# Rationalisation of Design Cost Estimation in the Construction Industry

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I certify that this thesis is the true and accurate version of the thesis approved by the examiners

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## ABSTRACT

This thesis describes a programme of research work which investigated the potential for the application of rational approaches, using historic cost data, to the determination of realistic fee estimates for design work in the construction industry. The development of the following research methodology for the programme of work, which was initiated at the request of industrial collaborators, is described and justified.

A survey of design practices is described that enabled a model of the cost estimation process to be developed. This was tested using a large sample of design organisations and proved to be valid. There was clear evidence in the survey of a polarisation in the use of two forms of cost estimation, with intuitive approaches being used frequently and rational data driven approach being seldom, if ever, used. It was also shown that there was a widely held view amongst designers that design work was not suited to accurate cost estimation and rigorous cost control and, consequently, design organisations had not developed links between their cost control and estimating systems.

Case studies are described which investigated the practicality of implementing an integrated cost monitoring system for single projects that would produce historic cost data. It was concluded that this was possible for individual projects, but the cost monitoring aspects of the spread sheet system proved to be too cumbersome to be applied to all projects within an organisation.

The development of a general simulation model of design cost estimation is described which used data from the case studies. A procedure for the application of the model to other projects was devised and the performance of the model was verified by its application to a further project. It was concluded that the model provided a realistic prediction of the required resource input for the project.

Finally, the principal conclusion from the research work is described, namely that the potential for rationalisation of design cost estimation is severely limited in design organisations because current design management practice has restricted the availability of relevant historic data. However the success of the data collection and cost modelling stages of the work indicated that further research in these areas would be valuable.

**Rationalisation of Design Cost Estimation in the Construction Industry**

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# CHAPTER 1

# INTRODUCTION

## 1.1 DESIGN IN A CHANGING ENVIRONMENT

This research programme was initiated in 1989 in collaboration with, what was then, Tayside Regional Council Water Services Department (now part of the North of Scotland Water Authority). Previous collaborative research between the author and the department (Blackwood, 1988) had investigated the effectiveness of the information systems which were used by the authority to manage its capital expenditure budget. It was concluded that the authority had developed effective systems for managing construction costs of projects but lacked expertise in estimating and controlling design fees. Additionally, the Department was aware of external developments that might affect the way in which it procured design services. The most significant were the increased use of fee competition and the trend towards compulsory competitive tendering for professional services.

Considering the former, the relationship between clients and their professional advisors was being fundamentally altered by external pressures. The philosophy behind competition amongst consultants on the basis of quality, with cost being determined by fee scales, had been under review by the Monopolies and Mergers Commission since 1977 (Rowdon and Mansfield, 1988) and was vigorously attacked by the Office of Fair Trading (Anon, 1991a). Despite opposition from professional organisations (e.g. Anon, 1991b; Anon 1991c), fee competition became widely established in the construction industry but concerns was being expressed that design qaulity was being adversely affected (Construction Industry Council, 1992; Latham, 1994). In addition to the more competitive environment amongst external providers of design services, the Department was aware of Government proposals to extend compulsory competitive tendering to the provision of professional services (Pigg, 1993) and was mindful of the need to ensure that in-house design costs were comparable with those in the private sector.

## 1.2 THE NEED FOR THE RESEARCH

Rowdon and Mansfield (1989) stated that design consultants earn less than they should due to a lack of well developed planning, cost estimation and cost control systems. The pressures of fee competition further increased the need for more accurate cost estimation by designers and this, together with the need for clients to have a greater understanding of the adequacy of design fee bids, suggested that the programme of research would be valuable and timely. Furthermore, the collaborating body was aware of a need to improve their own design cost estimation and was keen to promote and sponsor research work in this area.

## 1.3 THE DEVELOPMENT OF THE RESEARCH HYPOTHESIS AND AIMS

Hughes (1994) suggested that there were two criteria which must be met in the definition of an appropriate PhD programme; *worthwhileness* and *achievability*. The concept of worth can be subdivided to encompass the value of the research and the originality of the contribution to knowledge that will arise from it. The value of the research to the department was clear and the value to the construction industry was confirmed during the preliminary literature review. The review also identified a paucity of literature on design cost estimating which confirmed an initial assumption that the work would be novel. The second criteria, achievability, was ensured through the development of a hypothesis that could be tested to an appropriate degree of rigour by the achievement of a number of specific aims.

Hughes (1994) reviewed the work of Phillips and Hugh (1987) who identified three types of research:

- "*exploratory*" research which would be concerned with tackling new problems;
- *"testing-out"* research where the general conclusions from previous research are developed; and
- "*problem solving*" research where the objective is to produce a solution to a practical problem.

Initially, it was considered that the research would be of the third type; to develop a cost estimating model for the Department's in house design services that might also be used to assist in the evaluation of fee bids from external consultants. It was envisaged that the research methodology would follow the pattern of:

- a literature review to determine the state of the art in design cost estimating in the construction industry;
- the selection and development of an appropriate modelling approach;
- the collection of the necessary data to support the model; and
- the testing and validation of the model .

It was further envisaged that the majority of the work would be concerned with the third and fourth of these activities. However, on completion of a preliminary literature review it became apparent that a more fundamental review of the design cost estimating process was required. Rowdon and Mansfield (1989) suggested that there was a widely held view amongst designers in the construction industry that, by its very nature, design work was not amenable to prescriptive planning and rigorous cost control. Furthermore, the design process is essentially iterative and the cost of the service provided would be determined largely by the degree of refinement of the final design. This has been recognised by Latham (1994), who listed evidence that both architectural and civil engineering consultants were adapting the scope of their services to match the reduced fees available in the competitive environment.

The combination of these factors raised questions on: the practicality of the application of cost modelling to the design process; the extent of the development of estimating skills amongst designers; and the availability of data to support the estimating process. It was concluded that exploratory research was required rather than testing-out or problem solving research and that the research hypothesis (or theory) had yet to be fully defined.

The grounded theory approach, developed by Glaser and Strauss (1967), was deemed to be appropriate for this research because the basis of their research method is that the theory is generated from the data. This means that:

> *"..... most hypothesis and concepts not only come from the data, but are systematically worked out in relation to the data during the course of the research"* (Glaser and Strauss, 1967: p 6).

Grounded theory recognises that the research does not begin with a theory which is then validated or rejected, but begins with an area of study, with the relevant concepts being allowed to emerge as the study begins. The general method used is one of comparative analysis whereby evidence collected from other comparative groups is used to test whether the initial evidence was correct. The data collection process uses a theoretical sampling approach in which:

*"the analyst collects, codes and analyses his data and then decides what data to collect next and where to find them, in order to develop his theory as it emerges"* (Glaser and Strauss, 1967: p 45).

## 1.4 RESEARCH HYPOTHESIS AND AIMS

In keeping with the grounded theory approach, the research hypothesis and aims were developed during the initial stages of the research work as described in Chapter 4, but are summarised here.

The following overall hypothesis was developed:

> *that there exists the potential for the development of a rational approach to the estimation of construction industry design costs by the application of cost modelling, based on historic cost data.*

The following aims were established:

- to identify and quantify the use of design cost estimating and cost control approaches that are currently applied by designers;
- to evaluate the extent to which current practice could facilitate the application of a more rational approach to cost estimating;
- to evaluate the practicality of enhanced data collection to support a more rational approach;
- to select and develop a form of model that is appropriate for the available data; and
- to verify the performance of the cost model.

## 1.5 RESEARCH METHODOLOGY

In keeping with the grounded theory approach, the research methodology was developed as the project aims and hypothesis emerged, in order that they could be fully achieved. This is described in detail in Chapter 4, but the stages of the methodology are summarised here.

The first stage comprised a literature review which enabled both an evaluation of the design process in the construction industry and an assessment of current and potential design management approaches to be made. The second stage comprised a survey of design management practice using interviews and a postal questionnaire to test and expand upon the conclusions from the literature review. The literature review and survey provided the qualitative and quantitative data that were necessary to achieve the first and second project aims.

The third project aim was achieved through the third stage of the methodology which involved a case study approach to test the feasibility of introducing an enhanced data collection system within design organisations. This third stage also provided data for the final stage which involved the development and testing of a cost estimation model in order that the fourth and fifth project aims could be achieved.

## 1.6 STRUCTURE OF THE THESIS

Chapters 2 and 3 present the results of a comprehensive literature review of the design process and of design cost estimation and control. In particular, Chapter 2 investigates the nature of the design process, both in general and in the context of the construction industry. Chapter 3 reviews current approach to construction industry design management and identifies other approaches that might be used to promote more rational cost estimation.

Chapter 4 documents and explains the development of the research hypothesis and aims. The selection of the research approaches and research instruments at each stage of the process is described and justified.

Chapter 5 contains the results of the comprehensive survey of design management practice and includes both a qualitative and quantitative interpretation of the results.

Chapter 6 presents the results of the data collection case study which was required to: assess the feasibility of the implementation, in industry, of a more comprehensive data collection system; and to provide data for cost modelling. The rationale behind the use of spreadsheets for data collection purposes is given and the practical problems encountered in its operation are described.

Chapter 7 describes the selection, development and testing of the cost model which was required to assess the potential for the practical application of such an approach. The justification for the selection of a risk analysis approach is given and the extent of verification of a general risk model for design costs in the water sector of the construction industry is reviewed.

Chapter 8 presents the conclusions of the study and, in view of the exploratory nature of the research, identifies a number of recommendations of areas of further study.

Appendices are presented which contain additional information in support of the study and publications arising from the work are included.

## 1.7 SUMMARY OF MAIN CONCLUSIONS

The principal conclusion from the research was that, currently, the potential for rationalisation of design cost estimation was severely limited in design organisations because design management practice restricted the availability of relevant historic data. However, the data collection case studies were successful and demonstrated that design cost data could be produced and used to develop a validated cost model. Finally, limitations to the widespread practical application of the data collection approach were identified and further research in this area was recommended.

# CHAPTER 2

# THE DESIGN PROCESS IN THE CONSTRUCTION INDUSTRY

## 2.1 SCOPE OF THE LITERATURE REVIEW

There is a widely held view amongst designers in the construction industry that, by its very nature, design work is not amenable to prescriptive planning and rigorous cost control (Rowdon and Mansfield, 1989). The potential for rationalisation of design cost estimation will be highly dependent on the validity of this opinion and it was necessary to:

- analyse the nature of the design activity and of the design process;
- identify the way in which the design process is integrated into overall construction industry procedures;
- identify and evaluate the cost estimation and cost control approaches that are currently being used by designers; and
- identify and evaluate cost estimation and cost control approaches that may be successfully applied to more effectively manage design work.

As part of this evaluation, a comprehensive literature review was carried out and, for convenience, the results of the review are presented in two chapters. Chapter 2 provides an analysis of the nature of design in the construction industry whilst Chapter 3 identifies and evaluates cost estimation and cost control approaches that are currently used by designers, as well as those with the potential for future application.

## 2.2 THE NATURE OF THE DESIGN PROCESS

Abdul-Kabir and Price (1995) noted, in the context of productivity improvement studies, that the processes involved in the management of the construction phase of building and civil engineering projects have been well researched but that the conceptual stage of projects has been severely neglected. An initial literature review for this thesis identified a corresponding scarcity of published work on management of the design processes in the construction industry.

It was essential during the development of this project that the design activity be fully investigated and understood. There are a large number of publications on the nature of design, mostly in the context of engineering design for manufacturing and production. This section is concerned with design in its wider sense, whilst Section 2.3 investigates the application of these concepts to the construction industry.

### 2.2.1 The Nature Of The Problem

Asimow (1962) described design as being an activity that is directed toward the goal of the fulfilment of human needs by the production of a template which allows the replication of an artefact. Engineering design can be distinguished from other forms of design because of the extent to which technological factors contribute to the achievement of the goal. He suggested that there are fourteen fundamental principles of design that can be usefully grouped into two closely related categories. Six of the principles are concerned with the nature of the design activity and can considered to be a statement of the design problem whilst the remaining eight are concerned with the nature of the design process. The principles concerned with the nature of the design problem are:

- "*Need*". — Must be a response to individual and social needs.
- "*Physical Realisability*". — Must be practicable.
- "*Economical Worthwhileness*". and "*Financial Feasibility*". — Must be economically viable, both in terms of the creation and utilisation of the artefact.
- "*Optimality*". — Should represent the optimal solution when measured against design criterion.
- "*Design Criterion*". — May be established by the user of the artefact or the designer.

Archer (1984) defines design in similar terms to Asimow's by considering the relationship between need and the development of a solution to that need.

> *"There can be no solution without a problem; and no problem without constraints; and no constraint without a pressure or need. Thus, design begins with a need. Either the need is automatically met, and there is no problem, or the need is not met because of obstacles or gaps. The finding of means to overcome these obstacles or gaps constitutes the problem. If solving the problem involves the formulation of a prescription for subsequent embodiment as a material object, then it is a design problem"* (p 59).

Before any meaningful analysis of this problem solving process can be made, it is essential that the significant components of the design process can be identified and the constituent activities understood. The remaining eight Asimow's principles of design can be considered to be concerned with the nature of the design process and describe the evolution of a design solution. These are:

| | |
|---|---|
| • "*Morphology*". | The design is a progression from the abstract to the concrete through a; |
| • "*Design process*" | which is essential iterative, containing; |
| • "*Subproblems*" | which are uncovered whilst addressing the main problems, and which must be solved in order to solve the main problem. This process leads to a; |
| • "*Reduction in uncertainty*" | about the success of the artefact. In solving sub-problems. |
| • "*Minimum commitment*" | should be made at any stage of the design since firm commitments at an early stage of the design may limit choice at a later stage. The extent of the design process can be established by reference to; |
| • "*The economic worth of the evidence*" | which measures the cost of evidence against the significance of that evidence to the success or failure of the artefact and to; |
| • "*The basis for decision*" | which is the point that sufficient confidence has been gained in the design to allow the next stage to proceed. Finally a design will have its existence to the extent to which it can be expressed through; |
| • "*Communication*". | |

Models have been developed to describe this process. These tend to be either descriptive or prescriptive and a number of these are reviewed by Cross (1989). Descriptive models are concerned with a representation of the stages involved in the design process and predictive models are concerned with developing the most efficient sequence of activities for effective design. The common theme of the models can be summarised as a process comprising three elements as shown in Figure 2.1.

