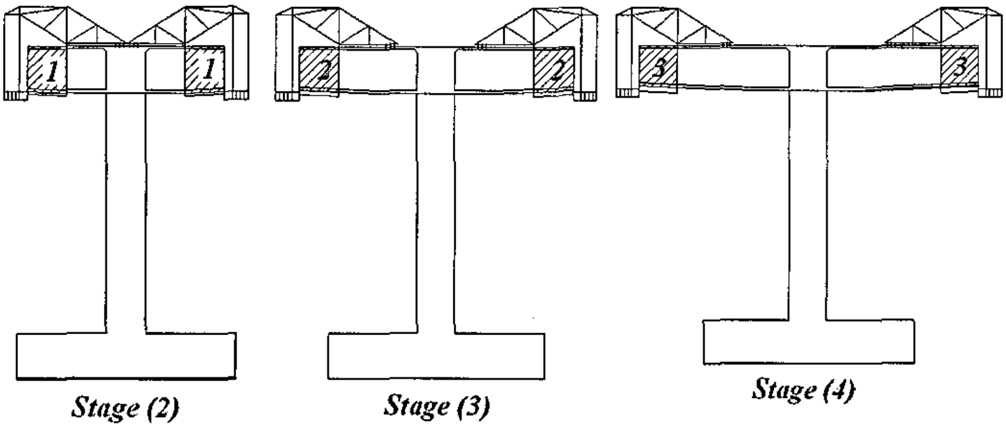


Figure 3.19: Stages 2, 3 and 4 (Mathivat, 1979)

3. One of the two form travellers is dismantled and the other one advances to support the central gap at mid span. Steel reinforcement and prestressing ducts for the bottom slab are installed and then concreting takes place. The prestressing cables in the bottom slab should be stressed in order to cater for continuity stresses and the remaining form traveller is removed from the bridge. Figure 3.20 illustrates the central gap.

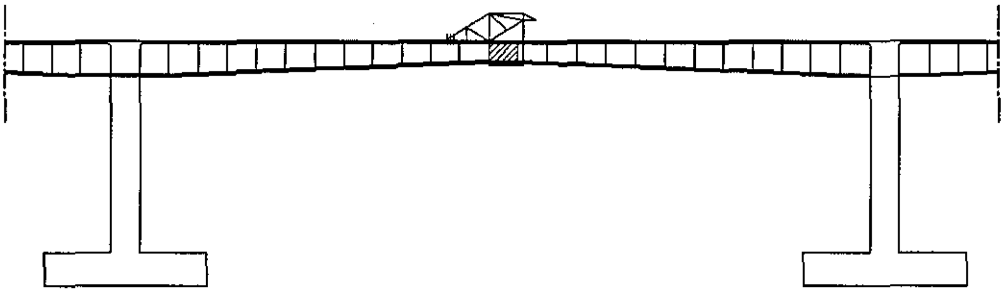


Figure 3.20: Constructing the Central Gap of the Superstructure (Mathivat, 1979)

4. There are two important issues that should be highlighted;

   A- Careful consideration for camber calculations is required in order to ensure that the two sides of the superstructure and central gap match. The contractor must also observe any differences during construction and report it to the designer so that calculations can be adjusted.

B- The Superstructure must be fixed to bridge piers during construction. If not, temporary fixation is required as illustrated in Figure 3.21. This connection can be removed after finishing the central gap.

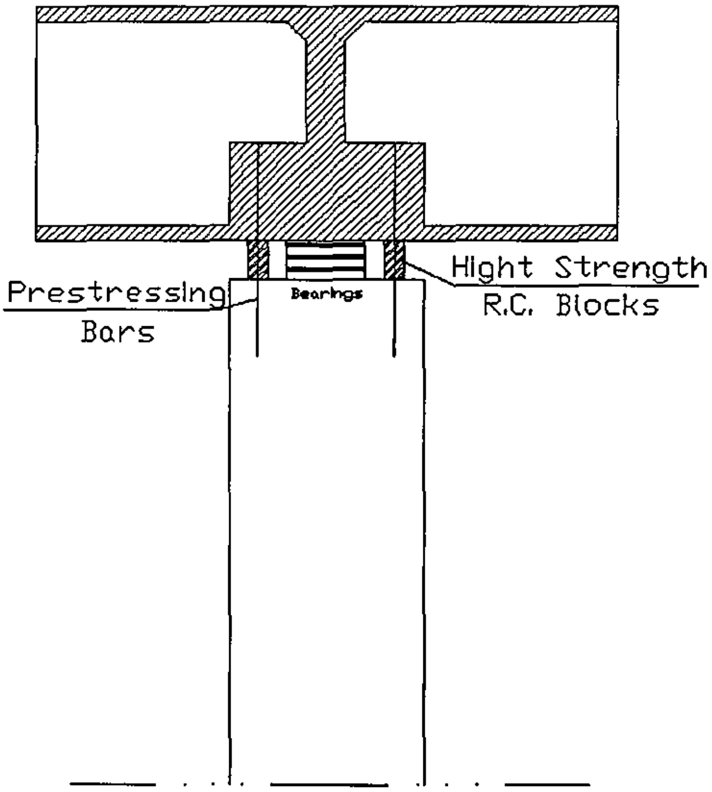


Figure 3.21: Temporary fixation of the stump (The Arab Contractors, 1996a)

3.6.6 Cantilever Construction by In-situ Concreting Using One Form Traveller and Stationary System

It may be possible in some instances to use only one traveller and stationary formwork if the ground conditions are favourable in order to reduce cost or to overcome limited resources.

3.6.6.1 Main components

The main components in this method are one form traveller, as illustrated in Section 3.6.5.1, and stationary system, as in Sections 3.6.4.1 and 3.6.3.1. Concrete blocks are normally used to balance the weight of the form traveller on the other side.

3.6.6.2 Scope of application and characteristics

Bridge physical characteristics

This is as discussed in Section 3.6.5.2 but taking into consideration that the height above ground complies with the requirements outlined in Sections 3.6.4.2 and 3.6.3.2.

Surrounding environment and site conditions

It is generally used in instances where one part of the structure is over water while the other is over ground. The part using form travellers should comply with Section 3.6.5.2 while the part over ground should comply with the requirements outlined in Sections 3.6.4.2 and 3.6.3.2 for stationary systems.

Construction method characteristics

The characteristics of the part using a form traveller are presented in Section 3.6.5.2 while the characteristics of the part using a stationary system are discussed in Sections 3.6.4.2 and 3.6.3.2. The method requires efficient synchronized work in the movement of the form travellers and concrete blocks.

3.6.6.3 Common Construction Sequence

The construction stages involved in this method are as follows:

1. The stump is constructed using one of the methods described in Section 3.6.5.3.
2. After constructing the stump the form traveller is erected at the same time with stationary falsework on the other side.
3. In order to counter balance the effect of the loads resulting from the form traveller's weight, a number of concrete blocks are placed on the previously finished section of the superstructure, as illustrated in Figure 3.22. The blocks are mounted on steel I-Beams on the top slab. The number and arrangement of the blocks should be determined by the designer.

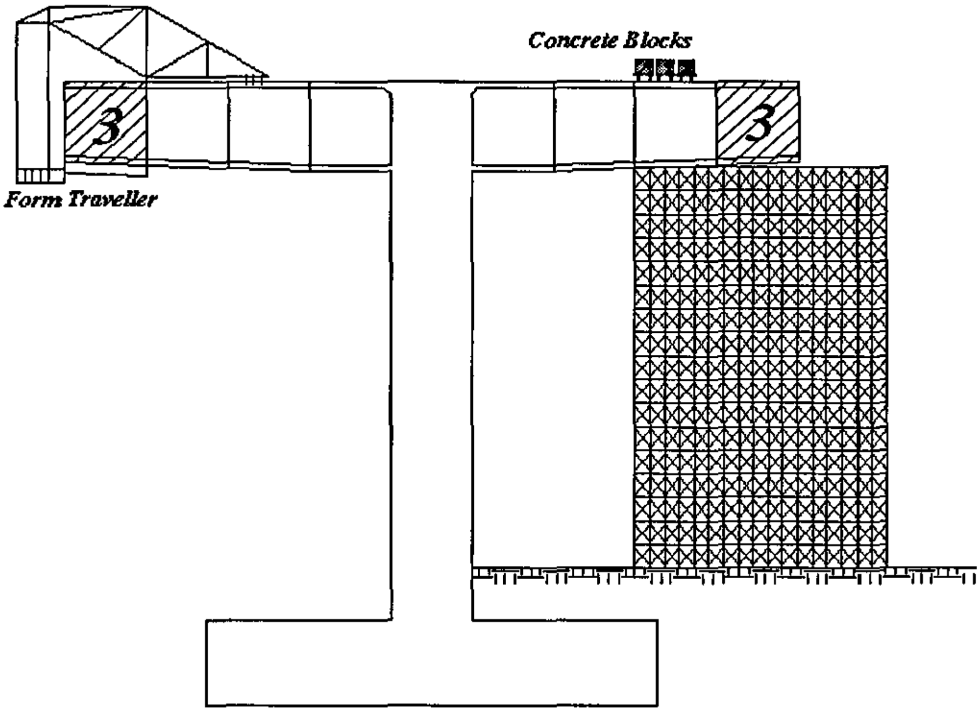


Figure 3.22: Using one form traveller and a stationary system (Dar Al-Handasah, 1990)

As the form traveller moves forward to the next position, the concrete blocks are transported to the next section on the other side of the cantilever. Figure 3.23 illustrates this method during operation.

Figure 3.23: Using stationary system to construct one of the cantilevers ends

(The Arab Contractors, 1991)

3.6.7 Advancing Shoring System

3.6.7.1 *Main Components*

This system is progressive and is supported on brackets fixed to bridge piers. The main components of the system are two main trusses, either above or below the superstructure, two brackets and a system of formwork as illustrated in Figure 3.24.

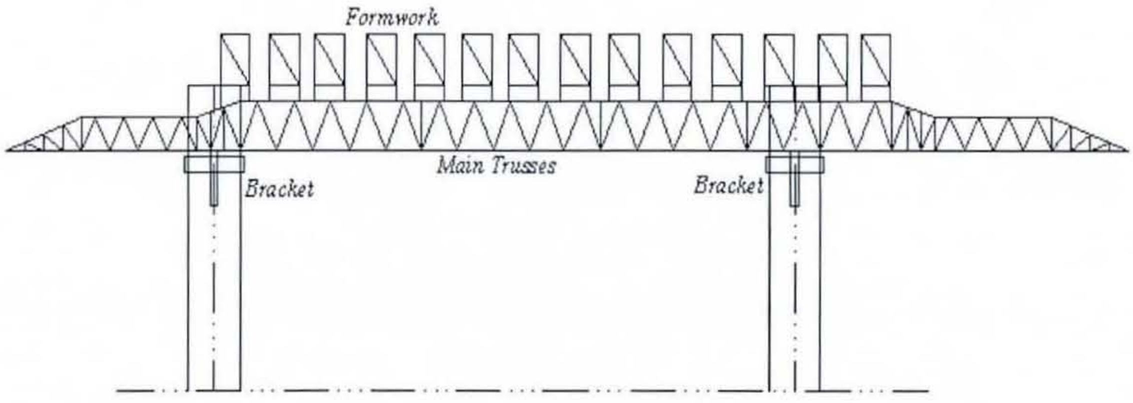


Figure 3.24: Components of advancing shoring system (Thyssen, 1999)

3.6.7.2 Scope of application and characteristics

Bridge physical characteristics

This system can be used for a box section (this is commonly associated with this method in Egypt) and for beam and slab cross sections. It can be used for any height, provided that there is enough space for system components, except in the case of using cranes to erect brackets at each span. It is normally used for 40m spans (Liebenberg, 1992). Mathivat (1979) extends this range to 85m. This method requires straight alignment although it may cater for small horizontal curvatures in the deck (Liebenberg, 1992). It is normally used for cast in-situ prestressed concrete.

Surrounding environment and site conditions

The superstructure is constructed irrespective of the ground conditions so obstacles are of little effect on construction except during erection and dismantling where cranes are required. Work is mostly done on the superstructure with little interference with the public.

Construction method characteristics

This method is characterised as machine-intensive, thus its initial capital cost is high and requires skilled labour for operation. The system may be reused after modification for similar projects. Bridge design should take into account the effect of brackets on piers and the effect of supporting the whole system on the superstructure as will be seen later. The system is designed with minimum weight so deflection considerations during concreting are very important, otherwise cracks may appear at the construction joint.

3.6.7.3 Construction Sequence

Construction stages involved in this method are as follows:

1. The system is assembled on the ground and then lifted into position. Recesses should be shaped in bridge piers in order to erect brackets. The system is illustrated in Figure 3.25.

Figure 3.25: The system lifted into position using cranes (The Arab Contractors, 2000)

2. Construction is done in stages, where each stage ends at the point of zero bending moment. Figure 3.26 illustrates an example of the sequence of these

stages.

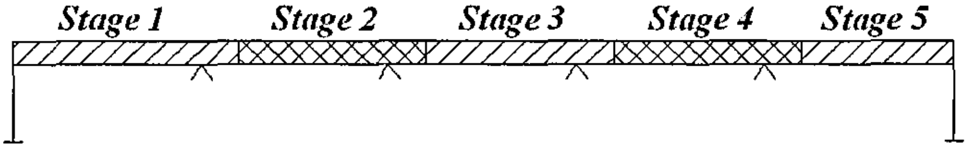


Figure 3.26: Stages of construction (Liebenberg, 1992)

3. The construction of a typical stage starts by lowering formwork to free it from the bottom slab and webs. Figure 3.27 illustrates the starting position of the system.

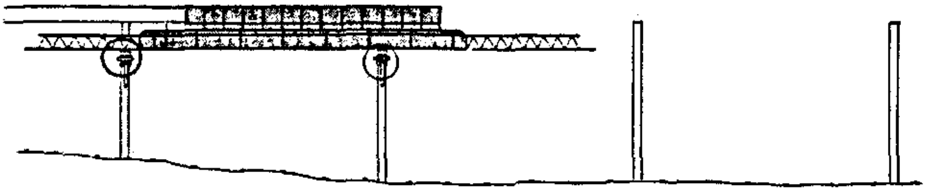


Figure 3.27: Formwork freed from superstructure (Thyssen, 1999)

4. The brackets are required to move forward to support the next span. Accordingly, the main girders and formwork move forward until the girder ends pass the next column in a manner that would preserve system stability, as shown in Figure 3.28.

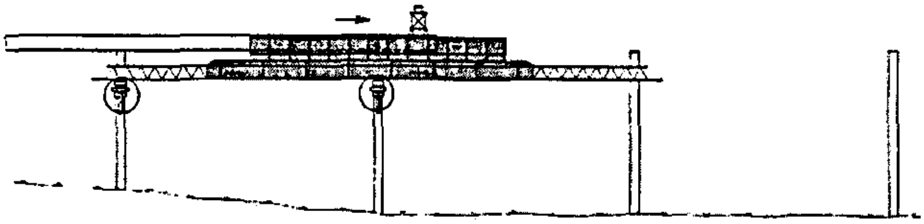


Figure 3.28: Main trusses and formwork moving to next span (Thyssen, 1999)

5. The main trusses are supported temporarily on the superstructure by means of

high tensile bars. The brackets are dismantled from their current position and travel along rails fixed on the bottom chord of the two trusses until they reach the required position. This stage is illustrated in Figure 3.29.

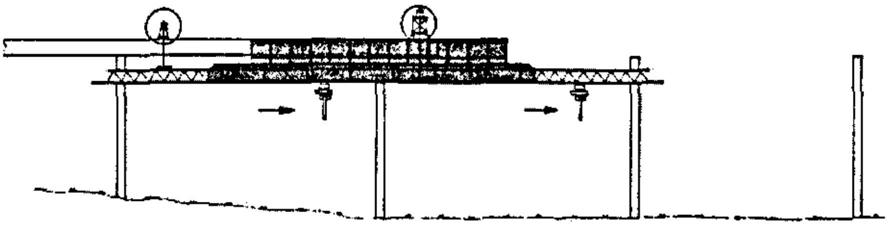


Figure 3.29: Brackets travelling on rails to the next position (Thyssen, 1999)

6. The main girders are lowered to rest on brackets and then travel to their final position as illustrated in Figure 3.30

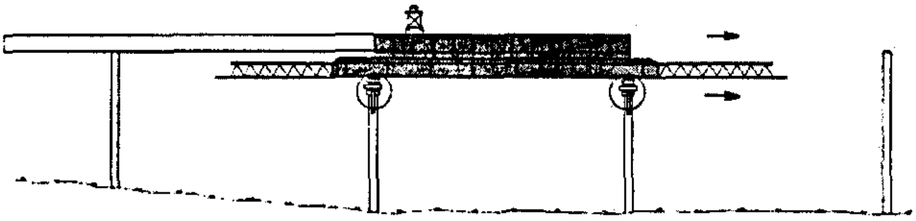


Figure 3.30: Main trusses travelling to their final position (Thyssen, 1999)

7. Formwork levels are adjusted as well as carpentry works. Steel reinforcement and prestressing components are fixed for the bottom slab and webs. Concreting is performed normally in two stages, bottom slab and webs and then top slab. After the concrete of the bottom slab and webs gains sufficient strength the formwork of the inner sides of the webs are dismantled. The same activities are repeated for the top slab, and the span is stressed after it gains the required strength. The casting sequence is extremely important in order to control deflections of the system, otherwise cracks at the

construction joints may occur (Liebenberg, 1992). Sometimes partial prestressing of the bottom slab and webs is performed to limit deflection. The system in its final position is illustrated in Figure 3.31 and the same stages are repeated for constructing the next span.

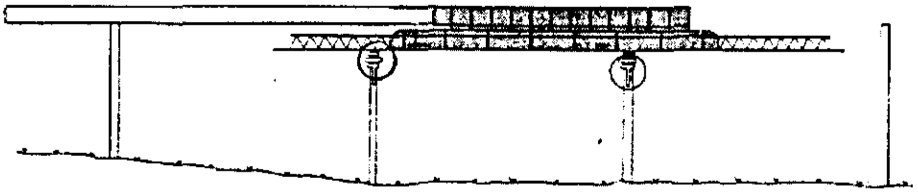


Figure 3.31: The system in its final position (Thyssen, 1999)

3.6.8 Using Launching Trusses to Erect Precast Prestressed Beams

3.6.8.1 Main Components

The system normally consists of two trusses that are supported over bridge pier heads. The trusses are supported over steel chairs and are equipped with moving hoists that travel freely over them. The precast beams are transported from casting yard to the required span using two transport trolleys (i.e. sometimes called MAFI trolleys). The main components of the casting yard are generally a number of moulds and a gantry crane. The main components of the launching system are illustrated in Figure 3.32.

3.6.8.2 Scope of application and characteristics

In this system precast prestressed girders are transported from the fabrication area and erected in position.

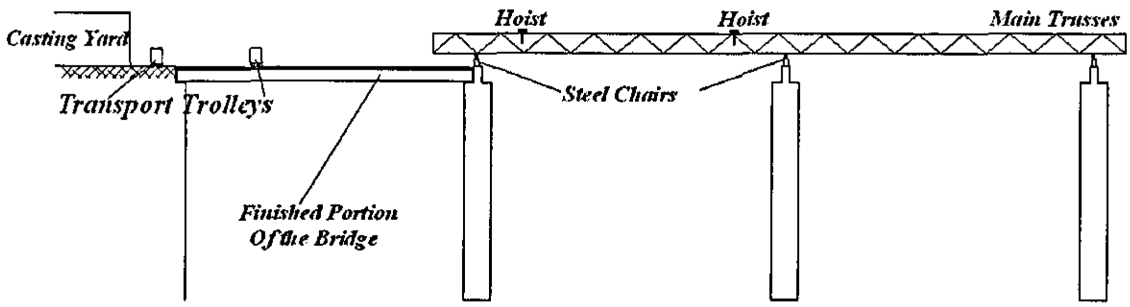


Figure 3.32: Main Components of Launching Girder Method (DSI, 1995)

Bridge physical characteristics

This system is used for erecting prestressed precast beams of beam and slab bridges. It is used for the erection of straight line bridges although very limited horizontal curvatures may be accommodated. It works irrespective of the ground, so ground conditions have a limited effect on the construction process. It is normally used for spans ranging between 30 and 60m according to Liebenberg (1992), and between 20-60m according to Mathivat (1979).

Surrounding environment and site conditions

It can be used to cross any type of obstacle, although it has been used successfully in downtown areas and to cross small waterways. The method requires little interference with the public so it can be used efficiently in crowded areas or where there is traffic. Cranes are required to work from the ground to install steel chairs over bridge piers.

Construction method characteristics

Bridge piers should be designed so as to accommodate system loads. Enough space should be allowed at the pier head for installing steel chairs to support main trusses. This system can be characterised as machine intensive and it is relatively expensive. It requires skilled labourers for its operation. It may be used for similar projects after modifications are made. The quality of concrete is generally better than other methods as a result of casting in factory conditions. The system requires less initial investment compared with advancing shoring and cantilever carriage systems.

3.6.8.3 Construction Sequence

The following stages are generally adopted in using this system:

1. Precast beams are transported by means of two trolleys from the casting yard to the launching trusses as illustrated in Figure 3.33. The beams are normally prestressed initially at the casting yard.

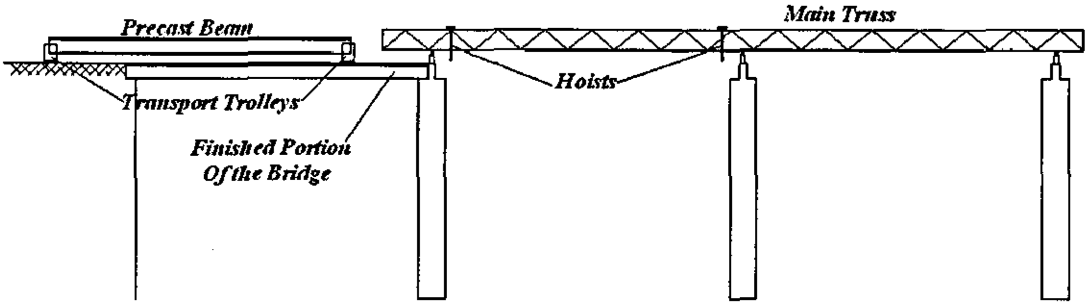


Figure 3.33: A precast beam transported to the launching trusses (DSI, 1995)

2. The trusses load the beam by means of hoists and transport it to the required span as illustrated in Figure 3.34.

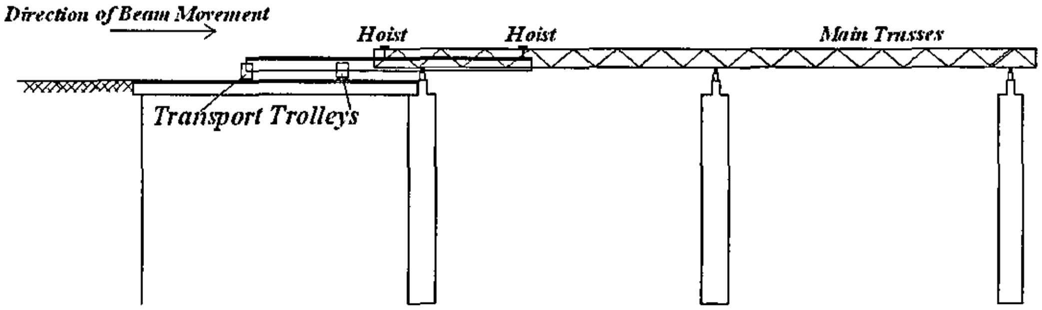


Figure 3.34: Trusses loading a precast beam (DSI, 1995)

3. The hoists move over the trusses and the beams are erected in position, as illustrated in Figure 3.35. The trusses can also move transversely to distribute beams over the bridge width, as illustrated in Figure 3.36.

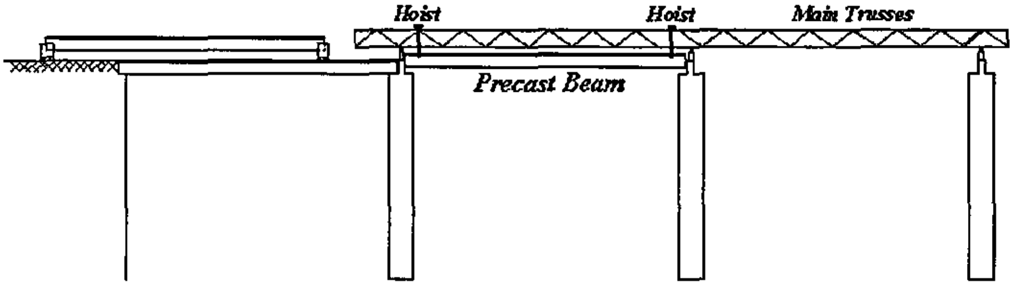


Figure 3.35: The precast beam is erected in position (DSI, 1995)

4. In the same manner, precast beams are erected on the next span as illustrated in Figure 3.37. It is important to mention that the strength and stability of the main trusses may not permit two spans to be launched from the same position. In this case, the trusses have to be moved again to erect the span as indicated in Figure 3.37 where the stability and strength requirements are achieved or to another position as recommended by the manufacturer.

Figure 3.36: Launching Trusses moving transversely to erect precast beams (The Arab Contractors, 1995)

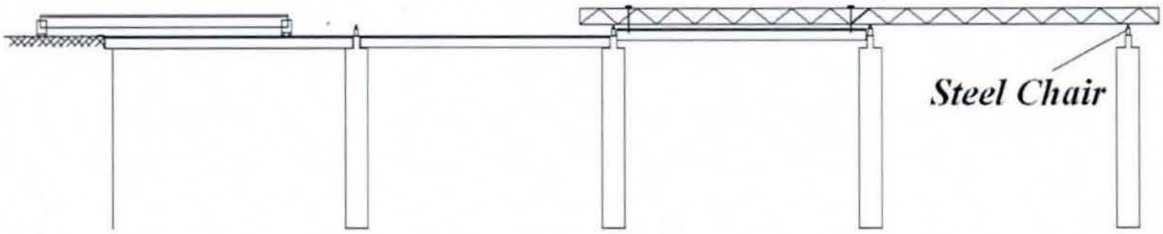


Figure 3.37: Precast beams are erected on the next span (DSI, 1995)

5. After erecting precast beams for the one span the top slab is concreted and final prestressing of the beams takes place. Precast slabs may be positioned and supported on the beams. A light mesh of steel reinforcement is fixed above it and a layer of concrete is poured to connect the beams to the slab.
6. The trusses then move to the next two spans and the same procedures are repeated.

3.6.9 Erecting Bridge Beams Using Cranes or Heavy Lifting

3.6.9.1 Main Components

This system uses either cranes or heavy lifting to erect the beams. One or two cranes may be used depending on the beam weight, length, and erection height. The main components are hydraulic jacks, high tensile steel bars and steel beams. The number and arrangement of jacks and bars is dictated by the beam weight.

3.6.9.2 Scope of application and characteristics

Bridge physical characteristics

This method can be used for steel beams comprising orthotropic decks as well as for concrete beams whether, prestressed or not. The beams can be produced curved and then lifted into position in order to accommodate the required curvature in the deck. The workable height from ground depends on the available crane capacity. On the other hand, heavy lifting is not affected by height although proper consideration of wind should be taken.

Surrounding environment and site conditions

It may suit a crowded area if special arrangements to the working hours are considered. It may be used in the presence of obstacles if the available cranes are suitable. On the other hand, heavy lifting can be used in the case of obstacles, provided beams can be placed under the span. It requires skilled labourers due to the delicacy of the process. Sufficient area for crane manoeuvring is required and the ground should be strong enough to sustain crane loads.

Construction method characteristics

There are virtually no considerable loads created to the structure that would affect design except in the case of heavy lifting. The process is straight forward, but requires skilled labourers. The time required is considerably less than other methods especially for a limited number of spans.

3.6.9.3 *Construction Sequence*

In the case of heavy lifting the following steps are involved:

1. The lifting jacks are erected above the superstructure and the lifting bars are extended to the ground level and attached to the beams as illustrated in Figure 3.38.

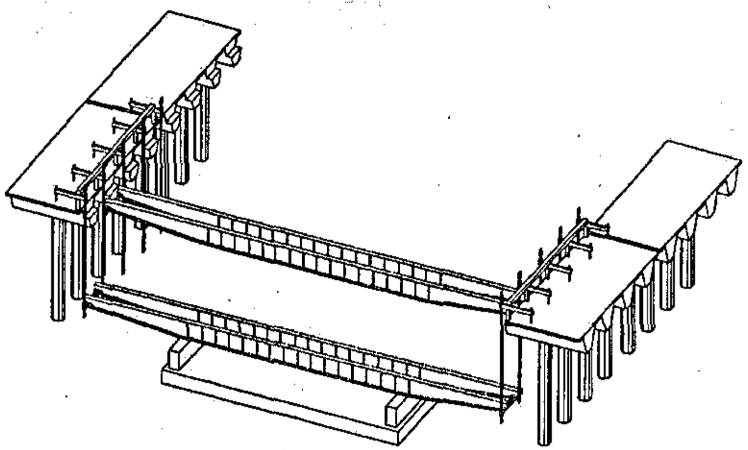


Figure 3.38: Heavy lifting of several beams (Liftslab Misr, 2000)

2. The jacks lift beams in stages defined by their maximum stroke. The jacks are allowed to release after reaching maximum stroke in order to start another stage. The process is illustrated in Figure 3.39

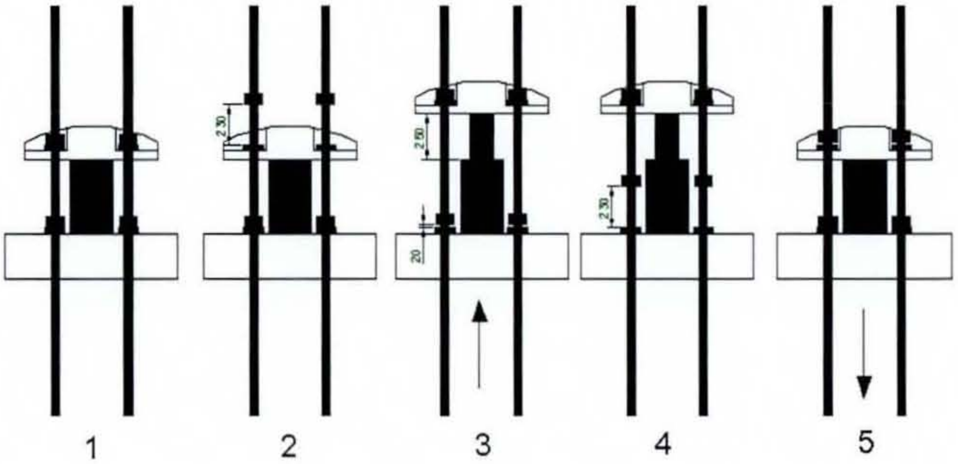


Figure 3.39: Example of one cycle of heavy lifting (Liftslab Misr, 2000)

3. In the case of using cranes the procedures are simpler. The method is simple and is comprised of lifting the beams using one or two cranes depending on the beam loads, span length and required height. An example of this process is illustrated in Figure 3.40.

Figure 3.40: Precast beams erected using cranes (The Arab Contractors, 2004)

3.6.10 Horizontal Incremental Launching system

3.6.10.1 Main Components

The system works by pushing precast concrete elements from the casting area to the required span. The main components are temporary columns to support formwork at the casting area; a steel nose is normally used to minimize the cantilever length of the segments during pushing, accompanied by a system of jacks. Other accessories are also used such as Teflon sheets and grease.

3.6.10.2 Scope of application and characteristics

Bridge physical characteristics

The method is used for box cross sections. It can accommodate limited constant horizontal curvature of the deck. It works irrespective of the ground, so it can be used for any height of the superstructure except for the casting area where height should enable casting segments. Mathivat (1979) states that it can be used for spans up to 100m. The segment length usually ranges between 15-30m (Liebenber, 1992). The bridge is pushed in the direction of down grade (if available) in order to reduce resistance to pushing. This method is used for prestressed concrete.

Surrounding environment and site conditions

This method has been used in downtown areas successfully as it causes minimum interference with the surrounding environment. It can be used to cross most obstacle types. Ground conditions have limited impact as the system is totally supported over bridge piers normally.

Construction method characteristics

Although this method can be described as machine-intensive, it is not generally expensive (Raina, 1988). This method requires skilled labour and experienced staff and the design is highly affected by the construction stages.

3.6.10.3 Construction Sequence

Construction is carried out in the following stages:

1. A casting area is prepared at one end of the bridge. Two casting areas may be required one at each end of the bridge, depending on the bridge length. The formwork is supported on four temporary columns and two temporary beams. Each segment is usually concreted on two stages, the bottom slab and webs and then the top slab. The temporary beams are equipped with hardwood at the top to facilitate the pushing process, as illustrated in Figure 3.41.

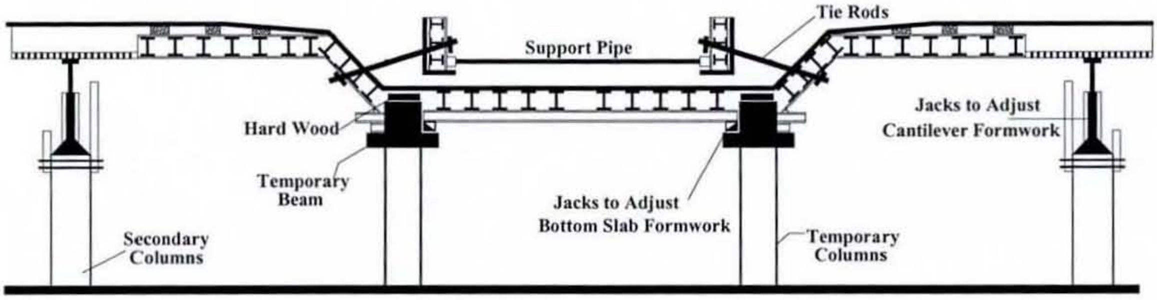


Figure 3.41: An Example of the Formwork for bottom slab and webs as well as temporary columns at the casting area (The Arab Contractors, 1996b)

2. After concreting the segments, the formwork is stripped and a lightweight steel nose is fixed to the segment front in order to limit the moments due to the cantilevering effect, as illustrated in Figure 3.42. Bridge bearings are provided with temporary sliding bearings made up of steel or concrete with a stainless steel surface and side guiding plates to keep the superstructure to the correct alignment. The bearings are coated with Teflon on the sliding surface in order to facilitate sliding with minimal friction.

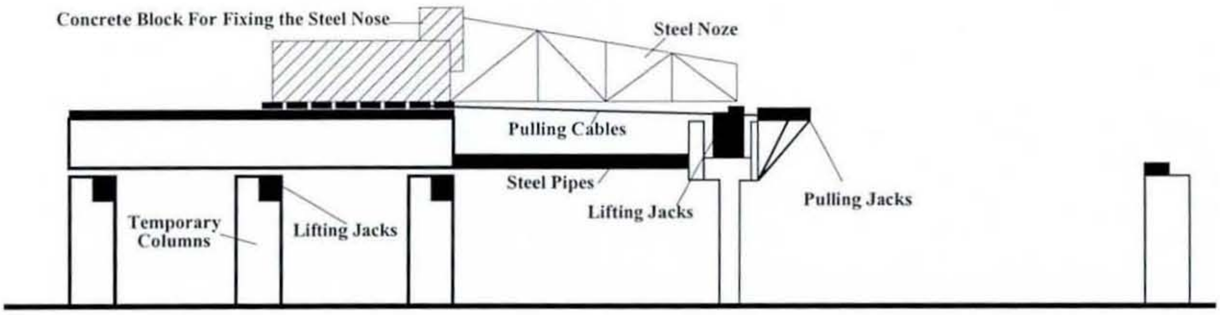


Figure 3.42: Preparation for pulling the first segment (The Arab Contractors Manual, 1996b)

3. After pushing the first segment to the required position, the second one is concreted over temporary columns and the same process is repeated and the segments are prestressed as illustrated in Figure 3.43.

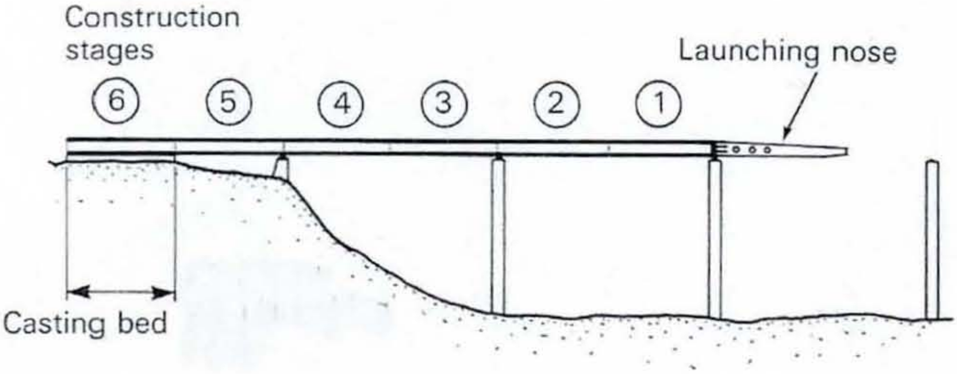


Figure 3.43: Bridge during construction (Liebenberg, 1992)

4. After finishing the prestressing, the temporary bearings should be replaced with permanent ones. However, the modern practice is to use permanent bearings during construction as well (Liebenberg, 1992). Figure 3.44 shows the system during operation.

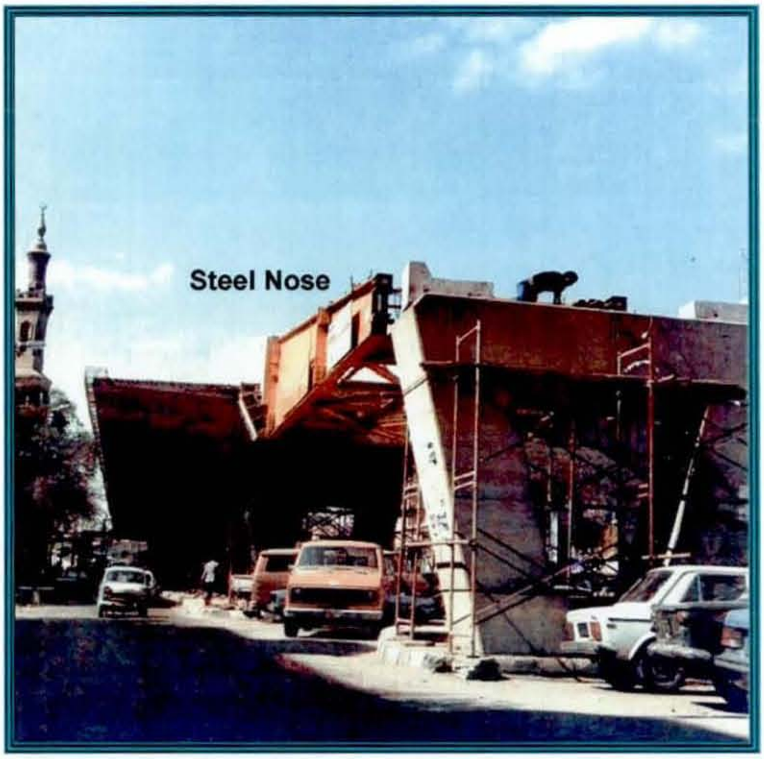


Figure 3.44: Steel nose fixed to segment (The Arab Contractors, 1996b)

3.6.11 Custom Systems

Custom systems refer to instances where combinations of the aforementioned methods are used. It also covers other innovative techniques that cannot be categorized under any of these methods (Youssef *et al*, 2005). Such innovative techniques are normally one-off and designed to cater for very specific and rare, site conditions.

Figure 3.45 illustrates one of these innovative techniques. The site previously contained an old steel bridge, the Abu-El-Ella bridge. This bridge had been dismantled and another one was to be built crossing the Nile beside it. The constructor used the piers of the old bridge as supports for the falsework of the superstructure of the new bridge. An elevated platform was assembled on shore and then loaded on to two ships. The ships travelled along the Nile and placed the platform in position using heavy lifting equipment that was already installed on the ships. The platform was supported on the piers of the old bridge. The falsework and formwork were erected over this platform.

Figure 3.45: Creating an elevated platform and erecting falsework (The Arab Contractors, 2004)

Table 3.1 summarizes the circumstances in which each construction method is used.

Table 3.1: Summary of Bridge Construction Methods

Construction Method	Circumstances of use
Stationary System Supported on Ground	• It can be used for span of up to 300m • Ground should be levelled and without obstacles • Does not Require Skilled Labours • Cost is relatively small compared with other systems especially when using standardized proprietary systems which can work in many projects • It is used for cast insitu concrete in Egypt
Stationary System Using An Elevated Platform	• It can be used for any span length provided that there are intermediate towers every 20-25m • It can be used for heights of up to 25m • Some variation in the land topography is tolerable • It is used in case of obstacles such as railway lines and small canals • The time required for erection and dismantling is less than with stationary formwork • It is used for cast insitu and precast concrete in Egypt

Construction Method	Circumstances of use
Cantilever Construction by In-Situ Concreting Using Two Form Travellers (Concreting Carriages)	• The optimum span range is between 50-150m, although it may be used for up to 240m. • It can be used for any height of the superstructure • It is used to cross obstacles such as waterways. • It requires highly skilled labourers • The construction method affects bridge design drastically • Relatively expensive • It is used for prestressed concrete
Cantilever Construction by In-Situ Concreting Using One Form Traveller and Stationary System	• It is used when part of the cantilever is above the ground • Construction affects drastically the bridge design • It is less expensive when compared to the previous method • It is used for prestressed concrete
Advancing Shoring System	• It is normally used for 40m spans and can be up to 85m • It can be used for any height above ground • It can be used to cross most obstacles on the ground • It has limited ability in catering for horizontal curves • There is less interference with the public • Bridge design should take into account the loads resulting from construction sequence • Careful consideration should be taken for deflection • It is used for prestressed concrete
Launching Trusses	• It is used for spans ranging between 20-60m • It is used to erect precast prestressed concrete girders • It can be used for obstacles in down town areas or to cross small waterways • It has limited ability to accommodate horizontal curvature • It requires less initial investments
Erecting Bridge Beams using Cranes or Heavy Lifting	• The span range depends on the capabilities of the available equipment • It is used to erect precast prestressed girders • Requires enough area for crane manoeuvring
Horizontal Incremental Launching	• It can be used for spans up to 100m • It accommodates limited horizontal curvature • It proves efficient in crowded areas • It requires skilled labours and experienced staff • The design is highly affected by construction sequence • This method is used for precast prsestressed concrete

3.7 CRITERIA FOR SELECTING CONSTRUCTION METHODS

There are many criteria affecting the choice by bridge professionals of construction method. Troitsky (1994) and Liebenberg (1992) are of the view that the choice of construction method depends on the nature of obstacles to be crossed, cross-sectional area of the superstructure, bridge height, ground conditions, span length, and total bridge cost. Besides these obvious engineering and economic criteria, Walter and Scalzi (1976) state that the evaluation process should take into account familiarity with the construction system, amount of risk involved, interference with traffic or navigation during construction, construction scheduling, the complexities shed on design due to construction system and, finally, cost. The importance of the criteria varies: while Bindra and Bindra (1976) emphasize the importance of the availability of construction labour and equipment, others such as GangaRao *et al* (1988) emphasise ease of construction especially in low volume road bridges and the dependence of criteria on regional anomalies.