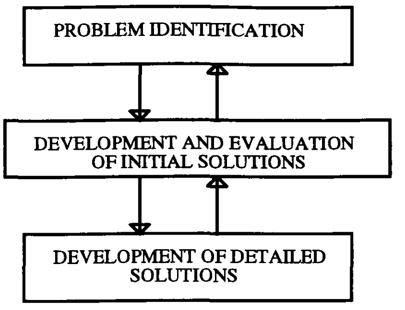



**Figure 2.1:- General model of the design process**

The general model identifies three key stages in a projects life cycle and recognises that the process is not one directional but that interaction between the various stages are required, as demonstrated by the feedback loop between the stages. Asimow recognised the iterative nature of design and considered this to be the result of the existence of sub-problems that emerge as the main problem is being considered. Furthermore these "horizontal" iterations were taking place within the general "vertical morphology" of the design solution. The two dimensional nature of the design process can be illustrated as shown in Figure 2.2. (Markus, 1972).

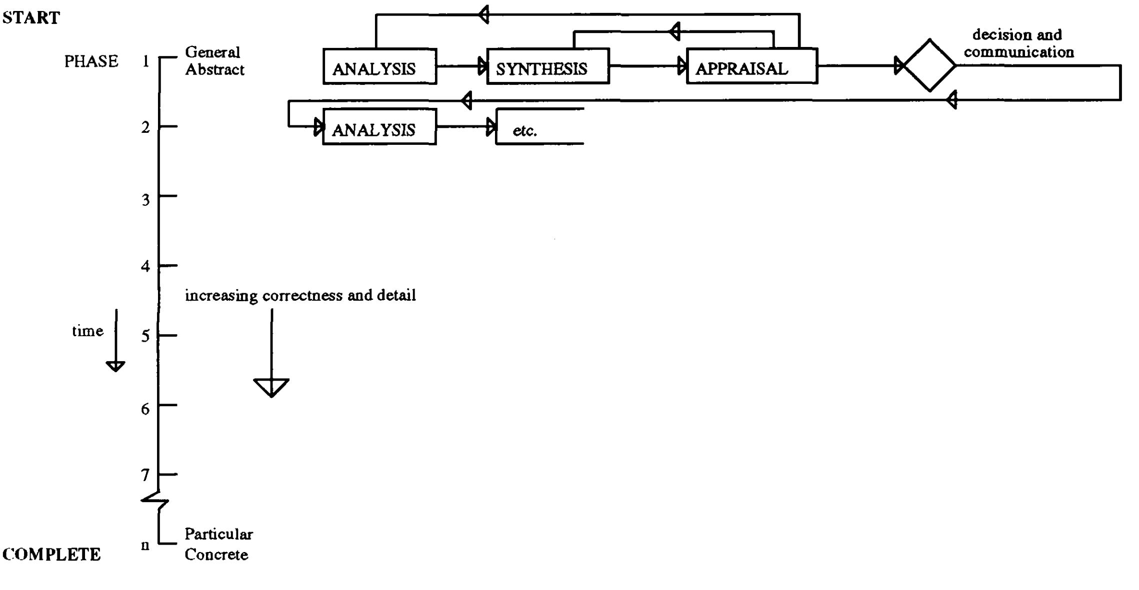



**Figure 2.2: - Marcus's model of the design process**

Hickling (1982) produced a more complex model that highlighted, to a greater extent than the above, the cyclical nature of the design process. Hickling's model identified two forms of iteration:

- the iteration and evaluation within each part of the process (described as the phases by Markus); and

- the iteration and evaluation between the parts.

The iterations during the phases in the Markus model are in fact simplistic models of the decision making process. Howard (1988) proposes a similar three stage model for general decision making but uses the terms "formulate", and "evaluate" in place of analysis and synthesis, although the description of the model is virtually identical to that of Markus. It is evident from Figure 2.2 that the design process progresses essentially as a series of decisions during the design morphology and therefore the nature of these decisions must be understood if effective and efficient design is to be achieved. The general nature of decisions and of the decision making process have been widely researched, and whilst a full review of that research is beyond the scope of this thesis, an overview of decision making was undertaken.

The extent to which design work can be quantified is generally influenced by the "degree of rationality" (March and Simon, 1958) of the decision making process. Rational decisions would lead to the optimal choice being made but would require a highly specified and clearly defined environment. Many recent publications on decision making make reference to early work by Simon (1976), March and Simon (1958) and Lindblom (1959), who all noted that decision making in practice is seldom structured and that often "satisfactory" solutions are reached in an ad-hoc basis. Astley et al (1982), reviewing the above, concluded that "decision making can be seen as a process of muddling through towards a satisfactory and sufficient outcome as opposed to necessarily obtaining the optimal solution". March and Simon question the ability of the "rational" decision maker to make optimal choices and distinguish between optimal and satisfactory solutions to problems.

They describe a solution as being optimal if:

- there exists a set of criteria that permits all known alternatives to be compared; and
- the alternative in question is preferred, by these criteria, to all other alternatives.

An alternative is satisfactory if:

- there exists a set of criteria that describes minimally satisfactory alternatives; and
- the alternative in question meets or exceeds all these criteria.

They conclude that most human decision making is concerned with the discovery and selection of satisfactory rather than optimal alternatives and describe this process as "satisficing".

The concept of "satisficing" is particularly relevant to planning design work as it is directly comparable with Asimow's principles of the "bases for decision" within the design process. This bases for decision must be related to evidence, and the "economic worth" of that evidence must be considered, that is the cost of obtaining that evidence against the value of the evidence to the correctness of the decision. In essence, the quality of the solution may vary dependent upon the time and effort expended to produce a solution and although many "satisfactory" solutions may exist some will be closer to the optimal solution than others.

Another complicating feature of the decision making process is the diverse nature of the information that is required to support a decision. Kreiger and Barnes (1992) identified an array of issues that must be confronted including the discipline base of the decision maker, the level of analysis to be chosen and the degree to which non-rational, political and emotional aspects are considered. Similarly, Astley et al (1982) suggested that there are two concepts that must be considered in decision making, namely the technical "complexity" of the problem and the political "cleavage" of the interests involved in the decision, which is a measure of the non-rational aspects of the decision. In the case of engineering design, it is axiomatic that, in its later stages technical complexity is of paramount importance to the decision making process (consider Asimow's definition of design), although in the early stages other non-tangible considerations, (cleavage) will be very influential. The change in the nature of decisions during the development of a design is also described by Starkey (1993) who classified decisions into three categories: Fundamental, Intermediate and Minor. The classification was based on both the data available to the decision maker and the significance of the decision to the outcome of the design process. Early in the design process fundamental decisions must be made and Starkey noted that;

> *"Not only is each fundamental (decision) highly significant to the success of the overall design, it is always made right at the front end of the design process, when the designers knowledge of the way ahead is minimal. Thus the most critical decisions have to be made with the minimum data available"* (p 2).

Conversely, in the later stages of the process minor decisions are required, which will occur in vast numbers covering aspects of the final details with the maximum information available to the designer.

The changing nature of the design decisions will inevitably require a range of approaches to be applied at the various stages of the design process. In considering the application of artificial intelligence to decision analysis, Dewhurst and Gwinnet (1990) discussed the human skills that are brought into decision making and these are applicable to the technologically complex problem of design. They classify these skills into three major categories: experience, intuition, and logical deduction. Experience is built over time by individuals and organisations working in and developing an understanding of some environment, intuition is the acknowledgement of "gut-feeling" which is often routed in experience and logical deduction is the application of some accepted principles and approaches such as mathematical models. In the early stages in the design process, fundamental decisions, supported by little data but made more complex by the existence of a range of non-technical considerations, must be made. Designers at this stage will place greater emphasis upon experience and intuition in reaching a decision, although this will be supported, where appropriate, by logical deduction. In the later stages of the design process, minor decisions will rely almost exclusively on the application of accepted principles and mathematical models, or logical deduction.

It is apparent that the nature of the design activity is influenced by the irrational nature of the decision making process and complexity of the decisions to be taken. Furthermore, the approaches used to make these decisions changes as the morphology of the design progresses. It is therefore necessary to: understand the various stages of the design process; identify the nature of the decisions to be made at these stages; and, identify the problem solving approaches that are applied in making the decisions.

### 2.2.2 The nature of the process

French (1975) proposed a useful eight stage model of the design process as shown in Figure 2.3, that represented in more detail the vertical morphology of the model in Figure 2.2.

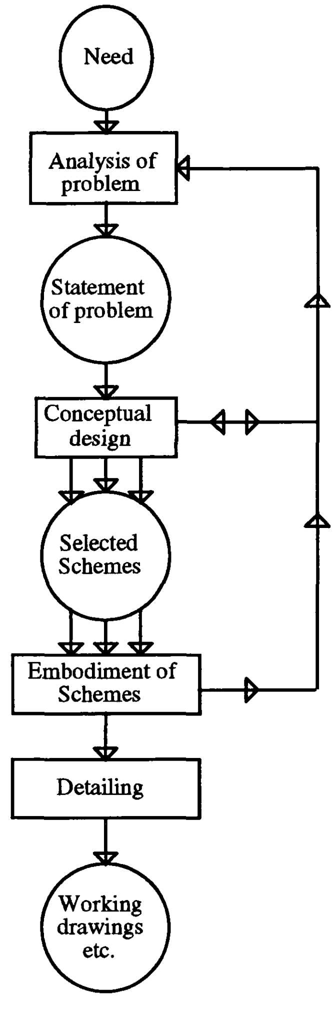



**Figure 2.3: - French's model of the design process**

## Problem Definition

The first three stages, although not identified explicitly by Asimow, have an important influence on the remainder of the design process. They are concerned with the translation of a perceived need into a statement of the design problem and consequently give rise to the level of definition of the design problem. Cross (1989) suggested that design problems are particularly difficult to deal with because they are ill-defined or ill-structured, therefore, the highly specified and clearly defined environment which is necessary for rational decision making does not exist. He summarises the characteristics of an ill-defined problem as follows.

- There is no definitive formulation of the problem. The goals are vague, many constraints and criteria are unknown and the problem is complex.
- Any problem formulation may embody inconsistencies. Conflicts and inconsistencies will exist in the problem and will emerge in the process of problem solving.

- Formulations of the problem are solution dependant. The way in which the solution is conceived influences the way in which the problem is conceived.
- Proposing solutions is a way of understanding the problem. Constraints and criteria emerge as a result of evaluating a solution.
- There is no definitive solution to the problem. Optimality is difficult to define and different solutions may be valid responses to the original problem (again consider Simon's concept of satisficing)

Simon (1984) discussed the relationship between well-structured and ill-structured problems. Well-structured problems, he argued, are at the other extreme of a continuum of degrees of definiteness from ill-structured problems and he suggested criteria for well-structured problems which are broadly opposite to those of Cross above. He further stated that:

> *"In general terms the problems presented to problem solvers by the world are best described as ISP's (Ill-structured problems). They become WSP's (Well- structured problems) only in the process of being prepared for the problem-solvers. It is not exaggerating much to say that there are no WSP's, only ISP's that have been formalised for problem solvers"* (p 150).

This is in fact a useful definition of the first three stages of the model in Figure 2.3. The model also shows an interaction between "conceptual design" and "analysis of the problem". Such an interaction is predicted by Cross in his third and fourth criteria for an ill-structured problem.

**Conceptual Design**

French described the conceptual design stage as taking the statement of the problem and generating broad solutions to it in the form of schemes, and noted that this is the stage at which the most important decisions are made. There are a range of contrasting views on the nature of the conceptual design process. At one extreme it could be viewed as being purely creative and at the other a mechanistic systematic process.

Pahl and Beitz (1988) produced a detailed prescriptive model of the design process that included a systematic view of conceptual design. They defined conceptual design as:

> *"that part of the design process which, by the identification of the essential problems through abstraction, by the establishment*

*of function structures and by the search for appropriate solution principles and their combination, the basic solution path is laid down through the elaboration of a solution context"* (p 57).

Their approach to the conceptual design process consists of a systematic analysis of the problem by:

- decomposition of the problem statement by the abstraction of the most important elements;
- identifying the requirements of each of these elements;
- determining the relationships between these requirements; and
- combination of the above into the possible solutions or "concept variants".

Nevertheless, they recognise that identification of the concept variants will often involve intuition in which the solution comes to the designer in a flash after a period of search and reflection.

Other authors placed more emphasis on the intuitive or creative nature of conceptual design. Jansson (1990) describes conceptual design as the generation of new ideas and distinguished between this and the development of ideas, as shown in Figure 2.4.

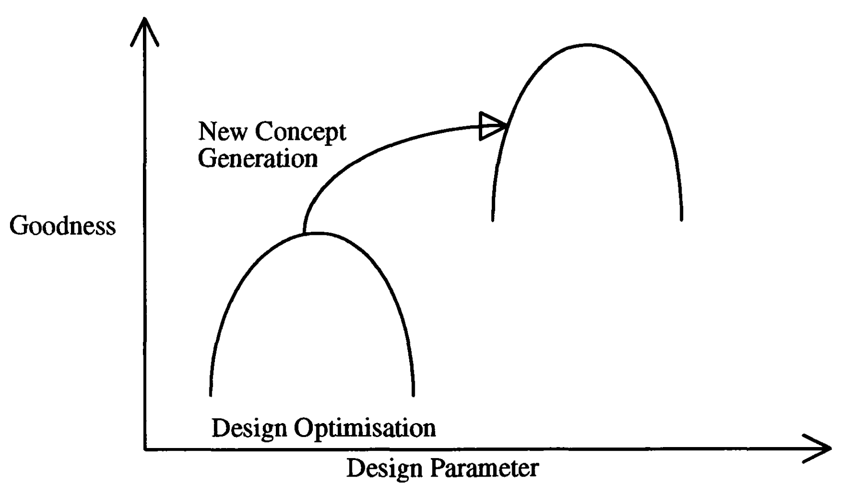



**Figure 2.4: - Creativity in the design process**

Creativity is the means by which the "leap" from one concept or configuration to an entirely new concept and configuration, but Jansson acknowledged that such a leap is a rare event in engineering design practice and that most conceptual solutions are a step further towards the optimal of a particular concept of configuration (consider March and Simon's concept of satisficing). Holt (1990) suggested an overall model of the design process that is less structured than that of French or Pahl and Beitz, and places greater emphasis on creativity. He suggested that design consists of the following four stages:

- preparation, including thinking and deep involvement, collection of information, definition and reformation of the problem;
- incubation, characterised by subconscious processes at an intuitive level, the problem being dropped from the conscious level;
- illumination, the synthesis and creation of an idea brought from the subconscious level to the conscious - the "aha moment" (Koestler, 1964); and
- verification which consists of evaluation, elaboration and refinement of the idea.

The stages in this model differ from the other models only to the extent that the processes of incubation and illumination, which would result in the leap described by Jansson, replace those concerned with conceptual design. Holt suggested that the creative ability necessary for incubation and illumination is rare and that creative designers are of particular value to the design organisation.

This elitist view of creativity is not shared by Rickards (1991) who questions the view that it is:

> *"some rare, mysterious, immeasurable, innate attribute of exceptional people"* (p 296).

He reviewed work by a number of other authors and concluded that there is no extraordinary process that can be associated with extraordinary successful "creative" people, but that creativity was the result of "ordinary" thinking applied to extraordinary goals. In simple terms creativity would occur when it was a necessary part of the problem definition stage.

Rickards interpretation of the role of creativity is more appropriate in the context of design for the construction industry where most solutions would be evolutionary rather than revolutionary, unless a novel solution was expressly required by the client at the problem definition stage.

Asimow described conceptual design as

> *"a synthesis of component elements which hurdles the obstructing difficulties and, neither exceeding the available resources nor encroaching upon limits set by the constraints accomplishes the prescribed goals"* (p 45).

He considered the identification of these component activities to be largely a result of experience and intuition rather than as a result of creativity in the sense suggested by

Holt. Whilst acknowledging the role of creativity in the design process he proposed a useful definition of creativity in the design process as:

> *"a talent for discovering combinations of principles, materials and components, which are especially suitable as solution to the problem"* (p 21).

He suggested that synthesis need not involve the development of novel elements as this is the domain of research rather than design.

The relationship between the nature of the design problem and the nature of the process of conceptual design is discussed by Simon (1984). Taking architectural design of a house as an example, he suggested that this would lie towards the ill-structured end of the problem continuum but modifies this to the extent that the architect is being "creative". Highly creative design would indeed represent an ill-structured problem but he suggested that architectural design is often an adaptation of a previous solution and therefore there is some initial structure to the problem. This is significant because the approach to be adopted to solve the problem will vary depending on the nature of the problem. Newell (1959) emphasised the relationship between problem structure and problem solving methods and characterised the domain of an ISP as the domain in which only weak problem solving methods were available. In terms of Dewhurst and Gwinnet's categories of human skills, weak problem solving methods place greater emphasis on experience and intuition rather than logical deduction. This introduces further difficulties in the quantification of design effort, particularly at the conceptual design stage but also at all stages of the design process, as the time required to carry out design functions will be influenced by the personal attributes of the designer.

Moxely (1991) identified three attributes which must be considered in appointing professional staff. These are:

- qualifications;
- experience; and
- age;

with experience being the most important at the conceptual design stage when weak problem solving methods are required.

The impact of the experience of the designer on design costs and durations was also identified by MacKinder and Marvin (1982). The authors concurred with the view that design was essentially a decision making activity and that the experience of the architect was of fundamental importance to the decision making process. They identified three types of experience.

- Experience of the decision making process, enabling the architect to predict in advance what problems might arise and to be aware of information sources which might be appropriate. This form of experience would be of central importance to design cost estimation, particularly with regard to the time required for the conceptual design stage.
- Experience of the technical content of the design, i.e. building construction, gained from both education and practice. This form of experience is more relevant to the scheme selection and detailed design as it enables decisions to be made more effectively on the appropriateness of alternative components.
- Experience of the performance of design decision which were taken in previous projects, which will result in improved decision making and a reduction in abortive design work.

It is apparent that the conceptual design stage is particularly difficult to quantify as it is affected to a greater extent than other stages of the design process, by the level of requirement of creative input, and by the experience of the design team. It will therefore be necessary to gauge the extent of:

- creative input by an examination of the problem statement, as suggested by Perkins; and
- experience of the design team, which will be particularly difficult to quantify as the "value" of experience, in terms of design efficiency, will be dependant on its time scale, its relevance to the current project, and the abilities of the individuals to benefit from the experience.

The final stages of the conceptual design stage will involve the reduction, by a process of elimination of the conceptual solutions that will be developed at the next stage of the design process. As an integral part of the conceptual design stage, the concept variants must be checked for compliance to the statement of the problem. During this stage, some of the proposals will be rejected on a compliance/non compliance basis and others may be rejected on the basis of their relative technical and financial merits. The concept variants will exist in the form of sketches, notes and outline drawings and although it will be possible to apply quantitative approaches to these decisions an element of intuitive judgement will still be required and weak decision making approaches will still predominate. Ultimately one, or more if some concept variants appear at this stage to be of equal merit, will be taken forward for embodiment of the scheme and detailed design.

**Embodiment and Detailed Design**

According to French, the input to the embodiment stage is the concept variants from the conceptual design stage. It will be necessary at this stage to simultaneously produce a layout plan to a similar level of detail for each concept variant in order to obtain more information to permit a full technical and financial appraisal of the variants. Quantitative, and possibly quantifiable, design decision making approaches based on logical deduction will predominate at this and subsequent stages of the deign process. The outcome of this stage will be a definitive layout plan of the selected scheme which will allow the detailed design to proceed.

Pahl and Beitz describe detailed design as:

> *"the phase in the design process in which the arrangement, form, dimensions and surface properties of the individual parts are finally laid down, the materials specified, the technical and economic feasibility rechecked and all the drawings and production documents produced"* (p 42).

Significantly they, and the other authors, say little about the constituent activities of the detailed design stage, but identify that this stage will consist of the application of standard technical and financial analysis procedures. In terms of Dewhurst and Gwinnet's categories of problem solving skills, logical deduction will now be required. As in the conceptual design stage, the time required for detailed design will be influenced by the personal attributes of the designers, but in this case qualifications will be as important as age and experience.

The precise nature of the constituent activities of the detailed design stage will be dependent on the nature of the design under consideration. A fuller analysis of the embodiment and detailed design stages of construction industry projects is therefore required and this is included in section 2.3 below.

### 2.2.3 Summary - the nature of design

The purpose of this section of the literature review was to analyse the nature of design work and thereby identify the factors that will influence the selection of necessary design resources for a design project. The following conclusions are drawn.

- The design process is essentially a decision making process and consists of a series of iterative stages.

- The required input to the design process will be greatly affected by extent to which optimal rather than satisfactory decisions are made during the design process.

- The degree of rationality of this process will be affected by:
    - the extent to which the problem can be defined;
    - the degree of influence of non-technical criteria;
    - the extent of the application of intuitive approaches rather than logical deduction to decision making;
    - the necessity for creativity in the development of the solution; and
    - the personal attributes of the designers

- The dominance of the factors which influence the design resource requirements will vary throughout the stages of the design process.

## 2.3 DESIGN IN THE CONSTRUCTION INDUSTRY

The previous section has investigated and drawn conclusions on:

- the fundamental nature of the design activity;
- the constituent stages of the design process; and
- the decision making approaches that are brought to bear during the evolution of a solution to a design problem.

The same general processes will occur in construction design, but consideration must be given to the ways in which these processes are integrated into, and affected by, the practices and procedures of the industry. Abdul-Khadir and Price (1995) stated that the construction procurement process should be viewed as being an organic and holistic entity, and their work on the conceptual phase of projects highlighted the inter-relationship between tasks and the iterative nature of the process. The design activity in construction can not be considered in isolation and the effect of the interaction between designers and other parties must be evaluated.

## 2.3.1 The role of design in the construction industry procurement process

Hillebrant (1984) described the stages involved in the development of construction industry projects and noted that there were a number of systems of project development (procurement systems). A distinguishing feature of these systems was the means of interaction between the various parties involved in the development process. She stated that these systems have been developed with the aim of attaining a common purpose amongst the parties whilst ensuring efficiency in achieving this purpose. The general design process described in Section 2.2 will form an integral part of each of these systems but the efficiency and content of the process may be affected by the manner of operation of the procurement system.

The characteristics of the traditional system of procurement of construction works are illustrated in a general model produced by NEDO (1978). The sections of that model which deal with design stages are shown in Figure 2.5 and this is similar to the general models of the design process which were introduced in Section 2.2.

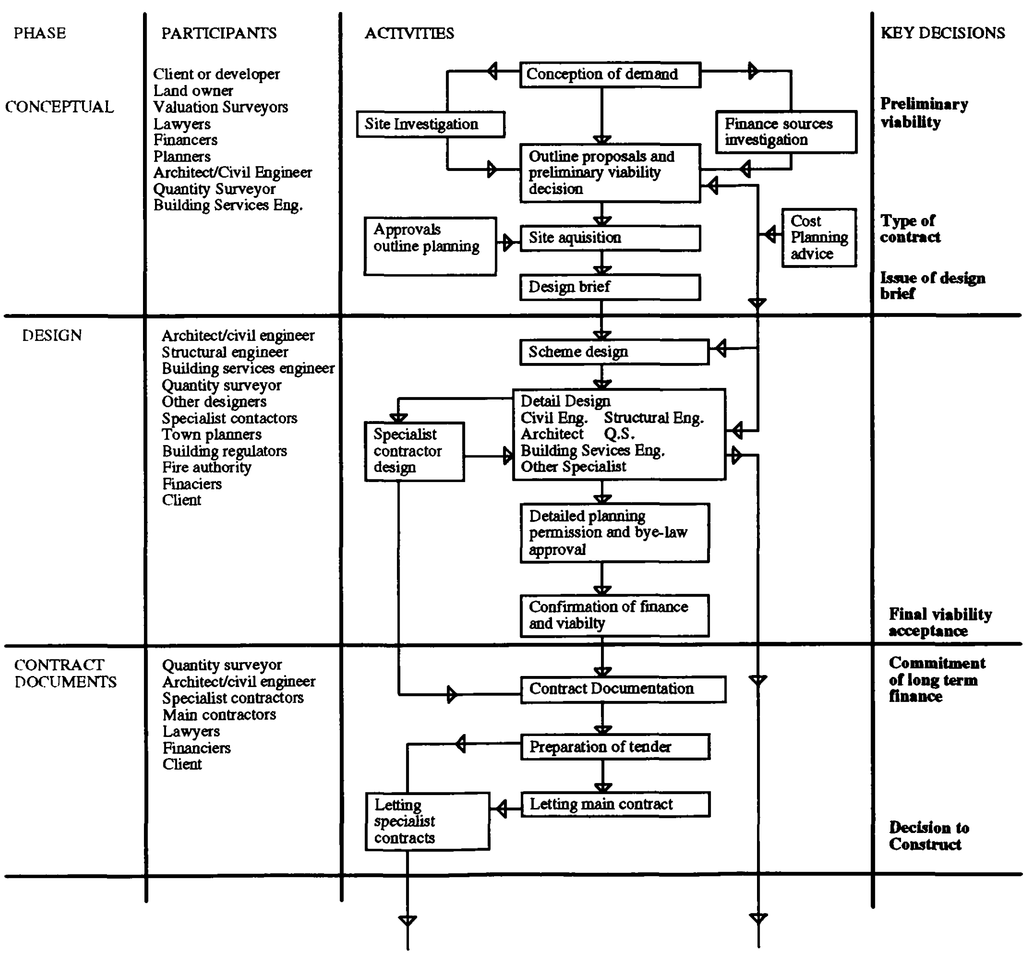



**Figure 2.5: - The traditional procurement system**
(From NEDO, 1978)

In particular, the stages of problem definition, conceptual design and detailed design appear in this model and a footnote to the figure in the NEDO publication made particular reference to the two directional nature of the flow between activities. The most significant additional feature of this model is that it illustrates the contribution of a large number of parties to the project development process. In total thirteen independent parties are shown and the complexity of the relationships between the parties is noted by Hillebrant.

The interaction between the parties adds a level of complexity to the design management process that would not normally be encountered in the management of the constituent activities of the construction process. In design work the principal influence on the required time scale for an activity will often be quite different from that of the requirements for the necessary design resource input (or cost). For example, a design activity may require input from an architect, a structural engineer and a building services engineer. The estimate of overall duration of the activity on the design programme of each discipline would involve consideration of the design times required by each design team plus an additional time allowance for any correspondence or other communications between the parties. However the cost of the activity for each discipline would be based on an estimate of the required staff resources to carry out the design work on an activity of that nature. Consequently, any data abstracted from individual projects for inclusion in a database of standard design costs would have to be modified to allow for the influence of the other parties on the efficient performance of the design team.

The efficiency of the design team could be affected by:

- time taken in communication with other parties;
- delayed and fragmented work patterns due to delays in the receipt of information from other parties; and
- abortive work or re-design work due to inaccurate information or changes to design parameters by other parties.

Latham (1994) also noted the complexity of the design process and its potential for a lack of co-ordination. He concluded that effective management of the design process is crucial to the success of the project and that this required effective management of the exchange of information between consultants. Similar concerns had earlier been expressed by the British Property Federation (BPF, 1983) who had identified a need for a design team leader to be appointed to co-ordinate all design input and to arrange the allocation of design work packages on a fixed fee basis. The BPF suggested that, to aid the design teams cost estimation, the lead designer should prepare a schedule of requirements outlining the design input in terms of number and types of drawings. Paradoxically, they proposed that this should be non-contractual, perhaps indicting their acknowledgement of the difficulties in quantifying design services to the extent that would be necessary for fee bidding on a fixed price basis.

It is apparent that the integration of design into the construction process will result in the involvement of many parties in the design process which will require a frequent interchange of information which will inevitably effect the duration and cost of design activities. The extent and nature of this interchange of information will be influenced by the characteristics of the chosen procurement system.