Basha and Gab-Allah, (1991) used the results of the study performed by GangaRao *et al* (1988) and after interviewing ten bridge practitioners in Egypt, they concluded that eight criteria can be used to evaluate bridge construction methods:

- Construction cost;
- Resource availability;
- Ease of construction;
- Durability;
- Construction progress rate;
- Service life;
- Design efficiency;

- and maintenance.

However the criteria developed by GangaRao *et al* (1988) were intended to evaluate the whole design and not only construction methods. Perhaps a more reliable approach would be to interview practitioners without any prior frame of thoughts as dictated by the criteria presented to respondents in Basha and Gab-Allah's (1991) research. Nevertheless, Basha and Gab-Allah (1991) found that in six out of the fourteen concrete bridge projects constructed in Egypt, the adopted construction method was not the best one. This means that in 43% of cases the chosen construction method was not the best choice.

The appreciation of the importance of adopting a systematic approach in dealing with this selection problem is fuelled not only by the results illustrated above but also by the increasing market competition, shrinking profit margins, tight work programmes and growing complexity of construction projects. An approach that integrates the constraints dictated mainly by technical considerations as well as the other important intangible considerations would be beneficial.

3.8 ISSUES RELATED TO THE CONSTRUCTION INDUSTRY IN EGYPT

There are two main issues to discuss in this section which have a bearing on the research problem: contractual arrangements, and factors affecting construction quality. Morcous (1997) states that there two main types of contracts used in Egypt for bridge projects: negotiated contracts and competitive contracts. In negotiated contracts, work is mainly awarded on a cost plus fixed fees basis where it is agreed that the contractor will be paid the work cost plus a fixed percentage for his overheads and profit. It is normally used when project documents are not yet prepared and it is of essence to save the time required for formal bidding procedures. However, costs are normally higher compared with the competitive arrangement, as there is no incentive for the contractor to reduce project costs. Furthermore, the impact of intangible criteria other than cost reduction is more pronounced. This view is supported by Basha and Gab-Allah (1991), as the projects judged not to have used the best construction method were contracted under this arrangement.

In competitive contracts the contractor is invited to submit his total offer beforehand either on a lump sum basis or based on unit prices that are applied to the consultant's estimate of the quantities involved for each of the various job items. The latter case is often used in Egypt. The unit price method enables the contractor to receive payment for the actual quantities of work done based on field measurements made during the construction works. The determinant factor in this arrangement is cost, as stipulated in Egyptian administrative law. This law determines relations between the government and other entities. The impact of other factors is normally less pronounced in this arrangement.

Abdel-Razek (1998) identifies sixteen factors as influencing construction quality in Egypt. These factors and their percentage of relative importance are as follows;

- Improving design and planning during the pre-construction phase (16.67%),
- Developing and improving quality assurance and control systems (10.52%),
- Improving the financial level and standard of living of employees

(9.2%),

- Improving the accuracy of cost estimating (8.38%),
- Proper classification of contractors, consultants and projects (7.07%),
- Employees' conscientiousness (6.25%),
- Improving training for contractors, owners and consultants (5.26%),
- Encouraging ISO 9000 (5.1%),
- Increasing contractors technical and managerial efficiency (4.93%),
- Improving maintenance systems during and after construction (4.93%),
- Improving utilisation of resources (4.93%),
- Encouraging and improving specialization in construction work (4.27%),
- Cooperation between construction industry and scientific organizations (4.27%),
- Participating and cooperating with advanced international organizations (3.12%),
- Defining responsibilities between project parties (2.96%), and
- Encouraging innovation for simpler and more accurate work methods (2.14%).

The research was based on the views of 150 participants representing industry in Egypt. The results apparently suggest that the design and preconstruction activities require improvement. This should be based on methods that stem from the local economic and technological background that must be turned into advantages to give a competitive edge instead of being regarded as a constraint.

Given the exceptional relationship between bridge design and construction, as described in Section 3.5, and the results of Abdel-Razek's (1998) work, priority should be given to research in bridges in Egypt to understanding and possibly devising a systematic approach to integrating the design and construction processes.

3.9 SUMMARY

This chapter has discussed the problem of evaluating construction systems of the superstructure of concrete bridges. The bridge development process consists of five main stages: conceptual phase; detailed design; construction; service and maintenance; and demolition or collapse. The design process of bridges usually undergoes four main stages: conceptual design; scheme design; preliminary design; and detailed design. The choice of the construction method is normally performed at the preliminary design stage as part of the overall Buildability issue. Despite several attempts to evaluate bridge design alternatives such as quality index and structural utility, they do not effectively deal with both subjective and objective criteria together. A model was proposed whereby the influential criteria, such as buildability, durability, maintainability, aesthetics and cost, are represented during preliminary design. The construction methods used in Egypt have been discussed in terms of their characteristics, main components, construction sequence and scope of application. One of the major aspects to enhance quality in Egypt is to improve design and planning during pre-construction phase. Chapter 4 will explore various facets of decision making and propose a multiple criteria decision approach to solve the research problem.

CHAPTER 4: INTELLIGENT DECISION MAKING

4.1 INTRODUCTION

This chapter begins by introducing the main themes that distinguish different artificial intelligence systems and then focuses on decision making. The main approaches used to solve multicriteria decisions are scrutinized including: single criterion synthesis approach and outranking approach. Seven main guidelines were used to choose an appropriate multicriteria decision aid method for the research and the reasons for using the Analytic Hierarchy Process (AHP) are discussed. Consequently, AHP is examined in terms of hierarchy structure, prioritization procedures, synthesis, fundamental assumptions and critical points. Decision making stages are also reviewed and the research problem is portrayed within these stages. Examples of problems solved using AHP are demonstrated. Finally a brief review of decision support systems is presented.

4.1.1 Artificial Intelligence (AI)

Laudon and Laudon (1998) define AI as "the effort to develop computer based systems (i.e. hardware and software) that behave as humans". Sauter (1997) emphasizes the role of knowledge, and defines AI as "The emulation of human expertise through the encapsulation of knowledge in a particular domain and procedures for acting on this knowledge".

Perhaps, a more succinct and relevant definition to this research context is laid down by Russel and Norvig (2003), who define AI as "trying to systemize and automate intellectual tasks and therefore it is potentially relevant to any sphere of human intellectual activity". They illustrate that AI systems are developed along four main dimensions: systems that think rationally, systems that act rationally, systems that act like humans and systems that think like humans.

In the first dimension, systems are developed to think logically (i.e. abiding by the rules of thought). The adequacy of pure logic to construct systems is questionable as demonstrated in the views of many scientists and philosophers, including Kant (1934). Acknowledging such inadequacy the second dimension of AI emerged, where systems were developed to act rationally. Rational agents are developed so as to achieve the best result or the best expected outcome in cases of uncertainty. The third dimension aims to develop systems that act like humans whereby passing the Turing test, according to Winstanely (1990), is a measure of their success. This approach combines many capabilities such as natural language processing, knowledge representation, automated reasoning, machine learning, computer vision and robotics. Systems developed along the fourth dimension attempt to automate some of the human thinking capabilities such as decision making. This also involves the field of cognitive science that is concerned with the way information is mentally processed (Lu *et al*, 2001).

4.1.2 Decision Making

Turban and Aronson (2001) define decision making as "The process of choosing among alternative courses of action for the purpose of attaining a goal or goals." It is actually concerned with investigating the actions humans take in order to settle the differences between their views of the environment and its reality. The research problem can be qualified as a decision problem where feasible construction methods represent decision variables and benefit and cost represent intermediate result variables and the best construction method represents the result variable. The following sub-sections discuss some related aspects such as modelling and optimisation.

4.1.2.1 Modelling

Winstanely (1990) defines models as "An explicit representation of one's understanding of the situation.........it can be expressed in mathematics, symbols, or words but is essentially a description of entities and the relationships between them........". Turban and Aronson (2001) illustrate three types of models: iconic, analog, and mathematical. Iconic models are considered the best abstraction of reality, such as 3D prototypes and photographs. Analog models behave like the system but do not resemble it, such as maps, organization charts and blueprints. Mathematical models are mainly used to model decision problems and they are the least abstract of all model types.

Mathematical models can be classified, based on their way of searching for the solution, into simulation models, heuristics models, predictive models, optimization models and others. Simulation models try to find a good enough solution or the best among alternatives checked using experimentation. Heuristics models try to find a good enough solution using rules and are used to solve complex problems. Predictive models are used to forecast the future. Optimisation models search for the best solution from a set of solutions. This last type is widely used in construction as illustrated by Bastias and Molenear (2005) in their survey which revealed that optimisation based models represent around 20% of the models developed in the construction industry to deal with decision problems.

4.1.2.2 Optimisation

Optimisation means searching for the best solution from a set of solutions. According to Turban and Aronson (2001), the process of optimisation is natural and is performed by rational decision makers on the assumption that humans are economic beings (homo-economicus) who aim to maximize achievement of goals or their welfare. Taha (2003) illustrates that the decision maker in the classical optimization approach, optimizes a single objective function over a set of feasible solutions subject to a set of constraints. This process includes identifying decision variables (i.e. alternatives whether finite or infinite), an objective function (that needs to be maximized or minimized) and constraints. The solution may be achieved in one step using a single formula or using a set of procedures (algorithms).

Nevertheless, real life situations exhibit more complexity due to their multidimensional nature and the necessity to consider many criteria in order to find the best course of action (Bouyssou, 1993). This fact led many researchers to conclude that the decision making process extends beyond the classical optimisation approach and paved the way for the emergence of multi-criteria decision aid approach. Optimisation in multi-criteria problems is defined as searching for a single measure of merit of a solution that is greater than those of other solutions (Pongpen and Liston, 2003). In operational terms, there are three main approaches to finding an optimum solution:

1. Finding the alternative that has maximum goal achievement for a fixed

number of resources;

2. Finding the lowest cost alternative that meets a given level of goals;
3. Finding the alternative possessing the highest level of goal achievement to cost. This approach is used to optimise the research problem.

Bridge engineers as decision makers face a number of influential decision problems during the course of bridge development including choosing an appropriate construction technique for the superstructure. There are many criteria that affect the choice of construction techniques, some subjective and others objective. However, the traditional approach is to choose the least cost alternative subject to fulfilling a set of engineering constraints dictated mainly by bridge characteristics (e.g. span and height) and site conditions (e.g. soil strength). Bridge engineers tend to focus on objective criteria and pay less attention to subjective criteria, which may be considered implicitly without clear rationale in the decision process. This situation may be caused by their inability to deal with both subjective and objective criteria in a rational way that would justify their inclusion and assessment, should the need arise.

Accordingly, bridge engineers should be able to exhibit multi-criteria decision making capabilities in order to aggregate criteria and alternatives using their intuition and experience to find the best alternative. The following sections illustrate the characteristics of multi-criteria decision analysis (MCDA) in order to be able to develop a decision model for the research problem.

4.2 MULTI-CRITERIA DECISION ANALYSIS (AID)

Multi-criteria decision analysis (MCDA) is a term used to describe the tools used by decision makers to solve decision problems where many, possibly, contradictory points of view must be taken into consideration (Vincke, 1992). It is an important decision tool for many problems that are faced in engineering and science as illustrated in the views of many researchers such as Triantaphyllou and Mann (1995). This term is used interchangeably in literature with MCDM (Multi-criteria Decision Making). Steuer and Na (2003) illustrate that MCDM is the form that is often used by Americans while MCDA is used by Europeans. This is caused by the tendency in Europe to emphasize the distinction between decision maker and the management scientist providing aid or analytical support to the decision making (Costa *el al*, 1997).

MCDA methods can be presented as a process that consists of two main stages: construction and exploitation as illustrated in Figure 4.1. The construction process involves gathering input data and constructing a decision model. Determining the information type whether it is cardinal or ordinal, deterministic or non-deterministic is an important aspect in this stage. The modelling process is the way the decision problem is represented. For example, The Analytic Hierarchy Process (AHP) adopts a hierarchical representation for the objective, criteria and alternatives. The exploitation process involves aggregation and obtaining results. The aggregation procedure is the calculation stage where information is processed so as to arrive at a result. Examples of this processing include calculating eigenvectors as used by AHP, calculating value aggregation as used by multi-attribute value theory (MAVT), calculating disjunctive and conjunctive as used by ELECTRE TRI. The recommendation is the output form of MCDA methods. The form of the output of these methods vary as some methods offer choice and ranking such as AHP others such as MAVT and

Technique for Order by Similarity to Ideal Solution (TOPSIS) offer choice only. The modelling and aggregation processes are at the heart of MCDA, and collectively they may be called multi-criteria aggregation procedures (MCAP) (Guitouni and Martel, 1998).

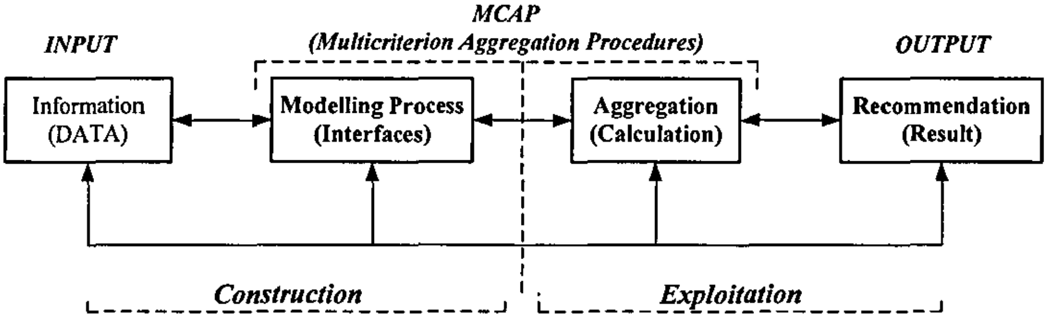


Figure 4.1: MCDA procedures (Bouyssou, 1996)

MCDA can be classified according to the decision space into Multi-objective Decision Making (MODM) and discrete multiple criterion problems. MODM is used to solve problems with continuous and infinite number of alternatives. They rely primarily on mathematical algorithms such as goal programming. According to Taha (2003), the basic idea of goal programming is to establish a numerical goal for each of the objectives and to formulate an objective function for each objective, and then seek a solution that minimizes the sum of deviations of these objective functions from their respective goals. There are two methods used to solve goal programming problems: weights method and the pre-emptive method. In the weights method a single objective function is constructed to represent the goals of the decision problem as follows:

Minimize $G_i, i = 1,2,\dots,n$ and the combined objective function is

Minimize $z = w_1 G_1 + \dots + w_n G_n$

Where $w_i, i = 1,2,...,n$ are positive weights that reflect the decision maker's preferences regarding the relative importance of each goal.

In the second method, the goals must be ranked in order of importance by the decision maker. The process is performed in stages where the result of each stage is a constraint on the subsequent stages. The process is carried out such that the solution obtained from a lower priority goal never degrades any higher priority solutions. Discrete multiple criteria problems involve selecting a suitable alternative, or ranking alternatives of a finite predetermined discrete number. This latter approach adequately addresses the research problem.

The methods used in MCDA problems can be divided into three categories as illustrated by Martel (1999), Vincke (1989) and Roy (1985): the interactive local judgements with trial and error approach, the single synthesis criterion approach (sometimes called multiple attribute utility methods) and the outranking synthesis approach. The first approach deals mostly with MODM problems (Martel, 1999). The single synthesis criterion and outranking synthesis approaches deal with discrete multiple criteria problems (Vincke, 1992). According to Vansnick (1990), these two approaches can be represented based on their formulation of the decision making situation in the $A, \mathsf{A}/F, E$ form where A is a set of feasible alternatives noted as: $A = \{a_1,...,a_i,....,a_m\}$ and A/F is noted as $\mathsf{A}/F = \{g_1,...,g_j,....,g_n\}$ and E is a set of performance evaluation of alternatives for each criterion and can be noted as

$$E = \begin{array}{c|ccccc} / & g_1 & \cdots & g_j & \cdots & g_n \\ \hline a_1 & e_{11} & \cdots & e_{1j} & & e_{1n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_i & e_{i1} & \cdots & e_{ij} & \cdots & e_{in} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_m & e_{m1} & \cdots & e_{mj} & \cdots & e_{mn} \end{array}$$

The single criterion synthesis approach utilises an $A - \mathbf{A} - E$ formulation where middle $\mathbf{A}$ represents criteria. The outranking approach utilises $A - F - E$ formulation of the decision problem where F represents a consistent family of the criteria. The single criterion synthesis approach and the outranking approach are potentially applicable to the research problem and will be discussed further in the coming sections.

4.2.1 Single Criterion Synthesis Approach

This approach is derived from the American school of thought (Martel, 1999). It is based on the axiom that any decision maker attempts implicitly to maximize some function aggregating all the different points of view, which are taken into account (Vincke, 1992). This approach attempts to formulate this function explicitly and optimize it in order to arrive at the best compromise solution among other solutions subject to decision makers' preferences. Preferences at each criterion level are aggregated into a single function that can be represented generally as follows:

$$g(a_i) = V[g_1(a_i), g_2(a_i), \ldots\ldots, g_n(a_i)]$$

Where g is the single synthesizing criterion, a_i is an alternative i, V is the aggregation function, and g_j are the attributes j (Hwang and Youn, 1981).

There are many methods that can be categorized under this approach and the key methods according to Martel (1999) are MAUT (Multiple Attribute Utility Theory), UTA (Utility Theory Additive), SMART (Simple Multiple Attribute Rating Technique), TOPSIS (Technique for Order by Similarity to Ideal Solution), and AHP (Analytic Hierarchy Process). In the MAUT method the aggregation is obtained by assessing partial utility functions on each criterion to establish a global utility function U, where U under some conditions can be obtained in an additive manner according to Vincke (1992), as follows:

$$U(a)=\sum_{j=1}^{n}U_J\left(g_j(a)\right)$$

or multiplicative manner as follows:

$$U(a)=\prod_{j=1}^{n}U_j\left(g_j(a)\right)$$

Where U_j is the utility function of criterion g_j and a is an alternative

In the UTA method the value function is estimated on each criterion using ordinal regression and the global value function is obtained in an additive manner. The SMART method is a simple way to implement the MAUT by using the weighted linear averages, which gives a close approximation to utility functions. In TOPSIS, the chosen alternative should have the profile which is the nearest (distance) to the ideal solution and farthest from the negative-ideal solution. In AHP the subjective assessments of relative importance is converted into weights. This technique applies decomposition, the comparative judgements on comparative elements and measures of relative importance through pairwise comparison matrices which are recombined into an overall rating of alternatives.

The main advantage of this approach is that the problem is reduced into a single objective function once the aggregation (utility) function is assessed in the right way, thus a best solution (compromise) can be obtained. The main disadvantage is that the solution process becomes complex with the increase in the number of alternatives because a single aggregation function must be developed for each criterion (Abdullah, 2003). Another disadvantage is that it does not accept incomparability between alternatives, should the case arise (Guitouni and Martel, 1998).

4.2.2 <u>Outranking Approach</u>

This approach is derived from the French school and was developed by B. Roy in 1968 at the University of Paris (Martel (1999), Saunders (2004)). It assumes that the decision makers' preferences can be modelled using binary relations (i.e. outranking relations). The outranking relation $S = P \bigcup Q \bigcup I$, where P represents a preference situation and Q represents weak preference situation and I represents indifference situation, is valid when there is strong reason to believe that with respect to all the n criteria of consistent family of criteria, an alternative i noted as A_i, is at least as good as or outranks alternative j noted as A_j and the outranking relation is expressed as $A_i S A_j$, without any reasons which absolutely prevent from saying so (Guitouni and Martel, 1998). In order to establish outranking relations, concepts such as concordance, disconcordance and thresholds should be defined. The concordance measure is a ratio computed by summing the weights for those attributes for alternative A_i which are superior to the attributes for alternative A_j divided by the weights for alternative A_i as a whole. The closer this ratio is to 1.0, the more superior alternative A_i is to alternative A_j. The disconcordance measure looks at the largest difference for the attribute sets of A_i over A_j compared to the largest difference over all alternatives (Saunders, 2004). The following equations illustrate the calculations involved in the outranking method. Given that;

$c(A_i, A_j)$ = Concordance Index, $d(A_i, A_j)$ = Disconcordance Index

C_j = Criterion j, w_j = Subjective weight of criterion j

We can calculate the concordance and discordance indices using the following two formulae:

$$c(A_i, A_j) = \frac{1}{\sum_{k=1}^{n} w_k} \sum_{\{k: g_k(A_i) \geq g_k(A_j)\}} w_k$$

and

$$d(A_i, A_j) = \left\{ \begin{array}{l} 0 \text{ if } g_k(A_i) \geq g_k(A_j) \text{ for all } k, \\ \frac{1}{\delta} \max\{\mathrm{g}_k(A_i) - \mathrm{g}_k(A_j)\}, \text{ otherwise.} \end{array} \right\} \text{where } \delta = \max\{g_k(A_i) - g_k(Aj)\}$$

Then we can define the outranking relation to be as follows:

$$A_i S A_j \text{ if and only if} \left\{ \begin{array}{l} c[A_i, A_j] \geq \hat{c}, \\ d[A_i, A_j] \geq \hat{d}, \end{array} \right.$$

Where $\hat{c}$, $\hat{d}$, are set by the decision maker and are considered as the thresholds. Given the outranking relation then we can find a set of alternatives $N \subset A$ for which:

$\forall B \in A - N \quad \exists A \in N$ such that ASB

$$\forall A, B \in N, ASB.$$

There are four main steps involved in outranking methods as indicated by Abdullah (2003):

1. Obtain the values of the attributes for each alternative with respect to the criteria;
2. Construct the outranking relations by following the concordance and disconcordance definitions and construct a graph to represent these relations;
3. Obtain the minimum dominating subset. If a Kernel exists, it is chosen as the minimum dominating subset;
4. If the subset has a single element or is small enough to apply value judgement, select the final decision. Otherwise, steps 2 through 4 are repeated until a single element or small subset exists.

Martel (1999) illustrates that the key methods associated with the outranking approach are ELECTRE, PROMETHÉE, ORESTE, and QUALIFLEX.

The outranking approach operates by reducing the number of alternatives until the best alternative is obtained thus it does not allow complete ranking of the alternatives because only partial prioritization of alternatives is computed. Carrying the results forward to calculate ratios such as benefit to cost is meaningless. Abdullah (2003) illustrates another two weaknesses. The first weakness is the fact that the ordinal way used to combine concordance and disconcordance sheds doubts on the accuracy of outcomes. The second weakness is the existence of some arbitrariness to the way the weights are assigned to the criteria as well as assigning values to the attributes.

4.2.3 MCDA Approach Used for the Research

The previous sections illustrate the multitude of methods that can be used to solve multicriteria decision problems. Despite this obvious wealth, the choice of a suitable method may be difficult as analysts may be motivated by their familiarity with a certain method (Guitouni and Martel, 1998). Accordingly, it is important to identify MCDA methods characteristics and match it against research problem characteristics. Guitouni and Martel (1998) present seven tentative general guidelines to help in choosing an appropriate MCDA method as follows:

1. Number of participants involved in the decision making whether single or group; the attributed lack of cooperation in construction problems between different parties may give preference to single decision making, nevertheless, group opinions may be required in some instances.
2. Preference elucidation method required such as pairwise comparison, tradeoffs, direct rating, etc; Pairwise comparison may be a suitable choice for practitioners as it provides a flexible yet robust approach in making comparisons as indicated by many authors including (Guitouni and Martel, 2003).
3. Output required by the decision maker: Roy (1985) illustrates that the output can be in many forms such as identifying the best alternative, select a limited set of the best alternatives (i.e. choice), to construct a rank order of the alternatives from the best to the worst ones (i.e. ranking), or

classify/sort alternatives into groups, or identify the major distinguishing features of alternatives; In many instances the decision maker requires to rank feasible alternatives in a way that reflects the degree of their goal attainment, in order to calculate the $Benefit/Cost$ ratio.

4. Input information characteristics, type and quantity and the ability to provide it: Abdullah (2003) illustrates three main types of data involved in MCDA methods: deterministic, stochastic, and fuzzy. Deterministic data requires that goal, criteria and alternatives be determined prior to solving decision problem. In stochastic data, the criteria are treated as random variables. Fuzzy data deals with uncertainty or imprecision. The input data for the research problem are deterministic in nature where the goal (choosing construction method), criteria and alternatives (construction methods) are predetermined before dealing with the decision problem. Input information is mainly dictated by the decision maker's knowledge and experience. Some of these data would require reference to previous projects information such as duration and cost. This basic information is normally available to bridge engineers in Egypt.

5. Required compensation degree: there are three degrees of compensation used by MCDA methods, total compensation (where absolute compensation between criteria evaluation is accepted), no compensation (no compensation is accepted between different criteria), or partial compensation (some kind of compensation between criteria evaluation is accepted) (Colson and Bruyn, 1989). Total compensation would imply the unimportance of some criteria relative to others, which may be the

case in some instances. In the case of decision problems where no compensation is a requirement for some of the criteria while others require partial compensation, a mechanism may be proposed whereby the alternatives are sieved to a reduced set that satisfies the requirements of non compensation for these criteria thus allowing the use of partial compensation. Partial compensation is widely used by most MCDA methods.

6. Fundamental hypothesis of MCDA method: check whether it meets problem characteristics and it will be discussed in Section 4.3.4.
7. Examine the availability and capabilities of software that automates the method (i.e. if available): methods that have software are preferred.

The single synthesis approach is used in instances where complete ranking of the alternatives is required. Complete ranking enables decision maker to understand the decision dynamics where the effect of changing preferences on the alternatives ranking as well as the sensitivity of alternatives to criteria can be viewed. It also serves in instances when it is required to calculate benefit to cost ratio.

The following table lists some of the major important methods that use single criterion synthesis approach as depicted by Guitouni and Martel (1998). These methods are illustrated in Table 4.1.

Table 4.1: Single Criterion Synthesis Methods (Guitouni and Martel, 1998)

Method	Preference Elucidation Mode	Decision Problematic	Information Features	Degree of Compensation	Fundamental Hypothesis	Software Package
Fuzzy weighted sum	Direct rating	Choice	Non-Det.	Total	Ind., com., inv., tran., dom.,	
TOPSIS	Direct rating	Choice	Det.	Total	Ind., com., inv., tran., dom.,	
MAVT	Trade-offs	Choice	Det.	Partial	Ind., inv., tran., dom.	✓
UTA	Trade-offs	Choice	Det.	Partial	Ind., inv., tran., dom.	✓
SMART	Trade-offs	Choice	Det.	Partial	Ind., com., inv., tran., dom.,	✓
MAUT	Trade-offs	Choice	Non-Det.	Partial	Ind., inv., tran., dom.	✓
AHP	Pairwise	Choice and Ranking	Det., non-Det.	Partial	Inner & outer independence, inv., dom.	✓
EVAMIX	Direct rating	Choice and Ranking	Det.	Partial	Ind., com., inv., tran., dom.	
Fuzzy Maximin	Direct rating	Choice	Det. and non-det.	Non	Ind., com., inv., dom.	
Ind.: Independence, Com.: Commensurability, Inv.: Invariance, trans.: transitivity, dom.: dominance, Det.: Deterministic, Non-Det.: Non-Deterministic						

According to this table, only two methods offer complete ranking of alternatives: AHP and EVAMIX. However AHP has software to automate it while EVAMIX does not. Accordingly, AHP is preferred for dealing with the research problem. Furthermore AHP offers many benefits including:

- Modelling information in a hierarchical form which is an easy to use and understand form;
- Accommodating both subjective and objective criteria and taking into consideration the effect of people's feelings and emotions in the decision making process;
- The ability to measure a decision maker's consistency in his judgement yet allowing for a certain degree of inconsistency in order to cater for the element of irrationality that is involved in the decision making process in real life;
- The wide use of AHP in different fields including the areas of social, manufacturing, political, engineering, education, industry, government, sports, management, and others. The applications of AHP in engineering constituted 26% of its total use according to Vaidya and Kumar (2006). This implies its acceptability by both practitioners as well as the research community in the different fields. This point will be discussed in detail on Section 4.3.5.
- The preference indicated to use AHP over other MCDA methods as presented by Triantaphyllou and Mann (1989) in their comparison between weighted sum, weighted product and AHP, Salomon and Montevechi (2001) in their comparison between AHP, TOPSIS and

ELECTRE, and Peniwati (1996) in her comparison of AHP to Delphi method, outranking, and goal programming (Abdullah, 2003).

- In AHP some of the criteria may not be relevant in some instances despite their existence in the hierarchy. So it can cater partly for the problem of full compensation.

Finally, the effect of the cognition style on people's acceptability to MCDA methods including AHP is undoubtedly paramount. According to many authors such as Rowe and Boulgarides (1992) and Lu and Gustafson (1994), rational multiple attribute decision models are especially good for thinking (judgement style) and sensation people (perception style). These styles are related to Myer's and Briggs Type Indicator (MBTI) for personality types, who illustrate that personality can be described along four main dimensions: interaction preference (Extrovert or Introvert), information gathering preference (Sensing or Intuition), decision making preference (Thinking or Feeling), and structure preference (Judging or Perceiving) (Johnson and Singh, 1998). Many would argue that the majority of experienced engineers fall to each type. In a former study performed by the author on ten Egyptian engineers using reduced version of MBTI questionnaire, it was found that the subjects scored more towards the thinking style. They also scored slightly more on intuition than sensation. Despite the limited number of study subjects, it would imply the potential acceptability of AHP by Egyptian engineers as a way to solve multi-criteria problems.

4.3 THE ANALYTIC HIERARCHY PROCESS (AHP)

AHP was developed in the 1970's by Dr. Thomas Saaty, while he was a professor at the Wharton School of Business, and in 1983, Dr. Saaty joined Dr.

Ernest Forman, a professor of management science at George Washington University, to co-found the software called Expert Choice. Saaty (1994) defines AHP as "A framework of logic and problem solving that spans the spectrum from instant awareness to fully integrated consciousness by organizing perceptions, feelings, judgements and memories into a hierarchy of forces that influence decision results". This definition emphasizes the ability of AHP to present people's feelings in the judgement. Others such as Nydick and Hill (1992) describe AHP as "A methodology to rank alternative courses of action based on the decision maker's judgement concerning the importance of the criteria and the extent to which they are met by each alternative". In summary, AHP is "a decision aiding tool for dealing with complex, unstructured and multi-attribute decisions" (Patrovi, 1992).

AHP helps decision makers to set priorities and to arrive at the best decision when both qualitative and quantitative aspects of a decision need to be considered. The method represents complex decisions in a hierarchical form and elucidates preferences through a series of pairwise comparisons, then synthesises the results. It provides a clear rationale for the decision.

Saaty (1994) outlines six main steps involved in AHP:

1. Structure the problem in a hierarchical fashion;
2. Derive judgements that reflect ideas, feelings or emotions;
3. Represent these judgements in meaningful numbers;
4. Calculate priorities of the elements in the hierarchy utilising these judgements;

5. Synthesize the results;

6. Perform sensitivity analysis to study decision dynamics.

Many researchers including Fong and Choi (2000) and Skibniewski and Chao (1992) tend to consolidate these steps into three main stages, constructing hierarchy structure, performing prioritization procedures and synthesis.

4.3.1 Constructing the Hierarchy Structure

Saaty (1994) defines a hierarchy as a representation of a complex problem in a multi-level structure whose upper level is the objective followed by criteria, sub-criteria and alternatives at the bottom level as illustrated in Figure 4.2. The purpose is to assess the contribution of the elements in the lower levels to the fulfilment of the elements at the level above, using pairwise comparisons.

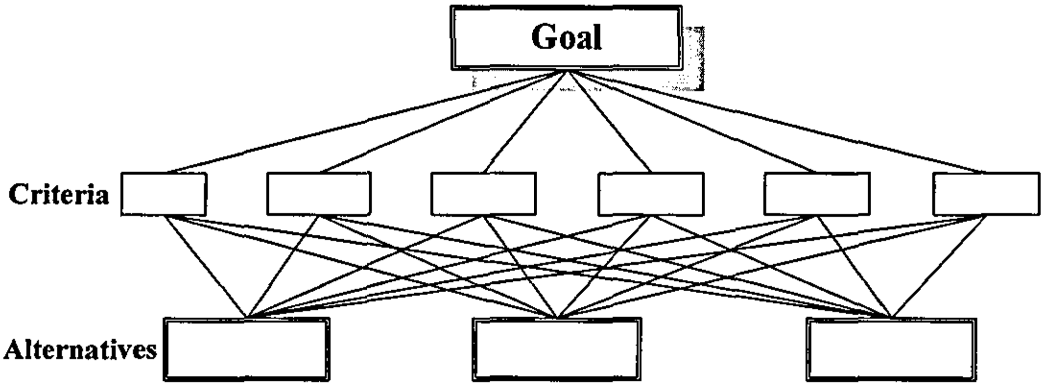


Figure 4.2: The Structure of a Hierarchy (Saaty, 1994)

There are two main types of hierarchies: structural hierarchies and functional hierarchies. In structural hierarchies, the system is decomposed into its constituent parts such as describing the universe in terms of galaxies, stars and planets. Functional hierarchies organise systems into parts based on the relationships between these parts.

The process of constructing the hierarchy requires creative thinking, association and other people's perspectives. The decision maker should include enough detail to describe the problem including the environment surrounding problem, the criteria that contribute to the problem, and participants to the problem. Related criteria should be clustered together where the general ones are located at higher levels and going down to the more definitive criteria. There are two ways to construct hierarchies either using a top-down approach or a bottom-up approach. The top-down approach is convenient when the number and type of alternatives is open and the decision maker needs to find a best choice from what is available at that time. The bottom-up approach is appropriate when the alternatives are limited in number.

According to Saaty (1994), there are three main benefits to the hierarchic structure employed by AHP:

- It shows how changes in priority at the upper levels affect the priority of the elements at the lower levels;
- It provides the decision maker with an overall view of the problem structure and the relationships between its constituent parts;
- It is stable and flexible; stable in the sense that small changes have a small effect and is flexible in the sense that additions to the hierarchy do not disrupt performance.

There is a criticism of the third point as AHP allows rank reversals in this case and this problem is discussed in Section 4.3.4.2. Having constructed the hierarchy, the next step is to perform prioritization procedures.

4.3.2 Prioritization Procedure

AHP performs prioritization procedures through pairwise comparisons. The decision maker compares criteria in pairs to assess their relative contribution to the fulfillment of the next higher level criteria linked to them. The same applies to the alternatives where they are compared to each other relative to the criteria at the next higher level (Vincke, 1992). AHP uses the term 'importance' in the comparison of criteria, preference in the comparison of alternatives, and likelihood in the comparison of different courses of action. It is important to note that criteria weights are often established independent of the alternatives. Otherwise they will be properties of a subset of alternatives and misleading results may occur. In general, the required number of pairwise comparisons in the case of comparing n number of criteria equals $n(n-1)/2$ judgements.

According to Saaty (1994), the ability to perform qualitative distinctions can be represented by five intensities: equal, moderate, strong, very strong and extreme. In order to ensure greater precision, compensation between adjacent intensities can be performed by adding weak, moderate plus, strong plus, and very very strong. The scale range is 1 to 9 because of the psychological limit that states that only 7 ± 2 items can be compared simultaneously in order to ensure reasonable precision of the results. The scale is illustrated in Table 4.2.

In some instances it may be necessary to incorporate group consensus for the judgement of pairwise comparisons when the decision maker prefers taking the views of other professionals. As illustrated by Vaidya and Kumar (2006) and Skibniewski and Chao (1992), this consists of preparing a questionnaire where other decision makers indicate their assessment on the fundamental scale. The average of their assessment can be used in the pairwise comparison. The next step is to organize the pairwise comparisons into a matrix and synthesize the results to obtain a ranking of the alternatives.

Table 4.2: The fundamental scale (Saaty, 1994)

Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak	
3	Weak importance of one over another	Experience and judgment slightly favour one activity over another
4	Moderate plus	
5	Essential or strong importance	Experience and judgment strongly favour one activity over another
6	Strong plus	
7	Demonstrated Importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

4.3.3 Synthesis

Synthesis is the process through which the pairwise comparisons are aggregated to produce a result. The following will illustrate the mathematical background of the synthesis process of AHP.

Saaty (1982), proposed that if we want to compare a set of objects $A_1, A_2, \ldots, A_n$ in pairs and their weights are $w_1, w_2, \ldots, w_n$, their pairwise comparison matrix can be represented by the following matrix of the underlying ratios (assumed to exist):

$$A = \begin{array}{c|cccc} & A_1 & A_2 & \dots & A_n \\ \hline A_1 & \frac{w_1}{w_1} & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_n} \\ A_2 & \frac{w_2}{w_1} & \frac{w_2}{w_2} & \dots & \frac{w_2}{w_n} \\ \dots & \dots & \dots & \dots & \dots \\ A_n & \frac{w_n}{w_1} & \frac{w_n}{w_2} & \dots & \frac{w_n}{w_n} \end{array}$$

The matrix has positive entries and satisfies reciprocal property of $a_{ij} = \frac{1}{a_{ji}}$

By multiplying matrix A by the column vector $w = (w_1, w_2, ...w_n)^T$ we obtain the vector nw and we have the following:

$$Aw = nw$$

Where A is known and w is required. In order to obtain w, we extend the above system to be in the following form:

$$(A - nI)w = 0$$

This equation has a non-zero solution if and only if, n is an eigen value λ of A, thus we can put it in the following form:

$(A - \lambda I)w = 0$ where $n = \lambda$ hence $|A - \lambda I| = 0$ in order to obtain a nontrivial solution

λ is the root of the characteristic equation of A that can be represented in the following form:

$\lambda^n + c_1\lambda^{n-1} + c_2\lambda^{n-2} + c_3\lambda^{n-3} + ... + c_n = 0$ (Iskandar, L. 1987)

w is required and represents the eigenvector of the characteristic equation and the required priorities of the objects $A_1, A_2, \ldots\ldots, A_n$.

However, A has unit rank since every row is a constant multiple of the first row. Thus all the eigen values $\lambda_i, i = 1, \ldots\ldots, n$ of A are zero except one

We also know that the trace of A can be calculated as follows:

$$\sum_{i=1}^{n} \lambda_i = tr(A) = \text{Sum of the diagonal elements} = n$$

Therefore only one of λ_i, we call it $\lambda_{\max}$, equals n and $\lambda_i = 0, \lambda_i \neq \lambda_{\max}$

Then we can easily calculate the corresponding eigenvector which represents the required priorities of the objects A.

There are two approximate ways to obtain the eigenvector w of the pairwise comparison matrix:

1. Multiply the elements in each row together and take the n^{th} root where n is the number of elements. Then normalize the column of numbers thus obtained by dividing each entry by the sum of all entries (Saaty, 1994); or
2. Normalize the elements by dividing them by their column summations hence obtaining the average of each row (Taha, 2003).

However, care should be taken as it may lead to rank reversal as illustrated by Saaty (1994).

AHP also measures consistency which actually determines to what extent the decision maker is exhibiting coherent judgement in specifying the pairwise comparison of the criteria or alternatives. In order to illustrate inconsistency mathematically Saaty (1994) illustrates that a small perturbation can be made as follows:

$a_{ij} = (w_i/w_j)\varepsilon_{ij}$, consistency occurs when $\varepsilon_{ij} = 1$

Looking at the original equation $Aw = \lambda_{\max} w$, we have for the ith equation:

$\lambda_{\max} = \sum_{j=1}^{n} a_{ij} \frac{wj}{wi}$ then we can define $\mu = -\frac{1}{n-1}\sum_{i=2}^{n} \lambda_i$

noting that; $\sum_{i=1}^{n} \lambda_i = n$ as n represents the sum of diagonal elements, which can be done by expanding $|A - \lambda I| = 0$ as follows:

$= (\lambda - \lambda_1) + ... + (\lambda - \lambda n)$ and equating coefficients, accordingly we can deduct that consistency index $C.I.$ can be written in the following form:

$$C.I. = \mu = \frac{\lambda_{\max} - n}{n-1}$$

Consistency ratio $C.R.$ is defined as the ratio between $C.I.$ and random consistency index $R.I.$. $R.I.$ represents the average eigen value to a randomly created reciprocal matrices using the scale $1/9, 1/8, ..., 1, ... 8, 9$

According to DeShutter's conjecture the random index can be put in the following form:

$$R.I. = 1.98 \frac{n-2}{n}$$

Finally consistency ratio can be put as follows;

$$C.R. = \frac{C.I.}{R.I.}$$

According to Saaty (1994) the value for consistency ratio should not exceed 10% in order to ensure a reasonable amount of consistency in the judgement. It is known that rational judgements have some element of inconsistency and that is why 10% was considered reasonable.

If the hierarchy is synthesised and the results are found to exceed the 10% inconsistency limit despite several attempts to change pairwise comparisons, this may suggest one of the following reasons (Cheng and Li, 2003):

1. Arbitrary response: this may happen if the information providers feel annoyed about the problem or if they are not willing to provide their judgements.
2. Careless mistake: this may happen if the questions are poorly designed so that the information providers are too confused to give accurate answers.
3. No relevant knowledge or experience: answers from people who do not possess the knowledge or experience to give appropriate judgement on the problem may not be built up logically.