In addition to the traditional procurement system, Hillebrant identified and described the:

- traditional system;
- design and construct system;
- project management system; and
- management contracting system.

More recently management contracting has been the subject of much criticism and has been largely superseded by the construction management system. The most recent development in procurement systems is the growing interest in Partnering (Bennett and Jayes, 1995; Lorraine, 1994).

There have been a number of publications on procurement in the construction industry and these can be broadly grouped into three categories of publications dealing with:

- features of procurement systems (e.g. Lorraine, 1994; Tatum, 1987);
- comparative studies on the effectiveness of procurement systems (e.g. Naoum and Mustapha, 1995; Walker, 1994); and
- the influence of the client on construction project success (e.g. Walker, 1995; Davenport and Smith, 1995).

The nature of the design process and the organisation and management of the design team are not considered in any detail in these publications. However, Luck (1993) investigated the effect the various procurement methods on the role of the architect in building projects and concluded that, whilst the range of services offered by the architect would be reduced in each system relative to the traditional system, the design activity itself would be least affected. She also noted that:

*" .. a finite number of services exist within the "traditional" architects role. When these services are not provided by the architect they are provided by another team member i.e. none of the services are eliminated by the selection of alternative procurement methods"* (p 46).

Similarly, Nicolson (1991) stated that project management, construction management and management contracting approaches virtually exclude the architect from all duties beyond the design of the building, but that these duties were assumed by the contractor or project manager.

It can be reasonably concluded that the nature of design work on the individual design activities of a project would not be significantly influenced by the selection of the procurement system, but that the flow of information would be managed by different parties. Consequently, the efficiency of the information transfer may not be similar within the various procurement systems and therefore an allowance must be made for the effect of this on the efficiency, and hence the cost of the design work.

Walker (1995) concluded that the choice of procurement system was not itself a determinant of project success but demonstrated that experienced or sophisticated clients are more likely to achieve a successful outcome, partly because they are more able to provide a clear definition of the problem. The importance of clear problem definition through the effective development of the clients brief was highlighted as a key recommendation by Latham (1994). This corresponds well with the proposition in Section 2.2 that the extent of the problem definition will significantly affect the cost of design work.

The extent of problem definition will however not be influenced directly by the choice of procurement system. Latham noted that:

*"...whether or not the scheme is design led the client must allow time and space for its wishes as expressed in the project brief to be further tested for the purposes of the design brief against questions of feasibility"* (p 18).

The extent of problem definition will be affected by the stage in the overall design process at which a design team is appointed. Blackwood, Sarkar and Price (1990) compared the traditional procurement system with the design and build system, and concluded that the difference between the systems, as far as the design work is concerned, was the way in which the client could choose to influence the outcome of the design. In the traditional system, the client would have a high degree of control up to and including the detailed design stage. The client could appoint separate design teams for the conceptual and detailed design stages which would ensure that the design team for the detailed design stage would receive a well defined problem. Design work could be similarly sub-dived in the management contacting, construction management and project management systems. In the design and build system, the client's influence would be lost once a contract has been entered into. Therefore, if the client wished to exert influence on a design solution they would have to provide the design and build contractor with a detailed brief or end-product specification which would be similar to the result of the conceptual design stage of the traditional system. It should be noted that the design activity in the final stages of design in the design and build system will be different from the other systems because of the removal of the division between the design and production stages of the project. In the traditional system, the design team would be required to produce fully detailed contract documentation which would be used by the contractor as production information, and therefore a significant proportion of the design process would be devoted to this activity. In the design and build system, production information would still be required but the level of detail of this information will differ from the traditional system as a result of the design teams closer involvement with the contractor.

There have been several recent publications on partnering (NEDO 1991, CII 1991, Bennett 1995) although it has been used for a number of years (Loraine 1994). The essential feature of partnering is that it is a continuous relationship between two parties based on trust dedication to common goals. The concepts of partnering will not affect the design process to any significant extent except that, particularly in the case of term rather than project specific partnering, the design team may have clearer understanding of the problem definition due to a close and continuous working relationship with a client.

In conclusion, it is apparent that, regardless of the choice of procurement system, every project will involve each of the stages of the design process, the essential difference between traditional and other procurement systems being a shift in the responsibility for the overall management of the project from the designer to other parties. Thus the selection of procurement system will influence design costs in two ways:

- the efficiency of the information interchange within the procurement systems will vary and this will effect the efficiency of the design team; and
- the degree of problem definition at the stage at which the design team is appointed will vary and this will effect the extent of the design work.

The selection of procurement system, and the role of the client within the system, will be a further source of variability in construction industry design cost data which must be allowed for in a predictive model of design costs.

In addition to variability in design cost data introduced by the different procurement systems, recent developments in the construction industry such as the Construction Design Management Regulations (CDM) and the imposition of EU directives, have changed the designer's responsibilities within the procurement systems and this will lead to variances between historic and future cost data.

Considering the former, the purpose of the CDM regulations was to ensure that designers avoid, design out or reduce potential hazards in construction projects. CIRIA (1995) suggested that the regulations need not require designers to do more than good design and good design management would achieve, but note that better records of the safety implications of design decisions would have to be kept. The Construction Industry Council (CIC, 1995) stated that duties that were implicit will be explicit and whilst the effect of this change on design costs is difficult to quantify there is the potential for the introduction of further variability in design cost data. The design process may be similarly affected by EU directives, in particular the Construction Products Directive 89/106 which attempts to ensure that a fitness for purpose concept for construction products is fully introduced across the EU and that this will be supported by introducing conformity in technical specifications. To facilitate this conformity some 2000 standards must be developed (Fewings, 1993) of which some 700 have already been developed. The introduction of revised standards will once again introduce variability between historic and future design cost data.

### 2.3.2 The appointment of the design team

It has been established in Section 2.2 that design is an iterative decision making process and that, in such a process, a range of appropriate solutions can be developed for every problem, ranging from solutions that are merely satisfactory to those that are truly optimal. This range of solutions will correspond with a similarly wide range of potential design costs since optimal solutions will require a greater number of iterations and hence greater design resource input than solutions which are barely satisfactory.

The mechanism of appointment of the design team must be chosen to ensure that the required level of service is apparent to the design team at the time of appointment and is provided by the design team during the development of the project. (The possible variations in levels of service supports the need for this programme of research namely; how can a benchmark be established for design cost for particular types of projects which will enable an evaluation to be made of the adequacy of design teams cost estimates against specific levels of service?) The mechanism of appointment of the design team introduces a further source of potential variability in design cost data.

Doree (1992) identified three possible methods of appointing the design team:

- acquisition of design in-house;
- acquisition of design as a design and construct package; and
- acquisition of design through in-house independent consultants.

He then considered the three methods of acquisition in the context of three, sometimes conflicting, overall project objectives, namely: to minimise design production costs; to minimise overall project costs; and to minimise life cycle costs. Doree drew no conclusions on the relative design production costs of design and build acquisition but did conclude that in-house design teams were more likely to produce a higher level of service at higher design production costs than independent consultants who, he argued, would tend to produce satisfactory rather than optimal solutions, but at lower design production cost. This analysis is simplistic in that it does not consider the possible methods of engagement of independent consultants which can influence the level of services provided.

Rowdon and Mansfield (1988) produced a comprehensive review of the methods of appointment of civil engineering consultants and analysed the significant changes over the past three decades. In particular, the change from mandatory fee scales set by the professional bodies to the widespread use of fee competition by clients, often on the basis of lump sum payment (as had earlier been proposed by the British Property Federation (1983)), was documented and explained. A similar move towards fee competition emerged for architectural services. A survey reported in the Architects Journal (1991) demonstrated a similar trend toward widespread fee competition, with 80 per cent of practices being involved in design work where payment was on a lump sum basis.

Rowdon and Mansfield also described the discussions of the Monopolies and Mergers Commission (MMC) and the Association of Consulting Engineer (ACE) which highlighted the dilemma facing clients and designers of ensuring value for money and at the same time ensuring the quantity and quality of professional services. Arguing against fee competition, ACE told MMC that:

> *"The ACE is of the opinion that competition in quality of service or by innovation based on research is a much tougher form of competition and produces entirely beneficial results. Price competition would lead to an undesirable degree of uncertainty and distrust between consulting engineer and client, and could lead to a reduced sense of public responsibility on the part of some members of the profession"* (p 87).

Howie (1989) and Cecil (1991) expressed concern that levels of service would also be compromised by the change in the legal entity of many design organisations from Partnership to Limited Liability organisations which was initiated by clients increasing use of fee competition (McFadzean-Fergusson, 1985). They believed that the reduction in liability of the partners would, in the more competitive environment, contribute significantly to levels of service being provided which would tend toward being minimal.

Latham (1994) also documented the widespread acceptance of fee competition for professional services but listed evidence that both architectural and civil engineering consultants were adapting the scope of their services to match the reduced fees available in the competitive environment. In particular, a survey of ACE members found, inter alia, that:

- 73 per cent (of respondents) give less consideration to design alternatives;
- 31 per cent give less consideration to checking and reviewing designs;
- 74 per cent admit that they are producing simpler designs to minimise the commitment of resources to a task;
- 35 per cent bid low with the intention of doing less than in the enquiry; and
- 65 per cent bid low with the intention of making up fees with claims for variations.

In support of fee competition, Rowdon and Mansfield referred to a 25 percent saving in professional fees achieved by the Department of Transport following the introduction of fee competition which supported the MMC proposition that the mandatory fee scales may not have represented good value to the client. The

Architect's Journal survey recorded a similar reduction in fees charged by Architectural Practices since the advent of fee competition.

The Construction Industry Council (CIC) reject the concept of competition by fees alone and refer in their publication "The procurement of Professional Services: guidelines for the application of competitive tendering " (CIC, 1993) to:

> *"The Brooks act which was established in the United States of America as a consequence of building failures which were partly attributed to the procurement of services on the basis of fee alone"* (p 2).

Instead, the CIC recommend the use of competition on "*quality tempered by price*" (p 2) and set out a series of procedures which can be used in the selection and appointment of consultants. The publication recommends a two stage process with initial pre qualification on ability and final selection on the basis of lowest bid. However the procedures in the publication are vague and do not explain in any detail how an assessment can be made of the abilities of the consultants and of the adequacy of the tender price.

The Construction Industry Research and Information Association publication "Value by competition - a guide to the competitive procurement of consultancy services for construction" (CIRIA, 1994) contains a more comprehensive treatment of the topic. Of particular relevance to this study is the observations regarding the problem of making comparisons between price bids. CIRIA concur with the findings of the ACE survey on the effects of fee competition that:

- the lowest price may be based on a minimum level of service and may preclude the offer of more valuable services, but more costly services, which may be of greater benefit to the project in the long run; and
- consultants may in times of recession bid below cost to keep staff working or may hope to secure additional, work from the client at a higher price during the currency of the project.

The guide identifies the difficulty of comparing bids as the level of bid will be influenced by a number of factors including:

- the state of the market for the services required;
- the consultant's assessment of the scope and level of services (i.e. whether satisfactory or optimal solutions are required);

- the consultant's modus operandi, (e.g. whether a "ready-made" team is available); and
- the consultant's experience of working with the client and the other project participants.

The guide also lists a number of factors which should be considered in assessing the consultants capabilities, all of which will be reflected directly or indirectly on the level of the fee bid. These are:

- the overall experience of the team;
- the facilities at their disposal; and
- the adoption of a Quality Management System.

### 2.3.3 Models of the design process in the construction industry

The model of the design process proposed by Markus (1972) was based on construction industry design, which has been shown in Section 2.3.2 to be directly comparable with general engineering design. The stages of the design process in the construction industry are listed and described in more detail in publications produced by the two bodies which represent the majority of designers in the United Kingdom: the Royal Institute of British Architects (RIBA), and the Association of Consulting Engineers (ACE).

The RIBA plan of work (RIBA 1973) was developed to describe the architect's involvement in construction industry design under the traditional procurement system. The work was divided into 12 stages which cover the development of the project from inception to completion and includes a feedback stage after completion. Stages A to F of the plan of work can be directly compared to French's general model which was shown in Figure 2.3, as illustrated in Figure 2.6.

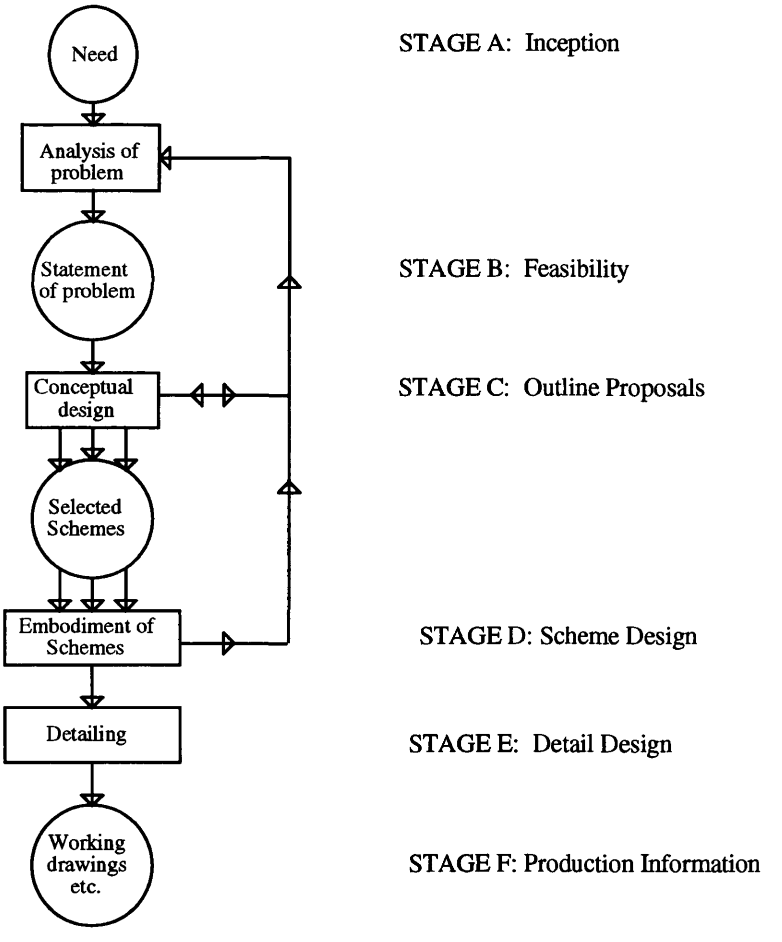



**Figure 2.6: - comparison of the general model of the design process with the RIBA plan of work**

The equivalent sub-division of civil engineering design work is described in the ACE standard Conditions of Engagement which, until 1993, formed the basis of agreement between the client and the Consulting Engineer (ACE 1981). These Conditions of Engagement comprise four agreements:

- Agreement 1: used for report and advisory work and which would encompass the feasibility stage of the general model of design work;
- Agreement 2: used where an architect has not been appointed by the client;
- Agreement 3: used where an architect has been appointed by the contractor; and
- Agreement 4: deals with work which is sub-contracted or work which relates to direct contract work.