Furthermore, Saaty (1994) suggests that it may indicate that the criteria are arranged without interrelation and a good way to improve consistency in this case, is to rearrange criteria in terms of their relevance.

4.3.4 Discussion

Turban and Aronson (2001) are of the view that reality is too complex and is usually simplified because it is hard to represent such complexity. For example, Karl Terzaghi, the father of soil mechanics assumed that soil has ideal properties such as homogeneity and isotropy, in order to be able to deal with complexities inherent in solving soil mechanics problems. AHP incorporates some fundamental assumptions that need to be highlighted. It is also worthwhile to discuss some of the critical points of the theory.

4.3.4.1 Fundamental assumptions

AHP is based on some fundamental assumptions including dominance and inner and outer independence (Guitouni and Martel, 1998). Saaty (1994) defines dominance as the link between relations among qualities and corresponding relations among magnitudes associated with these qualities. In order to specify dominance this question should be answered: given a pair of elements, how much more important is that one element compared to the other relative to fulfilling the goal. Another way is to specify the degree of closeness of each element to an ideal point. Importance, preference, and likelihood are used to express dominance of one criterion over another. A relative goal/criterion is required in this case for one entity to dominate another.

AHP assumes independence between alternatives and criteria and alternatives among themselves and criteria among themselves. According to Saaty (1994) outer dependence is the dependence of alternatives on an attribute in a set of attributes possessed by the alternatives. It is the degree or intensity with which that attribute is present in the alternative. Another form of outer dependence occurs in the opposite direction: which attribute of several is more important in this alternative. On the other hand, inner dependence is the dependence of an alternative on another alternative; it is the influence, contribution or impact of the second alternative on the first with respect to an attribute they have in common. It is clear in the research problem that the problem has a considerable degree of independence in terms of inner independence and outer independence although such independence is not easy to verify (Guitouni and Martel, 1998).

4.3.4.2 *Critical Points*

AHP, since its introduction in the 70s, has been criticised by some researchers for a number of issues including allowing rank reversal, its axiomatic basis and other issues. Belton and Gear (1983) and Dyer (1990), criticised AHP for allowing rank reversals. Rank reversal means that the ranking of alternatives changes whenever a new alternative (even irrelevant) is introduced. According to Millet and Saaty (2000), the axiom of rank preservation has its origins with Luce and Raiffa in 1957, who stated "The addition of new acts to a decision problem under uncertainty never changes old, originally non-optimal acts into optimal ones". This was considered by some including Millet and Saaty (2000) as a "poor suggestion". Nevertheless, the issue was subject to debate, until the third international symposium on the AHP reflected an integral view. It was agreed that AHP should support two different synthesis modes: one that preserves rank as proposed by Belton and Gear (1983) and Schoner *et al* (1993), ideal mode, and the original one that does not preserve rank, distributive mode.

Millet and Saaty (2000) explain that in 1994 Saaty accepted the two synthesis modes, distributive and ideal. The distributive mode normalizes alternatives' scores under each criterion so that they sum to one. This creates dependency on how well all other alternatives perform and hence the potential for rank reversal. On the other hand, the ideal mode preserves rank by dividing the score of each alternative only by the score of the best alternative under each criterion. Generally, the ideal mode should be used to obtain a single best alternative regardless of the other alternatives. The distributive mode should be selected if other alternatives do matter in the selection process.

Watson and Freeling (1982) highlighted the process of elucidating preferences in AHP by asking tedious questions such as: Which of these criteria is more important to the goal and by how much?. Some other researchers, Belton and Gear (1983) and Dyer and Wendel (1985), argue that AHP lacks a firm theoretical basis. On the other hand, Harker and Vargas (1987) and Perez (1995) discussed these criticisms and demonstrated that they are invalid and that AHP is based on a firm theoretical foundation. Furthermore, the wide use of AHP as expressed in literature shows that AHP is a viable, usable decision-making tool.

There are a number of instances in the history of science where theories have been used widely in practice before being proved theoretically. For example, there is evidence that the ancient Egyptians utilised the principles laid down in the Pythagorean Theorem (developed by Pythagoras, the Greek mathematician) in dividing land beside the Nile many years before it could be proved.

4.3.5 **Problems Solved Using AHP**

There is a wide diversity of applications that have used AHP. Vaidya and Kumar (2006), in their comprehensive review of 150 published articles on AHP applications, reveal that AHP was used for many themes such as selection, evaluation, benefit-cost analysis, allocation, planning and development, priority and ranking. It has been used both alone and in conjunction with other techniques such as neural networks, fuzzy theory, goal programming and dynamic programming. The wide use of AHP in different applications representing psychology, social science, manufacturing, politics, engineering, education, industry, and government, would imply its potential acceptability to practitioners as well as researchers. Some of the AHP applications are listed in Table 4.3.

Table 4.3: Some AHP Applications (Vaidya and Kumar, 2006)

Serial	Year	Authors	Application
1	2001	Al Harbi, K.M.	Contractor Selection
2	2000	Fong, P.S. and Choi, S. K.	Contractor Selection
3	2002	Mahdi *et al*	Contractor Selection
4	2000	Alhazmi, T. and McCaffer, R.	Project procurement system selection model
5	2001	Cheung, S., Lan, T., Leung, M. and Wan, Y.	Project procurement system selection model
6	2003	Marzouk *et al*	Evaluation of construction bids
7	2002	Abdullah and Anumba	Selection of demolition techniques
8	2002	Cheung, F.K.T., Kuen, J. L. F.	Evaluate architectural consultants
9	2004	Tabtabai *et al*	Negotiations and resolution of conflicts with an application in project management
10	1992	Skibniewski, M.J. and Chao, L.	Evaluate two types of cranes
11	2002	Al Khalil, M.I.	Select most appropriate project delivery method
12	2001	Byun, Dae Ho	Selection of a car
13	1994	Ceha, R. and Hiroshi Ohta	Aircraft selection for the operation on airport pairs

Serial	Year	Authors	Application
14	1999	Jung, H.W. and Choi, B.	Selecting best software product
15	2001	Kengpol, A., OBrien C.	Selection of Advanced Technology
17	1996	Korpela, J., Tuominen	Warehouse site selection
18	1999	Kuo, R.J., Chi, S.C. and Kao, S.S.	Selecting convenience store
19	2002	Lai, V., Wong, B.K. and Cheung, W.	Software selection using group decision making
20	1999	Lai V., Trueblood, R.P. and Wong, B.K.	Selecting software
21	1998	Mohanty, R.P. and Deshmukh, S.G.	Analyzing firms investment justification problem in advanced manufacturing technologies
22	2000	Noci, G. and Toletti, G.	Selecting quality based programs
23	1997	Schniederjans, M.J. and Garvin, T.	Select multiple cost drivers for activity based costing
24	1995	Shang J *et al*	Select appropriate flexible manufacturing system
25	2001	Tam, M.C.Y. and Tummala	Vendor selection of a telecommunication system
26	2001	Cagno, E., Caron, F. and Perego, A.	To assess and to evaluate the probability of competitive bidding
27	1994	Liberatore, M.J., Stylianou, A.C.	Strategic market assessment
28	1999	Sarkis, J.	Evaluation of environmentally conscious manufacturing program

Serial	Year	Authors	Application
29	1994	Weiwu, W. and Jun, K.	Method for comprehensive evaluation of highway transportation
30	1996	Angels, D.I. and Lee, C.Y.	A methodology that ties investment decisions to activity based costing
31	1999	Chin, K.S., Chiu, S. and Tammala, V. M. Rao	To evaluate success factors and to develop strategies to implement ISO14001
32	1997	Tummala, V.M. Rao, Chin, K. S. and Ho, S.H.	To check whether concurrent engineering could be implemented in the organization or not

Others such as Chim *et al* (2004) developed a generalised collaborative decision-making system that integrates the capabilities of the Internet, fuzzy logic and AHP.

4.4 STAGES OF DECISION MAKING

There is a multitude of methods that describe decision making stages such as the one mentioned by Turban and Aronson (2001) which consists of five stages: problem identification, generation of alternatives, choice, authorization and implementation. Kepner and Tregoe (1965) view decision making as being comprised of three main steps, problem analysis, decision analysis and potential problem analysis. Simon (1977) describes the rational decision making process as a four-stage process comprising intelligence stage, design stage, choice stage and implementation stage which are discussed in the forthcoming sections. It can be seen that these approaches are closely related.

4.4.1 Intelligence Stage

During this stage, the environment is investigated thoroughly and the final output is the problem statement. Many activities are associated with this stage such as problem identification, data collection, problem decomposition and classification.

4.4.2 Design Stage

During this stage the problem is represented (i.e. modelled), possible alternative solutions are identified and the principle for choosing these solutions is formulated. The problem representation should also be validated.

The research problem is represented in a hierarchical form where the objective (i.e. choosing the best construction method) is located at the top level and the alternative solutions are located at the bottom level. The criteria and subcriteria affecting choice are located at the intermediate levels linking the alternatives to the objective. The principle for choice is based on optimisation and the requirement is to find the construction method with the highest ratio of goal attainment to cost.

4.4.3 Choice Stage

During this stage, the model is utilised to arrive at the best solution. The search for an optimum answer to this model is done in four stages:

1. Identifying constraints that limit the use of construction methods. The output of this stage is a list of feasible construction methods;
2. Comparing feasible alternatives using AHP. The output of this stage is the ranking of feasible alternatives, which reflects the degree of their objective

attainment (i.e. benefit);

3. Calculating total cost of each feasible alternative;
4. Calculating benefit to cost ratio of each feasible alternative. The highest ratio represents the required optimum solution.

An important aspect of this stage is to study the dynamic behaviour of the optimal solution due to changes made in the model parameters. The effect of changes made to weights of criteria as well alternatives would result in a different result as indicated by Taha (2003) and Turban and Aronson (2001).

4.4.4 Implementation

This is the last stage in the decision making process at which the prototype is developed. The knowledge acquired from previous stages is represented. The decision support system developed to deal with the decision can be developed using a suitable software platform.

4.5 DECISION SUPPORT SYSTEMS (DSS)

Keen and Morton (1978) define a DSS as "Coupling the intellectual resources of individuals with the capabilities of the computer to improve quality of decisions. It is a computer based support system for management decision makers who deal with semistructured problems". DSS possess certain characteristics such as:

1. They support the decision maker in instances where computers alone cannot solve the problem. They require his/her views to control the whole process.
2. DSS are not meant to substitute the decision maker but rather to support him/her. Thus it should neither provide ready answers nor impose a

predefined sequence of analysis.

3. DSS may support some or all phases of the decision making process; intelligence, design, choice and implementation
4. DSS attempt to improve the effectiveness of the decision making process in terms of accuracy, time and quality. It requires a good interactive and enhanced dialogue between user and computer.

Multi-criteria Decision Support Systems (MCDSS) have developed in five stages starting from the early 1970's when the first primitive attempt took place. The latest generations of MCDSS integrate artificial intelligence capabilities such as learning, thinking and reasoning, and using knowledge and experience to manipulate the environment (Siskos and Spyridakos, 1999).

4.6 SUMMARY

The nature of the decision making process involves multi-criteria decision making. There are two main approaches that can be adopted to deal with the research problem which are the single criterion synthesise, and the outranking approach. The first approach prioritizes the alternatives in terms of goal attainment whilst the second one eliminates successively alternatives until identifying the appropriate one. Seven guidelines have been adopted in choosing a multicriteria method for the research problem where AHP was identified to have the potential to address the research problem effectively. It has been used successfully in many disciplines including engineering and economics. The next chapter discusses the procedures adopted to elicit knowledge from bridge experts to develop a system that evaluates construction methods of bridge superstructure.

CHAPTER 5: KNOWLEDGE ELICITATION

5.1 INTRODUCTION

This chapter discusses in detail the results of the techniques used in eliciting knowledge from bridge experts. Four main techniques were used: interviews; card sorting; questionnaires; and process tracing. The results for each of the techniques used are explained in the following sections.

5.2 SAMPLE

There are three main groups of participant to the decision to select an appropriate bridge construction method: contractors, designers and clients. The latter normally participate by approving the selected construction method proposed by the first two. Contractors are likely to possess a large portion of the expertise and knowledge to take this decision. However, designers in many cases pre-empt this decision during the early stages of project development especially if the contractor is not part of the development team. Ultimately, this research seeks to develop an intelligent decision support system using the knowledge of both designers and contractors.

Egyptian Law stipulates that all contractors and designers conducting contracting works in Egypt should be registered with the Egyptian Federation for Construction and Building Contractors. There are five main groups under which construction contractors can be registered. The first group is for buildings, foundations and specialised complementary services. The second group is for roads, bridges, railway, airports and tunnelling works. The third group is for water and wastewater treatment plants, and pipe networks for water, wastewater, natural gas and fuel. The fourth group is for water and thermal power stations and marine and dredging works. The fifth group is for electromechanical, electric and communications networks.

Under the second group for roads and bridges, there are seven categories that are differentiated on the basis of the financial capabilities to conduct contracting works in bridges and roads. These categories are illustrated in Table 5.1.

Table 5.1: Categories of Registered Contractors for Roads and Bridges in Egypt

(Dar Al Emara Al Dawlia, 2001)

Category number	Permitted value of work for a single project	Number of registered companies
1	Without upper limit	24
2	Max. £ 2,500,000	5
3	Max. £ 1,500,000	8
4	Max. £ 800,000	10
5	Max. £ 400,000	45
6	Max. £ 100,000	40
7	Max. £ 50,000	76

However, there were some limitations in using this table to obtain the survey sample of this research:

A- It represents registered companies for bridges and roads where the latter constitutes the majority of contractors;

B- Many of the contractors registered under the first category are foreign contractors that have not undertaken any or very limited bridge work in Egypt;

C- There are a number of companies that are working in other activities related to bridges such as repair work;

D- There are a number of companies working in the construction of steel bridges which are beyond the scope of this research.

Meetings were conducted with three bridge experts in order to identify the main players in the bridge construction industry. Two of these experts were contractors and the third one was a designer. The two contractors have been working in bridges for more than 25 years starting from site engineers to senior management positions. The designer had twenty years of experience in bridge design and his design office has been assigned most of the bridge works in Egypt. The results were as follows:

1. There are five main contractors working in bridge construction with long experience in Egypt and have constructed the majority of concrete bridge works in Egypt;
2. There are a number of small companies working on small bridges with spans between 10-15m which are located over small irrigation channels;
3. There are six main designers conducting most of the design for concrete bridges in Egypt with long experience in working for contractors and clients;
4. There are two main governmental organisations in Egypt that organise bridge works in Egypt.

Sixty experts were identified as possessing the expertise, and in many cases are the decision makers in their organisations, to select construction methods. They were also selected on the basis of their potential to cooperate with the researcher. These experts were used as the population for this research. They were approached by the researcher during the different stages of the research and the number of participants in each stage will be highlighted in the following sections.

5.3 SEMI-STRUCTURED INTERVIEWS

Several interviews were carried out at the beginning of the research in order to fulfil the following objectives:

1. To understand the selection process of structural systems and construction methods for concrete bridges in Egypt;
2. To understand the criteria affecting the choice of construction methods used in the sub-structure and superstructure;
3. To identify the construction methods used in Egypt; and
4. To familiarise participants with the research, explore their views of resource materials and their willingness to participate in future stages.

Semi-structured interviews are considered suitable because they encourage in-depth discussion and sufficient interaction between interviewees and the researcher whilst maintaining a level of comparability between interviewees. It also enables interviewees to express their opinions without being constrained or influenced by a previously defined framework. The interview questions were prepared as described in Section 2.4.3. The interview questions are presented in Appendix A. The sequence of asking questions to different interviewees was variable and depended on the course of the discussion.

Nineteen experts were contacted and only fourteen experts expressed their consent to provide the researcher with the required knowledge and cooperation. Seven of the interviewees had more than 25 years of experience, 4 had more than 20 years of experience, and 3 had more than fifteen years of experience in bridges. All sessions were recorded on tape except one interviewee who refused to record his session. Notes were taken in the latter case and analysed later. The recorded sessions were transcribed and the knowledge was extracted as will be illustrated in the next section. The distribution of the interviewees based on their profession is presented in Table 5.2.

Table 5.2: Interviewees by Role

Profession	Number of Interviewees
Contractors	10
Designers	3
Clients	1

5.3.1 **Results and Discussion**

The results and discussion will be aligned with the interview objectives as follows:

5.3.1.1 The Selection Process of Structural Systems and Construction Methods of Concrete Bridges in Egypt

At the early stages of the bridge industry development in Egypt, clients used to assign works to contractors on a cost plus fixed fee basis. Consultants used to prepare a preliminary estimate of the cost in order to determine the required budget for clients. During that time the decision of the construction techniques to be used was mainly in the hands of the contractor. Normally, budget overruns were unavoidable and lengthy procedures to assign additional funds for projects were encountered. Driven by the shortcoming of negotiated contracts and the changes in the world market, the competitive scheme was adopted on a wider scale. Recently, the government has adopted both competitive and negotiated forms with tighter control over the contractors in terms of costs and the influence of their appointed representative (i.e. designers) in the choice of the construction methods is more apparent.

In the case of design and build contracts, contractors apparently exhibit more freedom in selecting construction methods to be used when compared to build only contracts. Nevertheless, in the latter case, contractors normally present alternative solutions using different construction methods that they deem more competitive. Furthermore, it was also noted by interviewees that contractors, after being awarded a contract, may seek to alter the construction method as well as design, thus resulting in delays and excessive cost due to re-design. One designer highlighted an interesting point when he stated that in many of the build only contracts the designer must be well aware of the contractors' capabilities, so as to avoid tailoring the design to their specific construction capabilities. This will eliminate any claims of unfairness that may be posed by other contractors.

In the case of selecting structural systems the designer usually refers to previous cases of similar bridges and explores the use of their structural systems in new bridges. The interviewees attributed less attention to the choice of sub-structure construction system and focused on the superstructure as the main governing issue. They attributed that to the variety of alternatives and factors affecting the superstructure, thus making its selection process more difficult.

5.3.1.2 To Identify Criteria Affecting the Choice of Construction Methods Used in the Superstructure

The interviewees identified thirty seven criteria which they considered important in the selection process. These criteria are listed in Table 5.3 and are subsequently described in the following sections.

Table 5.3: List of Criteria Identified by Interviewees

Criteria		
1) Cost	14) System Complexity	27) Surrounding Area Nature
2) Duration	15) System Integrity	28) Accessibility
3) Deck Curvature	16) Effect of Construction Loads on the Design	29) Surrounding Road Network Capabilities
4) Deck Up/Down Grade	17) Percentage Applicability to the Bridge Structure	30) Obstacles
5) Deck Cross Section Shape	18) Competitive Advantage	31) Possession of Site
6) Superstructure Height	19) Future Use	32) Area for Storage
7) Span Length	20) Other Issues Affecting Stakeholder's Decision	33) Crane Manoeuvring
8) Machine Intensity	21) Site, Labour and Equipment Control Capabilities	34) Area for Workshops
9) Labour Intensity	22) Past Experience	35) Climate
10) Health and Safety for Constructors	23) Contractor Responsibility	36) Soil Conditions
11) Health and Safety of Third Parties	24) Contract Type	37) Land Topography Range
12) Quality of Concrete	25) Procurement	
13) Availability of construction method	26) Site Organization and Cleaning Levels, Emissions, Waste and Noise	

1) *Cost*

Cost is the most important criterion according to the interviewees; it refers to the cost required to complete the superstructure using a specific construction method. The participants outlined two main elements: the actual cost of construction and the cost of repair in case of problems arising during construction. The cost of construction entails many elements including the cost of procurement, system operation, and the cost of materials and other ancillaries.

The interviewees attributed the second element mainly to precast concrete as any deviations in the element properties from the client's requirements may prove costly as the segment in question may be scrapped and removed. Such a decision is not normally taken if cast in-situ concrete was being used.

The quantity of the materials associated with every construction method varies. It was also highlighted that the total cost of the bridge is a governing issue where normally highly expensive construction methods will not be used for small bridges or for bridges with a limited number of spans.

2) *Duration*

The main reason for adopting a cost-plus-fixed-fee approach by clients is the required speed in delivering the project. Thus most bridge projects have a tight time frame. There are two main elements contributing to duration according to the interviewees: duration required for normal operation and the time required for erection and dismantling. The time for normal operation is the time required for each cycle of the repetitive/non repetitive activities of the system. The time for erection and dismantling represents the time required for assembling units and lifting them into position until ready for normal operation and then dismantling them after completion. The latter is highly evident especially in advancing shoring, cantilever carriage and launching girder systems where considerable time is required for their assembly on the ground until ready for normal operation, and then dismantling them. In many instances the time for erection may take up to two or more months with lesser time for dismantling.

3) *Deck Curvature*

This criterion represents the horizontal curvature of the deck which is usually expressed in terms of the radius of curvature. In some techniques, the steel girders supporting the superstructure are supported on three piers. The presence of a straight line (or a curve having very high radius of curvatures) connecting supporting points is necessary to enable steel girders to have a sufficient area of support at the piers. This criterion is highly important in the advancing shoring, launching girder and horizontal incremental launching systems.

4) *Deck Up/Down Grade*

This criterion refers to the slope of the deck in the longitudinal direction. It is of relevance to many methods including advancing shoring system and launching girder systems where efficient brakes must be present in order to restrict the system from performing excessive movements. It is significantly more important in the incremental launching method where it is a contributing factor to the friction loads exerted on the pier top whilst pushing the system to the new position.

5) *Deck Cross Section Shape*

There are three main shapes used in the construction of the superstructure, box section, beams and slab section and slab section. Some methods can only be used for beam and slab cross section, box cross section or slab cross section while other methods can use any of these three cross section shapes.

6) Superstructure Height

This criterion refers to the height of the superstructure above the supporting ground and limits the use of some methods such as stationary formwork as explained by the interviewees.

7) Span Length

This criterion refers to the length between centre lines of the piers supporting the superstructure under study. It is important for all methods due to the limitations imposed by the system as longer spans entail heavier weight of both permanent structure and the construction method. Many methods are only possible for a certain limit of span length either because of strength problems or due to anticipated excessive deflections in the falsework.

8) Machine intensity

This criterion represents the amount of machinery involved in the construction technique where methods possessing this criterion are characterised by their significant dependence on machinery (e.g. cranes, hydraulic systems, etc.). The interviewees believed that such methods would yield better quality, safety and less time when compared to labour intensive methods. This criterion may be more important when working in remote areas where the cost of importing and accommodating labour may prove uncompetitive.

9) *Labour Intensity*

This criterion is attributed to instances where the use of labour is intensive. In some countries, such as Egypt, this criterion is favourable due to the low cost of labour.

10) *Health and Safety for constructors*

This refers to the safety of the personnel working on the construction site and the number of accidents and fatalities associated with each technique. Mixed responses were obtained from interviewees with some of them stating that in selecting a construction method it is of less significance as every method has its safety characteristics. Others stated that it should be considered as a major factor when deciding upon working in Egypt given the non-familiarity of Egyptian labourers with some techniques which may constitute a safety problem.

11) *Health and Safety of Third Parties*

This refers to the health and safety of the public. This item is especially important in downtown areas or in areas in close contact with roads and other utilities that involve the public.

12) *Quality of concrete*

According to the interviewees, this criterion refers to the quality of the finished surface of the concrete. The measures for strength should be fulfilled under all circumstances as it involves the structural safety of the bridge. The quality of the finished surface of concrete is important in bridges where in some methods, such as cantilever carriage, discrepancy in colours between segments (i.e. every 3-5m) may prove unsatisfactory to some clients. It is rare but it was classed as a factor by an interviewee.

13) *Availability of Construction Method*

This criterion represents the availability of the construction method with the contractor and has been considered by some as the basis for the selection of the construction methods. The availability of the construction method does not only mean less cost but also has impact on duration because of eliminating the time required for procuring new system. Nevertheless, in most cases extra costs will be incurred due to the modifications and/or maintenance required to the existing system.

14) *System Complexity*

This has been stated by some interviewees as a preference basis in certain circumstances. If there are two methods eligible for use with similar cost and time implications, the simpler system will be preferred. This criterion is evident when comparing stationary formwork to cantilever carriage or advancing shoring systems as the latter two types involve hydraulic and electrical control and are more sensitive to mistakes.

15) *System Integrity*

This criterion refers to the degree of dependence of the technique on other equipment during erection and dismantling. The interviewees illustrated how this criterion affects their decision by comparing the stationary formwork with an elevated platform with the advancing shoring technique. In the first technique the system when used for several spans, has to be handled with cranage and other supporting equipment. On the other hand the advancing shoring system is more integral as its repetitive movement and erection to the next span requires limited contribution of cranes. This does not negate the fact that most techniques require extensive loading equipment during first time erection and final dismantling.

16) Effect of Construction Loads on the Design

According to the interviewees, especially designers, if the proposed construction method produces excessive loads on the structure that would require extensive considerations in the design of the permanent structure, it may prove less competitive when compared to other methods with lesser effect on design. This fact also means that if there are unacceptable changes in the shape of the permanent structure to cater for the construction method's requirements, the method may be rejected.

17) Percentage Applicability to the Bridge Structure

Most interviewees generally preferred to use one construction technique for each project. However, if the site condition varies it is sensible and practical to use more than one method. For example, the range of usable methods for construction over water differs from that over land. Other cases of previously constructed bridges suggest that two construction methods have been used in order to shorten construction duration and to decrease cost.

18) Competitive Advantage

This criterion and the next two criteria, represent the hidden agenda of stakeholders of the decision process. In some instances the decision maker may choose to use a new technique because it increases his/her chances in future projects as clients would accord him/her higher scores during prequalification.

This criterion is more pronounced in cost-plus-fixed-fee projects where cost is not tightly constrained.

19) Future Use

Decision makers may prefer some construction methods as they may be used in future projects in hand with the decision maker. In other cases, the decision maker may contact a client to foresee their future intentions for new projects to be tendered and studies the techniques that may be used. However the latter case is not normally used as the basis for the decision making due to its unreliability. This unreliability is a result of the unforeseen changes in the government plan where projects may be postponed for the sake of others which are deemed more important.

20) Other Issues Affecting Stakeholders' Decision

Some of the stakeholders in the selection of construction techniques may have other issues affecting their decision, which are not related to any of the criteria mentioned here. Some clients and consultants may not approve of certain techniques because of their previous unsuccessful experience in other projects either through usage in Egypt or through some of the problems reported in books or journals. *Prima facie,* the technique under consideration is not approved, although extensive persuasion may lead to its acceptance. This criterion may explain the reason why some techniques were not used at all in Egypt despite their competitiveness in many projects.

21) Site, Labour and Equipment Control Capabilities

The ability of the contractor to control and organize the site is an important consideration. Some methods require high organisational capabilities of site, labour and equipment such as cantilever carriage and slip forms. The interviewees highlighted cases where construction was unsuccessful because the contractor was not able to manage his site resources efficiently.

22) Past Experience

This refers to the past experience of the decision maker's firm in using this construction technique. This criterion has important implications on the cost, duration as well as safety. The fact that the contractor has trained staff in a specific technique could mean a preference for using such a technique.

23) Contractor Responsibility

Design and build contracts entail more responsibility on the contractor when compared to build projects. In some instances, in design and build projects, the contractor may decline to use one construction technique because he/she is not happy with the amount of risk borne by him/her or because he/she is not very confident in his/her designers' capabilities. He/she may prefer to share the risk with the client or to revert to less risky techniques. It has to be noted, however, that the contractor is obliged by law to review and check designs but in that case the responsibility will be shared with the designer.

24) Contract Type

The type of contract, whether negotiated or competitive, affects the choice of one construction technique over another from the part of the decision maker. More freedom is exhibited under negotiated contracts by contractors, with more chances for profit. Conversely, clients face more chances of budget overruns.

25) Procurement

The Middle East region has faced a great deal of political instability in recent years with considerable impact on the economy and national revenue. It is more difficult to import techniques from abroad because of the possible lack of foreign currency during these times where locally manufactured techniques may be preferred. In certain projects that are built under grants from foreign countries, the grant agreement may endorse exemption from taxes on the techniques used thus encouraging decision makers to import from abroad.

26) Site Organisation and Cleaning Levels, Emissions, Waste and Noise

Some of the methods may have negative implications on the site organisation, such as stationary formwork, which may be unacceptable to some authorities in certain cases. The emissions, noise, and waste of the supporting equipment and the techniques may constitute a problem during construction of the superstructure.

27) Surrounding Area Nature

The nature of the area surrounding the site is an important aspect, whether it is a site of an archaeological and tourist nature, downtown area, desert, agricultural lands, etc. In tourist sites, the issues of safety and security are important. In downtown areas, techniques exhibiting less interference with the ground are generally preferred.

28) Accessibility

This criterion refers to the degree of accessibility to the site. It investigates the rules of access which may be constrained by the authorities or third parties for one reason or another.

29) *Surrounding Road Network Capabilities*

This refers to the ability of the existing road network in terms of width and permissible loads to be used to transport goods and construction components to and from site.

30) *Obstacles*

There are five main obstacles that have been identified by interviewees including waterways, railway lines, roads, valleys, and utilities. While some methods were predominantly used over water (such as cantilever carriage) other methods (such as stationary formwork) cannot be used normally over water. There are cases where stationary formwork on an elevated platform were used within waterways after making some changes to the site such as building an embankment or where temporary foundations on water are used as supports.

31) *Possession of site*

One of the interviewees stated that in many instances the handing over of the site is not full but partial, especially downtown. Thus techniques depending on progression from one point without interruption may not be preferred as they may come to a halt at some time during the construction process until possession of the relevant area has been done by the contractor.

32) *Area for Storage*

This criterion explores whether the site has enough space to cater for any special requirements of the construction techniques for storing material and equipment.

33) Crane Manoeuvring

Most of the methods used require cranes to help in the erection or operation of the construction technique. The existence of an area for crane manoeuvring is very important in that sense.

34) Area for Workshops

The availability of an area for workshops is important for many methods especially for precast methods where a relatively large area is required to establish the precast yard.

35) Climate

It is another criterion which refers to climatic conditions and their effect on the construction techniques. For example, if the site is located in the desert where high speed wind storms are expected, severe limitations on the use of some techniques under such circumstances may affect productivity drastically. In that case another method may be preferred.

36) Soil Conditions

The soil conditions are important in choosing construction methods with special regard to stationary formwork. In this case, the soil must have enough bearing capacity to sustain construction loads. In some methods where intermediate supports may be required, this criterion may prove important as well.

37) Land Topography Range

The variation in the levels of the ground may constitute a limitation in using some methods such as stationary formwork. While stationary formwork can be used for limited variations in the land topography levels, small adjustments to the site are required using bulldozers or loaders to enable its use.

5.3.1.3 To identify construction methods used in Egypt

Eight construction methods were identified as the main methods used in Egypt as follows:

1. Stationary system supported on ground
2. Stationary system using an elevated platform
3. Cantilever construction by in-situ concreting using two form travellers
4. Cantilever construction by in-situ concreting using one form traveller and stationary system
5. Advancing shoring system
6. Launching trusses used to erect precast prestressed beams
7. Erecting bridge beams using cranes or heavy lifting
8. Horizontal incremental launching system

The procedures and characteristics of each method were discussed in Chapter 3.

5.4 CARD SORTING

The main objective of this technique was to arrange the criteria identified from the semi-structured interviews in a hierarchical fashion. Two experts (one designer and one contractor) participated in a series of sessions so as to construct the hierarchy. One of the experts had over than 25 years of experience in bridge construction and the other one had 20 years of experience in design works. Each criterion was written on a magnetic backed strip and the participants were asked to arrange them on a steel board, under seven main headings: cost, duration, bridge physical characteristics, construction methods characteristics, stakeholders objectives, external constraints and surrounding environment. These headings were selected by the researcher after examining all the criteria identified in the semi-structured interviews in order to provide a starting point for the hierarchy. The experts were asked to verify these headings at first and to delete or add others if he/she deemed appropriate. After finalising the hierarchy it was printed on A3 paper and demonstrated to the same experts for further enhancement and finalisation. The finalised hierarchy was presented to four more experts for further scrutiny and enhancements.

5.4.1 Results

The constructed hierarchy is illustrated in Figure 5.1. The sub-criteria associated with cost are the actual cost of construction and the cost of repair in case of problems during construction. Duration was divided into two further criteria which are erection and dismantling, and the total cycles. Bridge physical characteristics were divided into method orientation (labour or machine intensive), health and safety, quality of concrete, system availability, system complexity, system integrity, effect of construction method loads on the permanent design, and percentage applicability of method to the structural design.

Stakeholders' objectives were divided into three sub-criteria. External constraints were divided into two more sub-criteria while the surrounding environment was divided into three sub-criteria: commercial aspects, environmental requirements and site condition.

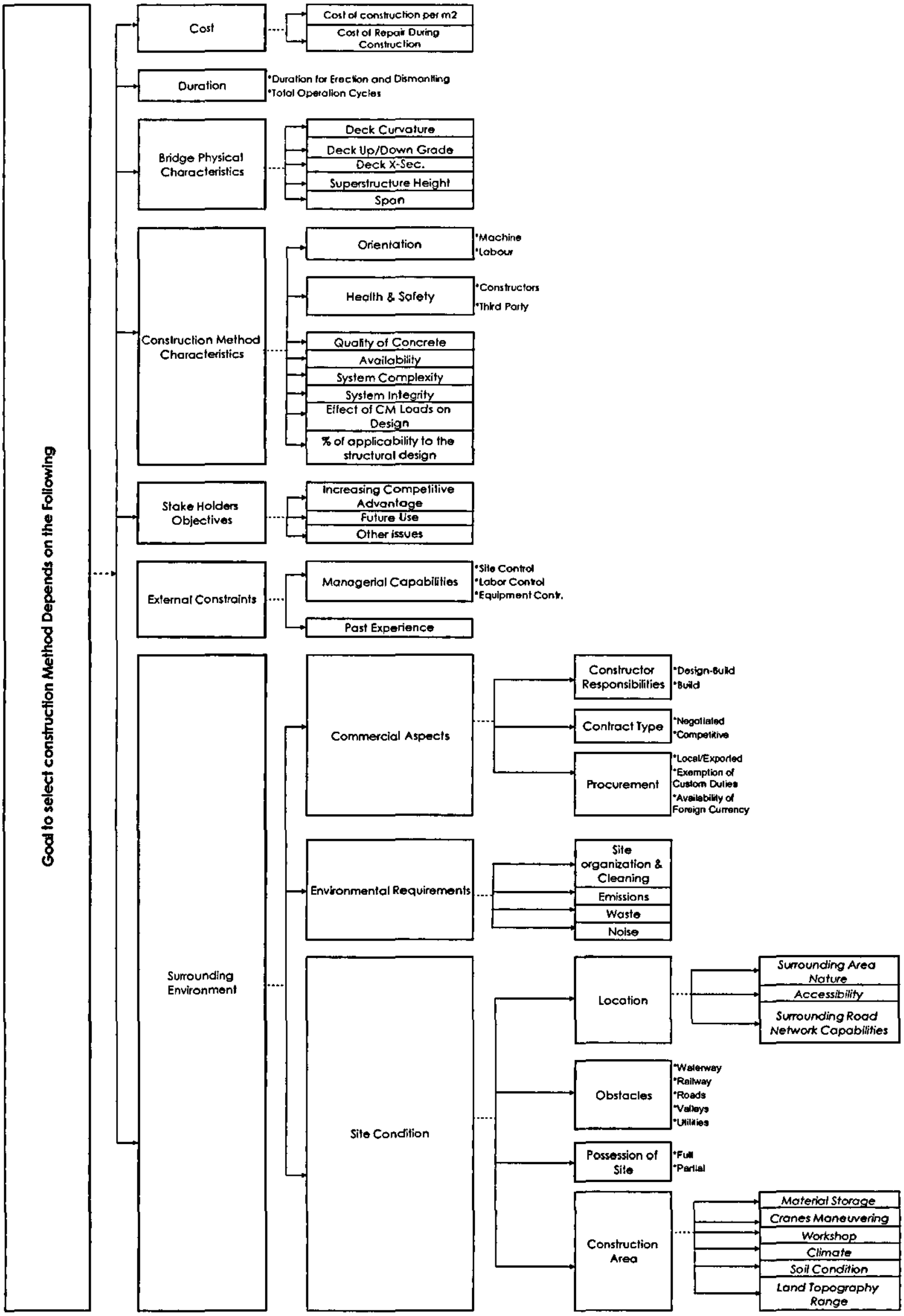


Figure 5.1: Overall Hierarchy of Criteria

5.4.2 Discussion

As discussed in Section 4.3.1 there are two types of hierarchies: structural hierarchies and functional hierarchies. The main attention was focused on organising criteria representing the second type as illustrated in Figure 5.1 in discrete boxes. However, sub-criteria deemed to be of a structural nature were also arranged and indicated in annotations beside the relevant criteria or sub-criteria and preceded by *. They provide further explanation of the corresponding main criteria. The developed hierarchy was part of the questionnaires sent to experts, as explained in the next section.

5.5 QUESTIONNAIRE SURVEY

The aim of the questionnaire survey was to obtain broad based knowledge from the bridge construction industry. There were two specific objectives for conducting the questionnaires survey:

- To obtain further information on specific aspects of the decision process;
- To rank criteria identified from the card sorting sessions in order of importance so as to produce a refined generalised hierarchy.

5.5.1 Questionnaire Design

The questionnaire was divided into three main parts. The first part works as an introduction where the research background was demonstrated and some basic information was required from respondents (e.g., name, organisation, etc.). The second part enquired about specific aspects of the decision making process including the decision maker, and the stage at which the decision takes place. The third part requires respondents to rank each level in the hierarchy of criteria and sub-criteria identified from card sorting session. The questionnaire is included in Appendix B.

5.5.2 Pilot Survey

In the research, a pilot survey was conducted to check the appropriateness and clarity of the questions and to capture the respondent's possible reactions to the questionnaire. Two bridge practitioners, from the group that will eventually complete the survey, were handed two copies to review and give comments. A meeting was conducted with each of them to ensure that their feedback was fully implemented by the researcher. Few modifications were made to the questionnaire survey as a result of these comments including:

- Several questions were rephrased and explained for clarity;
- The questions were referred to the corresponding level in the hierarchy;
- An Arabic translation of the questionnaires was provided in addition to the English version.

The latter point proved invaluable as the lack of English language competence among many respondents would have had negative consequences on their responses.

5.5.3 Survey Sample

The bridge engineers, and in some cases the top management of bridge contracting companies, are the persons responsible in making the decision to select the construction techniques. Therefore, the survey population was confined to targeted respondents in Egypt. Convenience sampling was adopted, with experts who were willing, and available, selected. All the targeted respondents were contacted by telephone to make sure of their willingness and to confirm their address before the questionnaires were sent. Finally, 52 respondents agreed to participate in the questionnaire survey. The questionnaires were distributed by hand or by special messenger. Several phone calls were made, to those who had not responded, reminding them about the questionnaire and asking for their response.

5.5.4 Results

Thirty two questionnaires were returned, out of the 52 questionnaires sent. Thirty one questionnaires were usable, which represents a response rate of 60%, and is relatively high when compared to what Fellows and Liu (1997) envisage in this type of survey: 25-35% response rate. This high response rate may be attributed to the fact that most respondents have been contacted by phone and were handed the questionnaires by the researcher himself or by a special messenger. One response was unusable because it was not complete as the respondent asked to meet the researcher and was reluctant to complete questionnaire by himself. Table 5.4 summarises the survey response data.

Table 5.4: Questionnaire Survey Responses

Number of questionnaires sent	52
Number of replies received	32
Number of usable replies	31
Percentage of usable replies	60%

Background Information

The survey was sent to design firms, construction companies and clients. Seventy four percent of the responses received were from contractors, 20% from designers and 6% from clients. The number of respondents for each profession is indicated in Table 5.5. The respondents who had 20 years or over of experience were the largest group constituting 57% of the total responses. Forty three percent of the respondents had between 10 to 19 years of experience, while 11% had between 4 to 9 years of experience constituting the lowest group. The distribution of responses among different years of experience groups is illustrated in Figure 5.2.

Table 5.5: Responses by profession

Profession	Number of Respondents
Contractors	23
Designers	6
Clients	2

The Decision Maker in the Process of Selecting Suitable Construction Method for the Superstructure

Thirty one percent of the respondents stated that the designer is the decision maker when it comes to selecting construction method, while 29% of the respondents felt that the decision for selecting a construction method lies with estimators, 19% considered it to lie with project managers, 12% the Engineer, 7% site managers, and 2% with clients (see Figure 5.3)

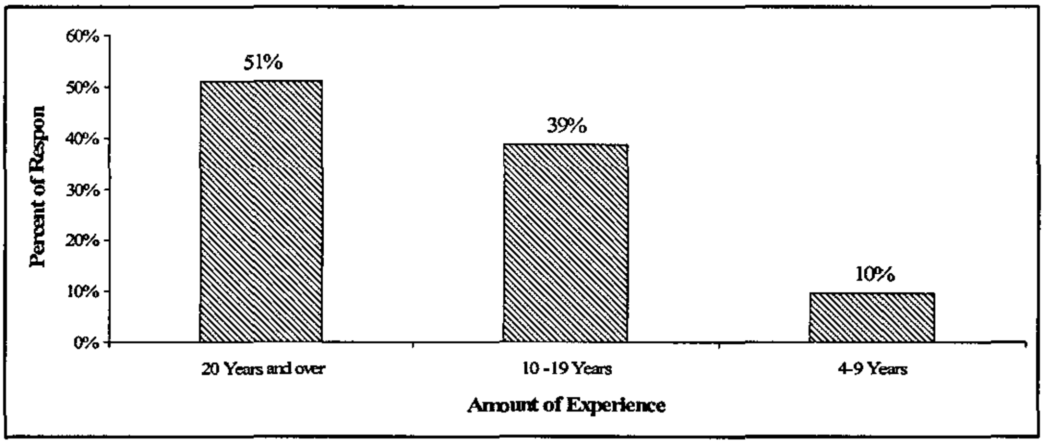


Figure 5.2: Distribution of Years of Experience among Respondents

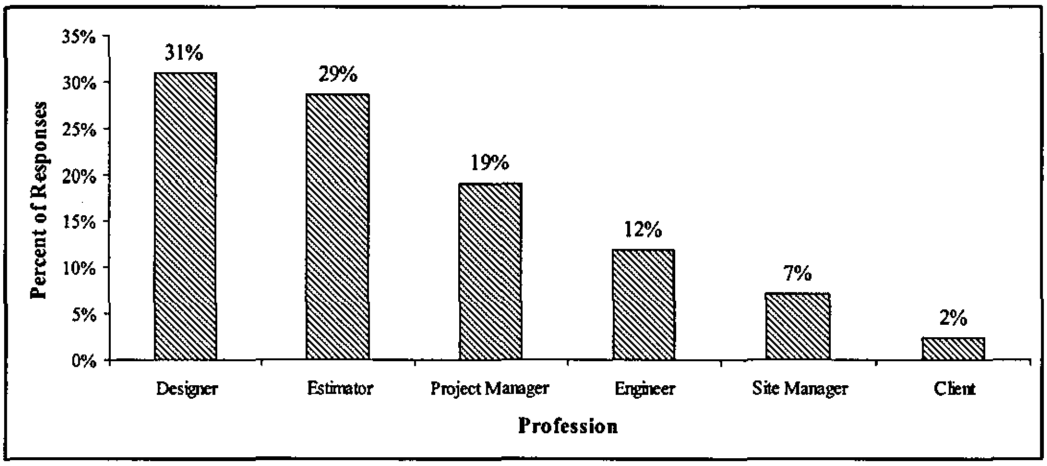


Figure 5.3: The decision makers of the construction methods of superstructure

The Stage at which the Construction Method is Selected

Forty seven percent of the responses stated that the decision is taken during scheme design, 41% conceptual design, 9% inception, and 3% detailed design. The distribution of the responses is shown in Figure 5.4.

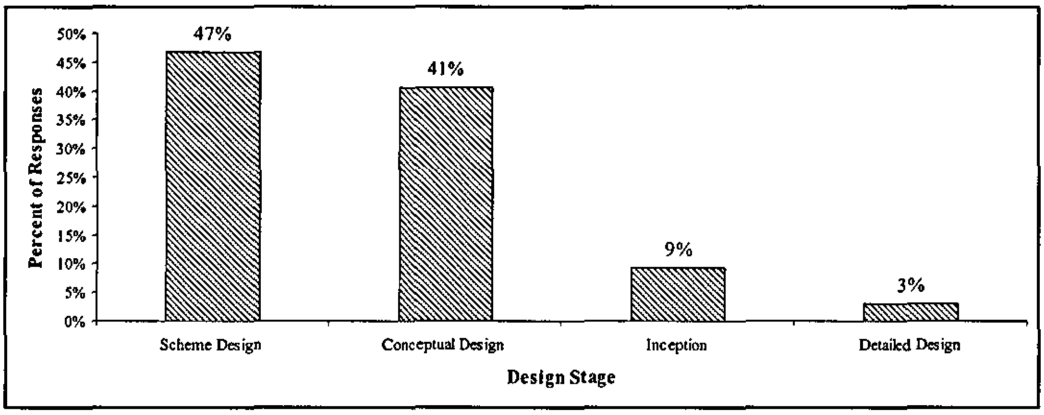


Figure 5.4: The percent of responses for design stages

Using Specific Procedures in Selecting Construction Methods

In responding to this question 68% of the respondents said that they use specific procedures, while 32% do not use any specific procedures.

Describing Procedures Used to Select Construction Methods

The respondents did not reveal any clear description of the selection procedures. They mentioned some of the criteria illustrated in the hierarchy attached to questionnaire such as site nature, obstacles, duration, cost, span, width of bridge, and availability of construction methods. They also mentioned bridge nature, strategic importance of the project, and site topography.

Using computers during this process

Fifty five percent of the respondents indicated that they use computers while 45% do not use any IT tools in the selection process.

Suggestions to Improve Selection Process of Bridge Construction Methods

The answers to this point highlighted the following points:

a) Designers should explore new bridge systems and avoid constraining themselves to their previous expertise;

b) Co-operation between designers and contractors should increase. It is also beneficial that contractors provide feedback based on their expertise;

c) The selection process should focus on achieving minimum duration with high quality and minimum cost;

d) The information related to construction techniques, stages, cost, and production rates as well as required resources, should be stored electronically at a central location. Others also indicated that a database should be developed for previous projects and should contain previous problems and their solutions;

e) Computers can be used more to increase effectiveness and efficiency;

f) The process of designing construction techniques and the quality of the produced drawings should be enhanced;

g) The economics of production for the different techniques should be explored thoroughly in future projects;

h) The chosen structural system should take into consideration the pre-requisites of the suitable construction method;

i) To search for the best expertise that suits a construction method before construction starts;

j) To co-operate with international companies to gain knowledge and expertise of the new techniques;

k) Explore criteria affecting choice of construction techniques and measure their influence where finished projects are considered as case studies with particular emphasis given to projects with similar conditions utilising different techniques;

l) Provide training to young engineers in order to transfer experience to them from experts.

Important Criteria

The respondents were asked to rank criteria at each level in the hierarchy from the most important 1 to the least important N. The ranking of each level represented one question in the questionnaire. The average rank for each level in the hierarchy was calculated (i.e. based on the number of criteria). The average ranking for the responses was calculated for each criterion. The criterion with an average rank that is less or equal to the average rank of its level, are considered important while criteria with an average rank above it are deemed less important to respondents. As an example for calculating rank average in the case of question 9 (i.e. Q9) illustrated in Table 5.3 is as follows:

$$\text{Rank Average of (Q9)} = \frac{1+2+3+4+5+6+7}{7} = 4$$

For the first level of the hierarchy, as cost will be used to calculate benefit/cost ratio, the first eligible criterion was selected (i.e. construction method characteristics) instead. The results of the average scores, the rank average and evaluation of each criterion are indicated in Table 5.6.

Table 5.6: Results of Criteria Ranking

Question No.	Criteria		aver.	Rank Aver.	Evaluation
Q9	Main Criteria	Cost	2.52	4.00	Important
		Duration	3.03		Important
		Bridge Physical Characteristics	2.65		Important
		Construction Method Characteristics	4.26		Less Important
		Stake Holders Objectives	5.42		Not Important
		External Constraints	6.00		Less Important
		Surrounding Environment	4.00		Important
Q10	Cost	Cost/M2	1.10	1.50	Important
		Cost of repair during construction	1.90		Less Important
Q11	Duration	Erection & Dismantling time	1.77	1.50	Less Important
		Total Cycles	1.23		Important
Q12	Bridge Physical Characteristics	Deck Curvature	3.00	3.00	Important
		Up/Down Grade	4.19		Less Important
		Deck X-Sec.	2.97		Important
		Superstructure height from ground	2.94		Important
		Span	1.90		Important
Q13	Construction Method Characteristics	Orientation	6.27	4.50	Less Important
		Health and Safety	4.31		Important
		Quality of Concrete	4.52		Less Important
		Availability of CM	3.53		Important
		System Complexity	5.53		Less Important
		System Integrity	4.28		Important
		Effect of CM Loads on Design	4.03		Important
		% Applicability to structural design	2.79		Important
Q14	Stakeholders Objectives	Increasing competitive advantage	1.65	2.00	Important
		Future Use	1.42		Important
		Other Issues	2.93		L. Import.

Question No.	Criteria		aver.	Rank Aver.	Evaluation
Q15	External Constraint	Managerial Capabilities	1.84	1.50	Less Important
		Past Experience	1.16		Important
Q16	Surrounding Environment	Commercial aspects	2.48	2.00	Less Important
		Environmental Requirements	2.26		Less Important
		Site Conditions	1.26		Important
Q17	Orientation	Machine Intensive	1.23	1.50	Important
		Labor Intensive	1.77		Less Important
Q18	Health and Safety	Constructors	1.19	1.50	Important
		Third Party	1.81		Less Important
Q19	Managerial Capabilities	Site Control	1.39	2.00	Important
		Labor Control	2.45		Less Important
		Equipment Control	2.16		Less Important
Q20	Commercial Aspects	Constructor Responsibilities	2.40	2.00	Less Important
		Contract Type	1.73		Important
		Procurement	1.87		Important
Q21	Environmental Requirements	Site Organization and Cleaning	1.87	2.50	Important
		Emissions	2.84		Less Important
		Waste	2.52		Less Important
		Noise	2.71		Less Important
Q22	Site Conditions	Location	2.32	2.50	Important
		Obstacles	1.74		Important
		Possession of Site	3.55		Less Important
		Construction Area	2.39		Important

Q.	Criteria		aver.	Rank Aver.	Evaluation
Q23	Constructor Responsibilities	Design-Build	1.07	1.50	Important
		Build	1.93		Less Important
Q24	Contract Type	Negotiated	1.71	1.50	Less Important
		Competitive	1.29		Important
Q25	Procurement	Local	1.48	2.00	Important
		Exemption of Customer duties	2.52		Less Important
		Availability of Foreign Currency	2.00		Important
Q26	Location	Surrounding Area Nature	2.00	2.00	Important
		Accessibility	1.84		Important
		Surrounding road network capabilities	2.16		Less Important
Q27	Obstacles	Waterway	2.19	3.00	Important
		Railway	2.68		Important
		Roads	3.61		Less Important
		Valleys	3.68		Less Important
		Utilities	2.84		Important
Q28	Possession of Site	Full	1.35	1.50	Important
		Partial	1.65		Less Important
Q29	Construction Area	Material Storage	4.29	3.50	Less Important
		Cranes Maneuvering	2.94		Important
		Workshop	4.45		Less Important
		Climate	4.68		Less Important
		Soil Condition	2.13		Important
		Land Topography	2.81		Important

5.5.5 Discussion

Although some of the respondents indicated that they use specific procedures in selecting an appropriate construction method, they were unable to identify them. Most respondents described the process in terms of the criteria involved. It implies that the use of a multi-criteria decision tool would satisfy their expectations for a successful decision support system for dealing with the selection problem. Although the respondents were asked to rank the criteria in terms of importance, careful consideration should be given to criteria that are deemed less important. The objective of this questionnaire is to generalise a problem where a refined hierarchy is to be produced. It means that in the majority of bridge projects, this hierarchy would include the necessary criteria. In order to cater for extreme cases the overall hierarchy identified through interviews will be made available to the users within the decision support system should the need arise.

The results suggest that 88% were of the view that the choice of the construction method is made very early in the bridge development life cycle. The majority of the respondents stated that they use computers but merely as away of storing data and/or performing calculations. The responses to other questions support this explanation as they suggested that having databases containing problems and their solutions, the stages in each method, resources, production rates, etc would be useful.

Figure 5.5 illustrates the refined hierarchy after performing the necessary modifications to reflect the respondents' ranking of the criteria.

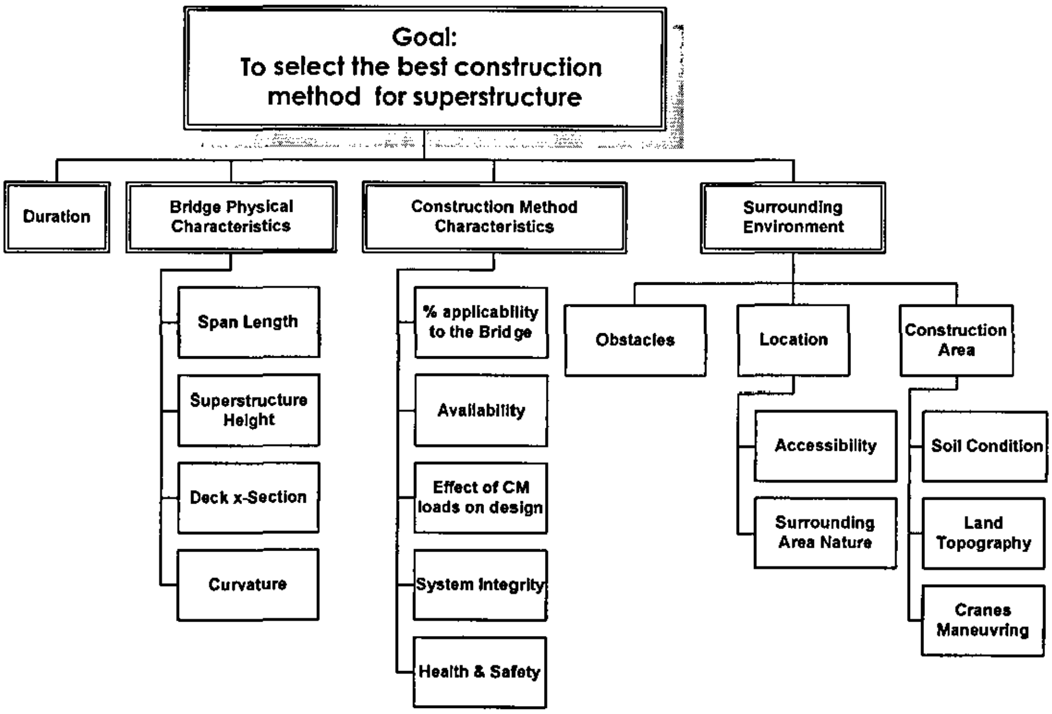


Figure 5.5: Refined Hierarchy of Criteria and Sub-Criteria

5.6 STRUCTURED INTERVIEWS

Structured interview sessions were conducted with three of the industry experts in order to obtain their views on the conditions governing the use of each of the construction methods in Egypt. These experts were 2 contractors and 1 designer. The two contractors had more than 25 years of experience while the designer had 17 years of experience. The main objective was to elicit their perception of the practical limits constraining the use of these construction methods. The interviewees were presented with an A3 tabular questionnaire and were asked to complete it. The interviewees completed a list of questions describing the conditions of using alternatives in terms of the shape of the cross section, height of the superstructure from ground, span, horizontal curvature, surrounding area nature, accessibility, type of obstacles, cranes manoeuvring capabilities, soil conditions, land topography range and type of concrete used.

5.6.1 Results

The results of the interviews are presented in Table 5.7. Ticks represent applicable methods whereas crosses identify unsuitable methods.

5.6.2 Discussion

The knowledge elicited during these interview sessions, explores the respondents' views on the conditions affecting choice of construction methods. The selected criteria represent bridge structure as well as site conditions which usually limit the use of certain construction methods. The main aim for eliciting this knowledge was to limit the number of methods compared in the decision support system as will be seen in Chapter 6. The methods of practical applicability to the given design should be utilised. On the other hand, there is a fear that some of these methods may be eliminated where they could have been included in the comparison. Accordingly, extreme caution should be exercised in utilising this knowledge in developing the prototype system.

The elicited knowledge was compared to the knowledge contained in textbooks such as Mathivat (1979). The comparison illustrates that, in some instances, the perception of Egyptian experts on the limits of using construction methods is behind techniques capabilities. For example, experts stated that both incremental launching and advancing shoring systems can be used for maximum spans of 50m and 60m respectively. However, Mathivat (1979) specifies that they can be used for up to 100m and 85m respectively. This implies that these two methods in Egypt have not been stretched to their full capacity. Although, predictably, in most cases this will entail at least modifying the existing systems, their presence in the selection domain is important as they may prove competitive when compared to other systems.

Table 5.7: Conditions of Using Construction Methods

Conditions of Use		Superstructure Construction Methods							
		Stationary formwork		Free Cantilever			Erecting beams		
		Stationary formwork	Creating an Elevated Platform	Using 2 travelers	Using 1 traveler	Advancing Shoring	Using launching Trusses	using Cranes	Incremental Launching
Suitable Deck X-Sec.	Box Section	✓	✓	✓	✓	✓	▨		✓
	Slab and Beam	✓	✓	✗	✗	✗	✓	✓	✓
	Slab	✓	✓	✗	✗	✓	▨		✓
Suitable Range of Superstructure Height above Ground	0-10 m	✓	✓	✓	✓	✗	✓	✓	✓
	10-15m	✓	✓	✓	✓	✓	✓	✓	✓
	15-20m	✓	✓	✓	✓	✓	✓	✓	✓
	20-30m	✗	✓	✓	✓	✓	✓	✓	✓
	30-40m	✗	✗	✓	✓	✓	✓	✗	✓
	40-50m	✗	✗	✓	✓	✓	✓	✗	✓
	50-60m	✗	✗	✓	✓	✓	✓	✗	✓
	>60m	✗	✗	✓	✓	✓	✓	✗	✓
Range of Span Length	0-10m	✓	✓	✗	✗	✗	✓	✓	✓
	10-20m	✓	✓	✗	✗	✗	✓	✓	✓
	20-30m	✓	✓	✗	✗	✓	✓	✓	✓
	30-40m	✓	✓	✗	✗	✓	✓	✓	✓
	40-50m	✓	✓	✗	✗	✓	✓	✓	✓
	50-60m	✓	✓	✗	✗	✓	✓	✗	✗
	60-70m	✓	✓	✓	✓	✗	✗	✗	✗
	70-100m	✓	✓	✓	✓	✗	✗	✗	✗
	>100m	✓	✓	✓	✓	✗	✗	✗	✗

Conditions of Use		Superstructure Construction Methods							
		Stationary formwork		Free Cantilever			Erecting beams		
		Stationary formwork	Creating an Elevated Platform	Using 2 travelers	Using 1 traveler	Advancing Shoring	Using launching Trusses	using Cranes	Incremental Launching
Suitable Horizontal Curvature	Small	✓	✓	✓	✓	✓	✓	✓	✗
	Medium	✓	✓	✗	✗	✗	✓	✓	✗
	Large	✓	✓	✗	✗	✗	✗	✗	✗
Suitable Surrounding Area Nature	Downtown	✗	✓	✓	✓	✓	✓	✓	✓
	Desert	✓	✓	✓	✓	✓	✓	✓	✓
	Agrarian	✓	✓	✓	✓	✓	✓	✓	✓
	Others								
Accessibility	Require accessibility	✓	✓	✗	✗	✗	✗	✓	✗
	Does not require accessibility	✗	✗	✓	✓	✓	✓	✗	✓
Obstacles	Waterway	✗	✓	✓	✓	✓	✓	✗	✓
	Railway	✗	✓	✓	✓	✓	✓	✓	✓
	Utilities	✗	✓	✓	✓	✓	✓	✗	✓
Cranes Maneuvering!	Require area for crane maneuvering	✓	✓	✓	✓	✗	✗	✓	✓
	Doesn't require area for crane maneuver.	✗	✗	✗	✗	✓	✓	✗	✗
Soil Condition	Strong	✓	✓	✓	✓	✓	✓	✓	✓
	Medium	✓	✓	✓	✓	✓	✓	✗	✓
	Weak	✗	✗	✓	✗	✓	✓	✗	✓
Land Topography Range	0-100cm	✓	✓	✓	✓	✓	✓	✓	✓
	100-200cm	✓	✓	✓	✓	✓	✓	✓	✓
	>200cm	✗	✓	✓	✓	✓	✓	✗	✓

Conditions of Use		Superstructure Construction Methods							
		Stationary formwork		Free Cantilever			Erecting beams		
		Stationary formwork	Creating an Elevated Platform	Using 2 travelers	Using 1 traveler	Advancing Shoring	Using launching Trusses	using Cranes	Incremental Launching
Type of Concrete	Prestressed-Precast	✓	✓	✓	✓	×	✓	✓	✓
	Prestressed/Cast in-Situ	✓	✓	✓	✓	✓	×	×	×
	R.C./Preacast	✓	✓	×	×	×	×	✓	×
	R.C./Cast In-Situ	✓	✓	×	×	×	×	×	×

5.7 PROCESS TRACING

The objective of using this elicitation technique is to investigate the items constituting the cost components for each of the construction methods. The knowledge on how the estimation process is performed by experts needed to be captured in order to compare the costs to the benefits arising from using different techniques. Since this knowledge involves "process", process tracing and protocol analysis were chosen to elicit this knowledge. There are two main objectives for undertaking process tracing:

1. To investigate how bridge experts estimate the cost of construction methods; and
2. To identify the cost elements involved in each type of construction technique.

An experienced estimator was asked to think aloud while generating the cost elements of the construction methods. He had fifteen years of experience and has been working as a bridge estimator for ten years. He was informed of the overall aim to compare these construction methods. A series of sessions were conducted and recorded. The finalised model of the cost elements was demonstrated to two other experts, who had more that 25 years of experience, to express their opinions, which were then discussed with the estimator, and the model was finalised.

5.7.1 Results

There are two main types of estimates by which bridge experts calculate the cost of construction methods. The first is by calculating the preliminary cost based on the cost per square metre of the bridge deck area. This is an approximate method and is used widely by experts either to determine a rough estimate of the cost at the beginning or to check the rationality of detailed estimates. The second type of estimate is detailed and offers better accuracy in calculating costs.

The detailed estimating process was traced and the protocols were constructed into a list that contains the elements of the cost involved for each technique. Nine main cost elements were identified by experts as constituting the cost involved in the calculation of the detailed cost for construction methods: general, formwork, falsework, concrete, steel reinforcement, prestressing, bearings, expansion joints and others. Some of these elements were further sub-divided into one or two levels depending on the technique used. It was found that the components of the items general, formwork and falsework generally vary from one technique to another. However, the components of concrete, steel reinforcement, prestressing, bearings, expansion joints are normally the same for all methods. These cost element are presented in Appendix E. The item, "others", includes the items that may differ from one bridge to another and are not covered by the above mentioned items.

5.7.2 Discussion

The participants suggested that preliminary cost estimates may be used based on the cost of the deck area per metre square. Although approximate, it provides enough guidance especially at the early stages of bridge development. Inflation should be taken into consideration in these calculations. Contractors revert to detailed cost estimates if they are required to submit an alternative solution with their basic offer, as their offer will be legally binding. There are three main items identified initially by the experts as the main components of the cost of any bridge project which are: direct cost, indirect cost and mark up. Direct cost elements were identified and discussed in Section 5.7.1. However, to simplify the process and taking into consideration that ultimately the requirements are to compare construction methods in terms of cost, it was decided to focus on the direct cost as the other items should normally be the same. The items pertaining to indirect costs would vary from one method to another and were included in the item "general" (e.g. general equipment). However, should further cases arise for changes between techniques in the calculations of the indirect costs and/or mark-up they can be included in the item "others". In some instances, the decision maker may decide to change mark up between techniques in order to cater for other objectives such as increasing competitive advantage. This item "others" may also include the total cost of substructure and piers as their cost may be affected by the changes in the superstructure.

5.8 SUMMARY

This chapter has discussed the knowledge elicitation process adopted in order to obtain the knowledge required to develop a decision support system that helps in selecting construction techniques of the superstructure. This process involved capturing and transforming appropriate information from bridge engineers into a manageable form that can be utilised. There were five main techniques used to fulfil this objective. Semi-structured interviews were conducted in order to capture and understand the criteria affecting selection of construction methods, whereby 37 criteria were identified. The card sorting technique was used in order to develop a hierarchy that organises these criteria into a comprehensible format. Questionnaire surveys were used to rank criteria in order of importance and to understand some of the specific facets of the decision making process. Structured interviews were conducted in order to capture the conditions for using each construction method. It revealed that the experts' perception about the use of some of the construction methods falls behind the methods capabilities. Process tracing and protocol analysis were used in order to identify cost elements of the construction methods. The next chapter discusses the development and operation of a prototype decision support system using the knowledge elicited in this chapter.

CHAPTER 6: SYSTEM DEVELOPMENT AND OPERATION

6.1 INTRODUCTION

This chapter presents the development and operation methodology of the prototype system development. The system architecture is presented and the process adopted in the development of the system modules. The operation of the prototype system, including data input and results, are also described.

6.2 SYSTEM DEVELOPMENT

Turban and Aronson (2001) define System Development as an orderly approach that is used to enable systems to become reality. The traditional system development life cycle provides a structured approach to development where four main phases are involved including planning, analysis, design and implementation. During the planning phase, the need for the system is identified and its feasibility is examined in terms of systems technicality, cost and organisational fit. The analysis phase addresses issues related to users and system objectives, leading eventually to the development of the process and data models. The design phase is concerned with explaining how the system works and it is when the details of software and hardware are specified, including the user interface, forms, displays, programs, databases, and files. The implementation stage integrates the results of the planning, analysis and design phases so as to construct the system and verify that it is free from errors. Satzinger *et al* (2004), indicate that these phases are sometimes referred to as the waterfall approach as shown in Figure 6.1.

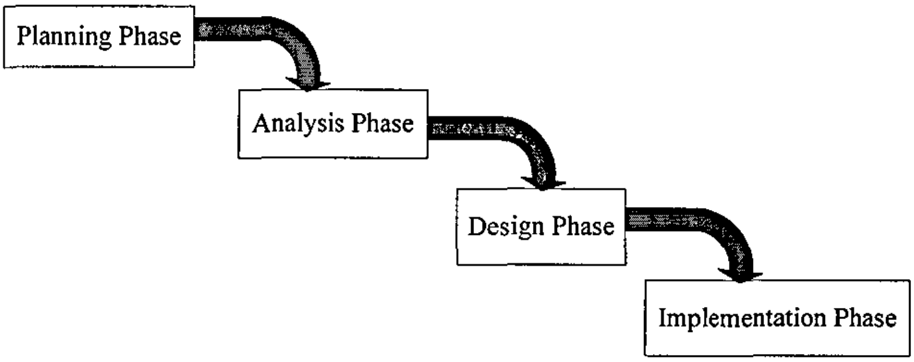


Figure 6.1: The Waterfall approach to the system development life cycle (Satzinger *et al*, 2004)

There are a number of methodologies for development under the traditional system development life cycle depending on the manipulation of the development phases. Examples of these methodologies are the parallel approach and the rapid prototyping approach. In the parallel approach the design and implementation phases are split into several concurrent sub-phases each addressing certain aspects (i.e. sub-systems) of the system. These sub-systems are integrated to compose the final product at the implementation phase. In rapid application development, the system is developed quickly and iteratively so that the user obtains some functionality at a very early stage.

Whitten *et al* (2004) identify two main reasons that instigate developers to use the rapid application development strategy. It enables the active participation of system users in the analysis, design and implementation activities. It accelerates the process through an iterative construction approach thus enabling the rapid presentation of the system to users.

Turban and Aronson (2001) state that there are three main methodologies for rapid application development including phased development, prototyping, and throwaway prototyping. In phased development, the system evolves sequentially in a series of versions where each version has more functionality than the previous one until the final product is reached. Prototyping is the major methodology used in developing DSS where analysis, design and implementation are performed concurrently and are repeated if necessary to enable rapid provision of the system where users' input can be used to refine the system. In throwaway prototyping, a design prototype is developed to help in understanding the system. This prototype is developed on simpler development platforms as pilot tests so as to understand user requirements as well as problems. Once the pilot test is successful, the prototype is discarded and a preliminary design of the real system takes place where it is completed following any of the system development life cycle models. The latter type is some times referred to as "discovery prototype" (Satzinger *et al*, 2004)

Turban and Aronson (2001), indicate that rapid prototyping may be regarded as a convenient approach to develop DSS which normally deals with semi-structured or unstructured problems. These problems are not normally fully understood by the researcher and the decision maker from the beginning. Rapid prototyping may also be referred to as iterative design or evolutionary development.

6.2.1 Rapid Prototyping

Rapid prototyping was the approach adopted to develop the decision support system BridgeConstruct. McGraw and Harbison-Briggs (1989) define rapid prototyping as "a technique in which a simplistic model of the system is devised to demonstrate some functionality, to experiment with different approaches, and to evoke user feedback". Chau *et al* (2003) demonstrate that rapid prototyping has its origins in the manufacturing of industrialised products. As presented earlier, rapid prototyping is one adaptation of the traditional system development life cycle. According to Hix and Hartson (1993), systems adopting this approach are developed sequentially in modules. After completing each module, it is refined and deployed to users. The next module is then developed, refined and added to the system over time, and so on. The system evolves as more and more modules are developed subject to the available budget and development time. Throughout the development process the researcher and users are able to refine the way older sub-systems work and use their new-found knowledge in developing new modules. As more is learned about the structure of the real system from decision makers new knowledge is incorporated into the newer modules and older ones are updated.

McGraw and Harbison-Briggs (1989) indicate that rapid prototyping is favourable in small, better understood problems rather than complex ones where other approaches may be deemed more appropriate. However, Turban and Aronson (2001) argue that it enables researchers dealing with decision problems to learn more about them as decision makers are involved in the various phases of the development process.

Hix and Hartson (1993) demonstrate the rapid prototyping process in Figure 6.2. The process starts with system analysis in order to understand the decision problem as reflected by Laudon and Laudon (1998) who define system analysis as "the analysis of the problem that the organisation will try to solve with an information system and consists of defining the problem, identifying its causes, specifying the solution and identifying the information requirements that must be met by a system solution".

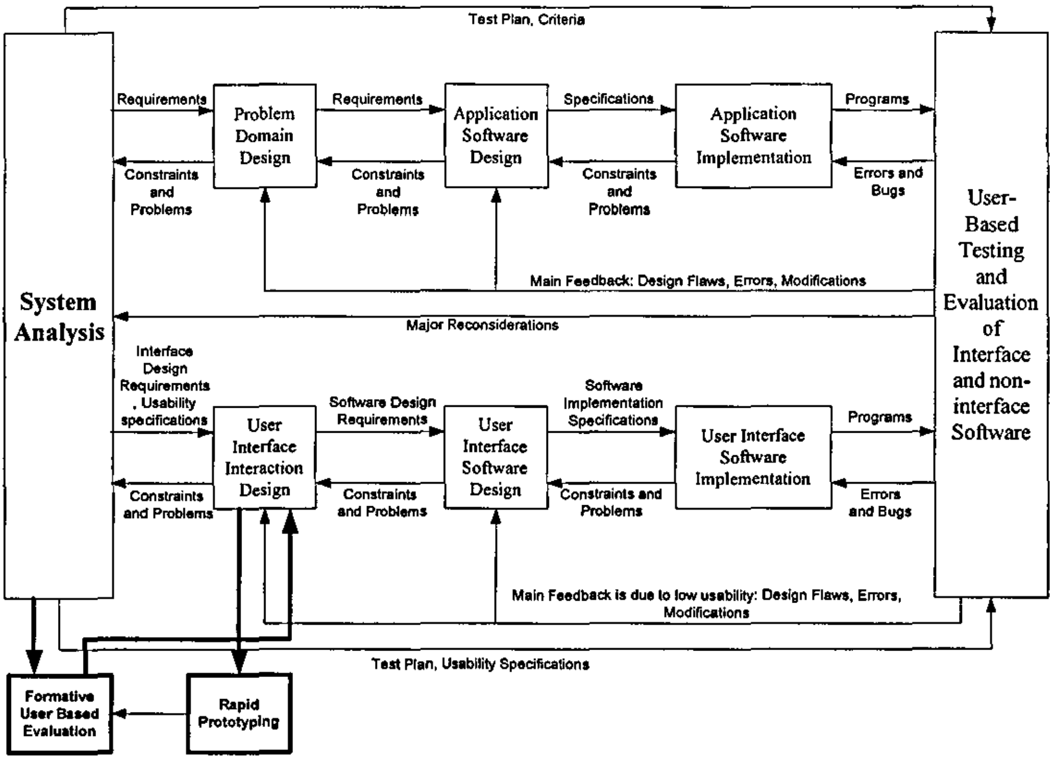


Figure 6.2: Rapid Prototyping Process (Hix and Hartson, 1993)

The process goes along two main courses, development of the application structure and the user interface. Along the first course, the structure of the database tables and their relationships, queries, SQL statements, and integrating Microsoft Access with Expert Choice constituted the main issues. The second course involved the development of the user interface including forms, combo boxes, list boxes and reports. In both directions the process is attributed with constant review and feedback so as to improve the system.

6.3 PROBLEM DEFINITION

The problem begins when bridge engineers are required to select an appropriate construction technique for the superstructure for a concrete bridge project. Bridge engineers are normally required to address a number of issues or criteria in the course of making this decision. These issues are incorporated into their decision and are assessed based on their experience as well as intuition, in order to arrive at a sound decision. According to Lu (1995), expert's intuition is good in defining important criteria but poor in combining and assessing them. The developed prototype system, which is called "BridgeConstruct", addresses this problem and enables bridge practitioners to assess the appropriateness of construction techniques by combining the important criteria affecting the decision whilst stressing the intuitive element that is usually attributed to this decision process. The functional architecture of the prototype that supports the decision maker in such decisions is presented in the next section.

6.4 FUNCTIONAL ARCHITECTURE OF THE PROTOTYPE SYSTEM

BridgeConstruct consists of four main modules that describe the system's functional decomposition as illustrated in Figure 6.3. The first module, the introductory module, informs the decision maker of the different components of the system, their objectives and how to use them. This module also includes information about different construction techniques. In the second module, the system identifies the feasible construction techniques based on the project and site conditions, which are input by the decision maker.

In the third module, the feasible alternatives are compared based on the developed hierarchy in order to obtain their prioritization (i.e. their relative weights). Module four deals with cost calculations which are determined by using either the preliminary cost model or detailed cost model. Finally the benefits calculated in module three are compared to the cost calculated in module four so as to rank alternatives in order of merit, where the highest ratio presents the most favourable construction technique.

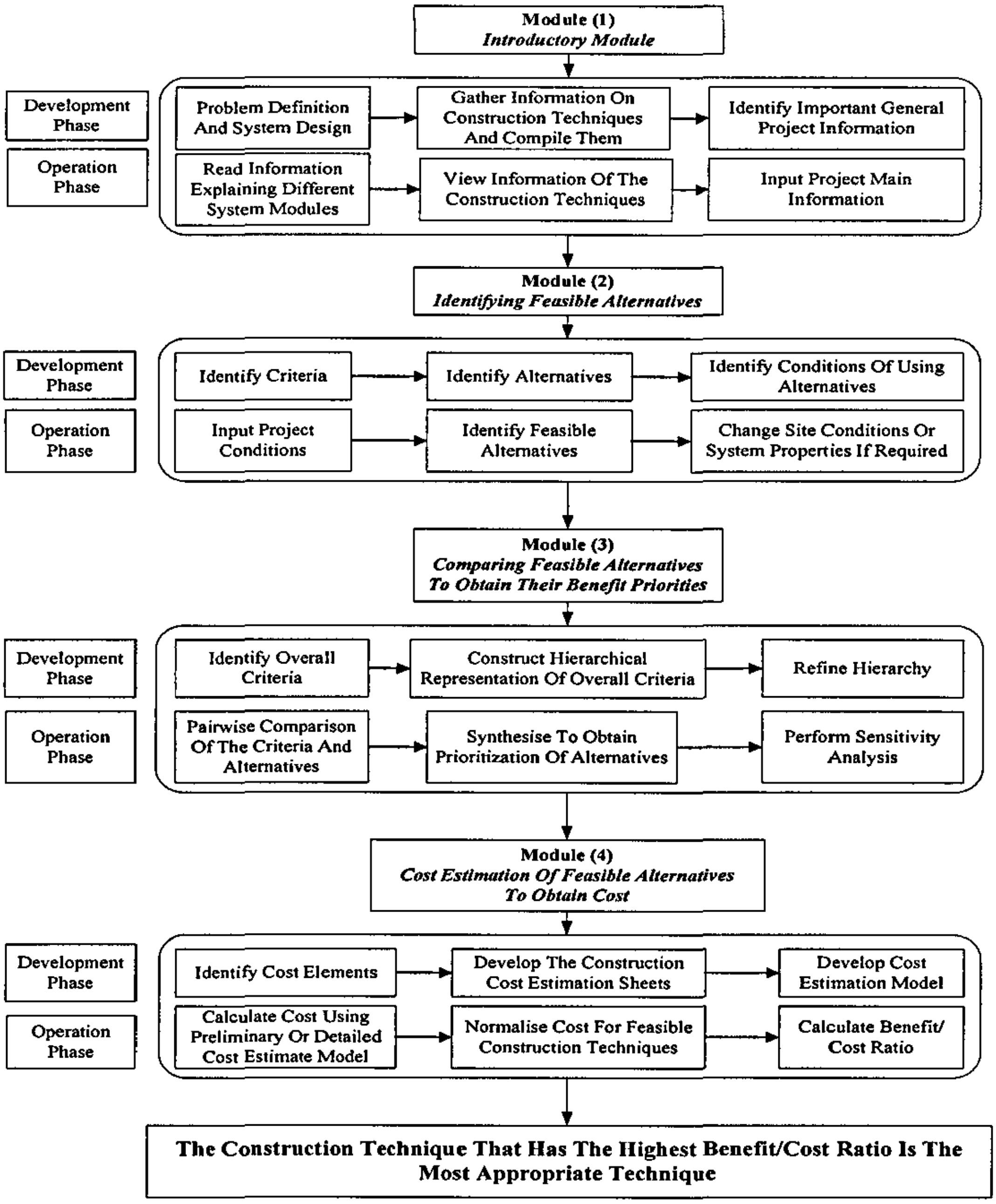


Figure 6.3: Functional Architectural Decomposition of the Prototype System

The concept of maximizing benefit to cost has its roots in the assumption that decision makers are economic beings who try to maximize benefit per unit cost as discussed in Section 4.1.2.2. By fulfilling the input requirements of these modules the decision maker will be able to make sound judgements taking into consideration the different criteria that contribute to his/her decision.

6.5 PROTOTYPE SYSTEM DEVELOPMENT

6.5.1 Context

Multi-criteria Decision Support Systems (MCDSS) as part of DSS consist mainly of three main components: data sub-system, model sub-system and dialogue sub-system. The data sub-system manages data storage, update and retrieval while the model subsystem includes the software that implements the multi-criteria decision making in a structured approach. The dialogue sub-system provides the interface between the system and the decision maker (Siskos and Spyridakos, 1999).

Little (1970) argues that in order for a DSS to be successful, it must be simple, robust, easy to control, adaptive, complete on important issues, and easy to communicate with. Lu *et al* (2000) in their research on one hundred and eight participants of senior Management Information Systems students concluded that the perceived ease of using DSS has no direct bearing on users' preference or willingness to use it. The findings suggest that DSS designers should place more emphasis on making users believe that a DSS is useful rather than focusing on the development of an easy-to-use interface.

6.5.2 Development Environment

Acknowledging these findings, BridgeConstruct integrates the capabilities of three software systems: Microsoft Access, Expert Choice and Microsoft PowerPoint. Microsoft Access is used as the main interface that incorporates project information, identifies feasible alternatives, and calculates both cost and benefit/cost ratio. Expert Choice is used to deal with the multi-criteria evaluation where the construction techniques are ranked in terms of their goal attainment. It is also used to examine their sensitivity of the construction techniques. Microsoft PowerPoint is used to view information on the different construction techniques. Microsoft Office products are used by most PC users which makes it advantageous to use Microsoft Access as the main interface for the prototype system and offers a tremendous usability advantage.

Multi-criteria evaluation could have been done using other packages such as Microsoft Excel, however the capabilities offered by Expert Choice, favoured its use. Abdullah (2003) lists some of the useful features of Expert Choice as follows:

1. It offers a friendly graphical display that enables the decision maker to build the model easily and view it conveniently using a tree view or a cluster view;
2. The methods of elucidating judgements using pairwise comparisons may be performed numerically, verbally or graphically;
3. Consistency is examined throughout the process for every level in the hierarchy;
4. It is capable of performing sensitivity analysis which is seen by many as one of its powerful determinants.

Furthermore, Expert Choice 2000 files are structured based on Microsoft's

Access (Expert Choice Manual, 2000). This fact reduces conflicts that may arise during system operation due to integrating Microsoft Access and Expert Choice.

The next sections will discuss the development of the prototype system modules.

6.5.3 Development of the Introductory Module (Module 1)

The introductory module presents the initial stage of the system that the user sees on activating the system. The main objective of this module is to provide the user with help in order to understand how the system works. It also contains hyperlinks to Powerpoint presentations that shed light on the various techniques used in the construction of the concrete bridge superstructure. Most presentations contain video files and all of them contain pictures describing construction techniques as well as the process used in construction. These presentations can also be placed on an organisation's server and accessed by users connected to the network. A pilot test was performed to verify that it operated without problems. The introductory module is primarily used as a way of communicating with users and can also be activated during the operation of the other modules.

6.5.4 Development of the Module that Identifies Feasible Alternatives (Module 2)

Semi-structured interview sessions were conducted and eight construction techniques were identified as being used in the construction of the superstructure of bridges in Egypt. During the development process some of these alternatives were eliminated by practitioners using rules of thumb. Such elimination permits the decision maker to focus on a limited subset of alternatives instead of examining them all in later modules where extensive effort is required. The conditions of use are portrayed along three main technical criteria that affect the decision problem, bridge characteristics, site conditions and concrete type, for each construction technique. The results obtained from Section 5.6.2 were used mainly in this module. However for the span length criterion, the results were complemented with findings from literature for two methods, advancing shoring system (85m) and incremental horizontal launching (100m) in order to present the decision maker with a wider perspective of the competitive construction techniques. The output of this stage was a list of feasible alternatives, which is used in modules three and four as discussed in the following two sections.

6.5.5 Development of the AHP Model (Module 3)

6.5.5.1 Developing the AHP Hierarchy

The AHP hierarchy is a representation of a complex problem on a number of levels where the first level represents the goal to be achieved, followed by criteria, sub-criteria and so on down to the lower level at which the alternatives are located. The criteria affecting the selection of construction techniques were classified into seven categories and presented in level 1 of the model to serve as the main criteria. Up to six levels of criteria were developed to create the overall hierarchy. The last level in the hierarchy presents the construction techniques that were used as alternatives. It was important in constructing the hierarchy to include the bridge experts' ideas and to debate these until the problem was clearly defined. For this reason, the criteria and alternatives resulting from knowledge elicitation were used to construct the overall hierarchy shown in Figure 5.1.

Card sorting was used to construct the AHP hierarchy for input into Expert Choice. This methodology involves creating, reviewing and modifying the decision hierarchy with the experts until the final hierarchy is developed. The overall hierarchy portrays the criteria identified by experts during semi-structured interviews and offers comprehensive representation of the criteria affecting the selection of superstructure construction techniques in Egypt. The complexity of this hierarchy may deem it impractical as indicated by some users. Accordingly, questionnaire surveys were sent, with the respondents required to rank the criteria at each level of the hierarchy in order of importance. The responses were analysed and a refined version of the hierarchy was produced as illustrated in Figure 5.5. Nevertheless, BridgeConstruct permits users to utilise either the overall hierarchy or the refined one. When using the overall hierarchy the decision maker may eliminate irrelevant criteria and use the remaining for comparison purposes.