Agreement 2 contained the stages of design for a civil engineering project from the feasibility stage to the working drawings stage and allows the most appropriate comparison between civil engineering design procedures and the general model of the design process to be made. The agreement splits the design work into two stages.

Design Stage I culminates in the production of

> *"... such documents as are reasonably necessary to enable the client to consider the consulting engineers general proposals for the construction of the works..."* (p 8).

This stage is virtually identical to stage C of the RIBA plan of work.

The Design Stage II comprises:

- preparing designs and tender drawing;
- advising on appropriate procurement system and contract forms;
- preparing schedules, specifications and bill of quantities; and
- advising the clients on the merits of tenders and estimates.

This stage is virtually identical to stages D to F of the RIBA plan of work and encompasses the embodiment, detailing and working drawings stages of the general model of the design process.

The 1995 form of the Conditions of Engagement (ACE, 1995) differs in two ways from the 1981 version:

- the range of agreements has been increased to six to reflect changes in procurement systems e.g. Agreement C - for use where a consulting engineer is employed by a design and construct contractor; and
- the stages of the design process have been redefined and relate more closely to the RIBA plan of work, including inception, definition, outline proposal, scheme design, etc.

The general models of the design process correspond well with the design procedures identified in the RIBA plan of work and the ACE Agreements. Whilst both provide a useful framework against which to map the design process, they do not address or identify in any detail the activities and processes which occur within the stages of the design process. There are, however, publications which attempt to identify and describe these activities.

Jergas (1989) produced a detailed model of the design process which identified a series of "procedures" similar to those listed in the RIBA plan of work. The model used these procedures as its core and allocated to each a series of information requirements that require one or more design activities during the design process. These were:

- the information available from the participants;
- technical information from regulations, standards and codes of practice;
- functional requirements of the project, physical and spatial and aesthetics;

- location and site;
- operation aspects, project administration cash flows etc.; and
- social and economic data from previous projects, prices, user feedback etc.

This model is useful because it highlights the complexity of the design process and the need for effective information interchange within the process. The model contains approximately 60 procedures and approximately 50 information requirements, each necessitates at least one design activity and, if this model was to be used to identify work packages for planning and estimating the cost of design work, then a minimum of 100 work packages would be required. Significantly more would be necessary as many of the information requirements would require more than one design activity. This is particularly true of the section of the model which deals with detailed design. This part contained six procedures and three information sources but work by Austin et al. (1993) suggest that this would be a gross over-simplification.

Austin, Baldwin and Newton (1993) applied data flow diagram techniques to map the flow of information in a design and construct project and, using a top down decomposition analysis, divide the detailed design model into six levels as shown in Figure 2.7.

In the sixth level, six discrete activities have been identified but this is one of two activities at the fifth level, which is itself one of five activities at the fourth level and so on. Considering the six levels and assuming that each design branch could be similarly sub-divided, then there could be approximately 8000 activities (6 x 2 x 5 x 4 x 7 x 5) in the detailed design stage of this project.

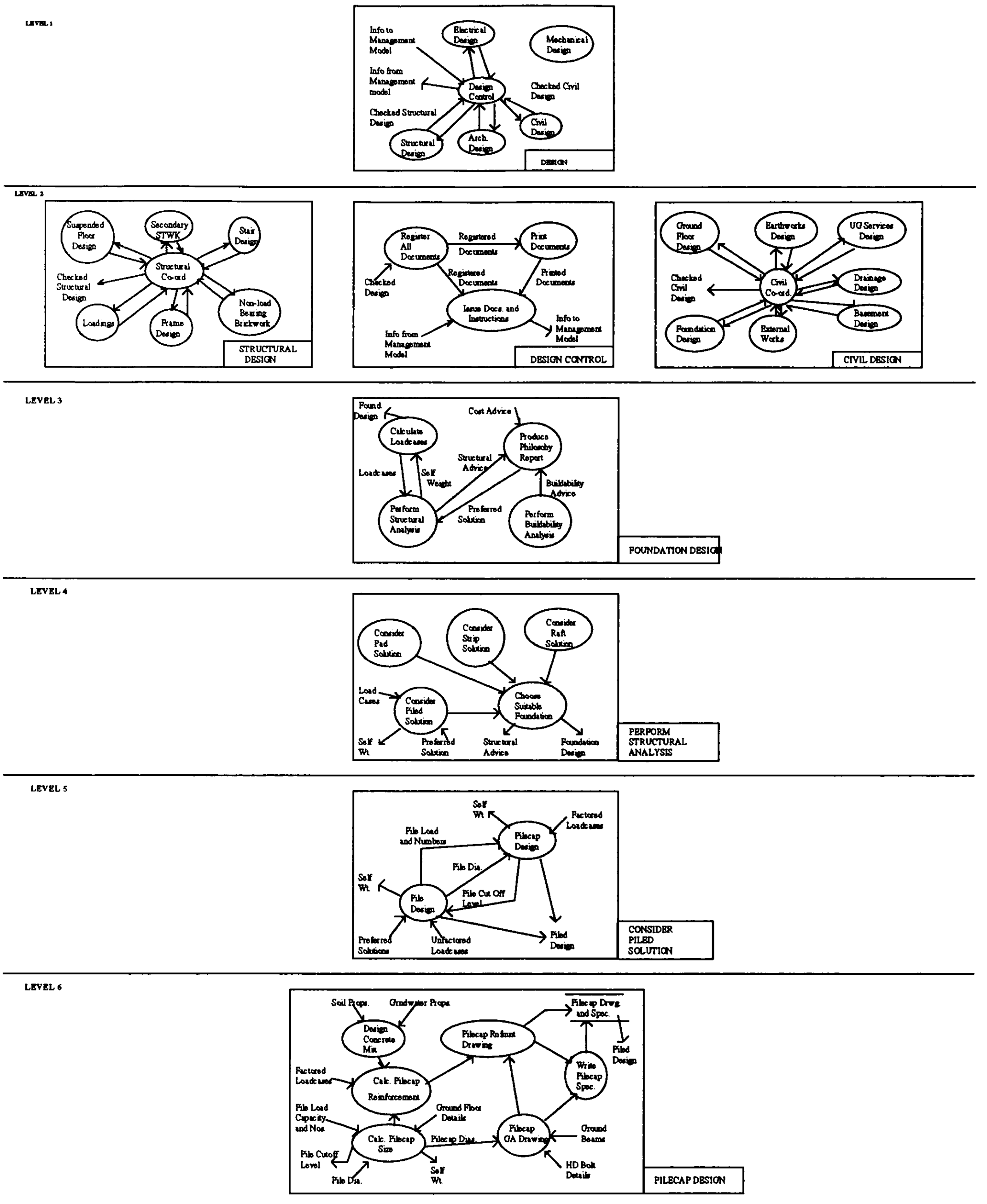



**FIGURE 2.7: - Austin, Baldwin and Newton's representation of a design problem**
Austin, Baldwin and Newton (1993, p 84)

Kim, Popescu and Hamilton (1994) describe the creation of work breakdown structure for project management throughout the life-cycle of a project and conclude that this can be best achieved by using design component to define the structure. This approach produced a breakdown of activities that was similar in terms of the level of detail to that of Austin and demonstrated again the large number individual design activities and decisions which are required during the design stages of a project.

### 2.3.4 Summary - integration of design in the construction industry

The purpose of this section was to compare the design process in the construction industry with that of general design and to investigate the way in which the process is affected by its integration with the industry's practices and procedures.

It can be concluded that the design process in the construction industry is broadly similar that of the general design activity in terms of both the stages of the process and nature of the design problem. However, the integration of design process within the construction industry influences the way in which the design activities within the stages of the process are carried out and this introduces complexities to the problem of developing more effective cost estimation and cost control systems for construction industry designers. The environment in which construction industry design occurs was examined and the number of parties involved in the process and the variety of relationships that can exist between these parties was identified. The existence of this range of procurement systems does not alter the fundamental nature of the design process, but will influence the nature of the design work associated with each stage of the process. The conclusions from Section 2.2 are therefore valid in the context of the construction industry but the existence of the different procurement systems adds additional complexity to the interpretation of data on design resource requirements.

This part of the review has also established that there has been a fundamental shift in the way in which design teams are appointed, and there are reservations that some recent methods of appointment may result in a reduction in the levels of service that are provided by designers. In the context of this study these issues are important in three ways:

- the changes in the mechanism of appointment will produce a barrier to the effective utilisation of historic cost data for future cost estimating;
- the continuing use by clients of different methods of appointment will cause additional variability in recently acquired data; and
- the rationale behind the need for the study has been fully vindicated because it is evident that some means of measuring the adequacy of fee bids against a specified level of service is necessary.

Finally it can also be concluded that models of the design process in the construction industry are readily available and these vary between general models (Markus, 1972) and very detailed models for specific projects (Kim et al., 1994: Austin, Baldwin and Newton, 1995). The potential for the application of these models to planning and estimating the cost of new design projects must be established. This is dealt with in Chapter 7 of the thesis.

## 2.4 SUMMARY OF CHAPTER 2

The results of the review of literature relating to the design process have been presented in Chapter 2. Conclusions have been drawn in section 2.2.3 on: the general nature of the design process and of the design problem, and on the influence of these on the degree of rationality of design work. In section 2.3.4 it has been concluded that design process in the construction industry is similar to the general process, but that its integration with the practices and procedures of the industry introduces further complexity to the process and hence causes further variability in design cost data.

It was now necessary to identify and evaluate the management approaches that were, or could be in future, applied to the management of the design process. Chapter 3 presents the results of the review of literature relating to design management approaches and draws conclusions on the contribution of the literature review presented in Chapters 2 and 3 to the achievement of the project aims.

# CHAPTER 3

# DESIGN MANAGEMENT IN THE CONSTRUCTION INDUSTRY

The previous chapter has dealt with the nature of design work in general and within the construction industry. This chapter presents the results of a review of literature on:

- current management approaches used in both civil engineering and architectural design organisations; and
- approaches that might be applied to more effectively manage design work.

## 3.1 CIVIL ENGINEERING DESIGN MANAGEMENT

The Institution of Structural Engineers established a task group to review design management practice and to consider the impact of Quality Assurance and BS5750 on design management. The task group's report, "Guide to Good Management Practice for Engineering Design Offices" (Institution of Structural Engineers, 1991) identified a range of management activities which are required in BS5750. The follwing activities relate to planning and cost estimation.

The guide indicated that personnel appointed should be made fully aware of the design brief and of their role and responsibilities in the fulfilment of the brief. To achieve this, these duties should be recorded in writing and the records must include target inputs and completion dates.

The guide stated that financial targets and cost control systems must be established for each project or stages of a project and that "the input required to achieve a required level of production" must be known. It suggested that this *"...usually has to be based on historic information"* but did not explain, other than by a passing reference to: the overall cost of the project; the parameters of the project (floor area, steel tonnage etc.); and the cost per drawing, how such information might be recorded and used in the estimating process. Freeman-Bell and Balkwill (1993) were similarly vague on the estimation of duration, in the context of general engineering design.

The guide stressed that programming and resourcing of a project should not be left to "intuition" but offers little practical guidance other than recommending the use of commercially available Project Management software packages. The guide does, however, highlight the importance of the identification on the programme of critical dates when information is required from, and by, other parties in the project.

The guide identifies the type of management systems that would be required in a design practice that would be capable of achieving accreditation to BS5750. Other publications include more information on the nature of planning, estimating, and cost control systems.

Rowdon and Mansfield (1989) suggested that professional practices earn less than they should due to ineffective planning and programming because the managers and supervisors believe that their type of work does not lend itself to planning. The authors identified staff costs as being the most important element of expenditure and note that with the advent of fee competition greater control is now required of staff resource effectiveness. The paper described a manual estimating and cost control system for staff resources which was based on a work package breakdown approach and had the following features.

- The project was broken down into work package task and sub-tasks, and these were assigned to supervisors and to individual engineers.
- The planned costs, developed from an estimate of man-hour resource requirements were established, and the staff members responsible for the packages were involved in this process. The planned costs were developed by breaking down the work package by itemising the work to a series of small tasks and identifying the grade or seniority (and hence the cost) of the staff involved in each task. Significantly, the means by which the estimate of the required staff input to the various tasks was not mentioned in the paper but it can be inferred that this was on an intuitive basis, although in the conclusions the authors identify the need for readily available base information on the likely duration of the various design office activities.
- A time and cost monitoring system was established, and this was used to give frequent updates of progress to the individuals involved in the design. A feature of the cost monitoring system was the method of comparison of actual and planned progress. In each work package, the percentage of cost expended was determined and an estimate of the likely input to complete the work was made. The aggregate of actual time plus the estimated time to completion was compared with the total planned input on a regular basis.