6.5.5.2 The Pairwise Comparison

The second step in the development of the AHP model was to define the priority (or weight) for each criterion and alternative based on the decision maker's judgement using pairwise comparisons. At each level, pairwise comparisons are undertaken for each category with the ones in the adjacent upper level, and the ratings are entered into a comparison matrix as discussed in Section 4.3.2. The elements on the second level are arranged into a matrix, and the expert makes judgements about their relative importance with respect to the overall goal of selecting the most appropriate construction technique. The judgements are entered using the AHP pairwise comparisons scale as introduced in Table 4.2.

For example, when judging the relative preference of factors located at Level 1 with respect to the goal at Level 0, a rating of 1 may be assigned in the comparison between structure characteristics and site conditions. This indicates equal importance between the two criteria. On the other hand, if the decision maker decides to give a rating of 7 in comparing site conditions with time with respect to goal, this would indicate that the site conditions criterion is very strongly favoured or important when compared with the time criterion. All the remaining pairwise comparison matrices between the nodes in the hierarchy can be established by following the same procedure. Similar pairwise comparison tables exist for all levels in the hierarchy. The weights are assigned by the decision maker and depend on each project's circumstances. This is why it is important that the decision maker has enough experience so as to be able to assign reasonable and consistent weights. Expert Choice calculates the inconsistency in the resulting decision, based on the calculations presented in Section 4.3.3, which provides a convenient way to locate any inconsistencies among a set of pairwise judgements. Inconsistency can be improved by changing judgement and making a new paired comparison.

6.5.5.3 Synthesis of the AHP Model

Synthesis involves the process of weighting and combining priorities throughout the model after judgements have been made to derive the final result. The synthesis process converts all the local priorities into global weights of the alternatives. The global priorities for each alternative are then summed up to produce overall or synthesised priorities. The preferred alternative is the one with the highest priority.

There are two modes for synthesis that are offered by AHP, distributive mode and ideal mode. Expert Choice Manual explains that the distributive mode is used when all alternatives should be considered and matter to the decision maker. It basically distributes the weights of the objectives among the alternatives; thereby dividing the full objectives' weights into proportions relative to the percentage of preference of each of the alternatives. The ideal mode is used when the decision maker is only interested in knowing the best alternative and where the other alternatives are not important to him. It distributes the full priority of the objective to the alternative that ranks highest under that objective. The other alternatives are given a priority in proportion to each alternative and the highest alternative. The difference in the results between the two modes is usually very small and is of theoretical significance rather than of a practical one as explained by Abdullah (2003). The debate on the circumstances of each mode was presented in detail in Section 4.3.4.2.

Since the priority rating of all feasible construction techniques needs to be referred to again at Module 4, in order to compare it to cost, the distributive mode is used to derive the final result.

6.5.5.4 Sensitivity Analysis

The purpose of the sensitivity analysis tool offered by Expert Choice is to graphically see how the priorities of the alternatives change with respect to changes in the importance of the criteria and sub-criteria. There are five types of sensitivity analyses: performance sensitivity, dynamic sensitivity, gradient sensitivity, head-to-head sensitivity and Two Dimensional sensitivity. Performance sensitivity displays graphically how the alternatives perform with respect to all criteria. Gradient sensitivity demonstrates the composite priority of the alternatives with respect to the priority of a single criterion. Head-to-head sensitivity displays how any two alternatives compare with respect to each criterion and the goal. Two Dimensional sensitivity displays how alternatives perform with respect to any two criteria. In all cases, there must be at least two levels below the selected node. These levels can be comprised of at least one level of objectives and alternatives or two levels of only objectives (Expert Choice Manual, 2000).

6.5.6 Developing Cost Estimation Model Module (Module 4)

After completing module 3 and obtaining the priorities (weights of benefit) of each construction technique, the decision maker has to calculate cost for each of the feasible construction techniques. The items involved in such calculations have been elicited by tracing the process of estimation as performed by bridge experts as explained in Section 5.7. Initially, the experts' knowledge was compiled in Microsoft Excel format so as to facilitate the modification process. Finally, these elements were developed in Microsoft Access. The cost for each feasible construction technique can be estimated using either preliminary cost estimate or detailed cost estimate models. Bridge engineers can use the preliminary estimate model as a quicker, although less accurate, means to estimate construction cost based on the surface area of the deck. Detailed estimation is more accurate, but takes more time to complete. Both the preliminary cost estimate and the detailed costs are normalised so as to be able to perform meaningful comparison with the weights resulting from module 3. The next two sections discuss the development of these two cost estimation models.

6.5.6.1 Developing Preliminary Cost Estimate

The preliminary estimate is probably the most common kind of estimate the average bridge engineer utilises. It can be used when bridge engineers are estimating a project similar to another one they have done before, and where the structures are in relatively similar condition and were executed with the same construction technique. Preliminary estimates are usually calculated per square metre of the deck surface area. The total price per square metre of older similar projects is multiplied by the total area of the required bridge deck. The costs of each construction technique are calculated after taking into consideration inflation and the resulting estimates are then normalised.

Preliminary cost estimates are generally used by senior estimators as a way of verifying detailed cost estimates prepared by junior estimators. In BridgeConstruct, users may compare benefits resulting from module (3) for each construction technique so as to limit detailed estimates to a limited subset of feasible alternatives.

6.5.6.2 Developing Detailed Cost Estimation Model

Bridge engineers need to undertake a "take-off" exercise (i.e. to establish the quantities of the key components of the structure) before they can proceed with the detailed estimate, which is required to be accurate and realistic. When performing take-off, bridge engineers must consider the structural configurations of the bridge, drawings, specification, and site conditions.

The elements involved in the detailed cost estimate have been elicited using process tracing sessions with bridge experts as indicated in Section 5.7. Bridge costs were divided into nine main elements as illustrated in Appendix E. These elements have a maximum of a two more sub-elements. They may vary from one construction technique to another. The cost elements are developed in Microsoft Access forms that automatically collate all cost elements and calculate the total cost. The final estimates of construction techniques are then normalised to establish the relative cost of each construction technique. BridgeConstruct permits users also to modify cost elements by addition, elimination or modification so as to reflect their own needs.

6.6 PROTOTYPE SYSTEM OPERATION

BridgeConstruct provides a decision support tool to help bridge practitioners to select the most appropriate construction technique for a specified project. It is designed to allow judgemental input from users in the decision making process.

The operational objectives of BridgeConstruct are to:

1. Provide a structured framework for the decision making process in order to help bridge practitioners to select the most appropriate superstructure construction technique taking into account the various aspects of the selection process including technical and economical aspects;
2. Enable bridge engineers to make rational and justified decisions by using graphical reports and sensitivity analysis;
3. Provide information on the construction techniques to support the decision making process;
4. Provide practitioners with a bridge cost estimation model that is customized to solve some of the estimation problems (such as reducing the time to

perform estimate) that were faced by engineers;

As stated earlier, the system consists of four main modules, introductory module (Module 1), the module that identifies feasible alternatives (Module 2), AHP calculations module (Module 3) and cost estimation module (Module 4). The system operation process is illustrated in the flowchart presented in Figure 6.4.

6.6.1 System End-users

The end users of BridgeConstruct will be bridge engineers who have experience and knowledge in selecting construction techniques in their respective organisations. This characteristic is important because the prototype system is designed to incorporate expert judgement in the selection process. Inexperienced bridge engineers may also use the prototype system as a training tool, since the selection process is structured and the system offers considerable information on construction techniques.

6.6.2 System Requirements

BridgeConstruct has been developed on a personal computer running Microsoft Windows XP Home edition. It requires Microsoft Access 2002, Microsoft PowerPoint 2002 and Expert Choice 2000 (or later versions) to be installed. Microsoft Access and Expert Choice files require around 8 MB of data storage while 124 MB is required for PowerPoint files. PowerPoint files may be stored on a server if a network is available in order to reduce the storage requirements. The system also requires 37 MB of RAM in order to run Expert Choice Software and an extra 5 MB of data storage. BridgeConstruct is stored as a Microsoft Access file.

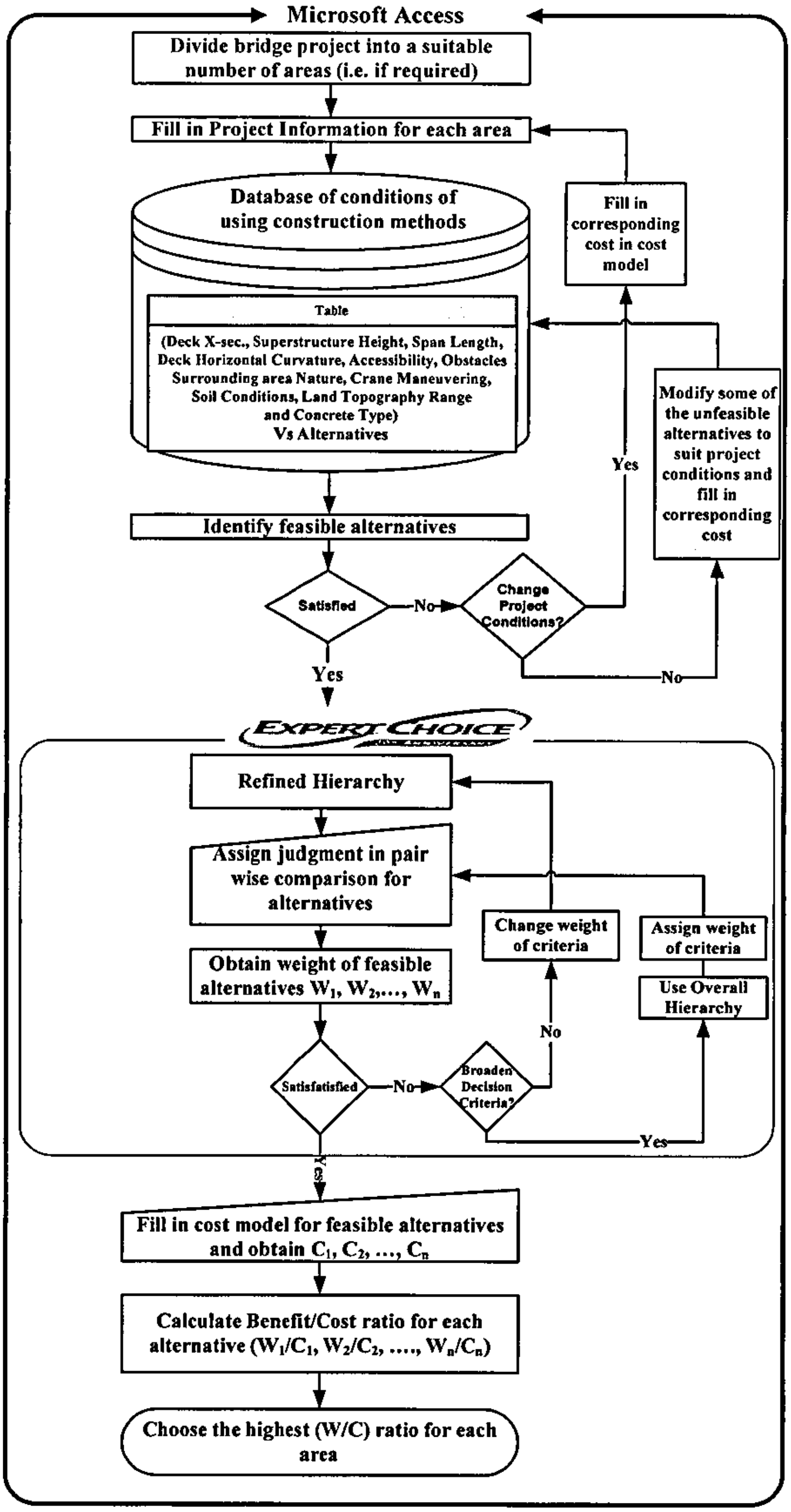
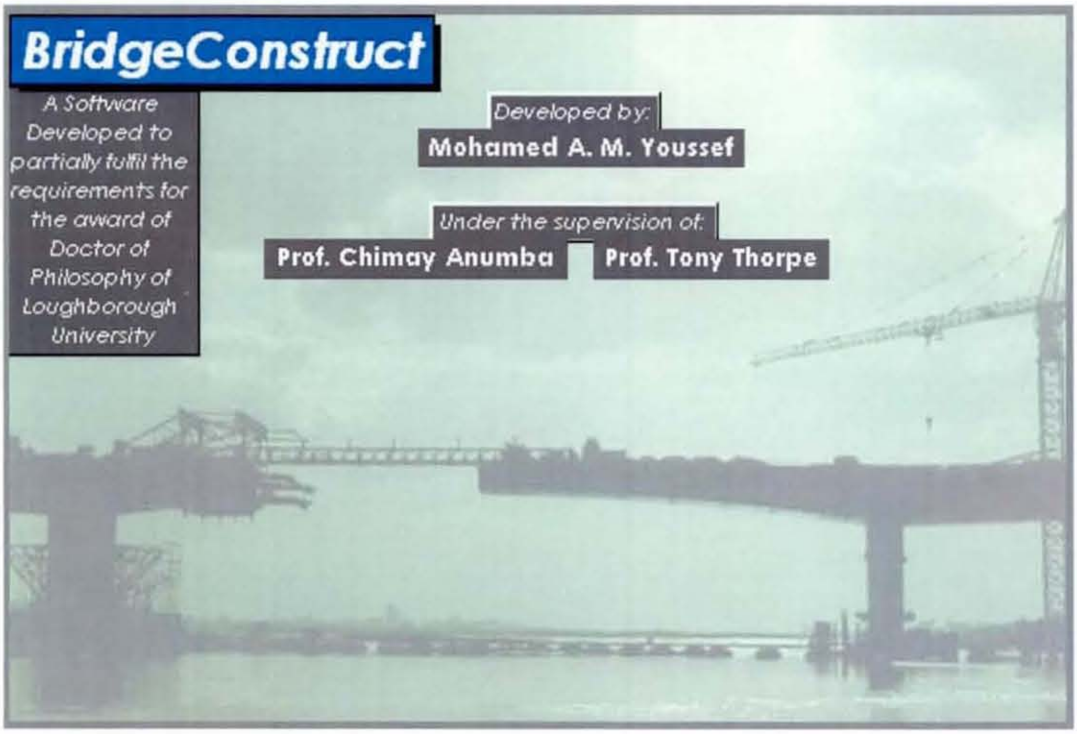


Figure 6.4: Prototype System Operation

6.6.3 Starting the Prototype System

MS Access manages the operation of the prototype system and it is from this that Expert Choice and Microsoft PowerPoint are activated. The system can be started by double clicking on the "BridgeConstruct" Icon. The user will view a screen that introduces the system as shown in Figure 6.5.



BridgeConstruct

A Software Developed to partially fulfil the requirements for the award of Doctor of Philosophy of Loughborough University

Developed by:

Mohamed A. M. Youssef

Under the supervision of:

Prof. Chimay Anumba

Prof. Tony Thorpe

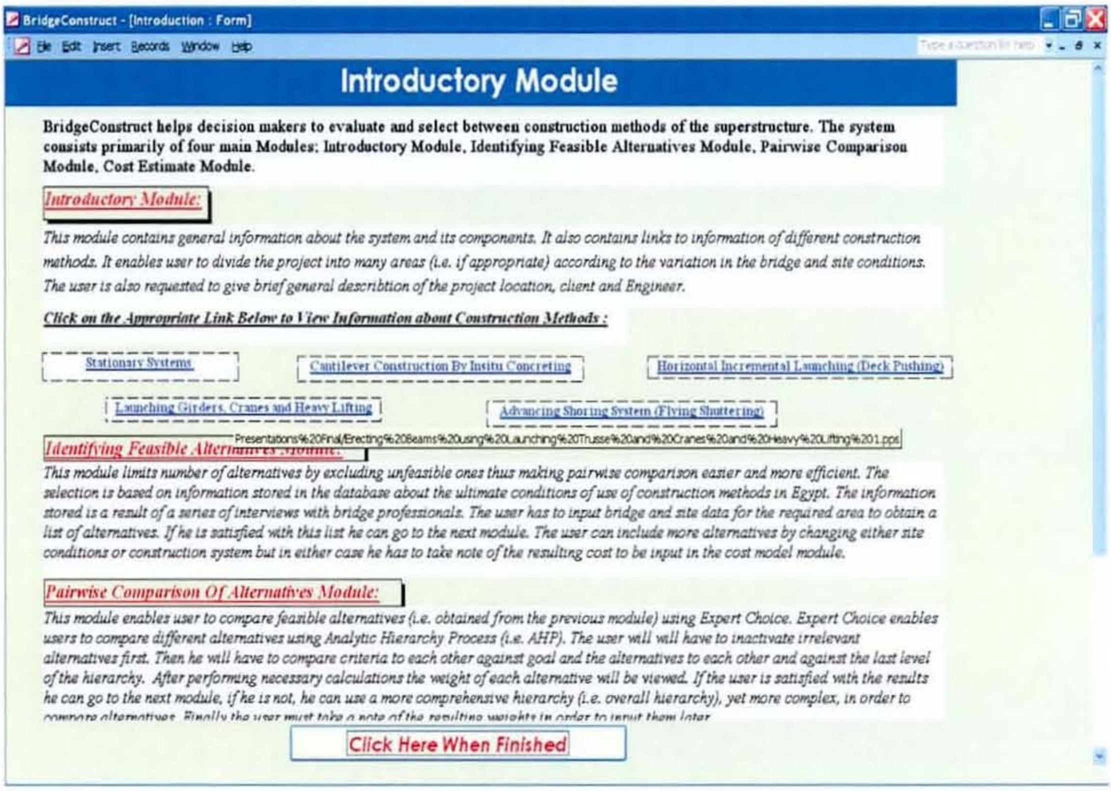
Figure 6.5: BridgeConstruct Welcome Screen

This screen lasts around 10 seconds and the following window appears as shown in Figure 6.6. The introductory module contains information about construction techniques which can be viewed using PowerPoint by clicking on the relevant hyperlink. The information contains video files, drawings, pictures and text describing the components of construction techniques as well as the process of construction. This module offers a brief summary of each module objective and its method of use.

6.6.4 Data Input for Project Main Information

The user has to specify basic project information including project name, description, location, client and engineer. A unique project code is automatically assigned by the system to each project.

The user may also choose to open an existing project so as to view its information or to add another area in later stages. This can be done by choosing the required project name from the combo box at the right hand side of the screen. Figure 6.7 illustrates a screen dump of the form containing data input for projects' main information.



BridgeConstruct helps decision makers to evaluate and select between construction methods of the superstructure. The system consists primarily of four main Modules: Introductory Module, Identifying Feasible Alternatives Module, Pairwise Comparison Module, Cost Estimate Module.

Introductory Module:

This module contains general information about the system and its components. It also contains links to information of different construction methods. It enables user to divide the project into many areas (i.e. if appropriate) according to the variation in the bridge and site conditions. The user is also requested to give brief general describtion of the project location, client and Engineer.

Click on the Appropriate Link Below to View Information about Construction Methods :

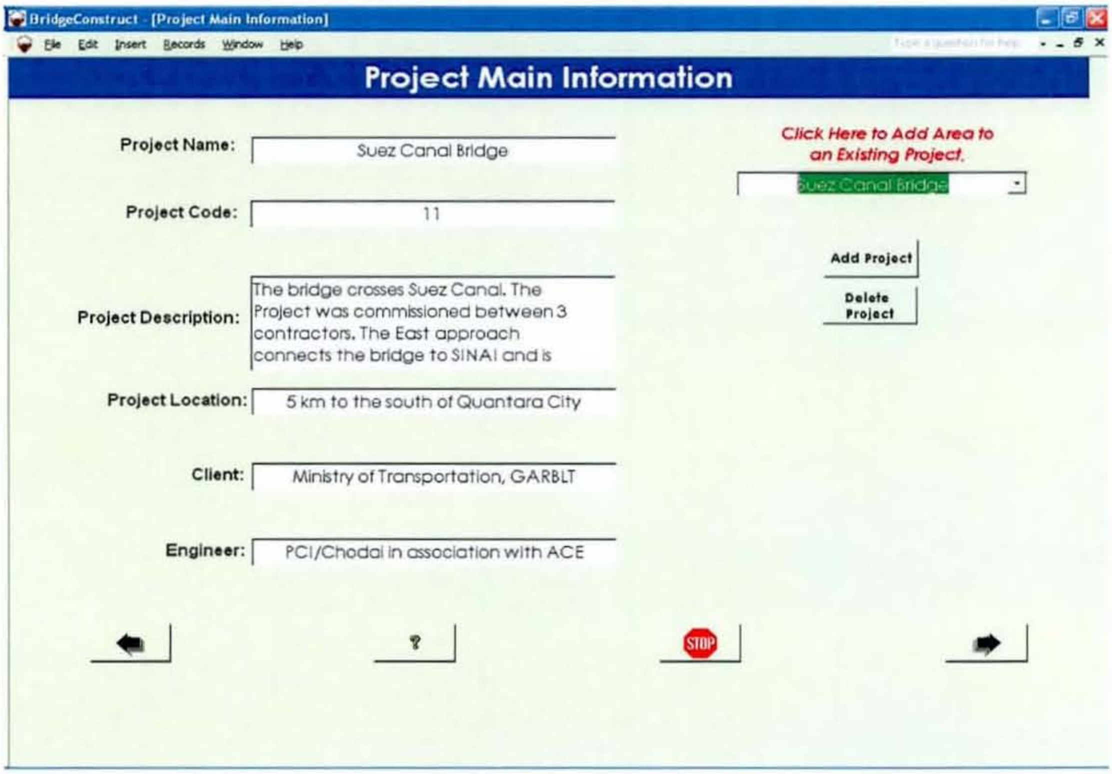
Identifying Feasible Alternatives Module:

This module limits number of alternatives by excluding unfeasible ones thus making pairwise comparison easier and more efficient. The selection is based on information stored in the database about the ultimate conditions of use of construction methods in Egypt. The information stored is a result of a series of interviews with bridge professionals. The user has to input bridge and site data for the required area to obtain a list of alternatives. If he is satisfied with this list he can go to the next module. The user can include more alternatives by changing either site conditions or construction system but in either case he has to take note of the resulting cost to be input in the cost model module.

Pairwise Comparison Of Alternatives Module:

This module enables user to compare feasible alternatives (i.e. obtained from the previous module) using Expert Choice. Expert Choice enables users to compare different alternatives using Analytic Hierarchy Process (i.e. AHP). The user will will have to inactivate irrelevant alternatives first. Then he will have to compare criteria to each other against goal and the alternatives to each other and against the last level of the hierarchy. After performing necessary calculations the weight of each alternative will be viewed. If the user is satisfied with the results he can go to the next module, if he is not, he can use a more comprehensive hierarchy (i.e. overall hierarchy), yet more complex, in order to compare alternatives. Finally the user must take a note of the resulting weights in order to input them later.

Figure 6.6: Part of the Introductory Module (Module 1)



Project Main Information

Project Name: Suez Canal Bridge

Project Code: 11

Project Description: The bridge crosses Suez Canal. The Project was commissioned between 3 contractors. The East approach connects the bridge to SINAI and is

Project Location: 5 km to the south of Quantara City

Client: Ministry of Transportation, GARBLT

Engineer: PCI/Chodai in association with ACE

Click Here to Add Area to an Existing Project.

Suez Canal Bridge

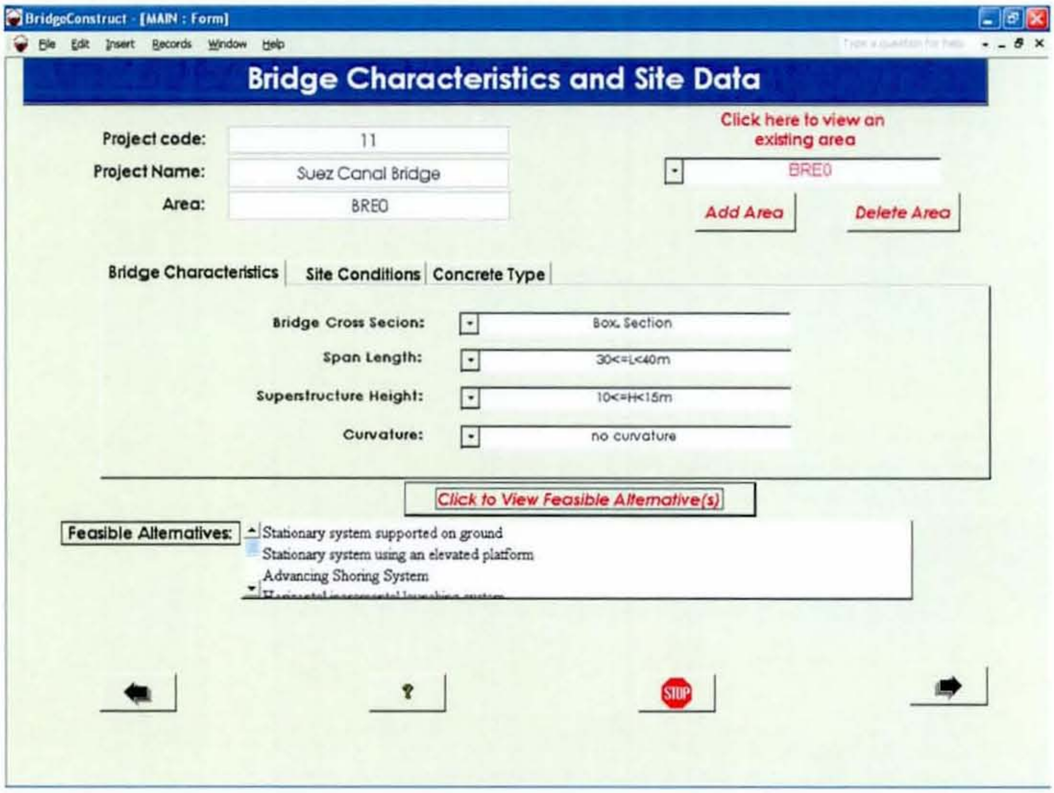
Figure 6.7: Data input for Project Main Information

6.6.5 Data Input for the Module Identifying Feasible Superstructure Construction Techniques

Long bridges cross sites of different nature thus resulting in differences in height, length, span, land topography, obstacles, soil condition, site conditions, etc. It might be appropriate in this case to divide the bridge into areas of similar nature in order to investigate feasible construction techniques for each individual area.

Several tables have been created in the database where the conditions of using each construction technique are stored and related to each other. Consequently, BridgeConstruct can choose the techniques that match information input by the user for bridge characteristics, site conditions and concrete type and fulfils the requirements of their conditions of use.

The bridge may be divided into several areas and the user is required to input each area name, the bridge cross section, span length, superstructure height, deck curvature, soil conditions, crane manoeuvring capabilities, land topography range, type of obstacle and concrete type. After making all the choices from the relevant combo boxes, the user has to click on the command button "Click to View Feasible Alternatives" so as to view the results. There are two navigation buttons which direct the user either to the next step or to go back to modify any of the project information. The user may activate the introductory module by clicking on the command button denoted by (?) at any time during system operation. The user may finish BridgeConstruct session by pressing the command button STOP. This process is illustrated using Figures 6.8, 6.9 and 6.10.



Project code: 11

Project Name: Suez Canal Bridge

Area: BREO

BREO

Bridge Cross Secion: Box. Section

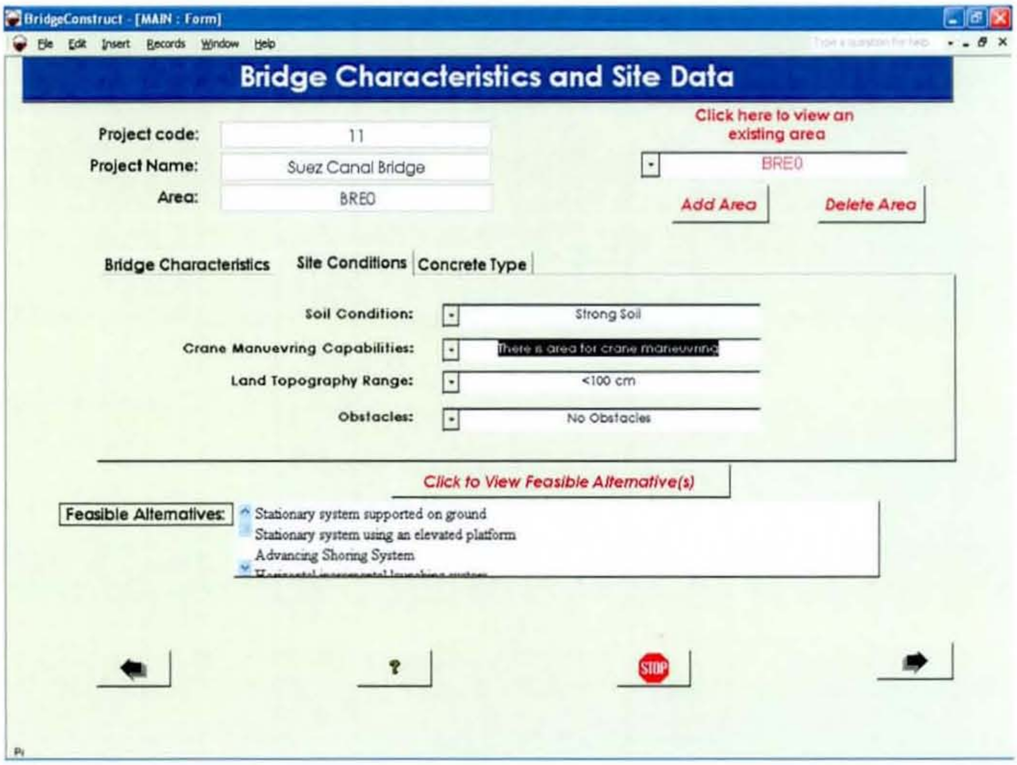
Span Length: 30<=L<40m

Superstructure Height: 10<=H<15m

Curvature: no curvature

Feasible Alternatives:
- Stationary system supported on ground
- Stationary system using an elevated platform
- Advancing Shoring System

Figure 6.8: Data Input for Bridge Characteristics



Bridge Characteristics and Site Data

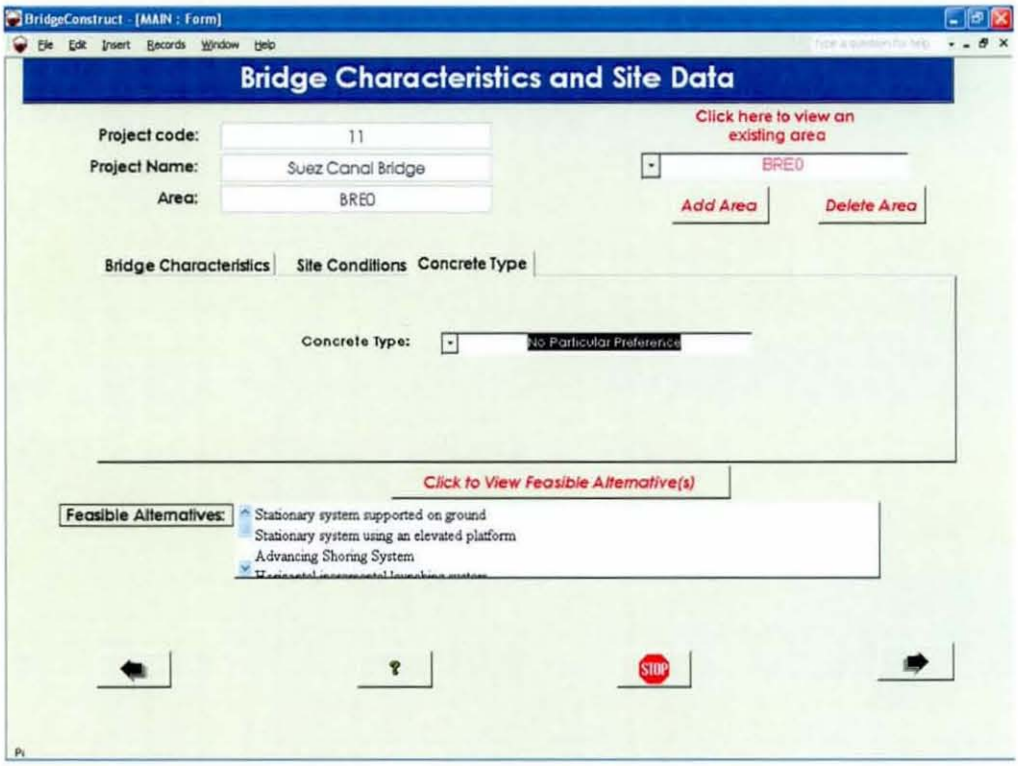
Project code: 11
Project Name: Suez Canal Bridge
Area: BREO

BREO

Soil Condition: Strong Soil
Crane Manuevring Capabilities: There is area for crane maneuvring
Land Topography Range: <100 cm
Obstacles: No Obstacles

Feasible Alternatives:
- Stationary system supported on ground
- Stationary system using an elevated platform
- Advancing Shoring System

Figure 6.9: Data Input for Site Conditions



Bridge Characteristics and Site Data

Project code: 11
Project Name: Suez Canal Bridge
Area: BREO

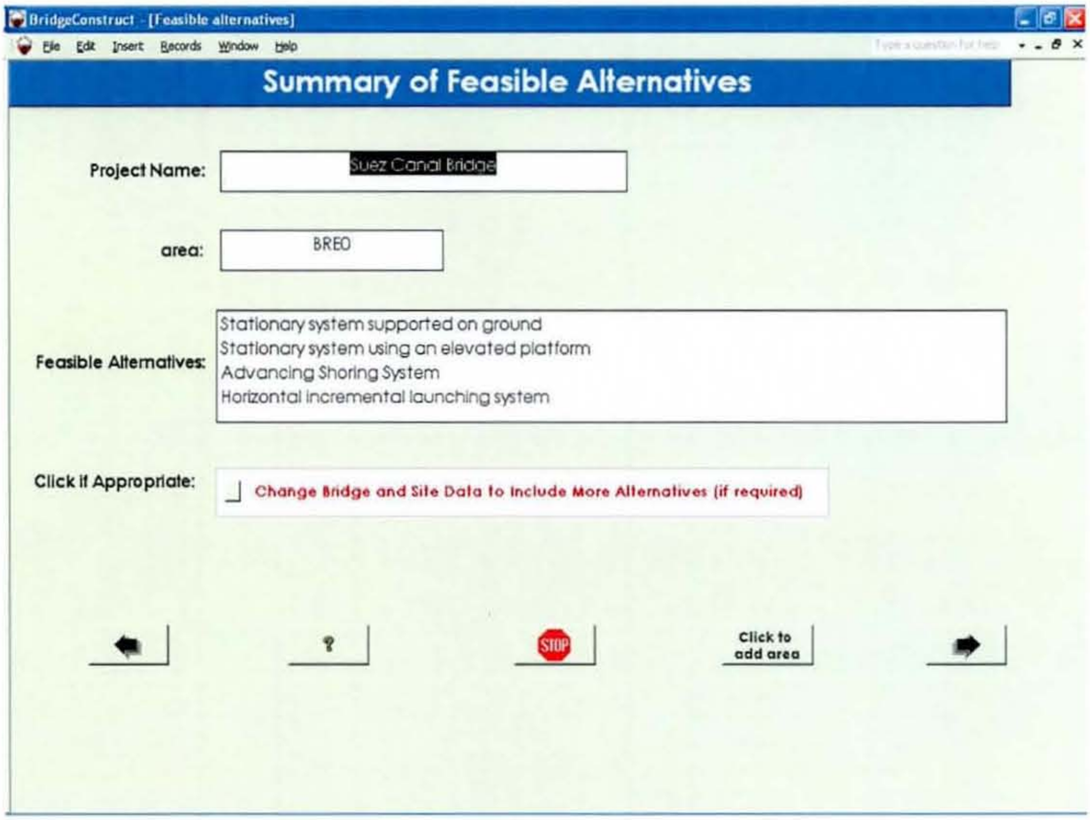
BREO

Concrete Type: No Particular Preference

Feasible Alternatives:
- Stationary system supported on ground
- Stationary system using an elevated platform
- Advancing Shoring System

Figure 6.10: Data Input for Concrete Type

The next screen that appears after pressing the forward arrow on Figure 6.10 displays a summary of the feasible alternatives. Users may change some of the bridge characteristics or site conditions in order to increase the number of alternatives by clicking on the corresponding button as illustrated in Figure 6.11. However, the user must take account of the corresponding costs so as to include them later in cost calculations.



Summary of Feasible Alternatives

Project Name: Suez Canal Bridge

area: BREO

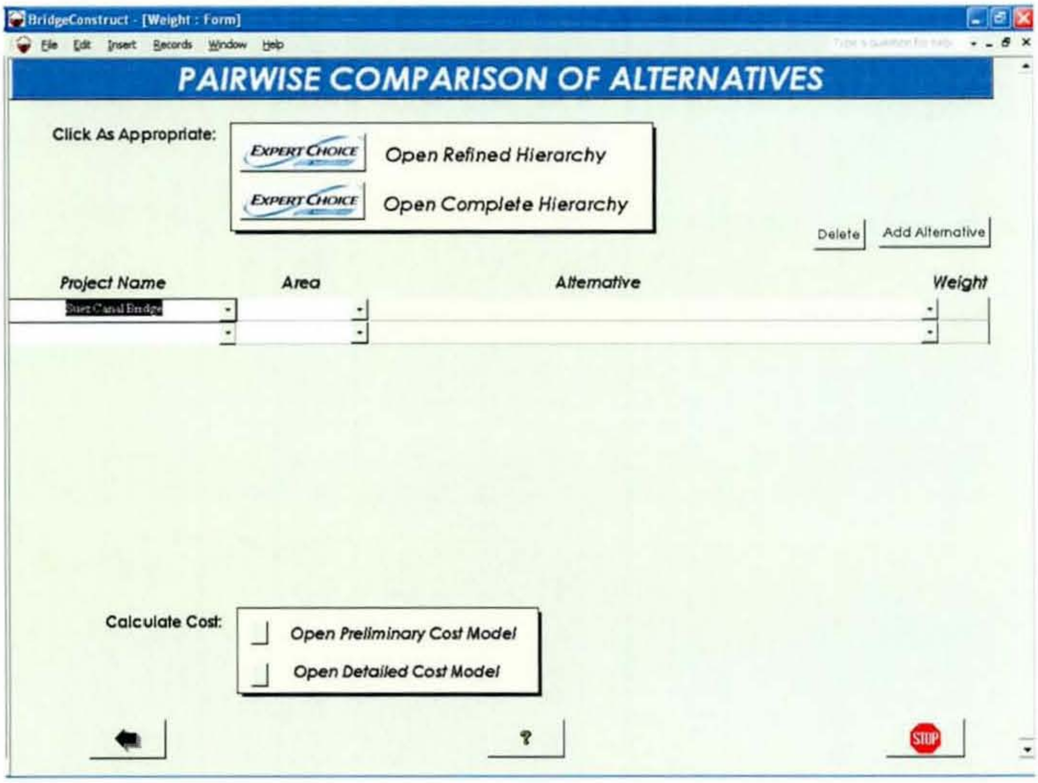
Feasible Alternatives:
Stationary system supported on ground
Stationary system using an elevated platform
Advancing Shoring System
Horizontal incremental launching system

Click if Appropriate: ☐ Change Bridge and Site Data to Include More Alternatives (if required)

Figure 6.11: Summary of Feasible Alternatives

6.6.6 Pairwise Comparisons

Having identified the feasible alternatives the next step is to perform AHP calculations. The user can use either the refined hierarchy presented in Figure 5.5 or the overall hierarchy presented in Figure 5.1. Each can be activated by clicking on the corresponding command buttons at the top of the screen as illustrated in Figure 6.12.



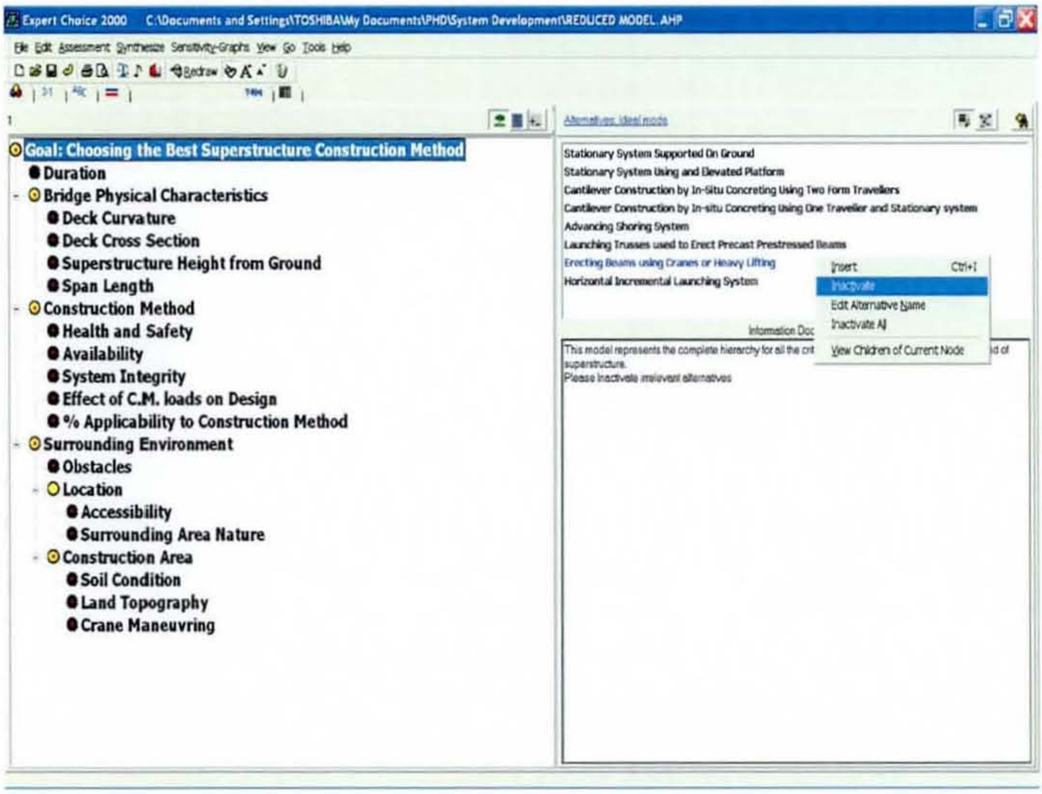
Project Name	Area	Alternative	Weight
Suez Canal Bridge			

Figure 6.12: Pairwise Comparison of Feasible Alternatives

Let us consider that the user chooses to click on the command button called "Open Refined Hierarchy", Expert Choice is activated and the file containing the refined hierarchy is opened. The file then has to be saved preferably using a name that relates to the project and area names. The user has to deactivate the alternatives that are not feasible by clicking the right mouse button while pointing at the required alternative. This is shown in Figure 6.13.