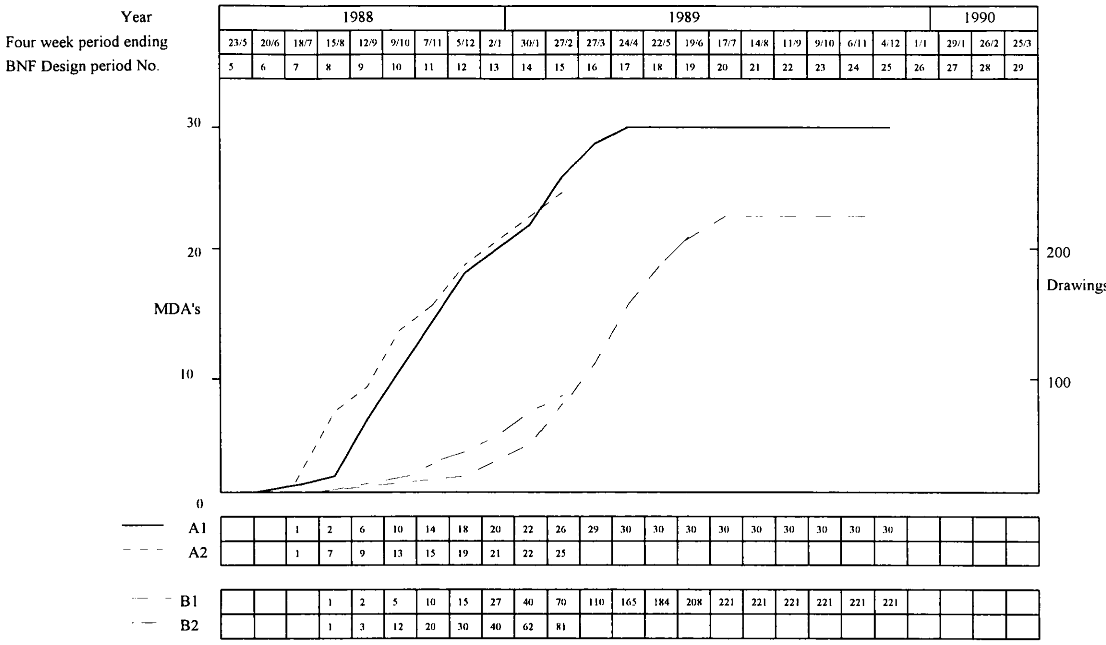
In developing the system, the authors identified the importance of giving due regard to the impact of the system on staff motivation and the related requirement to set clear, unambiguous and attainable goals for staff (as identified in the IstructE design guide above). This was achieved by the involvement of all staff in the cost estimate, by the issue of work package description outlining the scope of the work to staff, and by the provision of feedback from the cost monitoring system.

Dowling (1990) described an estimating and cost control system for large engineering design projects, used by British Nuclear Fuels plc (BNF). In this case the project programme, due to the magnitude of the project, was divided, into a number of levels as follows:

- a global/management programme with key dates for construction and commissioning;
- a project control programme which contained information relating to all design disciplines; and
- a design team programme for all the activities of analysis, design and detailing, which required the use of the smallest practicable work packages for planning and estimating.

This third level of programming was comparable with the scope of application of the estimating and cost control system developed by Rowdon and Mansfield. The BNF system was very similar with the following additional features. The programme was represented in the form of a bar chart and this bar chart was used to assess physical progress against planned progress, and to assess the effects of any delays on the overall programme. The overall progress on the project was determined by aggregating the progress, based on the number of drawings issued, on each of the constituent work packages and this information was presented graphically as shown in Figure 3.1.

As was the case with the other papers, the method of estimating the necessary resource requirements in terms of the man days allowances for the work packages were not described in detail but techniques, similar to those identified in the Institution of Structural Engineers Report (previously reviewed), were mentioned. Care was urged in the application of standard fee scale percentage figures as consideration must be given to the complexity of the project and the extent of interaction with other design groups and other organisations. Actual resource requirements were determined from an analysis of detailed time sheet information collected from every employee on the project. Dowling considered that the production of detailed time sheet information was essential to the cost monitoring progress but did not provide any information on the practicality of data collection.




**Key:**

| | |
|---|---|
| MDA | Man Day Allowance |
| A1 | MDA Programmed |
| A2 | MDA Actual |
| B1 | Working Drawings Programmed (Number) |
| B2 | Working Drawings Issued (Number) |

**Figure 3.1: - Accumulated expenditure and progress analysis curves (from Dowling, 1990: p61)**

Suarez and Green (1988) described a cost reporting system for professional design work in the United States of America which could be used by the Owner (Client). The system was spreadsheet based for use on a personal computer and the output comprised:

- graphical output of planned against actual progress, which was a system very similar to that shown in Figure 3.1; and
- a tabular report of actual hours of design resources expended, estimated physical progress expressed as a percentage, and earned value.

The paper usefully explained the basis of determining the above parameters. At the heart of the system was the estimate of physical progress. The authors considered that it was essential that the designer's estimate of physical progress could be verified and suggested typical units of measurement including: the number of completed drawings; the number of specifications draughted; or the number of contracts draughted. Earned value, in terms of hours of design effort, were determined for each work package using:

Earned Value (hours) = ESTPROG x ESTINPUT
Where:
ESTPROG = Estimate of physical progress (%)
ESTINPUT = Total estimated design input for the work package (hours)

The work package figures were then aggregated to produce totals for the entire project and ratios were then used to assess performance. Firstly, a Schedule performance index =

$$\frac{\text{Total Earned Value (as a percenrage of overall required design input)}}{\text{Planned Progress (\%)}}$$

and secondly a Cost Performance Index =

$$\frac{\text{Earned Value (hours)}}{\text{Actual Value (hours)}}$$

The paper provided a valuable description of a cost reporting system but did not explore or explain two important areas: the data collection methodologies and the methods of estimation of the design resource requirements. With regard to the former, the authors simply stated that data on actual hours expended are provided by the design engineers and they did not deal at all with the latter.

Rutter and Martin (1991) identified four methods which might be adopted to estimate design resource requirements based on:

- projected income from the project;
- historic cost data from schemes which are broadly similar;
- process related data expressed in terms of design input for likely quantities of reinforced concrete, weights of connections in relation to the tonnage of structural steel work etc., which could be taken as measures of the complexity of a project; and
- the number of drawings required together with an estimate of the man hours required to produce a drawing.

The text did not deal specifically with the means of collection, manipulation, and application of data to produce cost estimates.

Buckthorp (1990) described a cost control system for smaller projects which utilised a series of indices, based on:

> *"...the minimum fundamental project records that most offices maintain: namely estimated and actual income, estimated and actual salary costs and estimated and actual project expenses".* (p 39)

The indices included an allowance for profit and overheads and for offset costs such as postage telephone calls etc., but can be simplified as follows:

$$\text{Percentage complete} = \frac{100 \text{ x actual costs}}{\text{total estimated costs}} \quad \text{and,}$$

$$\text{Earnings to date} = \text{total estimated income x percentage complete.}$$

Buckthorp proposed that the performance on the project would be monitored by comparing the percentage complete figure with an assessment of actual progress. If actual progress is less than the percentage complete figure, then the earnings to date would also be less and the anticipated profit consequently reduced. Action would then be required to improve performance on the project. Estimated costs would be developed from historical records of time expended on previously similar projects but such an assessment must be made with extreme caution. As in the other two systems, actual costs would be determined from staff time sheets and the data would be processed on "desk top computer" using software developed by the author in the absence of commercially available software. The author did not describe the nature of the hardware or software, and in common with the other publications does not explain how the initial cost estimate would be developed from the historical records.

It is also useful to consider design management practice in the United States of America where, under the normal project procurement arrangements, the responsibility for detailed design rests with the contractors. It is possible that the close relationship between the design and construction teams would result in a greater application of project management systems to design management. A survey of design management practices by design teams on large (in excess of 10,000 man/hour) projects was commissioned by the Construction Industry Institute (CII), based at the University of Texas in Austin, and the report on the study (Diekmann and Thrush 1986) contains details of the results of a series of interviews with six major contractors. The report includes details of the project management techniques adopted by the contractors and draws the following conclusions on design management practice:

- there was an increasing emphasis being placed upon educating project personnel in project controls and on decentralising project controls;
- project control systems were not designed to support the people involved in the design activity;
- contractors were devoting a similar amount of resources to project control (about 7 per cent of overall costs);
- projects were broken down using work packages to an appropriate level of detail;
- there was a decline in the value placed on Critical Path Methods, because the dependencies between activities were neither clearly identifiable nor fixed;
- progress was measured using a count of physical production of documents and by comparing "earned value" with predetermined project milestones;
- man-hours were not tracked to specific activities but to groups of work packages, to keep management information to manageable levels; and
- small computers would offer enhanced prospects for project control.

The publication also gave examples of cost control output and these were very similar to that of Figure 3.1. As suggested by the title, and in keeping with the other publications, Diekmann and Thrush (1986) neither investigated nor documented the means of establishing the initial cost estimates against which the design team performance was monitored and controlled.

Hudgins and Lavelle (1995) noted that very little research work has been done on the accuracy of estimates of design services and reported on the results of structured interviews of eight professional design offices in the United States. The general conclusions were that:

> *"design firms typically rely heavily on the experience, judgement and personal recollection of previous similar projects by project managers for developing design estimates"* (p 21).

They also concluded that in arriving at the cost estimate:

- 95 per cent of projects have resource estimates prepared for bid and project control and that all these estimates were single point estimates;
- 63 per cent of firms use WBS task breakdown estimates as tools in project control;
- 55 per cent of project estimates are cross-checked by comparison to construction costs parametrics; and

- 50 per cent of project estimates are based on drawing cost parametrics.

## 3.2 ARCHITECTURAL DESIGN MANAGEMENT

Coles (1992), in considering Architects views on the management of design work, concurs with Rowdon and Mansfield's opinions of engineers and lists a number of obstacles to the establishment of appropriate design management systems. They are:

- the common belief that design work cannot be planned;
- the common belief that designers are impeded by factors beyond their control;
- resistance to having their working methods forced into a mould which inhibits creativity;
- a lack of understanding of planning and programming methods; and
- a fear that data collection and analysis will consume more time and energy than it is worth.

Furthermore, Gray et al (1994) identified a number of inherent difficulties in managing architectural design, namely that:

- the search for the perfect solution is potentially endless;
- the process involves finding as well as solving problems;
- design inevitably involves subjective value judgements; and
- there is no simple scientific approach to solving the design problem.

Nevertheless he and others have addressed the issue of effective architectural design management but, as was the case for civil engineering design, the literature either provided a broad overview of the principles of management or dealt in detail only with the cost control function. The estimating function was not explored in any depth, and surprisingly, the need for a feedback link from the cost control to the cost estimating was not identified.

Sawzuk (1992) stated that four basic ingredients were required in an architectural design management system. These were:

- the plan;
- the need for action in accordance with the plan;
- a system for regularly monitoring performance against the plan; and
- the need for feedback on performance to take into account any deviance from the plan.

He also identified the management process as being continuous through the life of a project but this concept can be extended beyond the boundaries of the individual project to allow project review information to be used in the cost estimation stages of new projects as shown in Figure 3.2.

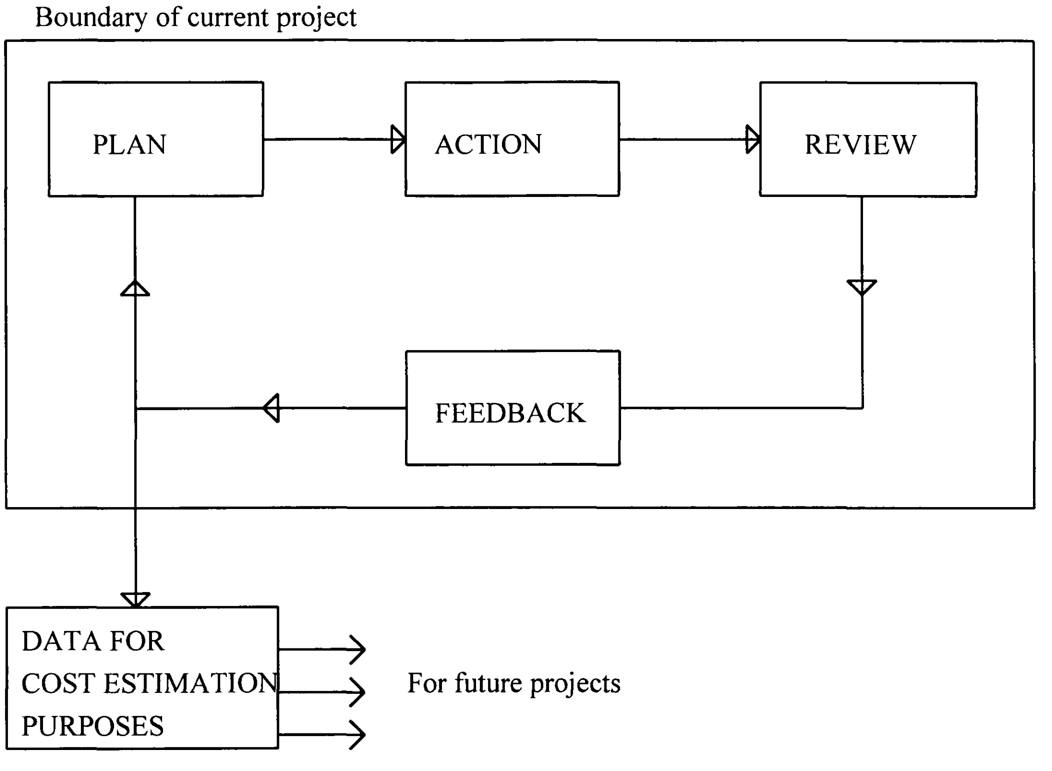



**Figure 3.2: - Design management cost control loop**

The constituent activities of the planning and review stages of the management process have been considered in more detail by others. In 1976, the management advisory committee of the RIBA produced the "RIBA Management Handbook Guide - Resources Control" (RIBA, 1976). The report contained guidance, and standard forms, for estimating and controlling design resource requirements with the following notable features.

- The estimate of design resource input (man hours) for each stage of the project was determined by dividing the available fee, established from the RIBA fee scales, by the "charge out rate" for employees. The use of a percentage of the value of a project determine a design budget, and hence to establish design resources, was again described in section A8 of the Architects job book (RIBA 1988). In the context of fee competition such an approach would not be beneficial to the client because design resources would be allocated to a project in response to the market value of the commission rather than as a result of careful consideration of the necessary design resources to provide an adequate professional service.

- Precedence diagrams were proposed for scheduling and programming the design.
- Data on actual costs for cost control purposes were collected via time sheets which were to be submitted weekly by design staff and these costs would be compared with the initial cost estimates. The guide highlights the importance of relating physical progress to the expended cost, but does not explain how this might be achieved.
- The guide distinguished between determining the time for an activity, which is dictated by external factors and the costs which are determined by the design resource input.

In a more recent publication the RIBA has noted, and accepted the move away from mandatory fee scales. Section A1.3 of the RIBA Handbook of Professional Practice and Management (RIBA, 1991) made reference to the fact that Architects should be competitive, competent and capable and Section A4.5 acknowledged that commissions for professional services will be let through competitive bidding and negotiation. However, no new guidance has been produced on the most appropriate mechanism of determining design resource requirements.

Around the time of publication of the RIBA Management Handbook guide, the American Institute of Architects (1978) produced comprehensive guidelines for determining levels of compensation (fees) for architectural and engineering services. These guidelines dealt at length with:

- the determination of the scope of services;
- the classification of reimbursable costs; and
- monitoring and controlling costs.

However, once again, the guide provided no details as to how required design times should be estimated other than to state that:

> *"This is largely a matter of judgement and experience, supported by reliable in-house design and cost records from past projects"* (p 13).

The publication noted the need for the development of a time data bank which would allow practitioners to compare design time data on similar projects

Coles (1992) suggested that man-hour requirements for design work could be estimated by considering the total number of drawings for the detailed design and production drawing stage of the process, but noted that allowance must be made for the gathering of information, developing preliminary designs and verifying the consistency of work. He referred to these activities as the *"silent majority"* (p 79) of the workload. Coles also considered in greater detail the nature of the progress review activity and suggested that the following parameters could be usefully employed.

Productivity which he defined as:

$$\frac{\text{Actual value of work done to date}}{\text{Planned value of work done to date}}$$

and Efficiency which he defined as;

$$\frac{\text{Actual cost of work}}{\text{Planned cost of work}}$$

Thomson (1990), in a standard text on Architectural design procedures, makes only passing reference to fee estimation and, whilst noting that fee scales are not mandatory, suggests that fees should still be estimated on the basis of a percentage of the cost of the final works.

In their publication subtitled "a handbook of building design management" Gray et al (1994) provided a broad overview of the architectural design process and its management. Surprisingly, the handbook did not deal with cost estimation and cost control of the professional services but it did include a useful appraisal of the applicability of standard programming techniques to design management. In total five programming methods were reviewed, namely:

- networks;
- bar charts;
- procurement schedules;
- information-required schedules; and
- information transfer schedules.

The three schedules operate on a similar principle whereby dates are identified for key tasks in the design programme, for example, the date at which the structural engineer will require basic layouts from the architects to allow structural design to commence. The authors drew no conclusions on the relative effectiveness of these approaches but did consider that network analysis was inappropriate for design process programming because of the need for the exchange of information during the process. It was concluded that even in a small project the volume of interactions and their complexity would swamp the network. The authors concluded that the interaction would also restrict the effectiveness of bar charts although they would be effective for up to 30 activities. Bar charts could be produced for individual work packages but these could not be easily combined to provide a programme for the whole project.

Nicolson and Popovic (1994) investigated more fully the problem of the estimation of the cost of design work. They noted that there was currently no accurate methodology for estimating the cost of Architectural design works, and suggested that architectural practices charge for their design at an assumed market rate which had been established using subjective criteria. They described three possible methods of design cost estimation which were similar to those proposed for civil engineering design cost estimation by Rutter and Martin. These were:

- the percentage scale method, where fees would be related to the price and complexity of the building with the selected percentage being guided by the RIBA published fee scales;
- the benchmark method, where overall design costs of previous commissions of similar type and complexities are used to provide a broad basis of the fee estimate for future commission; and
- the analytical method, where design costs evaluated by estimating design times and efforts in as much detail as current knowledge will allow.

The paper also described an experiment to examine the accuracy of each of the three methods of design cost estimation which involved the issue of a design brief and outline designs to a number of architectural practices who were requested to estimate the design fees using each of the above techniques. The authors found variations, in terms of the percentage variation from the lowest estimate, of as much as 300 percent between the fee estimates from the various practices, and up to 100 percent between the estimates from individual practices using the three techniques. It is evident that the wide variation in fee estimates gives cause for concern about the abilities of design managers to accurately estimate fees. Nicolson and Popovic conclude that the concept of analytical estimating should be developed but highlight the difficulties associated with this.

Theoretical approaches to design office management were suggested by Coles (1983) and Mackinder and Marvin (1981) but these are more appropriately dealt with in the following section.

## 3.3 SUMMARY - CURRENT APPROACHES TO DESIGN MANAGEMENT IN THE CONSTRUCTION INDUSTRY

The publications reviewed have identified the importance of the planning, estimating and cost control function of design managers. However, whilst some information is given on the nature of cost control systems including indices and parameters for measuring progress and efficiency, little detailed information is given on the practicality of the application of these systems, and less still on methods of estimation of design resource requirements.

It is particularly significant that the publications treated the cost control and cost estimation functions as unrelated activities. The literature suggests that design management is dominated by the application of cost control systems which monitor costs against estimates that have been derived in a simplistic manner. The potential opportunity for the establishment of a database for future cost estimating using cost control information on current projects is largely overlooked, being identified in only one of the publications, and there is no mention of such an approach in papers reviewed which deal with current practice. The need for, and novelty of, the current study has been clearly established.

## 3.4 ALTERNATIVE APPROACHES TO DESIGN COST ESTIMATION.

This section is concerned with the identification of techniques and approaches which might be applied to construction industry design management in order to develop an analytical approach to the estimation of design costs. This part of the literature review includes:

- an evaluation of cost estimation approaches used in other disciplines involved in the provision of professional services;
- examples of novel approaches to planning and estimating the cost of professional services.

### 3.4.1 Cost estimation approaches in other professional disciplines

Literature regarding the cost estimation approaches that are adopted by other providers of professional services were broadly similar in nature to that of the literature relating to professional services in the construction industry. The literature generally outlined the concepts which must be taken into account in the preparation of cost estimates, but often did not deal specifically with the methods of arriving at the cost estimate for individual tasks.

Ward (1994) reviewed the requirements of a system for managing consultancy projects for information systems. The paper usefully identified the following key features:

- stable and repeatable systems development procedures are required if information systems managers are to effectively plan, schedule and control work;
- estimates must be based on fact and must be developed by the individuals actually assigned to the work; and
- all project team members should report progress against the plan and schedule on a weekly basis.

The author did not give any guidance on the means of producing the cost estimate nor did he identify the potential link between the cost control and cost estimation functions.

Similarly, Sterling (1988) described an approach to pricing work for the provision of computer consultancy services. The advantages and disadvantages of using fixed price and cost reimbursement methods of remuneration were discussed, but although the factors which must be taken into account in the estimation of the cost of tasks were identified, no details were provided as to how these factors would be used in the development of the price for the task. The factors to be considered were:

- the sophistication of the clients current systems;
- the client level of participation in the process;
- the skill level of the clients staff;
- the size of the project; and
- the competence of the consultants staff assigned to the project.

The authors use of these factors suggest that, in common with construction industry design projects, the cost would be a function of the magnitude of the task and the complexity of the problem, and that these costs would be influenced by the personal attributes of the individuals involved in the task. Carew-Jones (1991) stressed the importance of allowing for each individual's skills, efficiency levels, experience and abilities in planning projects which involve skilled software or research and development staff. Unfortunately, the remainder of the paper comprised an advertisement for a proprietary project management system, and provided no information on either the operation of the system or its effectiveness.

Kelly (1987) was equally vague in her treatment of the estimation of fees for public relations consultancy work, stating simply that:

"... *you must learn to estimate how long a project will take. By keeping track of the time you spend on all projects you will soon get a feel for it.*" (p 30).

It is clear that the author considered that cost estimation for such services is based on experience and intuition.

Yeatts (1991), on the other hand, provided a comprehensive treatment of project management approaches for information systems with the chapter on estimating being particularly useful. The estimating process was described as comprising four stages:

- assessment of the project requirements;
- identification of all the activities;
- evaluation of the resource requirements; and
- costing the resources.

Yeatts suggested that the resource requirements of the feasibility and system design stages of projects can only be estimated using experience, supported by records of cost on completed projects. He also highlighted the need to encourage team members to maintain records of work expended during feasibility studies for analysis at the end of the project to assist in future estimation. However, the dual use of this data for cost control and estimating purposes is not identified.

In contrast to the other authors, Yeatts usefully deals in some detail with methods of estimation of cost of the software development stage of the project and a range of techniques were described. Two empirical approaches were identified. The first involved the application of standards rates of production of lines of computer language code to an estimate of the total numbers of lines of code requited by a particular activity. A range of standard rates can be used depending on the complexity of the project which is expressed as a linear scale with a maximum value of 5 as shown in Table 3.1.

| Complexity Factor | Statements per man day |
|---|---|
| 1 | 25 |
| 2 | 20 |
| 3 | 15 |
| 4 | 10 |
| 5 | 5 |

**Table 3.1: Complexity v Statements per man day**

Disappointingly, the author did not propose a methodology for the determination of the complexity factor for particular projects, but stated that this would be based on the experience of the estimator.

The second empirical technique was to apply formulae based on:

- the number of data types to be processed (T);
- the number of files (F); and
- the number of procedures to be executed (S).

Expressions were given for 10 constituent activities for this stage of the process and the sum of these activities is expressed as:

$$\text{Effort (hours)} \quad = \quad \frac{3\,T + 4\,S}{2} + \frac{12\,T}{F} + 28$$

Again, the author presented no evidence on the development of the expressions nor on their accuracy. Additionally, two advanced estimating techniques were identified. Firstly, the use of statistical estimating where average and standard deviation values are determined for activity durations using the Delphi approach. The duration of the project can then be determined using standard risk analysis and computer simulation approaches.

The second group of advanced estimating techniques identified by Yeatts were earlier developed by Boehm. Boehm (1981) derived a range of algorithmic cost estimation models, the Constructive Cost Model (COCOMO) using data collected from 63 software projects over a 15 year period (1964-79), covering a range of customer types, computer systems, and programming languages. Boehm contrasted this approach to a further six methods, generally similar to those used in design cost estimation, which were used to estimate software costs. These were:

- expert judgement;
- analogy - a broad comparison with one or more completed projects of a similar nature;
- Parkinson principle - work expands to fit the time available therefore the estimate should be based on the available resources;
- price to win - determining the costs on the basis of the "market value" of the project;
- top down approach - determining the costs on the global properties of the project then subdividing to elements; and

- bottom up approach - splitting the project into work packages to which resources can be reasonably assigned, then aggregating the results to produce the total figure.

The basis of the model is that it can be used to estimate necessary software development effort in terms of total man-months, with each man-month comprising 152 man-hours. The conversion to cost involves an estimate of the average cost of personnel during the different phases, because different phases would require different combinations of senior and junior staff.

The basic COCOMO equation estimates the necessary numbers of man-months (MM) in terms of the estimated number of thousands of delivered source instructions (KDSI) (lines of programming) in the software product as follows:

$$MM = 2.4(KDSI)^{1.05}$$

The time scale of the project in months is evaluated from:

$$TDEV = 2.5(MM)^{0.38}$$

Hence the average staffing level can be determined from:

$$\frac{MM}{TDEV}$$

In order to establish an appropriate distribution of the labour requirements with respect to the stages of development of the software, typical distributions of effort for each of the phases (e.g. planning, detailed design, integration and testing) are given in terms of a percentage of the overall effort, and the above calculations can be performed for each phase. Boehm refers to work by Norden (1970) and Putnam (1978) who demonstrated that the resource requirement profile for a project can be approximated well by a Rayliegh distribution but argues that the COMOCO model gives a more realistic distribution of staff requirements at the early and later stages of a project than the Rayliegh distribution.

The above equations were proposed for projects performed by relatively small software teams in familiar in-house environments, termed the organic mode by the author. Similar functions were proposed for larger and more tightly constrained projects (embedded mode projects) and for intermediate mode projects. Figure 3.3

demonstrates the performance of the Basic COCOMO functions against the actual performance on the sixty three projects in the data set.