6.6.6.1 Assigning Judgement in Pairwise Comparison

The user is required to assign his/her judgement concerning the relative importance of the criteria with respect to the node in the upper level. He/she will also be required to assign their judgements which reflect his/her preference to use alternatives. This preference is the result of comparing criteria to each other with respect to the criterion at the higher level of the hierarchy. Expert Choice offers three ways for the users to assign their judgements; linguistically (called verbally by Expert Choice), numerically and graphically. They all correspond to the same scale developed by T.L. Saaty for AHP as illustrated in Table 4.2. Verbal judgements permit users to perform judgements where words represent the magnitude of the scale. Numerical judgements enable the user to make judgements using numbers that represent the magnitude of the scale. Finally, the user may perform judgements graphically using bars that can be stretched or shortened to indicate the relative dominance of the criteria being compared. Figures 6.14, 6.15 and 6.16 demonstrate how different types of judgement work.

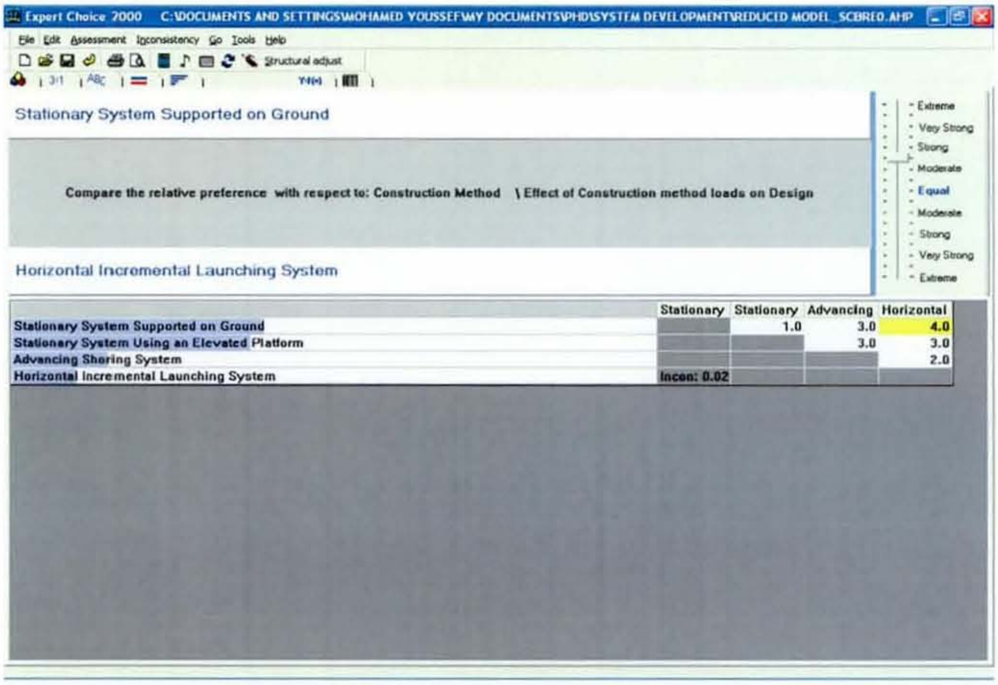


- Goal: Choosing the Best Superstructure Construction Method
  - Duration
  - Bridge Physical Characteristics
    - Deck Curvature
    - Deck Cross Section
    - Superstructure Height from Ground
    - Span Length
  - Construction Method
    - Health and Safety
    - Availability
    - System Integrity
    - Effect of C.M. loads on Design
    - % Applicability to Construction Method
  - Surrounding Environment
    - Obstacles
    - Location
      - Accessibility
      - Surrounding Area Nature
    - Construction Area
      - Soil Condition
      - Land Topography
      - Crane Maneuvring

Stationary System Supported On Ground
Stationary System Using and Elevated Platform
Cantilever Construction by In-Situ Concreting Using Two Form Travellers
Cantilever Construction by In-situ Concreting Using One Traveller and Stationary system
Advancing Shoring System
Launching Trusses used to Erect Precast Prestressed Beams
Erecting Beams using Cranes or Heavy Lifting
Horizontal Incremental Launching System

This model represents the complete hierarchy for all the crit … d of superstructure.
Please inactivate irrelevant alternatives

Figure 6.13: Deactivating Unfeasible Alternatives



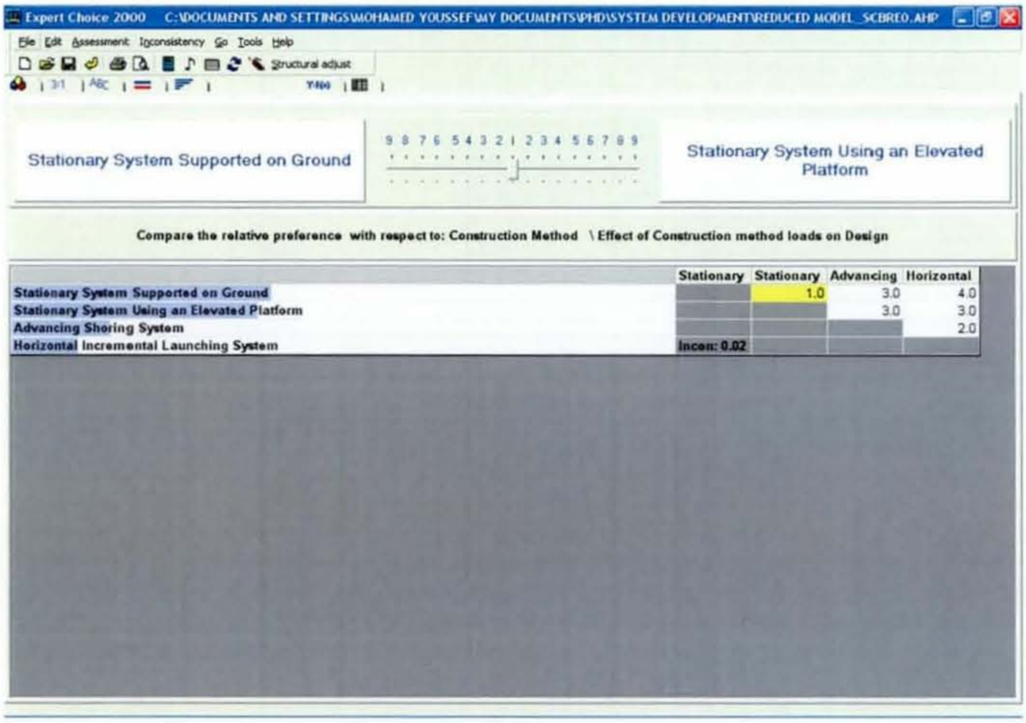
Stationary System Supported on Ground

Compare the relative preference with respect to: Construction Method \ Effect of Construction method loads on Design

Horizontal Incremental Launching System

	Stationary	Stationary	Advancing	Horizontal
Stationary System Supported on Ground		1.0	3.0	4.0
Stationary System Using an Elevated Platform			3.0	3.0
Advancing Shoring System				2.0
Horizontal Incremental Launching System	Incon: 0.02			

Figure 6.14: Assigning Verbal Judgement for Comparisons



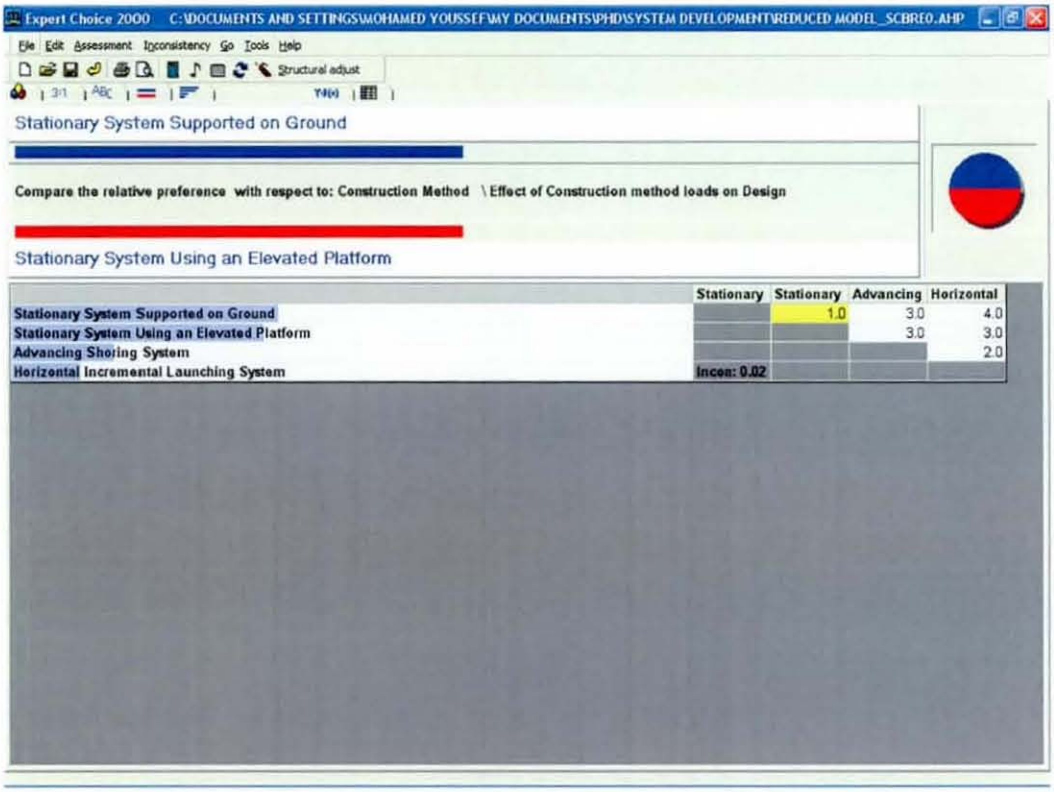
Stationary System Supported on Ground

Stationary System Using an Elevated Platform

Compare the relative preference with respect to: Construction Method \ Effect of Construction method loads on Design

	Stationary	Stationary	Advancing	Horizontal
Stationary System Supported on Ground		1.0	3.0	4.0
Stationary System Using an Elevated Platform			3.0	3.0
Advancing Shoring System				2.0
Horizontal Incremental Launching System	Incon: 0.02			

Figure 6.15: Assigning Judgements Numerically



Stationary System Supported on Ground

Compare the relative preference with respect to: Construction Method \ Effect of Construction method loads on Design

Stationary System Using an Elevated Platform

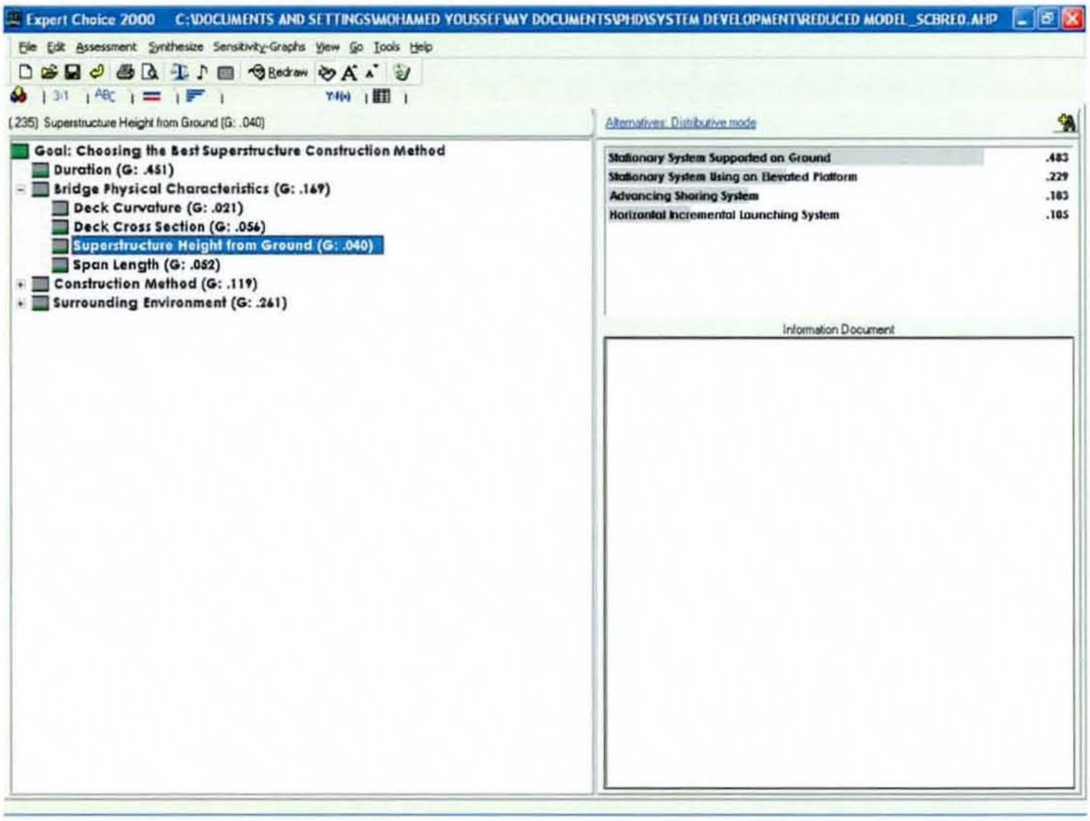
	Stationary	Stationary	Advancing	Horizontal
Stationary System Supported on Ground		1.0	3.0	4.0
Stationary System Using an Elevated Platform			3.0	3.0
Advancing Shoring System				2.0
Horizontal Incremental Launching System	Incon: 0.02			

Figure 6.16: Assigning Judgements Graphically

6.6.6.2 Synthesis

A synthesis is automatically performed after all judgements in the AHP model have been made and priorities have been calculated. When focus is returned to the model view the priorities for the alternatives are shown in the alternatives pane. The system presents priorities for the alternatives at the alternative pane with respect to the node in focus. Figure 6.17 demonstrates the priorities of the feasible alternatives with respect to Superstructure Height from Ground numerically and graphically.

In order to obtain the priorities of the alternatives with respect to the goal, 'synthesize with respect to goal' is selected where the results of the priorities of the alternatives are produced as illustrated in Figure 6.18. Two modes of synthesis can be used to prioritise: ideal mode and distributive mode as discussed in Section 6.5.3.3. Because each synthesis mode combines priorities differently, the user should know that each mode yields different, although normally very similar, results. The distributive mode has been used in this example.



(.235) Superstructure Height from Ground (G: .040)

- Goal: Choosing the Best Superstructure Construction Method
  - Duration (G: .451)
  - Bridge Physical Characteristics (G: .169)
    - Deck Curvature (G: .021)
    - Deck Cross Section (G: .056)
    - Superstructure Height from Ground (G: .040)
    - Span Length (G: .052)
  - Construction Method (G: .119)
  - Surrounding Environment (G: .261)

Alternatives: Distributive mode

Stationary System Supported on Ground	.483
Stationary System Using an Elevated Platform	.229
Advancing Shoring System	.183
Horizontal Incremental Launching System	.105

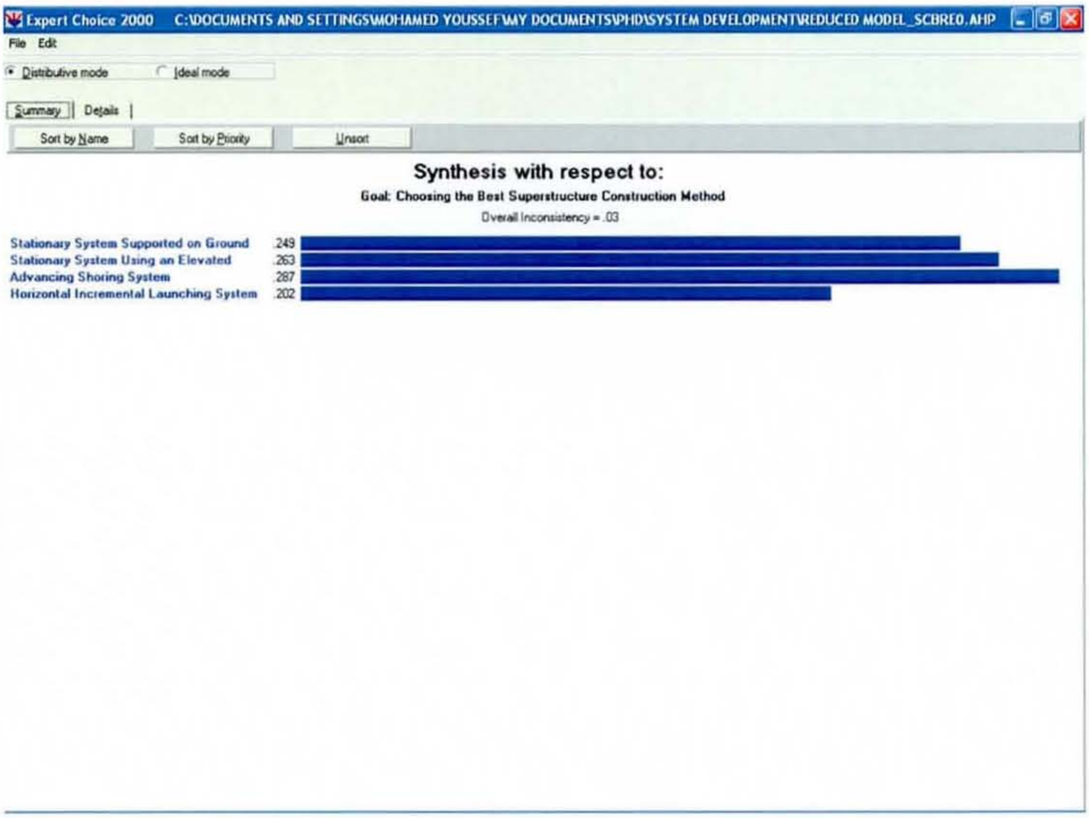
Figure 6.17: Derived priorities of the alternatives with respect to superstructure height from ground

6.6.6.3 Sensitivity Analysis

After completing the synthesis process to obtain the priorities of the construction techniques, the user can examine the sensitivity of the alternatives to the variations in criteria graphically via the sensitivity analysis tool. It shows the user how the priorities of the alternatives change when the weights of the criteria change.

As explained in Section 6.5.3.3, sensitivity analysis can be presented in five main ways: performance sensitivity, dynamic sensitivity, gradient, head-to-head and two dimensional as illustrated in Figures 6.19, 6.20, 6.21, 6.22 and 6.23. The user can perform this analysis with respect to the main criteria by highlighting the goal and selecting the option 'Sensitivity-Graphs' from the main menu and choosing the required sensitivity analysis.

The user must take note of the alternatives' weights obtained via distributive mode before exiting Expert Choice in order to input them again in Microsoft Access as illustrated in Figure 6.24.



● Distributive mode ○ Ideal mode

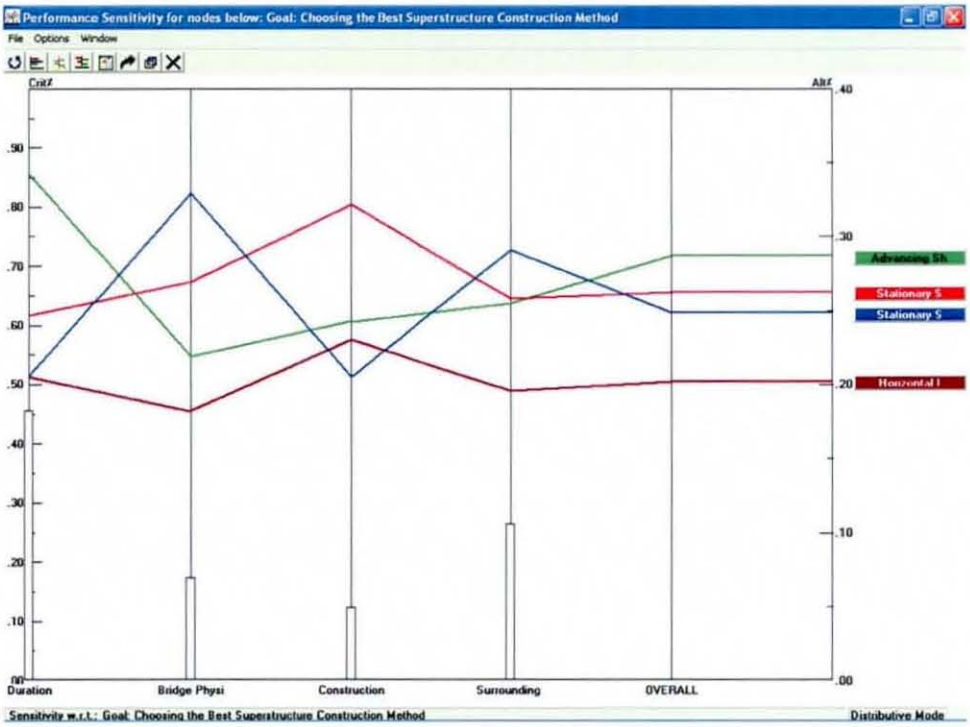
Synthesis with respect to:

Goal: Choosing the Best Superstructure Construction Method

Overall Inconsistency = .03

Stationary System Supported on Ground	.249
Stationary System Using an Elevated	.263
Advancing Shoring System	.287
Horizontal Incremental Launching System	.202

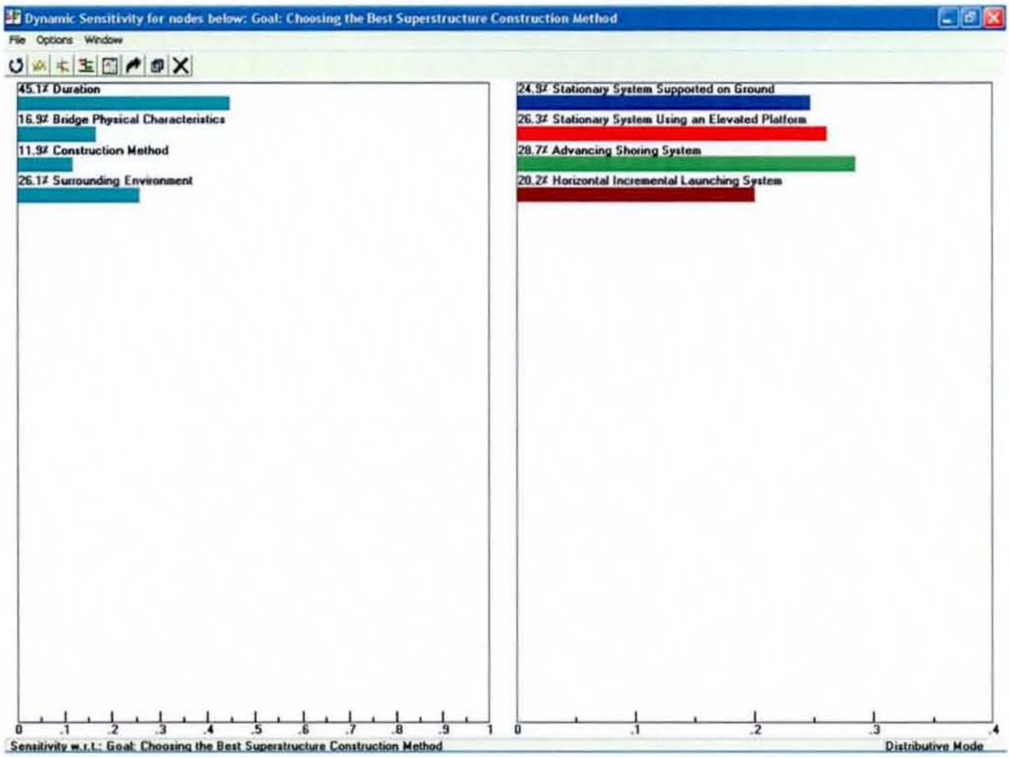
Figure 6.18: Synthesis with respect to objective



Sensitivity w.r.t.: Goal: Choosing the Best Superstructure Construction Method

Distributive Mode

Figure 6.19: Performance Sensitivity for the Nodes below the Goal



Sensitivity w.r.t.: Goal: Choosing the Best Superstructure Construction Method

Distributive Mode

Figure 6.20: Dynamic Sensitivity for the Nodes below the Goal

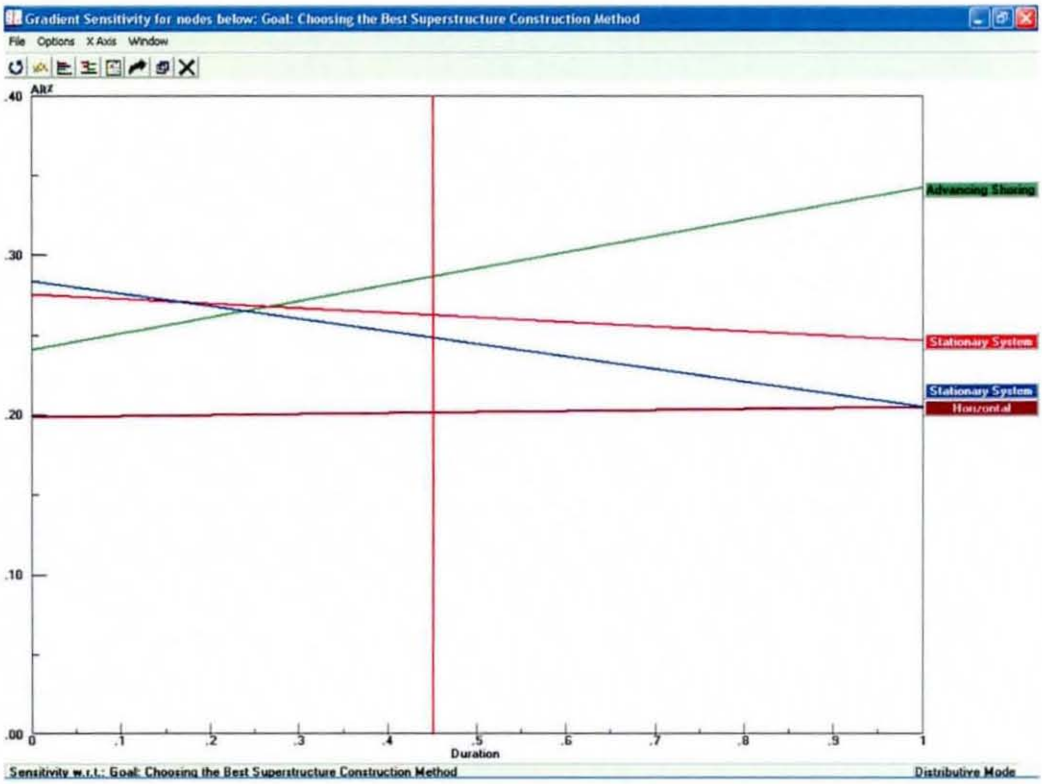


Figure 6.21: Gradient Sensitivity for the Nodes below the Goal

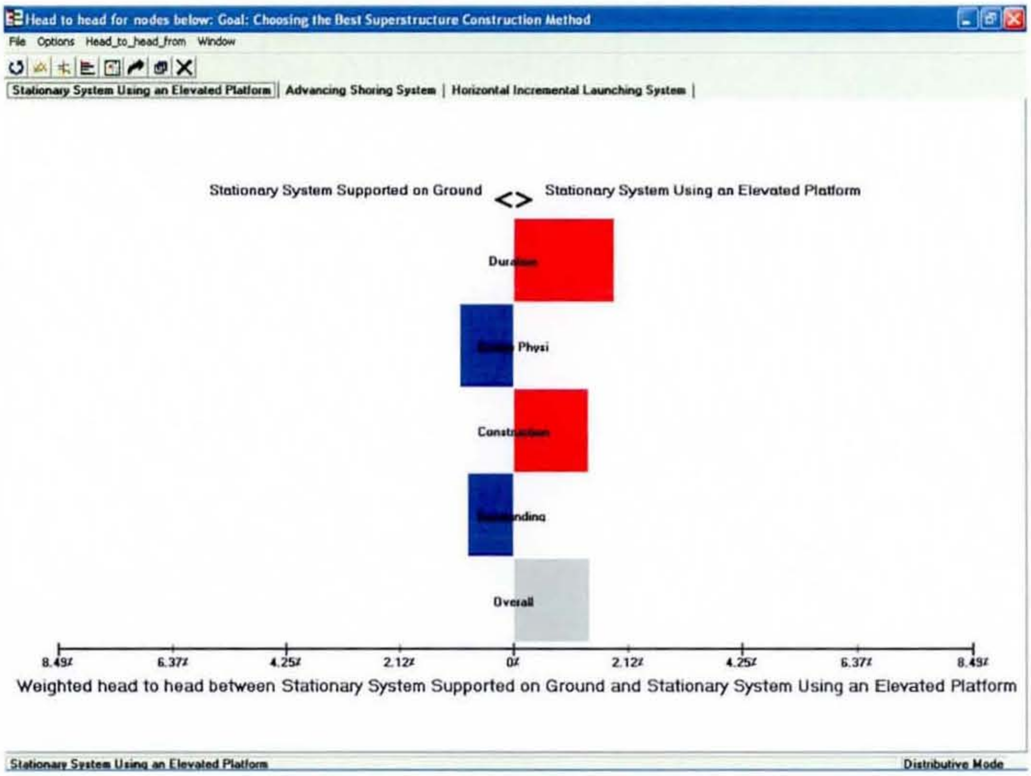


Figure 6.22: Head to Head Sensitivity for the Nodes below the Goal

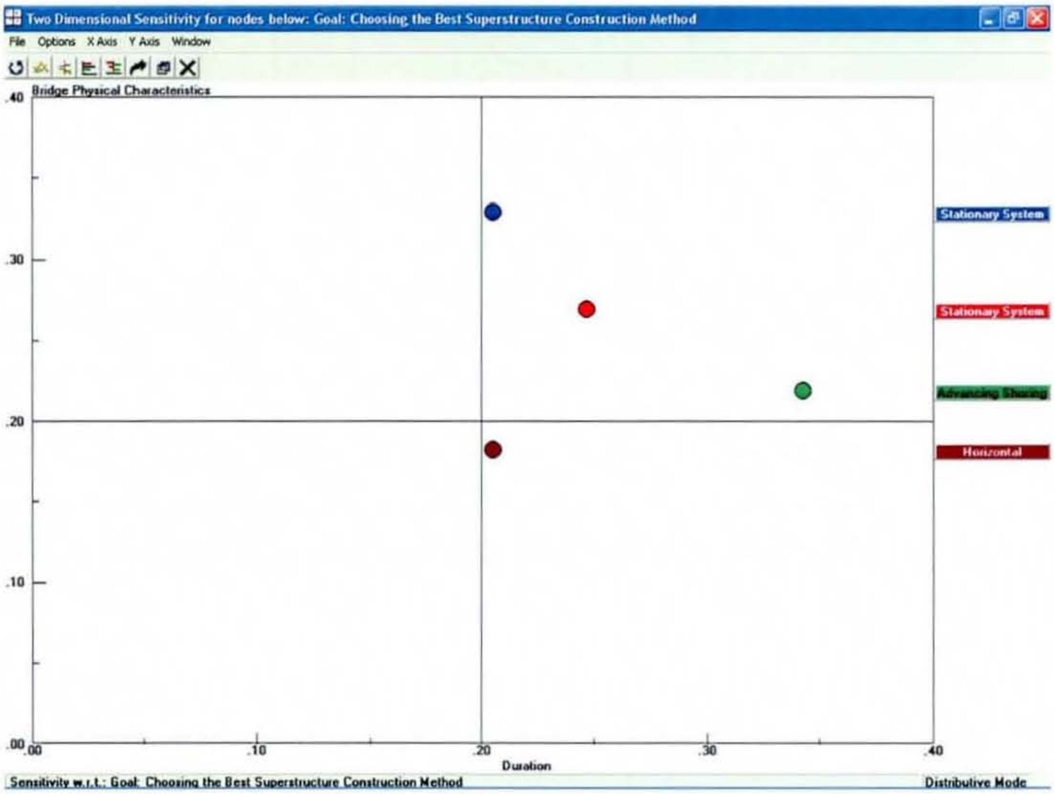


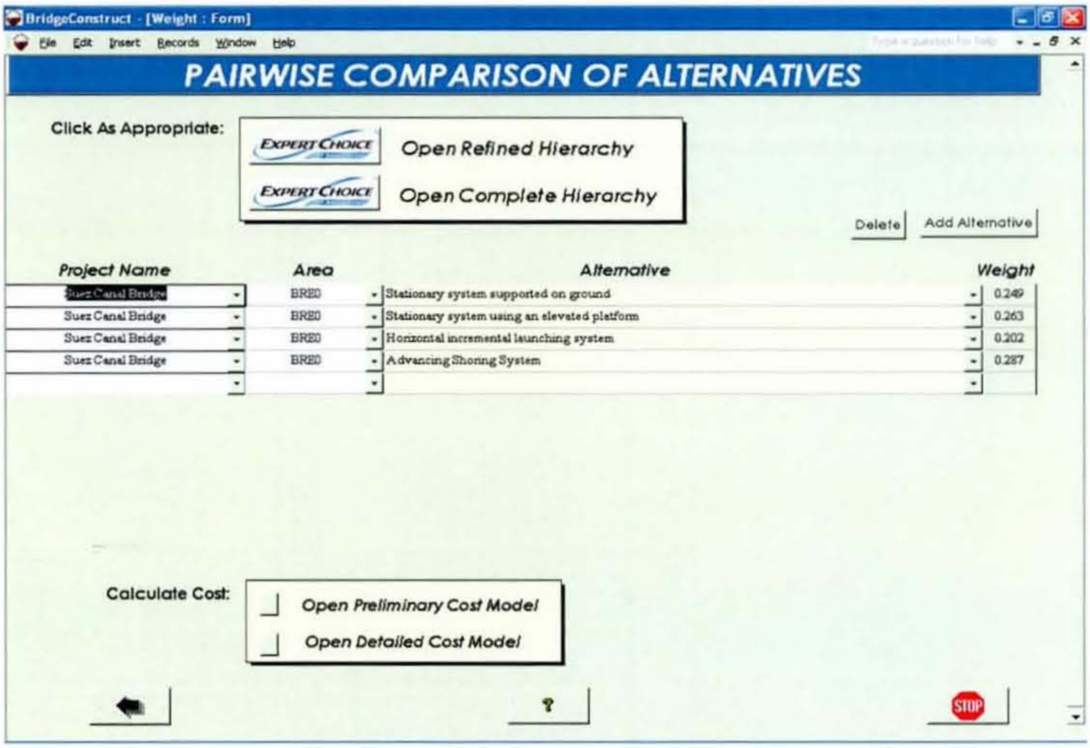
Figure 6.23: 2D Sensitivity Graph for the Nodes below the Goal

6.6.7 Cost Estimation Model

The cost estimate model has been developed to be used in one of two approaches, preliminary cost estimate and detailed cost estimate. The user can choose the approach that is required to be used by clicking on the appropriate button at the bottom of the "PAIRWISE COMPARISON OF ALTERNATIVES" form shown in Figure 6.24.

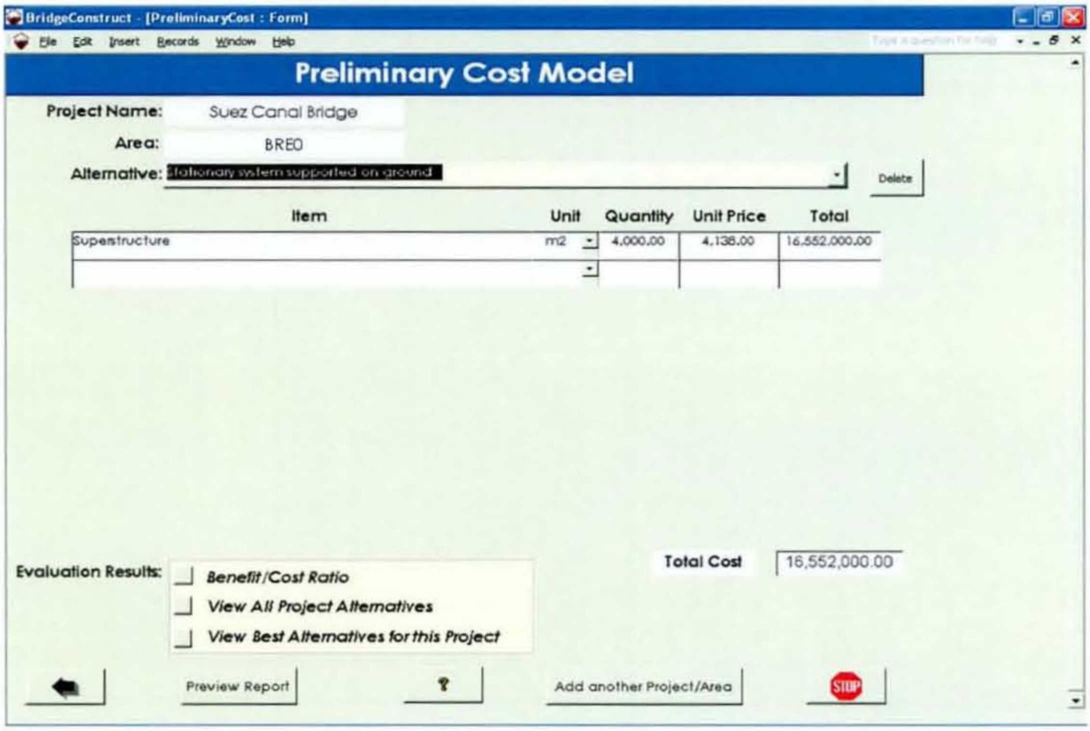
6.6.7.1 Data input for preliminary cost estimate

In order to use the preliminary cost model the user must have the price per metre square of the surface area of the bridge deck from previous similar projects. He/she must also calculate the proposed bridge deck surface area. The two figures are input by the user for each construction technique and the system calculates the estimated preliminary cost as shown in Figure 6.25.



Project Name	Area	Alternative	Weight
Suez Canal Bridge	BREO	Stationary system supported on ground	0.249
Suez Canal Bridge	BREO	Stationary system using an elevated platform	0.263
Suez Canal Bridge	BREO	Horizontal incremental launching system	0.202
Suez Canal Bridge	BREO	Advancing Shoring System	0.287

Figure 6.24: A Screen Dump of the Screen Showing Link to Cost Calculations



Project Name: Suez Canal Bridge
Area: BREO
Alternative: Stationary system supported on ground

Item	Unit	Quantity	Unit Price	Total
Superstructure	m2	4,000.00	4,138.00	16,552,000.00

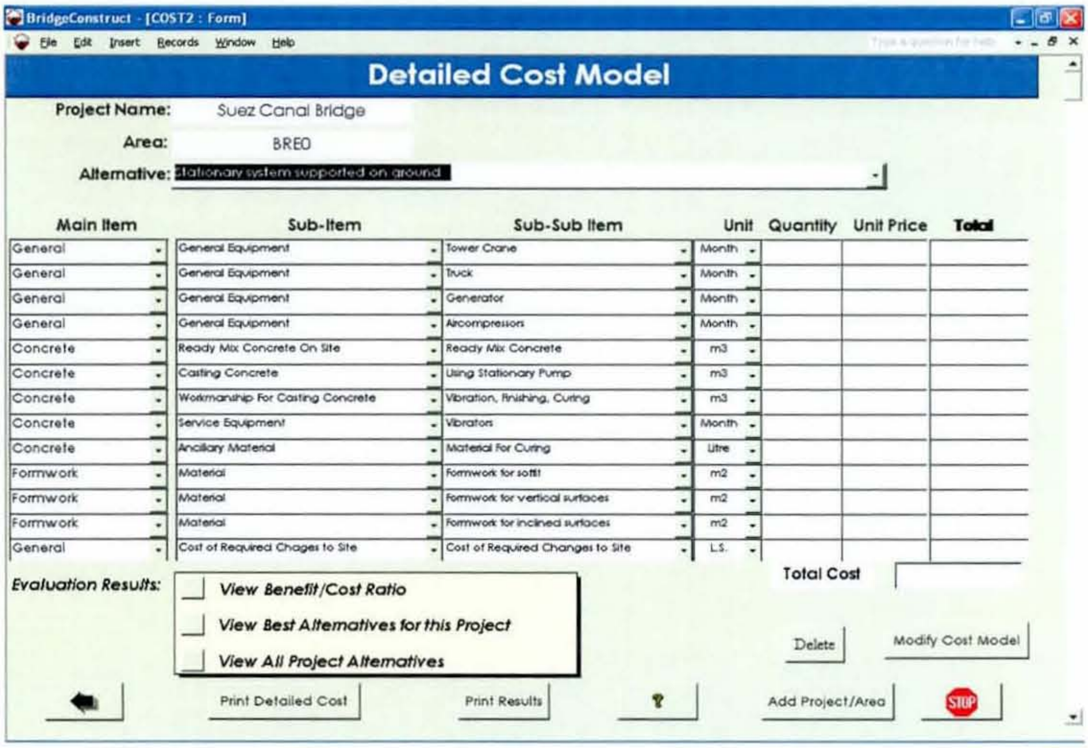
Total Cost 16,552,000.00

Figure 6.25: Data Input for Preliminary Cost Model

6.6.7.2 Data input for detailed cost estimate

The detailed cost estimate mandates that the user performs a complete take-off of the quantities. The user after clicking on the "Open Detailed Cost Model" button shown in Figure 6.24, is directed to the screen illustrated in Figure 6.26. The user has to select the first feasible construction technique from the designated combo box and the system automatically performs a query by which only the cost elements relevant to this technique will be presented. There are seven fields in this screen, Main Item, Sub-Item, Sub-Sub Item, Unit, Quantity, Unit Price and Total. The first field is selected by clicking on the relevant combo box where the related items are automatically filtered and available for the user in both Sub-Item and Sub-Sub Item fields and should be selected by the user. The user also inputs unit, quantity and unit price. The total for each row as well as the total cost for construction technique are calculated automatically by the system.

In many instances the user may be required to obtain an overview of the cost elements constituting the cost model or to input more equipment or other items that affect cost in order to cater for their own needs. By clicking on the button called "Modify Cost Model" illustrated in Figure 6.26, the user will be directed to the screen presented in Figure 6.27. If the user wishes to see all the items that are branching from each of the Main items he/she can click the forward arrow. He/she may also choose to modify these items by adding or eliminating any of them on the screens shown in Figures 6.27, 6.28, 6.29. The user may also assign some of the items to other alternatives by clicking on the 'Assign Alternatives' button as illustrated in Figures 6.28 and 6.29.

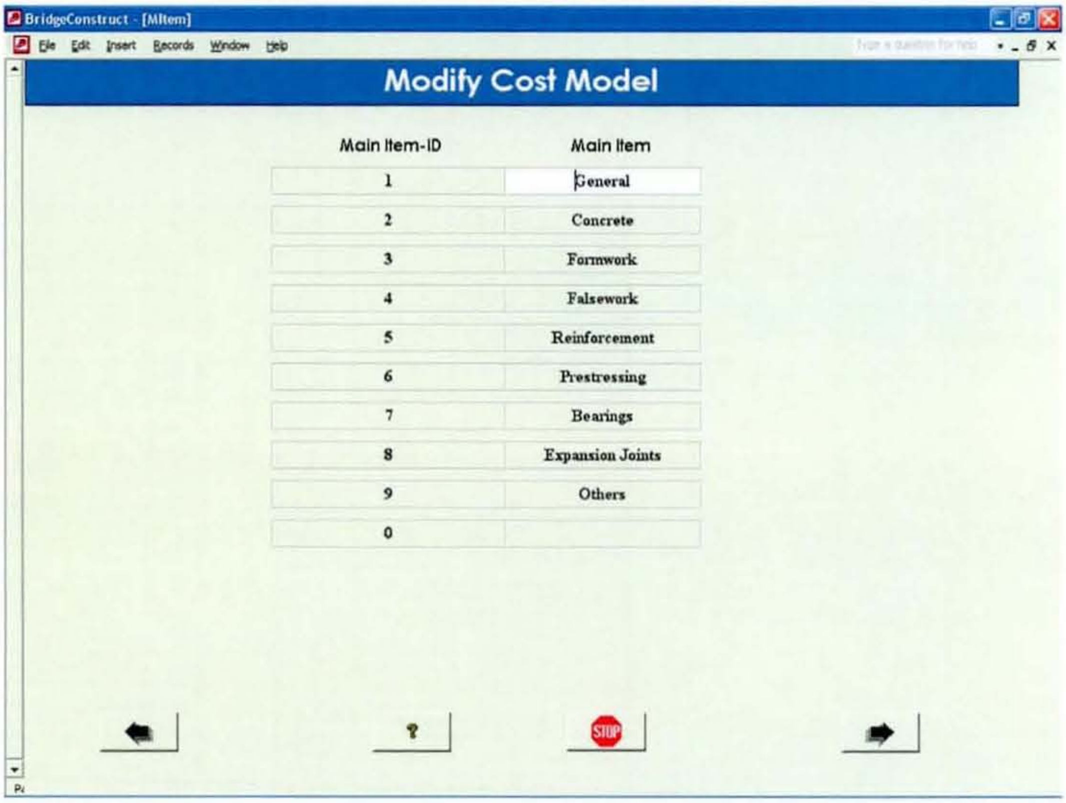


Project Name: Suez Canal Bridge
Area: BREO
Alternative: stationary system supported on ground

Main Item	Sub-Item	Sub-Sub Item	Unit	Quantity	Unit Price	Total
General	General Equipment	Tower Crane	Month			
General	General Equipment	Truck	Month			
General	General Equipment	Generator	Month			
General	General Equipment	Aircompressors	Month			
Concrete	Ready Mix Concrete On Site	Ready Mix Concrete	m3			
Concrete	Casting Concrete	Using Stationary Pump	m3			
Concrete	Workmanship For Casting Concrete	Vibration, Finishing, Curing	m3			
Concrete	Service Equipment	Vibrators	Month			
Concrete	Ancillary Material	Material For Curing	Litre			
Formwork	Material	Formwork for soffit	m2			
Formwork	Material	Formwork for vertical surfaces	m2			
Formwork	Material	Formwork for inclined surfaces	m2			
General	Cost of Required Chages to Site	Cost of Required Changes to Site	L.S.			

Total Cost

Figure 6.26: Data Input for the Detailed Cost Model



Main Item-ID	Main Item
1	General
2	Concrete
3	Formwork
4	Falsework
5	Reinforcement
6	Prestressing
7	Bearings
8	Expansion Joints
9	Others
0	

Figure 6.27: Modifying Cost Element GENERAL

SItem-ID	SItem	Unit
1	Casting Yard	
2	General Equipment	
3	Cost of Required Chages to Site	
4	Temporary Fixation of SS to Piers	
5	Precast Beams	
6	Cost of required changes to an existing system	
0		

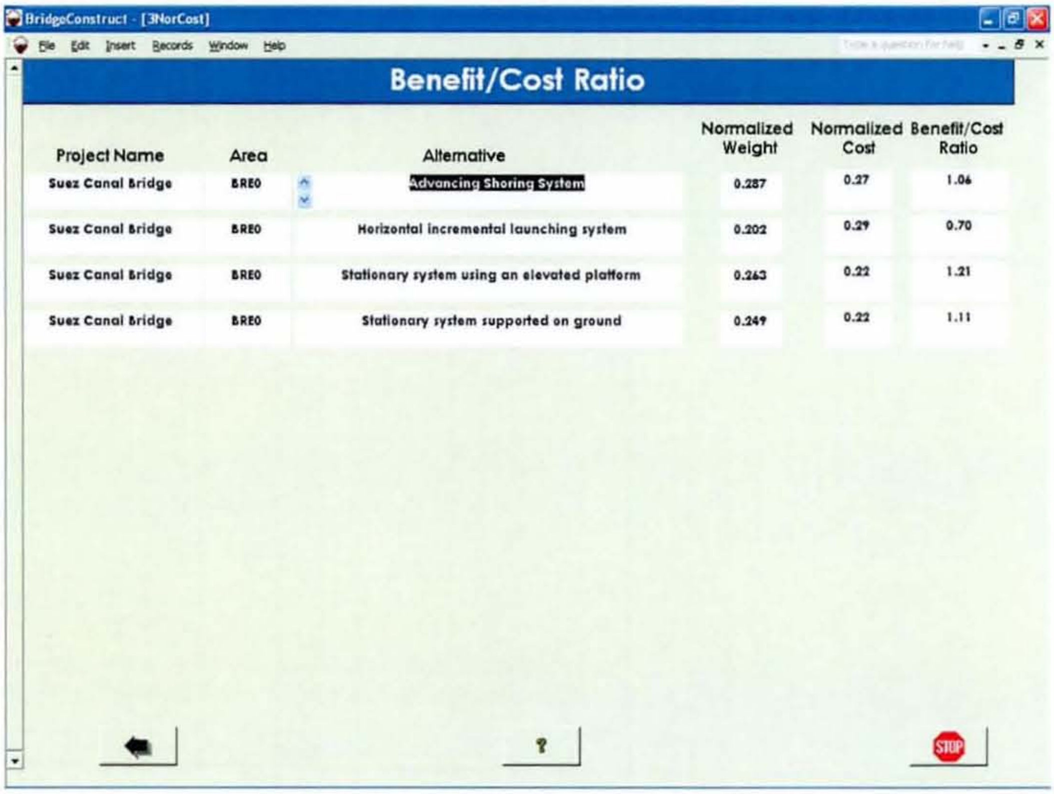
Figure 6.28: Modifying Cost Element General Equipment

SSItem-ID	SSItem	Unit
1	Marine Equipment	Month
2	Tower Crane	Month
3	Generator	Month
4	Aircompressor	Month
5	Water Tank	Month
6	Truck Flat Bed	Month
7	Tractor	Month
0		

Figure 6.29: Modifying the item Marine Equipment

6.6.8 Output

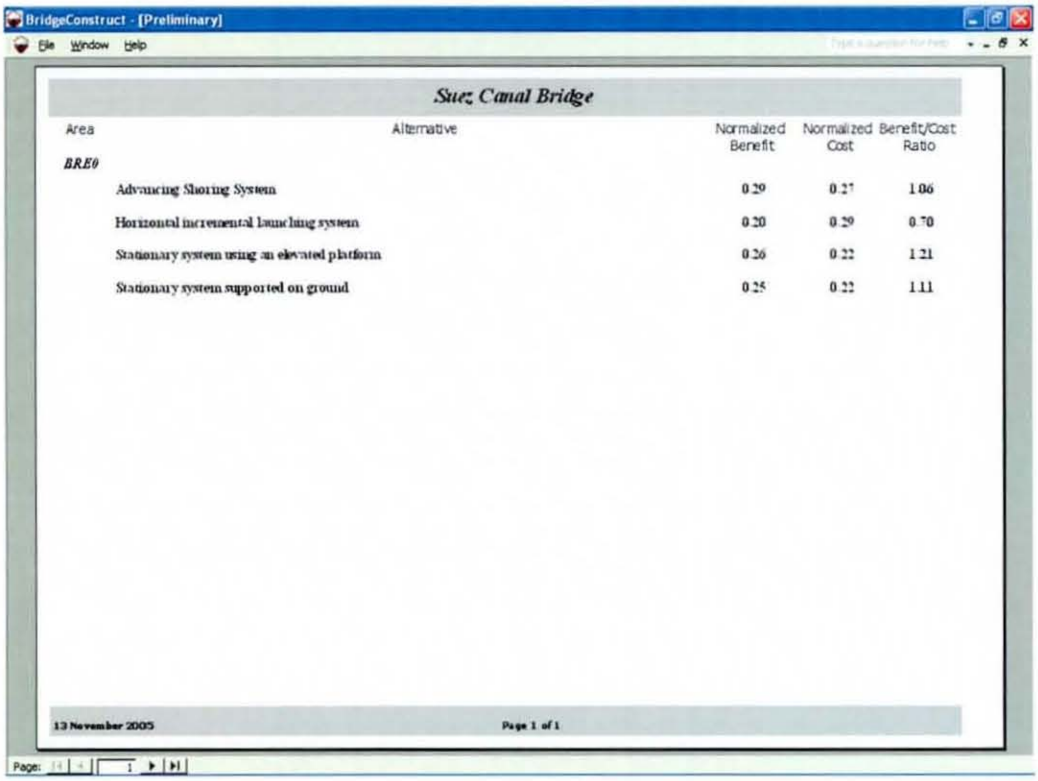
The results and recommendations of the system can be viewed either after performing the preliminary cost estimates or after performing the detailed cost estimate calculations. For each area the ratio between benefit to cost is calculated for each construction technique and the results for the area being calculated can be viewed by clicking the button "View Benefit/Cost Ratio". For each project, the results for all areas are presented together. The best alternatives for the project for all the areas can be viewed by clicking the button "View all Project Alternatives". These buttons are present in both preliminary and detailed cost estimates as illustrated in Figures 6.25 and 6.26. The results can be viewed on screen as presented in Figure 6.30. There is also a printable version of the results as illustrated in Figure 6.31.



Benefit/Cost Ratio

Project Name	Area	Alternative	Normalized Weight	Normalized Cost	Benefit/Cost Ratio
Suez Canal Bridge	BRE0	Advancing Shoring System	0.287	0.27	1.06
Suez Canal Bridge	BRE0	Horizontal incremental launching system	0.202	0.29	0.70
Suez Canal Bridge	BRE0	Stationary system using an elevated platform	0.263	0.22	1.21
Suez Canal Bridge	BRE0	Stationary system supported on ground	0.249	0.22	1.11

Figure 6.30: Results of Benefit/Cost for Alternatives



Suez Canal Bridge

Area	Alternative	Normalized Benefit	Normalized Cost	Benefit/Cost Ratio
BRE0				
	Advancing Shoring System	0.29	0.27	1.06
	Horizontal incremental launching system	0.20	0.29	0.70
	Stationary system using an elevated platform	0.26	0.22	1.21
	Stationary system supported on ground	0.25	0.22	1.11

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Figure 6.31: A Printable Version of the Output

6.7 SUMMARY

Rapid prototyping has proved beneficial as the methodology adopted for system development. The prototype consists of four main modules: introductory module, identifying feasible alternatives module, Pairwise comparison module, and cost estimate module. The prototype has been developed to be flexible and to work as a tool that supports the decision maker. BridgeConstruct has been developed in Microsoft Access environment and using Microsoft PowerPoint and Expert Choice during system operation. The system complemented the knowledge elicited from Egyptian experts with the information extracted from literature in module 2, that identifies feasible alternatives, in order to broaden the selection domain and familiarise Egyptian Experts with the international practice. Chapter 7 presents the results of the prototype's evaluation by industry practitioners.

CHAPTER 7: EVALUATION

7.1 INTRODUCTION

This chapter describes the evaluation of the prototype system. It includes the aim and objectives of the evaluation, the adopted methodology, the results and discussions on the overall evaluation process.

7.2 EVALUATION AIM AND OBJECTIVES

The aim of the evaluation of the prototype system was to determine its usability and functionality. The following objectives were the specific means to fulfil this aim:

1. To assess the performance and accuracy of the prototype system;
2. To determine the applicability of the prototype system to the bridge construction industry;
3. To assess the effectiveness of the system's user interface; and
4. To obtain comments and recommendations for improving the prototype.

7.3 METHODOLOGY

Two types of evaluation were conducted in this research project: formative evaluation and summative evaluation as discussed in Section 2.4.8. Formative evaluation was conducted during the course of system development as part of the rapid prototyping process, and involved a two-part process. The first was to obtain users' feedback on the input requirements of the system. It served as pilot testing before undertaking the major research stages. The second part involved further discussions with industry experts upon finalising each module of the prototype so as to obtain their feedback. Such feedback was then integrated into the prototype development. The development took the shape of an iterative process which continued until the system was ready for use.

After finishing the prototype system, a summative evaluation was undertaken: this involved a series of interviews with industry experts so as to validate and verify the prototype system. Validation is the part of the evaluation that deals with the performance of the system or 'building the right system' that performs with an acceptable level of accuracy. Verification is 'building the system right', with the system correctly implemented to its requirements. Several experts were interviewed by the researcher on an individual basis. Each session started with a presentation, where the system objectives were explained together with a schematic of the system operation. This presentation was followed by a demonstration of how the system worked using an example. The respondents were encouraged to participate by giving their comments during the session. Once the prototype was demonstrated, the interviewees were then asked to complete a questionnaire. Nine participants were engaged in the summative evaluation process, seven of whom had contributed to the various stages of the research and were part of the knowledge elicitation process at the outset of the prototype system development. The other two participants saw the system for the first time and had both an industrial background and research expertise.

7.4 QUESTIONNAIRE DESIGN

The questionnaire's design was based on the aim and objectives of the evaluation stated in Section 7.2. Eight respondents participated in the evaluation sessions where 4 of them had more than 20 years of experience, two had more than 20 years of experience and the remaining one had 5 years of experience. A sample of the evaluation questionnaire is provided in Appendix D. The questionnaire was divided into three sections as follows:

- Section A requested background information about the participant's name, position in their organisation and years of experience;
- Section B contained 29 questions addressing three main aspects of the system: prototype system modules including introductory module, identifying feasible alternatives module, pairwise comparison module and cost estimation module; the system in general; and its applicability to the bridge construction industry. To answer these questions the participants were asked to tick the box that best represented their assessment on a five point scale with the following ratings: 1 (poor), 2 (fair), 3 (satisfactory), 4 (good) and 5 (excellent);
- In Section C, the respondents were asked to outline the benefits of the system and to make suggestions for improvements.

7.5 EVALUATION RESULTS

This section presents the feedback obtained from the evaluation questionnaires. Nine interviews were conducted with eight questionnaires returned to the researcher. Table 7.1 summarises the results from Section B of the questionnaire, with the percentage of respondents that have answered each question presented on the assessment scale.

Table 7.1: Results of the Evaluation Questionnaire Survey

<table>
<tr><th colspan="2">Questions</th><th>1 Poor</th><th>2 Fair</th><th>3 Satis.</th><th>4 Good</th><th>5 Excel.</th></tr>
<tr><td colspan="7">***Module 1 (Introductory Module)***</td></tr>
<tr><td>1</td><td>How well does the introductory form help in understanding how the system works?</td><td></td><td></td><td></td><td>62.5%</td><td>37.5%</td></tr>
<tr><td>2</td><td>How well is the information about construction methods presented?</td><td></td><td></td><td>12.5%</td><td>25%</td><td>62.5%</td></tr>
<tr><td colspan="7">*Comments on Module (1):*
Soil conditions affect the proposed bridge structural system and the system needs to address this issue.</td></tr>
<tr><td colspan="7">***Module 2 (Identifying Feasible Alternatives)***</td></tr>
<tr><td>3</td><td>How appropriate is the data captured for the main project information?</td><td></td><td></td><td></td><td>62.5%</td><td>37.5%</td></tr>
<tr><td>4</td><td>Do the resulting alternatives satisfy your expectations?</td><td></td><td></td><td>25%</td><td>37.5%</td><td>37.5%</td></tr>
<tr><td>5</td><td>Do the identified bridge and site data cover the key issues?</td><td></td><td></td><td>12.5%</td><td>50%</td><td>37.5%</td></tr>
<tr><td>6</td><td>In general, how appropriate is this module?</td><td></td><td></td><td>25%</td><td>25%</td><td>50%</td></tr>
<tr><td colspan="7">*Comments on Module (2):*
• This module is too flexible
• The module explains in a good way the general information of the project
• Owners' views of the structural shape should be incorporated
• Weather conditions should be taken into consideration</td></tr>
<tr><td colspan="7">***Module 3 (Pairwise Comparison Module)***</td></tr>
<tr><td>7</td><td>How clearly are the selection criteria defined in the system?</td><td></td><td></td><td>12.5%</td><td>37.5%</td><td>50%</td></tr>
<tr><td>8</td><td>To what extent does the refined hierarchy represent your perception of the criteria affecting choice of alternatives?</td><td></td><td></td><td></td><td>75%</td><td>25%</td></tr>
</table>

	Questions	1 Poor	2 Fair	3 Satis.	4 Good	5 Excel.
9	To what extent does the overall hierarchy represent your perception of the criteria affecting choice of alternatives?				37.5%	62.5%
10	How effective is the sensitivity tool?			25%	50%	25%
11	To what extent do the identified alternatives represent all the methods that are used in Egypt?				25%	75%
12	In general, how appropriate is the pairwise comparison module?			12.5%	37.5%	50%

Comments on Module (3):

- A datum should be incorporated within the system so as to enable decision makers to compare their assessment to both national and international practice.

Module 4 (Cost Estimate Model)

	Questions	1 Poor	2 Fair	3 Satis.	4 Good	5 Excel.
13	How clearly are the cost elements identified?			12.5%	25%	62.5%
14	To what extent do the identified cost elements represent the cost of the superstructure?				37.5%	62.5%
15	In general, how accurate is the detailed cost estimate?			12.5%	50%	37.5%
16	In general, how accurate is the preliminary cost estimate?			12.5%	75%	12.5%
17	In general, how effective is the cost model in helping to choose a construction method?		12.5%		62.5%	25%

Comments on Module (4):

- The cost model is a subsidiary parameter although it has a prominent weight in selecting a construction method
- The accuracy of the cost model depends on the accuracy of the cost database which needs continuous updating taking into consideration variations between projects and countries
- The cost per metre square should also include the cost of the approaches
- An allowance for risk should be included

Questions		1 Poor	2 Fair	3 Satis.	4 Good	5 Excel.
General						
18	How well does the system reflect the decision-making process in a real situation?			25%	37.5%	37.5%
19	How well does the system help in understanding how superstructure methods can be selected?				87.5%	12.5%
20	How effective/accurate is the system in the selection of construction methods?			25%	62.5%	12.5%
21	How well organised (designed) is the system?			12.5%	37.5%	50%
22	How user friendly is the system?				50%	50%
23	How well integrated are the different components of the system?			12.5%	62.5%	25%
24	To what extent can the same approach extend to cover other elements of bridges (e.g. substructure)?			25%	50%	25%
25	What is your overall rating of the system?			12.5%	50%	37.5%

Comments on the General Aspects of the Prototype:

- The same approach may not be applicable to substructures due to their high redundancy especially in weak soils, subsided rocks or waterways susceptible to scour
- In general, professionals do not use all the information provided by the system; they use their experience in the decisions they make
- The accuracy of the system depends on the time available to study cost
- The overall view of the benefit/cost analysis to the whole project must be emphasised more, to verify its application on the individual areas

Applicability to Bridge Construction Industry						
26	How convinced are you that bridge engineering professionals will use this system (i.e. if made available)?			37.5%	50%	12.5%

	Questions	1 Poor	2 Fair	3 Satis.	4 Good	5 Excel.
27	How effective will the system be in speeding up the decision making process?			25%	37.5%	37.5%
28	To what extent does it represent an improvement (or help) in the decision making process?			37.5%	50%	12.5%
29	To what extent is the system flexible in choosing the most appropriate construction method?				50%	50%

Comments on Prototype Applicability to Bridge Construction Industry:

- Soil structure interaction should be taken into consideration so as to ensure an integrated appropriate construction method
- Bridge practitioners may utilise the system as a mean to confirm the decision that they have already made

Table 7.2 presents the answers provided by the evaluators in response to three questions regarding the main benefits of the system, possible suggestions to improve it, and any further comments.

Table 7.2: General Comments from Evaluators

Main Benefits of the Prototype	Ways to Improve Prototype	Further Comments
• The system is expeditious, decisive and easily implemented • The system is multi-functional and can be used in both design and estimation • It saves the time required for decision making where tight time schedules are a main attribute to bridge projects • It provides a checklist for experienced practitioners • It creates an electronic database for bridge construction	• Increase use of graphical representation • Introduce data from several sources • Add International and advanced construction methods even if they are not used in Egypt • Add national and international costs as a guideline • Integrate new construction methods information as they evolve	• The system needs to be faster during operation • The database requires timely updates. The updating process must be easy, otherwise data will be ineffective • The system combines science and practice in an easy and manageable way so as to permit it to be in the hands of practitioners

Main Benefits of the Prototype	Ways to Improve Prototype	Further Comments
• It provides the decision maker with alternatives which are ranked based on a rated scale system • It provides a good arrangement of data and information for bridge construction • It presents a real image of the project and its constituent parts • It helps the decision maker to choose the best construction method for a project • It helps in studying bridge feasibility • It provides good documentation of the decision making process • It provides clear analysis of the variables involved • It enables the inexperienced user to reach a decision that requires an expert	• Include the effect of other items such as foundations and piers • Apply system to many projects and integrate feedback with the system • Define clearly the assumptions upon which the system have been developed	

7.6 DISCUSSION

The results from the evaluation are discussed under four main headings: results, suggestions for improvement, benefits, and the appropriateness of the evaluation approach.

7.6.1 Results

The participants were asked to judge system's performance and effectiveness for each of the four modules comprising the prototype, the overall system and its applicability to the bridge construction industry. The results are discussed in the following sub-sections.

7.6.1.1 Module 1 (Introductory Module)

The evaluation of this module contained two questions, which were intended to measure respondent's reaction to this module. In average 50% of the respondents considered this module excellent, 44% considered it good and 6% considered it satisfactory. This implies that the information about the construction techniques in terms of their components and construction procedures proved beneficial to the users.

Some of the respondents commented that the effect of the soil conditions on the structural system should be taken into account. However, the effect of the soil conditions on the bridge structural system should have been taken into account in a previous stage. Accordingly, the scope of this system does not address the effect of the soil conditions on the bridge structural system.

7.6.1.2 Module 2 (Identifying Feasible Alternatives)

The evaluation of this module was the result of the answer on four questions. In average 41% rated this module excellent, 44% rated it good, and 15% considered this module satisfactory. The decrease in the excellent rate compared to the previous module may be because some of the respondents considered it too flexible because it allows the users to revise the resulting alternatives by modifying the site and project conditions.

However, this flexibility can be justified as in many instances the unselected alternatives may prove competitive if simple modifications are performed on the site conditions. Moreover, the resulting cost and time implications are taken into consideration by the system.

7.6.1.3 Module 3 (Pairwise Comparison Module)

Six questions were presented to the respondents in order to examine their views on this module. Forty Eight Percent of the respondents considered this module as Excellent. Forty Four Percent of the respondents considered this module as good. Eight Percent of the respondents considered this module as satisfactory. One of the respondents highlighted that the scoring should be compared to international scoring. However, the weights assigned to criteria and alternatives change based on the project context and they cannot be unified or compared to other projects especially in other countries.

Nevertheless, the system may include some of the international practice in module 2, by increasing the limits (e.g. maximum span length) set on using alternatives to reflect the international practice rather than Egyptian practice.

7.6.1.4 Module 4 (Cost Estimate Model)

This module was evaluated through four questions. Forty Four percent of the respondents considered this module Excellent, 47% of the respondents considered it good, and 9% considered it fair.

Some of the respondents illustrated that the cost of the bridge should also include the cost of the approach roads, this comment may be taken into account in calculating cost/m^2 of the bridge surface area or by including it under the item 'others' in the detailed cost estimate. However, such inclusion may result in misleading results as the cost of the approach roads are affected differently by the criteria affecting bridge. In some projects (e.g. Rades La Gaulette in Tunisia), the soil requires special treatment (i.e. by installing drains and allowing it to consolidate for a few months). Such treatment affects road costs significantly.

One of the participants proposed verbally during discussion that it may be useful if the alternatives are sieved first based on the preliminary cost model in order to decrease effort done during the detailed estimation process. It may be useful in this case if the user extends his selection to be based on the benefits as well as the cost of the alternatives. Accordingly based on the resulting Benefit/Cost ratio, the user may choose to perform the detailed cost estimate only on the most competitive alternatives.

Other respondents commented that the element of risk should be catered for. This element can be included under the item "others" in the detailed cost model.

7.6.1.5 General Aspects of the Prototype System

Eight questions were compiled in order to measure the general aspects of the prototype system. Thirty one percent of the respondents considered the system excellent, 55% rated it good and 14% rated it satisfactory. One of the respondents commented that the system may be comprehensive in dealing with the superstructure but it should be treated cautiously if the same approach is to be extended to deal with foundations. The applicability of this approach to foundations may be discussed further in future research projects. The respondents also illustrated that the benefit/cost analysis should emphasize the overall project view rather than an area-by-area view. This comment has been integrated to the system.

7.6.1.6 Applicability to the Bridge Construction Industry

This aspect was evaluated by asking the respondents to answer four questions.

Twenty eight percent of the respondents gave a rating of excellent, 47% gave a rating of good to this point and 25% gave a rating of Satisfactory. The respondents were moderately convinced that the system could be used by bridge professionals. These results may reflect the unfamiliarity of Egyptian professionals with the benefits and usage of IT tools and more specifically decision support systems.

7.6.2 Suggestions for Improvement

Table 7.2 presents the respondents suggestions to improve the system. These suggestions can be summarised and discussed as follows:

- The system should increase the use of the graphical representation. Visualising the project and its parts is beneficial in this context and can be investigated in further research works;
- The system should include an information database of the cost of other construction methods that are used internationally. However, the effect of the varying economic circumstances and legislations governing different countries should be taken into consideration when compiling such a database. The construction of such a database can be investigated further in the future;
- The system should be updated by new techniques that are used in Egypt as they emerge. The system is designed to enable the addition of new construction techniques. The collective effort of constructors, owners, designers and suppliers plays an important role in this issue.
- The respondents pointed out that the speed of the prototype needs more

attention as the system appears to be relatively slow during operation. This issue has been relatively enhanced following these comments;

- The respondents also illustrated that the assumptions upon which the system is built should be clearly defined. The underlying assumptions of the system have been clearly identified in Chapters 3, 4 and 6.

7.6.3 Benefits of the Prototype

Throughout the evaluation, and as mentioned in Table 7.2, the respondents identified several potential benefits of the prototype, these benefits can be summarised as follows:

- It provides bridge practitioners with an effective and efficient systematic approach in selecting bridge construction techniques;
- It documents the decision making process as well as the underlying assumptions, saves the time required for decision making and can be easily implemented;
- It provides a structured approach for young engineers to the evaluation process while learning about methods and technicalities with the guidance of senior practitioners;
- Senior practitioners may also use it as a mean to verify their decision or as a check list of the important issues that should be tackled before making their decisions;

7.6.4 Appropriateness of the Evaluation Approach

The evaluation approach adopted helped to test the main aspects of the system identified in the evaluation objectives and was successful. This was confirmed by the positive feedback received from respondents. Despite the comments raised on the prototype, further evaluation and improvement of the system would facilitate the use of the prototype for practical purposes. The evaluation approach conducted, highlighted several points including:

- Most of the evaluators were bridge experts with considerable experience in bridge construction and this ensured a relatively thorough assessment on the practicality of the prototype;
- The questionnaire covered all the major aspects of the prototype that needed to be evaluated and was useful for obtaining essential feedback from the respondents.

7.7 SUMMARY

This chapter described the evaluation of the developed prototype system. The research adopted the questionnaire technique in the summative evaluation of the prototype system. The results demonstrate that the prototype has a good performance and is suitable for use in the bridge construction industry, although there is scope for improvement. The respondents highlighted that the system should contain an information database of the cost of the construction methods used internationally. The respondents also commented that it should be updated with new techniques as they emerge. The results suggest that the systems' structured and documented approaches are amongst its main benefits. Many of the comments from the evaluation were used to refine the prototype system. The next chapter presents the conclusions and recommendations of the research.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS

8.1 INTRODUCTION

This chapter presents the conclusions and recommendations of this research. The focus of this research and its various stages was the development of the decision support system (BridgeConstruct) for choosing the most appropriate concrete bridge construction method in a given situation. This chapter summarises the overall findings of the research, its benefits and limitations, and makes recommendations for future work.

8.2 SUMMARY

This research was instigated by the need to create a structured approach that improves and automates the seemingly haphazard selection process of concrete bridge superstructure construction methods in Egypt. In order to respond to this need, the aim of the research was to investigate the factors involved in the selection of construction methods for the superstructure of concrete bridges in Egypt and to develop an intelligent decision support system that is effectively able to evaluate and recommend a suitable construction method for a given bridge design. This aim was fulfilled through the following objectives:

1. Review related work on the selection of alternative bridge construction methods for a given situation, as well as the application of intelligent decision support techniques to construction problems;
2. Identify and investigate the criteria necessary for the evaluation of alternative

superstructure construction methods in Egypt and investigate the situations under which different construction methods are used;

3. Develop an intelligent decision support system to help bridge practitioners in Egypt to decide on the most appropriate superstructure construction method for a given design; and
4. Evaluate the developed system using real examples with industry experts.

In order to carry out the above, a research methodology was developed where various strategies were employed as demonstrated in Figure 2.1, which offers a comprehensive view of the research methodology.

The specific tasks undertaken in this research are summarised below with respect to research objectives.

1) ***Review related work on the selection of alternative bridge construction methods for a given situation, as well as the application of intelligent decision support techniques to construction problems.***

A comprehensive literature review was carried out where the main elements constituting the research problem were investigated (see Section 2.4.2.1.) Three main elements were identified and reviewed: concrete bridge construction methods, decision making and research methodologies.

The literature review on concrete bridges revealed that bridge engineers do not have an effective systematic approach to help them select construction methods despite its paramount importance and effect on the overall project outcomes. Practically, experts rely heavily on their skills, knowledge and experience. Furthermore, bridges are now becoming more and more complex with many criteria that need to be considered before selecting the most appropriate construction method. With the current practice, bridge engineers in Egypt may mistakenly leave out influential criteria in the absence of any formal structured or systematic approach that can be followed. Chapter 3 discusses the various aspects of bridge construction including the stages involved in the development of bridge projects, preliminary design as well as the technical aspects and procedures involved in the various construction techniques. The chapter ends by highlighting some of the issues that are related to the construction industry in Egypt.

Intelligent decision support techniques that can be used in the proposed prototype were reviewed in Chapter 4. The review revealed that the Analytic Hierarchy Process (AHP) could be used to provide an appropriate framework for modelling complex decision scenarios. AHP integrates perceptions, feelings, judgements and experiences of people and represents them in a hierarchical form that allows an overall view of the problem. It permits experts to understand better the problem and its dimensions, which are presented in the form of the decision criteria and possible choices.

Research methodologies and their underlying philosophies as well as some of the relevant knowledge elicitation techniques were reviewed in Chapter 2. This research adopted a mixed approach where both the qualitative and quantitative techniques were used interchangeably. The qualitative approach was used at the beginning to obtain an in-depth understanding of the problem without being constrained to a specific framework. The quantitative approach was used in later stages to generalise the problem and refine the outcomes of the qualitative approach.

The review stage was complemented by the researcher's participation in conferences and seminars to interact with other researchers in similar areas as well as bridge practitioners.

2) ***Identify and investigate the criteria necessary for the evaluation of alternative superstructure construction methods in Egypt and investigate the situations under which different construction methods are used***

Knowledge elicitation was considered a mandatory part in the development of any intelligent decision support system that would help the selection of concrete bridge construction methods. This was because the decision making process needs to be captured in order to develop a decision model for the system. The knowledge elicitation process used in this research was presented in Chapter 5. It involved capturing and transforming the appropriate knowledge from experts into a manageable form in order to develop a decision model. The knowledge captured included the relevant criteria, which influence the choice of the most appropriate construction technique. The criteria and alternatives captured from experts were then represented by a decision hierarchy based on the AHP approach to develop a decision model. The research adopted multiple approaches to knowledge elicitation including semi-structured interviews, questionnaire surveys, card sorting, structured interviews and process tracing.

Semi-structured interviews were conducted with industry experts in order to obtain the basic knowledge required for the research. It was selected as a start to the research as it does not restrict respondents to a previously prepared framework, as is the case with questionnaires. Experts were permitted to think freely about their views of the criteria affecting selection of construction methods. These interviews were followed by card sorting sessions whereby the problem model was represented in a hierarchical fashion. Afterwards, the research utilised questionnaire surveys mainly to produce a refined version of the developed hierarchy. The next step was to conduct structured interviews whereby the knowledge related to the conditions of using construction methods were acquired from experts. The researcher also utilised protocol analysis and process tracing in order to capture the experts' knowledge in order to develop the cost estimation model. The objective of these methods was to develop a list of cost items that are involved in the estimation process for each construction method.

3) Develop an intelligent decision support system to help bridge practitioners in Egypt to decide on the most appropriate superstructure construction method for a given bridge design

The captured knowledge was used to develop the prototype using rapid prototyping. The proposed prototype system was called "BridgeConstruct". The development and operation of BridgeConstruct is described in Chapter 6. Since the research utilised the AHP model to deal with the problem in selecting the most suitable construction method, the Expert Choice software was chosen for structuring the decision problem into a hierarchy and synthesizing judgements. This simplified the system development by eliminating complicated calculations. The Capabilities of Expert choice in performing AHP calculations are integrated with the capabilities of Microsoft Access. Microsoft Access was used as the application that manages the system and performs the preliminary selection of the feasible alternatives. This approach helped to increase efficiency of using

Expert Choice where the user focuses only on comparing the feasible alternatives rather than the whole list of alternatives. Microsoft Access is also used to perform cost calculations and to produce the necessary reports.

The architecture of BridgeConstrct consists of four main modules; introductory module, identifying feasible alternatives module, pairwise comparison of feasible alternatives module, and finally the cost estimation of the feasible alternatives module. The introductory module enables users to obtain the necessary information about the different construction methods and to understand the functional architecture of the system. The second module is concerned with identifying the feasible construction methods based on the technical conditions that limit the construction techniques use. Module 2 considerably increases the effectiveness of module 3 which is concerned with performing comparisons between feasible alternatives taking into consideration the criteria using AHP. Module 4, which is concerned with developing cost estimate model, complements the selection process whereby users can use either preliminary estimate or the detailed estimate. The benefits obtained from module 3 are compared to the corresponding cost of alternatives and the highest ratio presents the most appropriate alternative.

4) Evaluate the developed system using real examples with industry experts

The prototype was evaluated during and after the development process to verify and validate it. The summative evaluation of the prototype system was conducted after it has been developed as explained in Chapter 7. The researcher conducted a series of evaluation sessions whereby the system was demonstrated to the participants. The participants were then asked to complete a questionnaire. The results of the evaluation confirmed that, even though there is scope for improvement to make the system more effective, it provides many benefits, demonstrates good performance, and is applicable for use in the industry.

It can be seen from the above, that the objectives of the research project have generally been achieved through the relevant tasks.

8.3 BENEFITS

Besides the benefits identified by the respondents during evaluation in Section 7.6.3, BridgeConstruct offers many other advantages to the users who are involved in the selection of bridge construction techniques:

1. It serves as an information resource that contains a variety of data on bridge superstructure construction techniques and construction procedures;
2. The system is easy to use and its underlying techniques can be easily comprehended by practitioners thus giving the system greater potential for application in the construction industry;
3. The detailed cost model enables decision makers to calculate cost easily by completing the items pertaining to the construction method in the system in an easy and structured way, as it is divided into several items. The decision maker can also calculate cost using the preliminary model which calculates cost on the basis of an overall view;
4. The documented rationale offered by the system increases the potential use of some of the construction methods that may have been deemed inappropriate because of some criteria. The ability to express those

criteria and their effect enables the decision maker to express his/her judgement better when discussing the matter with others especially in higher levels in his/her organisation;

5. The system caters for most of the decision makers' requirements whilst selecting concrete bridge construction methods because of its flexibility that is highly reflected in Modules 2 and 3.
6. The system enables users to check their consistency in making the decision by using the consistency index;
7. The system enables decision makers to have an integrated view of the project. The impact of varying the weights of the criteria is reflected on the resulting benefits of the alternatives and can be viewed graphically using the sensitivity tool; and
8. The system can be used as a means to present decisions related to the construction method selection process to clients thus giving them a well informed view of the possible courses of action and offers a competitive edge due to its positive impression on clients.

8.4 CONCLUSIONS

There are many conclusions that can be drawn from this research project, these include:

1. The selection of bridge construction methods mirrors the randomness that often characterises the construction industry. It is performed in an intuitive and unstructured fashion and relies heavily on the experience, skill, knowledge and judgement of bridge engineers. This provides scope for errors

and inconsistencies in the resulting decisions in the absence of any clear framework. Furthermore, it does not provide the decision maker with a well documented rationale that would help him/her to justify his/her decision or to clearly capture lessons learnt in order to help in future situations;

2. The selection process is highly affected by cost, duration of construction, bridge physical characteristics, construction method characteristics, and the surrounding environment and, to a lesser extent, by stakeholders' objectives and external constraints;
3. There are eight main construction methods that are used in the construction of bridge superstructures in Egypt: stationary systems that are supported on the ground; stationary systems that are supported using an elevated platform; cantilever construction by in-situ concreting using two form travellers; cantilever construction by in-situ concreting using one form traveller and a stationary system; advancing shoring system; launching trusses that are used to erect prestressed precast beams; erecting bridge beams using cranes or heavy lifting; and horizontal incremental launching. Despite this broad categorisation there are a variety of arrangements that can be considered within each method to cater for the specific needs of each individual project;
4. Experts do not usually consider these methods together but use their experience and knowledge about their limitations to narrow down their selection before commencing a detailed study;
5. The prototype system offers greater benefit when used during the early stage of project development life cycle, specially the design phase, when assessing alternative structural systems from the construction perspective.

6. The developed prototype system provides users with a clear, systematic and structured framework that could improve the decision making process. The technical, economical and managerial aspects of the decision are considered in order to ensure that a sound and rational judgement is made in selecting the most appropriate superstructure construction method in a given situation;
7. Engineers normally give more credit to systems that present them with choices and alternative courses of action instead of black box systems that limit their judgement during the decision making process;
8. The analytic hierarchy process is a suitable approach to use because of its benefits which are:
    a) It improves the decision making process, where the hierarchical structure used in formulating the AHP model enables bridge engineers to have an overall view of the problem in a systematic fashion where the influential criteria, subcriteria and alternatives are viewed together;
    b) It allows bridge engineers, who are usually accustomed to quantifiable criteria to also consider the qualitative aspects of the problem. AHP also takes into consideration judgements that are based on people's feelings, emotions as well as thoughts. These capabilities represent the decision making process to a great extent;
    c) The method is capable of measuring the inconsistencies that are attributed to experts' judgements. It also recognises that innovative decisions are not necessarily fully consistent and allows for a limited

degree of inconsistency;

d) The nature of the numerical and graphical representations of the results and input allows the user to interact better and perform the selection process efficiently;

e) The availability of Microsoft Access on most PCs and the availability of Expert Choice for purchase in the market facilitate system's use; and

f) The above results resemble the conclusions of studies on similar problems that reflected the advantages of AHP in dealing with multi-criteria decision making.

9. The ease with which a bridge can be constructed is directly influenced by its design. Concepts such as buildability are important and need further consideration by all the parties involved, especially designers. Designers should make adequate provisions in their design to ensure that bridges are constructed safely, economically and in an environmentally sustainable manner;

10. Despite the wide variety of techniques that are used by the industry internationally, the bridge industry in Egypt has experienced them. There may be variations in their use between different countries but all are under the main methods used in Egypt. This fact may encourage the researcher to argue with caution that the research applicability and possible use may be extended beyond Egypt; and

11. It is advisable that bridge clients in Egypt adopt design-build contractual

arrangements rather than the traditional build contracts. Design-build contracts enable contractors to thoroughly investigate the design alternatives and their impact on construction to arrive at an appropriate selection, which should ultimately provide the clients with better value for money bridges.

8.5 LIMITATIONS OF THE RESEARCH

There are some limitations that should be considered when using the outcomes of this research:

1. The system is designed to act as a tool that supports the decision making process by structuring and systematically evaluating the criteria that affect the selection of construction techniques. The system depends on expert's judgement to assess all the criteria based on the developed framework;
2. Although the system examines the sensitivity of the benefit with regard to criteria priorities, it does not look at the sensitivity of the benefit to cost ratio;
3. The developed system is limited in its applicability to the procedures mentioned for the identified construction methods. It may not cater for some of the variations that may be performed by some contractors, especially in the detailed cost model. However, the system is flexible and practitioners may reflect their own case in its modules;
4. Although the formative evaluation was carried out during the development process and summative evaluation after the prototype was developed and both were conducted by experts, the system requires

further trials using real life case studies to ensure its accuracy and effectiveness;

5. Despite the importance of the superstructure construction methods and their paramount influence on the project, the system should be integrated with other approaches to be used in the selection of construction methods for other elements of the bridge (such as substructure and piers) so as to reflect their contribution to the overall bridge construction process; and
6. The system is of limited use if the cooperation between the contractor and designer is not fulfilled fully early at the design stage.

8.6 RECOMMENDATIONS FOR FURTHER RESEARCH

The research has revealed a number of issues for further research and development, including:

1. The quality of the prototype system could be improved by adopting the following:
    a) Regularly updating the system with the new and latest construction techniques available in the industry;
    b) Improving the system's speed by using other database applications such as Oracle in order to provide better stability and speed to the system;
2. Exploring the possibility of constructing a cost hierarchy similar to the one constructed for the problem. It can be used by well experienced practitioners to obtain the cost weighting for each alternative and to compare it to benefits, instead of calculating the cost in the manner presented in this research. This

approach may prove to be helpful as it saves the time consumed in producing detailed cost estimates;

3. Testing the system using more than one real life case study with various types of structural systems. The feedback from these cases can further improve the system's applicability to the different types of bridge structural systems;
4. It is not unusual during the early stages of bridge development to put together a multidisciplinary team where the views of different practitioners with regard to construction are included. The system's capability to perform group judgement, although not tested in this research, can be easily implemented and evaluated. This one should be investigated by further research;
5. Research should study possible ways of increasing co-operation amongst bridge contractors in using construction methods. This issue was reflected by some experts, who expressed their willingness to participate in a database for systems that are available in the market. Generally, bridge construction techniques require considerable investment. Usually, they are used for one or two projects then remain dormant in stores with the possibility of being scraped. Increasing co-operation would facilitate the search for bridge construction techniques and help contractors to utilise their available resources efficiently. It will also decrease cost as well as the time consumed in procuring systems and may be considered as a step forward towards a more sustainable environment; and
6. The system reflects the Egyptian experience in concrete bridge construction, which may be argued to represent many of the developing countries.

However, further work should examine case studies in developed countries where the capabilities of the construction methods used are deemed more effective and efficient. This will enrich the system, possibly by introducing new criteria and/or construction procedures. It will also extend the scope of applicability of the system.

8.7 CLOSING REMARKS

The research has revealed that the current selection process for concrete bridges superstructure used by bridge engineers is based mainly on their knowledge and experience without any clear systematic procedure that can be followed to support the decision making process. This research has demonstrated how a structured DSS can provide users with a clear, systematic and structured framework that improves their current selection process. The use of AHP has proved to be an effective approach as it allows for considering both qualitative and quantitative criteria that affect the decision making process. Bridge engineers should take advantage of the system presented in this thesis as it presents many benefits to the construction industry.

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APPENDIX A : INTERVIEW QUESTIONS

1. How does the designer go in choosing a concrete bridge structural system?
2. How does the designer decide the proper construction method?
3. What are the criteria that affect the choice of the construction method in the conceptual design phase for the substructure (i.e. foundations and Piers)?
4. What are the criteria that affect the choice of the construction method in the conceptual design phase for the superstructure?
5. Do you consider the possibility of using a combination of construction methods within the same element in the same project?
6. What are the construction methods that are used in the construction of the superstructure of concrete bridges in Egypt?

APPENDIX B: QUESTIONNAIRE

Centre for Innovative Construction Engineering

Department of Civil and Building Engineering
Loughborough University Loughborough Leicestershire LE11 3TU UK

Loughborough University

CJA/JCB

Date:
Attention: Mr.

Direct Line: +44 (0)1509 222615
Fax: +44 (0)1509 223982
E-mail: C.J.Anumba@lboro.ac.uk
Website: http://www.lboro.ac.uk/cice

Dear Sir,

Please find enclosed a questionnaire from one of my part-time PHD Researchers, Mr Mohammed A. M. Youssef.

This questionnaire is part of his PHD study that is concerned with evaluation of concrete bridge superstructure construction methods with special regards to Egyptian experience.

I would be most grateful if you could find the time to respond to the attached questionnaire and return it to Mr. Youssef in the envelope provided, call him back, or send him an e-mail to collect it from you. His phone numbers are:

012 3983407 - 4035066 - 4035067 – 5249610, in Cairo, Egypt.

E-Mail: M.A.M.Youssef@lboro.ac.uk

Your assistance would be greatly appreciated.

Yours sincerely

Professor C J Anumba

Supervisor

Survey on the Selection Criteria For Concrete Bridge Superstructure Construction Methods

أستقصاء رأى عن العوامل (المعايير) المؤثره فى أختيار طرق تنفيذ الهيكل العلوى للكبارى الخرسانيه

This Survey is part of a research program at Loughborough University to establish the selection criteria for concrete bridges superstructure construction method (i.e. C.M.) within the Egyptian Construction industry. Structured Questions have been formulated to achieve this goal. Although you are required to respond to most questions by ticking or filling in a box, there is also the opportunity for you to add your comments. Your response to this questionnaire is highly valued and will be treated with the strictest Secrecy. It will be used for academic purposes only. Thank you

هذا الأستقصاء يعد جزءا من مشروع بحثى للحصول على الدكتوراه يتم القيام به فى جامعة لافبرا بالمملكه المتحده و ذلك لتحديد و تقييم العوامل (المعايير) المؤثره فى أختيار طرق تنفيذ الهيكل العلوى للكبارى الخرسانيه فى مصر. سيطلب منكم الأجابه عن مجموعه من الأسئله عن طريق الأختيار أو أضافة ماترونه مناسبا من تعليقات للأجابه عن السؤال. أجاباتكم عن هذا الأستقصاء ستعد سريه و ستستخدم للأغراض الأكاديميه الخاصه بهذا البحث فقط.

Background Information

a. Name (Optional) الأسم (أختيارى): --
b. Position (الموقع الوظيفى):--
c. Please State Your Experience in the concrete bridge construction (in years)
(عدد سنوات الخبره فى أعمال الكبارى الخرسانيه):--
d. Company/Institution/others Name (أسم الشركه/الهيئه/و خلافه التى تعملون بها):------------------------------
----
e. Tel: -------------------Fax:---------------------E-mail:--

Aim of research:

The aim of the research is to investigate the factors involved in the evaluation of alternative concrete bridge superstructure C.M. and to develop an intelligent decision support system that is able effectively to assess construction cost and time as well as any other important criteria.

الهدف من هذا البحث هو البحث عن العوامل (المعايير) التى تتدخل فى تقييم و أختيار طرق التنفيذ المختلفه للهيكل العلوى للكبارى الخرسانيه ثم تصميم نظام لدعم أتخاذ القرار له القدره على تقييم الوقت و التكلفه و كذا أى معايير أخرى تتدخل فى الأختيار.

__Please respond to the following questions:__ *__برجاء القيام بالرد على الأسئله التاليه:__*

1. Please describe your experience in the following concrete bridges C.M. (Tick √ as appropriate):

1- برجاء وصف خبرتك فى كل من طرق التنفيذ المشار اليها عن طريق وضع علامه √ على الأختيار المناسب

Construction Method طريقة التنفيذ				Experience الخبره			
				High	Medium	Low	No
Superstructure الهيكل العلوى	Precast سابقة الصب	Incremental Launching (e.g. Deck Pushing) دفع الهيكل العلوى					
		Hoisting and Lifting (e.g. Heavy Lifting) الرفع بالجاكات (لفت سلاب)					
		Launching Girders اللونشنج جيردر					
		Free Cantilever العربات المتحركه					
	Cast in-situ الصب بالموقع	Stationary Formwork الشده المعدنيه أو ما يماثلها من شدات ثابته على الأرض					
		Traveling Formwork (e.g. Flying Shuttering) الشده الطائره أو ما يماثلها					
		Free Cantilever العربات المتحركه					
	Others, Please Specify خلافه						
Columns/Piers الأعمده		Precast سابقة الصب					
	Cast in-situ مصبوبه بالموقع	Climbing Formwork الشده المتسلقه					
		Sliding Formwork الشده المنزلقه					
		Traditional Formwork الشدات العاديه					
	Others, Please Specify خلافه						
Foundations الأساسات		Shallow سطحيه					
	Piles الخوازيق	Replacement	Bored بالحفر				
			Precast سابقة الصب				
		Displacement	Precast Driven سابقة الصب بالدق				
			Driven Cast In Situ بالدق و مصبوبه بالموقع				
			Driven Steel حديديه بالدق				
	PileCaps القواعد فوق الخوازيق	Cofferdams عمل علبه بالستائر و خلافه					
		Lowering بالتغويص					
		On Ground على الأرض					
	Caissons القيسونات	Open Well أبار مفتوحه					
		Pneumatic نيوماتيك					
	Others, Please Specify خلافه						

2. Who decides on C.M. to use? (Please tick)

2- من الذى يقوم بتحديد طريقة التنفيذ؟

Estimator (دارس أسعار المشروع) ☐
Project Manager (مدير المشروع) ☐
Site Manager (مدير التنفيذ) ☐

Client (العميل) ☐
Designer (المصمم) ☐
Engineer (أستشارى المالك) ☐

3. At what stage in the project is C.M. chosen? (Please Tick)

3- ماهى المرحله التى يتم فيها أختيار طريقة التنفيذ؟

Inception (مرحلة تكوين الفكره الأساسيه للمشروع) ☐
Conceptual Design (مرحلة دراسة التصميم المبدئي للمشروع) ☐
Scheme Design (مرحلة التصميم المبدئى) ☐
Detailed Design (مرحلة التصميم التفصيلى) ☐

4. Do you use specific procedures to select C.M. for concrete bridges?

4- هل تستخدم خطوات محدده لأختيار طريقة التنفيذ للكبارى الخرسانيه؟

Yes ☐ No ☐

5. If you answer yes to question (4), Please describe these procedures?

5- إذا كانت الأجابه على السؤال رقم (4) بنعم، برجاء وصف هذه الخطوات؟

6. If you answer yes to question (4), Please indicate whether you use computers/Information technology during these procedures or not?

6- إذا كانت الأجابه على السؤال رقم (4) بنعم، برجاء تحديد إذا كنتم تقومون بأستخدام الحاسب الآلى خلال هذه الخطوات أم لا؟

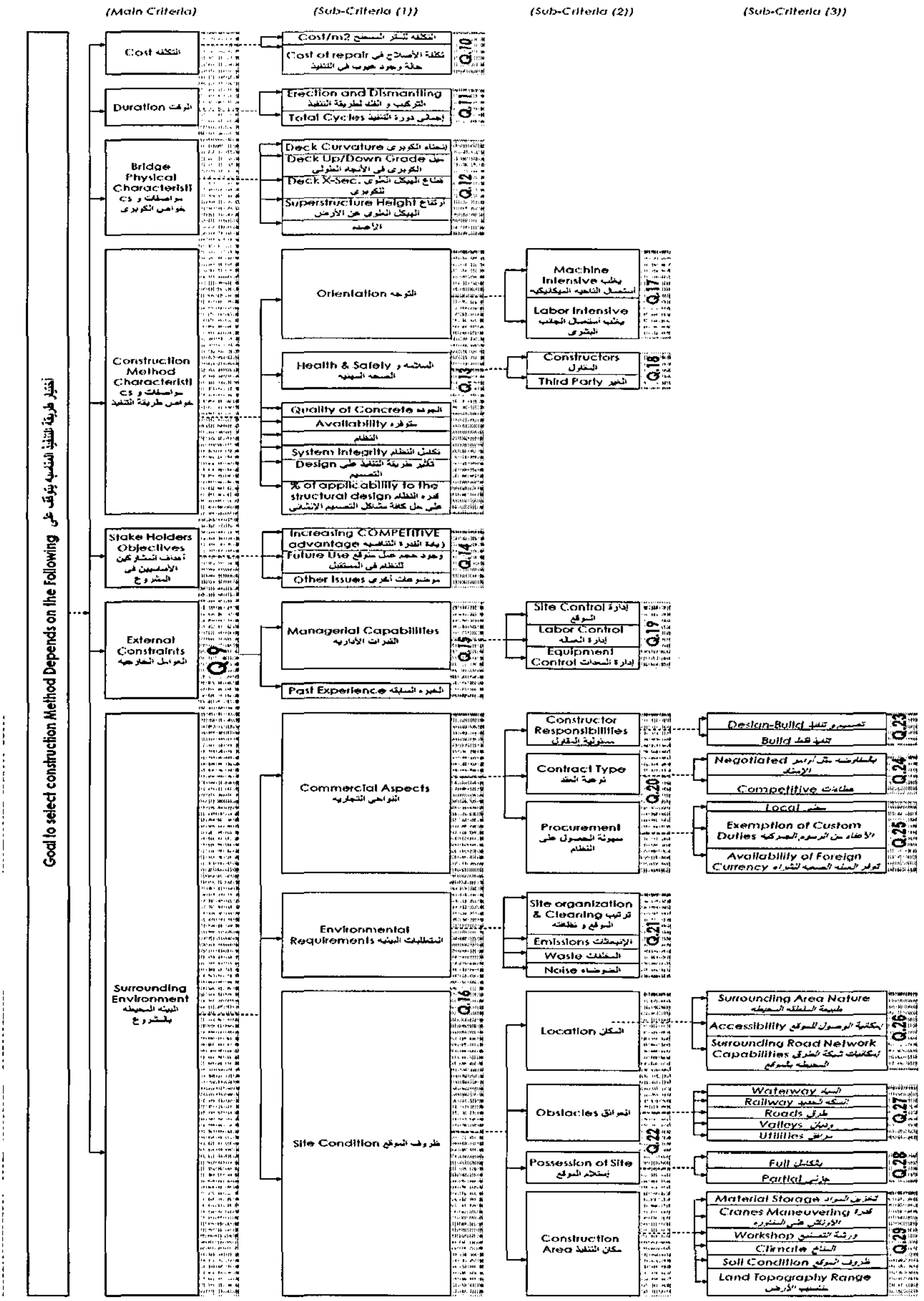
Yes ☐ No ☐

7. Do you have any suggestions to improve selection process of C.M.?

7- هل لديك أى مقترحات لتحسين عملية أختيار طريقة التنفيذ؟

8. The Following hierarchy contains a proposed model for the selection of concrete bridges superstructure C.M., Please read it and answer the following Questions: Every question number is related to hierarchy

8- هذا الشكل يوضح الهيكل الخاص بالعوامل المؤثره فى أختيار طريقة تنفيذ الهيكل العلوى للكبارى الخرسانيه و كل مجموعة عوامل عليها سؤال يوجد رقمه بجانب مجموعة العوامل و ذلك لمساعدتكم فى التقييم



9. Please rank the following Main criteria of C.M. in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

9- برجاء ترتيب العوامل (المعايير) الرئيسيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Main Criteria	Cost التكلفه	Duration الوقت	Bridge Physical Characteristics مواصفات و خواص الكوبرى	Construction Method Characteristics مواصفات و خواص طريقه التنفيذ	Stake Holders Objectives أهداف المشاركين الأساسيين فى المشروع	External Constraints العوامل الخارجيه	Surrounding Environment البيئه المحيطه بالمشروع
Rank	-------	------------	---------------------	--------------------	----------------	----------------	-----------------

10. Please Rank the following Sub-criteria 1 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

10- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-criteria 1 *(Cost) التكلفه*	Cost/M2 التكلفه للمتر المسطح	Cost of Repair during construction تكلفة الأصلاح فى حالة وجود عيوب أثناء التنفيذ
Rank	-----------	--

11. Please Rank the following sub-criteria 1 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

11- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 1 *(Duration) الوقت*	Erection & Dismantling التركيب و الفك لطريقة التنفيذ	Total Cycles أجمالى دورة التنفيذ
Rank	----------------------------------	---------------------

12. Please Rank the following sub-criteria 1 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

12- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 1 *(Bridge Physical Characteristics)* *خواص الكوبرى*	Deck Curvature أنحناء الكوبرى	Up/Down Grade ميل الكوبرى فى الأتجاه الطولى	Deck X-Sec. قطاع الهيكل العلوى للكوبرى	Superstructure Height From Ground أرتفاع الهيكل العلوى من الأرض	Span Length طول البحر بين الأعمده
Rank	-----------	---------------	--------------	----------------	--------------

13. Please Rank the following sub-criteria 1 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

13- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 1 ***(CM Characteristics)*** ***خواص طريقة التنفيذ***	Orientation	Health & Safety السلامه	Quality of Concrete الجوده	Availability متوفره	System Complexity صعوبة النظام	System Integrity تكامل النظام	Effect of CM loads on design	% Applicabilit to structural design
Rank	----	---------	------------ --	--------------	--------------	------------	---------	--------------

14. Please Rank the following sub-criteria 1 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

14- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 1 ***(Stake Holders Objectives)*** ***اهداف المشاركين***	Increasing Competitive advantage زيادة القدره التنافسيه	Future Use وجود أعمال فى المستقبل للنظام	Other Issues موضوعات أخرى
Rank	-----------	---------------	---------------

15. Please Rank the following sub-criteria 1 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

15- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 1 ***(External Constraints)*** ***العوامل الخارجيه***	Managerial capabilities القدره الإداريه	Past Experience الخبره السابقه
Rank	-----------	---------------

16. Please Rank the following sub-criteria 1 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

16- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 1 ***(Surrounding Environment)*** ***ظروف المشروع***	Commercial Aspects النواحى التجاريه	Environmental Requirements المتطلبات البيئيه	Site Condition ظروف الموقع
Rank	-----------	---------------	---------------

17. Please Rank the following sub-criteria 2 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

17- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 2 ***(Orientation)*** ***التوجه***	Machine Intensive يغلب أستعمال النواحى الميكانيكيه	Labor Intensive يغلب أستعمال الجانب البشرى
Rank	------------------------	--------------------

18. Please Rank the following sub-criteria 2 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

18- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 2 *(Health & Safety)* *السلامه*	Constructors المقاول	Third Party الغير
Rank	-----------	---------------

19. Please Rank the following sub-criteria 2 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

19- برجاء ترتيب العناصر التاليه و التى تتحكم فى أختيار طريقة التنفيذ من الأكثر أهميه (رقم 1) إلى الأقل أهميه (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 2 *(Managerial Capabilities)* *القدره على الإداره*	Site Control إدارة الموقع	Labor Control إدارة الموارد البشريه	Equipment Control إدارة المعدات
Rank	-----------	---------------	---------------

20. Please Rank the following sub-criteria 2 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

20- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 2 *(Commercial Aspects)* *النواحى التجاريه*	Constructor Responsibilities مسئولية المقاول	Contract type نوعية العقد	Procurement سهولة الحصول على النظام
Rank	-----------	---------------	---------------

21. Please Rank the following sub-criteria 2 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

21- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 2 *(Environmental Requirements)* *المتطلبات البيئيه*	Site Organization & Cleaning ترتيب الموقع و نظافته	Emissions الأنبعاثات	Waste المخلفات	Noise الضوضاء
Rank	-----------	--------------	---------	--------

22. Please Rank the following sub-criteria 2 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

22- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 2 *(Site Condition)* *ظروف الموقع*	Location المكان	Obstacles العوائق	Possession of Site أستلام الموقع	Construction Area مكان التنفيذ
Rank	-----------	---------------	----------	--------

23. Please Rank the following sub-criteria 3 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

23- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 3 *(Constructor Responsibilities)* *مسئولية المقاول*	Design-Build تصميم و تنفيذ	Build تنفيذ فقط
Rank	-----------	-------------

24. Please Rank the following sub-criteria 3 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)
24- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 3 *(Contract Type)* *نوعية العقد*	Negotiated بالمفاوضه (مثل أوامر الإسناد)	Competitive عطاءات
Rank	-----------	-------------

25. Please Rank the following sub-criteria 3 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)
25- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 3 *(Procurement)* *الإمداد*	Local محلى	Exemption of Customer Duties الإعفاء من الرسوم الجمركيه	Availability of Foreign Currency توفر النقد الأجنبى
Rank	-----------	-------------	-------------

26. Please Rank the following sub-criteria 3 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)
26- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 3 *(Location)* *موقع المشروع*	Surrounding Area Nature طبيعة المنطقه المحيطه	Accessibility إمكانية الوصول للموقع	Surrounding road network capabilities إمكانيات شبكة الطرق المحيطه بالموقع
Rank	-----------	-------------	-------------

27. Please Rank the following sub-criteria 3 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)
27- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 3 *(Obstacles)* *العوائق*	Waterway المياه	Railway السكه الحديد	Roads الطرق	Valleys وديان	Utilities المرافق
Rank	-----------	-------------	-------------	-------------	-------------

28. Please Rank the following sub-criteria 3 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)
28- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 3 *(Possession of Site)* *استلام الموقع*	Full بالكامل	Partial جزئى
Rank	-----------	-------------

29. Please Rank the following sub-criteria 3 in order of importance from the most important (1) to the least (n), as per schematic shown in page (4)

29- برجاء ترتيب العوامل (المعايير) الفرعيه التاليه و التى تتحكم فى أختيار طريقة التنفيذ حسب الأهميه من الأعلى (1) إلى الأدنى (ن) طبقا للرسم الموضح فى صفحة رقم (4)

Sub-Criteria 3 ***(Construction Area)*** ***مكان التنفيذ***	Material Storage تخزين المواد	Cranes Maneuvering قدرة الأوناش على المناوره	Workshop ورشة التصنيع	Climate المناخ	Soil Conditions ظروف الموقع	Land Topography Range مناسيب الأرض
Rank	-----------	-------------	-----------	----------	-----------	-------------

APPENDIX C: INTERVIEWS FOR CONDITIONS OF USING ALTERNATIVES

Conditions of Use		Superstructure Construction Methods							
		Stationary formwork		Free Cantilever		Advancing Shoring	Erecting beams		Incremental Launching
		Stationary formwork	Creating an Elevated Platform	Using 2 travelers	Using 1 traveler		Using launching Trusses	using Cranes	
Suitable Deck X-Sec.	Box Section						▨		
	Slab and Beam								
	Slab						▨		
Suitable Range of Superstructure Height above Ground	0-10 m								
	10-15m								
	15-20m								
	20-30m								
	30-40m								
	40-50m								
	50-60m								
	>60m								
Range of Span Length	0-10m								
	10-20m								
	20-30m								
	30-40m								
	40-50m								
	50-60m								
	60-70m								
	70-100m								
	>100m								

Conditions of Use		Superstructure Construction Methods							
		Stationary formwork		Free Cantilever		Advancing Shoring	Erecting beams		Incremental Launching
		Stationary formwork	Creating an Elevated Platform	Using 2 travelers	Using 1 traveler		Using launching Trusses	using Cranes	
Suitable Horizontal Curvature	Small								
	Medium								
	Large								
Suitable Surrounding Area Nature	Downtown								
	Desert								
	Agrarian								
	Others								
Accessibility	Require accessibility								
	Does not require accessibility								
Obstacles	Waterway								
	Railway								
	Utilities								
Cranes Maneuvering!	Require area for crane maneuvering								
	Doesn't require area for crane maneuver.								
Soil Condition	Strong								
	Medium								
	Weak								
Land Topography Range	0-100cm								
	100-200cm								
	>200cm								

Conditions of Use		Superstructure Construction Methods							
		Stationary formwork		Free Cantilever		Advancing Shoring	Erecting beams		Incremental Launching
		Stationary formwork	Creating an Elevated Platform	Using 2 travelers	Using 1 traveler		Using launching Trusses	using Cranes	
Type of Concrete	Prestressed-Precast								
	Prestressed/Cast in-Situ								
	R.C./Preacast								
	R.C./Cast In-Situ								

APPENDIX D: EVALUATION QUESTIONNAIRE

(BRIDGECONSTRUCT)

Name (Optional): --

Organization: --

Your position (e.g. project manager, estimator, etc): ----------------------------------

Years of Experience: --

(Please tick as appropriate on one box only for every question and add your comment)

Questions		Evaluation (1) is poor, (5) is excellent				
		1	2	3	4	5
The system						
Introductory Module						
1	How well does the introductory form help in understanding how the system works?					
2	How well is the information about construction methods presented?					
Comment: -- -- --						
Identifying Feasible Alternatives Module						
3	How appropriate is the data captured for the main project information?					
4	Do the resulting alternatives satisfy your expectations?					
5	Do the identified bridge and site data cover the key issues?					
6	In general, how appropriate is this module?					
Comment: -- -- --						
Pairwise Comparison of Alternatives Module						
7	How clear are the selection criteria defined in the system?					
8	To what extent does the *refined* hierarchy represent your perception of the criteria affecting choice of alternatives?					
9	To what extent does the *overall* hierarchy represent your perception of the criteria affecting choice of alternatives?					
10	How effective is the sensitivity tool?					
11	To what extent do the identified alternatives represent all the methods that are used in Egypt?					
12	In general, how appropriate is the pairwise comparison module?					
Comment: -- -- --						

Questions		Evaluation (1) is poor, (5) is excellent				
		1	2	3	4	5
Cost Estimate Model						
13	How clear are the cost elements identified?					
14	To what extent do the identified cost elements represent the cost of the superstructure?					
15	In general, how accurate is the detailed cost estimate?					
16	In general, how accurate is the preliminary cost estimate?					
17	In general, how effective is the cost model in helping to choose a construction method?					
Comment:						
General						
18	How well does the system reflect the decision-making process in a real situation?					
19	How well does the system help in understanding how superstructure methods can be selected?					
20	How effective/accurate is the system in the selection of construction methods?					
21	How well organized (designed) is the system?					
22	How user friendly is the system?					
23	How well integrated are the different components of the system?					
24	To what extent can the same approach extend to cover other elements of bridges (e.g. substructure)?					
25	What is your overall rating of the system?					
Comment:						
Applicability to Bridge Construction Industry						
26	How convinced are you that bridge engineering professionals will use this system (i.e. if made available)?					
27	How effective will the system be in speeding up the decision making process?					
28	To what extent does it represent an improvement (or help) in the decision making process?					
29	To what extent is the system flexible in choosing the most appropriate construction method?					
Comment:						

General Comments:

1-What are the main benefits of the system?

2-In what way can the system be improved?

3-Further Comments

APPENDIX E: COST ESTIMATION TABLES

Stationary Formwork on Ground

#	Item			Unit
1	***General***			
	1.1	General Equipment		
		1.1.1	Cranes	Month
		1.1.2	Generators	Month
		1.1.3	air compressor	Month
		1.1.4	Water pump	Month
		1.1.5	Truck for Transportation	Month
	1.2	Cost of Scaffold		LS
	1.3	Cost of required changes to Site		LS
2	***Formwork***			
	2.1	Material		
		2.1.1	Formwork for soffit	m^2
		2.1.2	Formwork for Vertical Surfaces	m^2
		2.1.3	Formwork for inclined surfaces	m^2
		2.1.4	Formwork for special requirements	m^2
		2.1.5	Architectural Treatment	m^2
	2.2	Workmanship		
		2.2.1	Formwork for soffit	m^2
		2.2.2	Formwork for Vertical Surfaces	m^2
		2.2.3	Formwork for inclined surfaces	m^2
		2.2.4	Formwork for special requirements	m^2
		2.2.5	Architectural Treatment	m^2

#	*Item*			*Unit*
	2.3	Equipment		
		2.3.1	Lifting Equipment	Month
		2.3.2	Ancillary Equipment	Month
3	***Falsework***			
	3.1	Material On Site		
		3.1.1	Falsework 0-4 m Height	Month
		3.1.2	Falsework 4-8 m Height	Month
		3.1.3	Falsework 8-12 m Height	Month
		3.1.4	Falsework 12-15 m Height	Month
	3.2	Workmanship		
		3.2.1	Falsework 0-4 m Height	m^2
		3.2.2	Falsework 4-8 m Height	m^2
		3.2.3	Falsework 8-12 m Height	m^2
		3.2.4	Falsework 12-15 m Height	m^2
	3.3	Equipment		
		3.3.1	Erection, Dismantling, and Transportation	LS
		3.3.2	Service Equipment	Month
	3.4	Cost of required changes to an Existing system		LS

Stationary Formwork on Elevated Platform

#	Item			Unit
1	**General**			
	1.1	General Equipment		
		1.1.1	Marine Equipment	Month
		1.1.2	Generators	Month
		1.1.3	Aircompressor	Month
		1.1.4	Water pump	Month
		1.1.5	Truck for Transportation	Month
		1.1.6	Cranes	Month
	1.2	Cost of Scaffold		LS
	1.3	Cost of required changes to Site		LS
2	**Formwork**			
	2.1	Material		
		2.1.1	Formwork for soffit	m^2
		2.1.2	Formwork for Vertical Surfaces	m^2
		2.1.3	Formwork for inclined surfaces	m^2
		2.1.4	Formwork for special requirements	m^2
		2.1.5	Architectural Treatment	m^2
	2.2	Workmanship		
		2.2.1	Formwork for soffit	m^2
		2.2.2	Formwork for Vertical Surfaces	m^2
		2.2.3	Formwork for inclined surfaces	m^2
		2.2.4	Formwork for special requirements	m^2
		2.2.5	Architectural Treatment	m^2

#	***Item***			***Unit***
	2.3	Equipment		
		2.3.1	Lifting Equipment	Month
		2.3.2	Ancillary Equipment	Month
3	***Falsework***			
	3.1	Material On Site		
		3.1.1	Vertical Supports, Bailey Units	L.S.
		3.1.2	Vertical Supports, Heavy Shoring	L.S.
		3.1.3	Brackets on Piers	L.S.
		3.1.4	Temporary Foundations	L.S.
		3.1.5	Longitudinal Beams for Platform	M
		3.1.6	Transversal Beams for Platform	M
		3.1.7	Falsework above platform 0-4m	Month
	3.2	Workmanship		
		3.2.1	Erection, Dismantling and Transportation	m^2
		3.2.2	Vertical Supports	Month
		3.2.3	Temporary Foundations	Month
		3.2.4	Longitudinal Beams for Platform	Month
		3.2.5	Transversal Beams for Platform	Month
		3.2.6	Shoring above Platform 0-4m	m^2
	3.3	Equipment		
		3.3.1	Erection, Dismantling, and Transportation	LS
		3.3.2	Lifting Equipment	Month
		3.3.3	Ancillary Equipment	Month
	3.4	Cost of required changes to an Existing system		L.S.

Cantilever Construction by In-situ Concreting Using Two Form Travellers or One Traveller and A Stationary System

#	Item			Unit
1	**General**			
	1.1	General Equipment		
		1.1.1	Marine Equipment	Month
		1.1.2	Generators	Month
		1.1.3	Aircompressor	Month
		1.1.4	Water pump	Month
		1.1.5	Truck for Transportation	Month
		1.1.6	Cranes	Month
	1.2	Cost of scaffold		LS
	1.3	Cost of required changes to Site		LS
	1.4	Temporary Fixation of SS to Piers		LS
2	**Formwork**			
	2.1	Material		
		2.1.1	Formwork for soffit	m^2
		2.1.2	Formwork for Vertical Surfaces	m^2
		2.1.3	Formwork for inclined surfaces	m^2
		2.1.4	Formwork for special requirements	m^2
		2.1.5	Architectural Treatment	m^2
	2.2	Workmanship		
		2.2.1	Formwork for soffit	m^2
		2.2.2	Formwork for Vertical Surfaces	m^2
		2.2.3	Formwork for inclined surfaces	m^2

#	*Item*			*Unit*
		2.2.4	Formwork for special requirements	m^2
		2.2.5	Architectural Treatment	m^2
	2.3	Equipment		
		2.3.1	Lifting Equipment	Month
		2.3.2	Ancillary Equipment	Month
3	***Falsework***			
	3.1	Material For Stump on Brackets		
		3.1.1	Brackets	L.S.
		3.1.2	Longitudinal and Transversal Beams	M
		3.1.3	Falsework above platform 0-4m	L.S.
		3.1.4	Erection and Dismantling	L.S.
	3.2	Material For Stump on Bailey units		
		3.2.1	Bailey Units Rental/Depreciation	Month
		3.2.2	Longitudinal and Transversal Steel Beams	M
		3.2.3	Falsework above Platform 0-4m	Month
		3.2.4	Erection and Dismantling	L.S.
	3.3	Material for Stump on Scaffolding		
		3.3.1	Falsework 0-4m height	Month
		3.3.2	Falsework 4-8m height	Month
		3.3.3	Falsework 8-12m height	Month
		3.3.4	Falsework 12-15m height	Month
	3.4	Materials for Spans Constructed using travellers		
		3.4.1	Rental/Depreciation	Month
		3.4.2	Lost Items	L.S.

#	Item			Unit
		3.4.3	Erection and Dismantling	L.S.
	3.5	Material for Shore Segment		
		3.5.1	Falsework 0-4m height	Month
		3.5.2	Falsework 4-8m height	Month
		3.5.3	Falsework 8-12m height	Month
		3.5.4	Falswework 12-15m height	Month
	3.6	Workmanship		
		3.6.1	Erection, Dismantling and Transportation	L.S.
		3.6.2	Crew for Stump on Brackets Excluding falsework	Crew/ Month
		3.6.3	Crew for Stump on Bailey Unit (Excluding Falsework)	Crew/ Month
		3.6.4	Crew for stump on scaffolding (Excluding falsework)	Crew/ Month
		3.6.5	Crew for spans constructed using travellers	Crew/ Month
		3.6.6	Workmanship for falsework 0-4m height	m^2
		3.6.7	Workmanship for falsework 4-8m height	m^2
		3.6.8	Workmanship for falsework 8-12m height	m^2
		3.6.9	Workmanship for falsework 12-15m height	m^2
	3.7	Equipment		
		3.7.1	Erection Dismantling and Transportation	L.S.
		3.7.2	Lifting Equipment	Month
		3.7.3	Ancillary Equipment	Month
	3.8	Cost of required changes to an Existing system		L.S.

#	Item			Unit
1	***General***			
	1.1	General Equipment		
		1.1.1	Marine Equipment	Month
		1.1.2	Tower Cranes	Month
		1.1.3	Generators	Month
		1.1.4	Aircompressor	Month
		1.1.5	Water pump	Month
		1.1.6	Truck for Transportation	Month
		1.1.7	Cranes	Month
	1.2	Cost of Scaffold		LS
	1.3	Cost of required changes to Site		LS
2	***Formwork***			
	2.1	Material		
		2.1.1	Formwork for soffit	m^2
		2.1.2	Formwork for Vertical Surfaces	m^2
		2.1.3	Formwork for inclined surfaces	m^2
		2.1.4	Formwork for special requirements	m^2
		2.1.5	Architectural Treatment	m^2
	2.2	Workmanship		
		2.2.1	Formwork for soffit	m^2
		2.2.2	Formwork for Vertical Surfaces	m^2
		2.2.3	Formwork for inclined surfaces	m^2
		2.2.4	Formwork for special requirements	m^2
		2.2.5	Architectural Treatment	m^2

#	***Item***			***Unit***
	2.3	Equipment		
		2.3.1	Lifting Equipment	Month
		2.3.2	Ancillary Equipment	Month
3	***Falsework***			
	3.1	Material		.
		3.1.1	System Rental/Depreciation (including hydraulic system main trusses, brackets, inclusive)	Month
		3.1.2	Transportation of system to Site	L.S.
	3.2	Workmanship		
		3.2.1	Erection, Dismantling and Transportation	L.S.
		3.2.2	Crew to operate system	Month
	3.3	Equipment		
		3.3.1	Transportation	L.S.
		3.3.2	Lifting Equipment	Month
		3.3.3	Ancillary Equipment	Month
	3.4	Costs of Required Changes to an Existing Site		L.S.

#	Item			Unit
1	***General***			
	1.1	Casting Yard		
		1.1.1	Land Rental	Month
		1.1.2	Preparation of Land	LS
		1.1.3	Moulds (Rental/Depreciation)	Month
		1.1.4	Crew for erection, dismantling, and transportation of the yard	Month
		1.1.5	Crew for Normal Operation	Month
		1.1.6	Equipment for Erection, dismantling and transportation	Month
		1.1.7	Lifting Equipment during operation	Month
		1.1.8	Service equipment for operation	L.S.
	1.2	Precast Beams		
		1.2.1	Launching System (Depreciation/Rental)	Month
		1.2.2	Crew for erection, dismantling and transportation of the system	Month
		1.2.3	Crew for operating system	Month
		1.2.4	Equipment for erection, dismantling and transportation	Month
		1.2.5	Transportation from casting yards to required spans (Depreciation/Rental)	Month
	1.3	General Equipment (Rental/Depreciation)		
		1.3.1	Marine Equipment	Month
		1.3.2	Tower Cranes	Month
		1.3.3	Generators	Month
		1.3.4	AirCompressor	Month
		1.3.5	Truck for Transportation	Month
	1.4	Cost of Scaffold		LS
	1.5	Cost of Required Changes to Site		LS

#	*Item*			*Unit*
	1.6	Cost of required changes to an existing system		LS
2	***Formwork***			
	2.1	Material		
		2.1.1	Formwork (Permanent/Temporary)	m^2
		2.1.2	Formwork for special requirements	m^2
	2.2	Workmanship		
		2.2.1	Formwork (Permanent/Temporary)	m^2
		2.2.2	Formwork for special requirements	m^2
	2.3	Equipment		
		2.3.1	Lifting Equipment	Month
		2.3.2	Ancillary Equipment	Month
		2.3.3	Trucks for transportation	Month

Incremental Horizontal Launching (Deck Pushing)

#	Item			Unit
1	***General***			
	1.1	Casting Yard		
		1.1.1	Land Rental	Month
		1.1.2	Preparation of Land	LS
		1.1.3	Manpower for Operation	Month
		1.1.4	Lifting Equipment (Rental/Depreciation)	Month
		1.1.5	Service Equipment	Month
	1.2	General Equipment (Rental/Depreciation)		
		1.2.1	Marine Equipment	Month
		1.2.2	Tower Cranes	Month
		1.2.3	Generators	Month
		1.2.4	aircompressor	Month
		1.2.5	Water pump	Month
		1.2.6	Truck for Transportation	Month
	1.3	Cost of Scaffold		LS
	1.4	Cost of required changes to the Site		LS
2	***Formwork***			
	2.1	Material		
		2.1.1	Formwork for soffit	m^2
		2.1.2	Formwork for Vertical Surfaces	m^2
		2.1.3	Formwork for inclined surfaces	m^2
		2.1.4	Formwork for special requirements	m^2
		2.1.5	Architectural Treatment	m^2
	2.2	Workmanship		
		2.2.1	Formwork for soffit	m^2

#	*Item*			*Unit*
		2.2.2	Formwork for Vertical Surfaces	m^2
		2.2.3	Formwork for inclined surfaces	m^2
		2.2.4	Formwork for special requirements	m^2
		2.2.5	Architectural Treatment	m^2
	2.3	Equipment		
		2.3.1	Lifting Equipment	m^2
		2.3.2	Ancillary Equipment	m^2
		2.3.3	Trucks for transportation	m^2
3	***Falsework***			
	3.1	Material		
		3.1.1	System Rental/Depreciation	Month
	3.2	Workmanship		
		3.2.1	Erection, Dismantling, and Transportation	LS
		3.2.2	Crew for Operation	Month
	3.3	Equipment		
		3.3.1	Erection, Dismantling, and Transportation	LS
		3.3.2	Service Equipment	Month
	3.4	Cost of required changes to an Existing system		LS

Concrete, Steel Reinforcement, Prestressing, Bearings, Expansion Joints, and Others for all Construction Methods

#	*Item*			*Unit*
4	**Concrete**			
	4.1	Ready mix concrete on site		m3
	4.2	Casting Concrete		
		4.2.1	Using Cranes and Buckets	m3
		4.2.2	Using Stationary Pump	m3
		4.2.3	Using Mobile Pump	m3
	4.3	Workmanship for Casting Concrete		
		4.3.1	Vibration, Finishing and Curing	m3
	4.4	Service Equipment		
		4.4.1	Vibrators	Month
	4.5	Ancillary Material		
		4.5.1	Material for Curing	m3
5	***Steel Reinforcement***			
	5.1	Material On Site		
		5.1.1	Rebar cut and bent on site	Ton
		5.1.2	Spacers	Ton
		5.1.3	Binding Wire	ton
		5.1.4	Welding Electrodes	ton
		5.1.5	Mechanical couplers	ton
	5.2	Manpower		
		5.2.1	Erection of rebar	ton
	5.3	Equipment		
		5.3.1	Lifting	Month

#	Item			Unit
		5.3.2	Ancillary	Month
		5.3.3	Cutters	Month
		5.3.4	Welding Machine	Month
6	***Prestressing***			
	6.1	Material On Site		
		6.1.1	Strands	ton
		6.1.2	Bars	ton
		6.1.3	End Anchorages	No.
		6.1.4	Couplers	No.
		6.1.5	Sheath	m
		6.1.6	Grouting	Litre
		6.1.7	Ancillary	L.S.
		6.1.8	Installation	ton
	6.2	Manpower		
		6.2.1	Installation	Ton
	6.3	Equipment		
		6.3.1	Decoiler	Month
		6.3.2	Jacks	Month
		6.3.3	Strand Pusher	Month
		6.3.4	Hydraulic Pumps	Month
		6.3.5	Grouting Pump	Month
		6.3.6	Jack Carrier	Month
		6.3.7	Lifting	Month
		6.3.8	Ancillary Equipment	Month
7	***Bearings***			
	7.1	Material On Site		
		7.1.1	Bearings (Elastomeric/Pot/Others)	No.

#	***Item***			***Unit***
		7.1.2	Grouting	L.S.
		7.1.3	Ancillary Material	L.S.
	7.2	Manpower		
		7.2.1	Installation	No.
	7.3	Equipment		
		7.3.1	Lifting	Month
8	***Expansion Joints***			
	8.1	Material		
		8.1.1	E.J. (Rubber/Saw Tooth/Others)	No.
		8.1.2	Grouting	L.S.
		8.1.3	Ancillary Material	L.S.
	8.2	Manpower		
		8.2.1	Installation	No.
	8.3	Equipment		
		8.3.1	Lifting	Month
		8.3.2	Asphalt Saw	Month
		8.3.3	Ancillary Equipment	Month
9	***Others***			