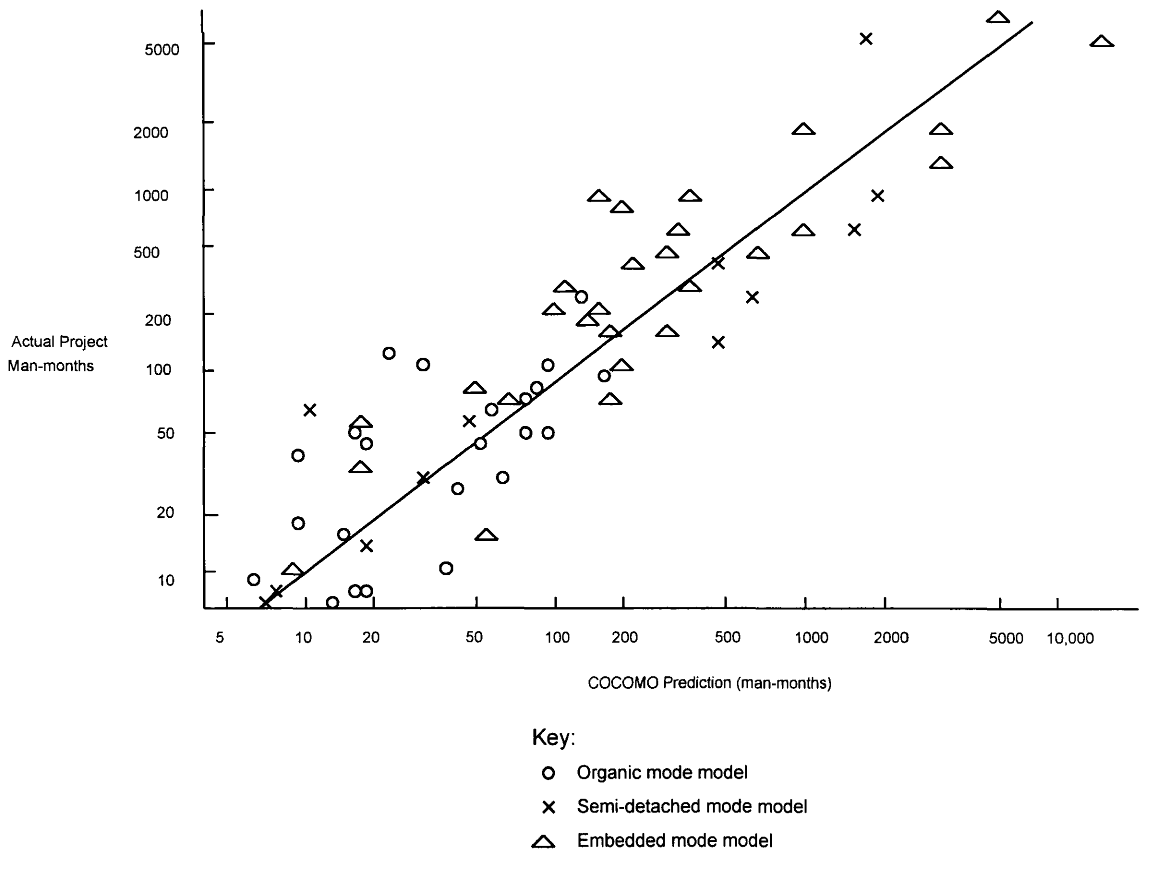



**Figure 3.3: - Basic COCOMO prediction v actual effort (from Boehm 1981, p 84)**

Boehm noted that the COCOMO estimating equations were empirical and were not least-squares fits to the data for reasons of simplicity, stability and consistency with later, more detailed estimating models. Furthermore, the basic equations estimate actual data points within a factor of 1.3 only 29 percent of the time and within 2 only 60 percent of the time. It is useful to compare this level of accuracy with that exhibited by the architectural practices in the survey by Nicolson and Popovic (as described in Section 3.2) who found variations, in terms of the percentage variation from the lowest estimate, of as much as 300 percent between the fee estimates from the various practices, and up to 100 percent between the estimates from individual practices using the three techniques

More complex models were also developed from the data set, for greater accuracy in estimation of the detailed analysis stages of projects. These models involved the introduction of adjustment factors of between 0.70 and 1.65 for up to fifteen "cost drivers" grouped under the headings of:

- product attributes; required reliability, data base size, product complexity;
- computer attributes; execution time, main storage, machine volatility, turnaround time;
- personnel attributes; analyst capability, applications experience, programmer capability, machine experience, programming language experience; and
- project attributes; use of modern programming practices, use of software tools, required development schedule.

Values of each the cost drivers were selected by the estimator by determining the degree of influence of the variable on a scale ranging from very low to very high, and relating these to coefficients that had been determined by expert judgement. The refined model appears to predict actual man-hours to within 20% accuracy in up to 68% occasions when compared to the projects in the database. Whilst this adds a degree of rigour to the cost estimation process the technique is still heavily reliant on intuitive judgement and the data set was not sufficiently large to permit rigorous testing of the validity of the cost driver values.

A review of literature related to the estimation of the cost of accountancy services revealed few significant studies. Papers were found which describe data collection methodologies for cost control purposes and these are reviewed in Chapter 6. A useful study of the factors affecting the cost of Financial Auditing services was described by O'Keefe, Suminic and Stien (1994). The approach used in the study was to examine the empirical relationship between client characteristics and the nature and mix of labour resources used by auditors. The analysis was performed on a large data set based on 249 audits carried out by an international accountancy practice. As with the work of Boehm, resource input was measured in terms of man-hours, but in this case the total hours were disaggregated by reference to the rank of personnel within the organisation. The authors did, however, make reference to an alternative approach adopted by others where audit fees were considered in the analysis as an alternative to labour hours, and to previous work by others which attempted to develop a relationship between the size of the client and audit fees. The empirical relationship between man-hours and client characteristics used by the authors was non-linear and of the form:

$$h_j = e^{\beta_{j0}} A^{\beta_{j1} + \sum_{i=2}^{K} \beta_{ji} \gamma_i} \qquad \forall_j$$

where:

$h_j$ - man hours for each grade of employee
$\beta$ - coefficient
A - size of the client, typically total assets
$\gamma$ - other explanatory variables

This function recognised the size of the client as the key determinant of audit hours and the other explanatory variables affect the relationship by changing the curvature of the function in the same way as the cost drivers in Boehm's work affect the basic relationship between MM and KDSI, which was itself a measure of the size of the project.

The following specific issues were investigated during the study:

- the nature of the client - size, complexity and risk characteristics; and
- whether there was any evidence of a learning curve in auditing a client over time.

It was concluded that the following variables significantly affected the necessary mix of personnel:

- size as expressed in terms of the client's assets;
- complexity of the audits in terms of the nature of the organisation; and
- risk expressed as a measure of the probability that the financial statement being audited might contain material mis-statements.

There was no statistical relationship evident for the effect of the learning curve in performing repeat audits over a number of years for the same client although there was evidence that fees may have been cut in early years to secure new business (i.e. the price to win approach identified by Boehm).

It is useful to compare the mathematical functions and cost drivers, selected by Boehm for software development and O'Keefe for Financial Auditing Services, with the factors which were identified in Section 2.2.3 as affecting the degree of rationality of the design process. It is clear that many of the factors which influence the cost of intellectual processes such as software development and financial auditing will similarly influence design costs.

Miles, Moore and Price (1995) described the integration of a model for the capital costs of bridge projects within a suite of Knowledge Based System packages. The authors identified serious limitations in the application of KBS systems to the design activity due to the diagnostic nature of the systems. This, they suggested, was because the process of design involves flexibility, innovation and creativity which were less important in diagnosis. This was overcome in the model by replacing the design heuristics with computation procedures based on codes of practice. These produced approximate member sizes from which approximate quantities were determined and used to produce a cost estimate. The default values for the unit rates were based on interviews of design engineers but alternative values could be set by the design team. In effect, a parametric cost model was produced with the input data comprising the geometric and physical properties of the proposed structure.

In addition to the parametric approaches above a number of authors described the application of probabilistic techniques to planning and estimating. Marston and Skitmore (1990) provided a useful review of earlier work in this field describing probabilistic planning and cost estimating systems which were developed by Bennet and Omerond (1984) and Thomson and Wilmer (1985). The former used Monte Carlo simulation to generate cost and time distributions from probabilistic activity times and allowed interference to the production process such as delays due to late instructions to be simulated. The latter was concerned primarily with risk assessment and was based on network plans evaluated using Monte Carlo methods. More recent applications of this method are described by Thomson and Perry (1992) and Thomson and Norris (1993).

Kidd (1991), in the context of a software development project, compared the durations and cost predicted by a simulation approach with those obtained using both a simple network approach and the Programme Evaluation and Review Technique (PERT). The simulation based technique was described by the authors as Venture Evaluation and Review Technique (VERT) which operated in a fashion similar to that of Bennet and Omerond, with probabilistic input of activity durations and probabilistic representations of interference with production. Kidd concluded that the simulation approach gave the longest, but most realistic, forecast of the project duration and suggested that the other approaches would always lead to shorter durations because of the estimator's tendency to underestimate durations of the constituent activities. Other applications of process simulation were provided by Davis and Cochrane (1987) (see section 3.4.2 below) and Dawson (1988) who utilised a map of all cost involved in the training and recruitment of employees and applied Monte Carlo simulation to enable suitable budgets to be forecast for a range of employment conditions. Cornwell and Modianos (1990) provided examples of simulation modelling of manufacturing process based on both fixed time step models and variable time step (event to event) simulation models. In each case the analysis was performed using standard spreadsheet packages with the cumulative probability functions in the Monte Carlo simulation being represented by look-up tables.

A number of authors used probabilistic approaches to model risks in terms of its effect on the accuracy of a projects cost estimate. The majority of papers described the practical application of risk analysis using spreadsheet based systems. The models generally operated on the basis of the probabilistic generation of the cost of individual work packages, with the project total cost being simulated by the summation, on a repetative basis, of the possible costs of the component work packages. Earlier papers (Catling and Westwood, 1985; Bradley, Powell and Soulsby, 1990; Selai and Banks, 1990) described simulation using the authors own software or using spreadsheets and look-up tables but more recent authors (Hudson, 1992; Touran and Bolster, 1994; and Uher, 1996) used the @risk software package which can be used with standard spreadsheet packages.

An alternative approach to planning and estimating construction work was proposed by Ock (1996) that would be appropriate in cases where directly applicable cost data is inadequate or unavailable, and where the subjective judgement of experts who have relevant knowledge and experience was to be used instead. The approach consisted of the application of Fuzzy Set Theory to activity duration quantification and the authors provided an example of the determination of the duration of a single risk associated activity. The paper did not discuss the use of this duration value in the determination of an overall project programme, the inference was that normal planning approaches would be applied using fuzzy set generated point estimates of durations for risky activities.

### 3.4.2 Alternative approaches to design cost estimation in the construction industry.

As previously stated, literature on design management tends to focus on cost control and, where design cost estimating is dealt with it is considered to be an intuitive process, often following the breakdown of the project into a number of small work packages where the extent of work can be envisaged. Some authors have, however, identified more novel approaches.

McKinder and Marvin (1982) carried out a study on the routes taken by Architects during the design process to reach decisions, and how information and experience were used in this process. There were two conclusions from this work that are of interest to this study. Firstly, experience was the primary source of information in decision making, indicating that the personal attributes of the designer will be a major factor in design process times and hence costs. Secondly the process of recording design decisions was found to be helpful in project management terms as it could provide useful input for subsequent projects. Clearly the nature and magnitude of the decisions could be used as a measure of a project complexity.

Coles (1989) explored a similar theme in a study at the University of Reading, noting that:

> *"Building design work proceeds neither deterministically nor probabalistically but by proposing and evaluating solutions in a network of decisions that is loosely derived from past experience."* (p 2).

Coles then proposed a method of project scheduling based on Design Information Transfers (DIT) which builds on previous work at Reading by Gray and Little (1985). They noted that design work on building design projects is characterised by information transfers between specialised design teams and professionals and suggested that an analysis of the patterns of information transfers would provide the basis of an effective tool for the managerial control of design work.

The importance of information transfers on the design process has already been discussed in Section 2.3.1 of this thesis. It was noted that there was a dichotomy between the estimate of the overall duration of an activity and the estimate of the required resource inputs and costs. The estimate of the duration of each activity would involve consideration of the design times required by each design team plus an additional time allowance for any correspondence or other communications between the parties. However, the cost of the activity for each discipline would be based on an estimate of the required staff resources to carry out the design work and prepare correspondence on an activity of that nature. Coles dealt partially with this problem by proposing that the work schedule would be produced using the DIT approach but did not investigate how design resources and costs would be allocated, simply suggesting that these would be done intuitively or using the "man-hours per drawing approach".

It is apparent that some allowance must be made for the cost of information transfers in any predictive model of design costs, but as in the case of the nature of the design

decisions, the extent of information transfer may be most effectively included in a global cost estimating model as a parameter in some project complexity function.
The concept of design complexity and its influence on design resource requirements was also investigated, in the context of electrical engineering design by Culverhouse (1993). Culverhouse argued that it should be possible to measure real engineering problems in terms of likely new knowledge requirements and staff design experience and form a simple "metric" which places a single numeric value on "design complexity". Complexity, according to Culverhouse, would consist of two separate components:

- design magnitude; and
- design novelty.

The metric of complexity could be used to generate a metric of design yield which would allow the necessary man-hours for a project to be determined.

Kaara et al (1989) investigated the application of planning and scheduling approaches to a study of repetitive and sequential design activities in a Government Engineering Department in United States of America, with a view to determine more effective working practices. Whilst this paper did not deal specifically with design cost estimation some useful issues were raised. Firstly, data was collected on the constituent activity durations and, despite the repetitive nature of the work, there was a large variation in the durations due to a range in the "difficulty" of the projects. In this particular case, due to the repetitive and sequential nature of the work, the line of balance approach was adopted, modified to reflect the probabilistic nature of the data by the application of, firstly, the PERT approach and secondly simulation based on the known properties of activity duration distribution. The authors concluded that it was possible to model the existing performance of the design teams using the simulation approach and that the verified model could be used to investigate the effectiveness of proposed changes to working practices. This suggests that a simulation approach, using data from previously completed projects could be used for cost and time modelling of future projects.

A simulation approach was also applied by Davis and Cochrane (1987) in a multi-disciplinary practice to establish overall staffing levels. This work was of a theoretical nature but did demonstrate the potential for the application of simulation to resource allocation problems in design offices. It was disappointing that, as with many other papers relating to design management and control, the authors do not explain the basis of allocating design resources to the various design activities which were used in the simulation.

### 3.4.3 Summary - alternative approaches to design cost estimation

This review of estimating approaches identified literature which was similar to that relating to construction industry design management. Cost estimation is generally driven by experience, is intuitive and is loosely supported by non-specific records of previous projects. However, this section has identified possible forms of cost estimating models that might be applied to construction industry design, these were:

- parametric cost estimating models utilising non-linear functions, based predominantly on the size of a project adjusted by other cost significant factors;
- probabilistic methods involving process simulation or risk analysis; and
- the application of fuzzy set theory.

The review of alternative approaches to design management also highlighted the following cost significant factors which will have to be considered in design cost estimation:

- the magnitude of the project;
- the complexity, which might be determined in terms of the number of data transfers and the novelty of the project;
- the levels of experience of the project team; and
- the dichotomy between scheduling and cost estimation.

## 3.5 SUMMARY OF CONCLUSIONS FROM THE LITERATURE REVIEW

The literature review has confirmed the novel nature of this research work, and an appropriate methodology for a project of this nature is described in Chapter 4. The following conclusions can also be drawn from the literature review.

The design process is essentially a decision making process that comprises a series of iterative stages. The appropriate quantity and level of input to this intellectual process is difficult to quantify because it is affected by a number of intangible factors and, additionally, the required input to the design process will be greatly affected by the extent to which optimal rather than satisfactory decisions are made during the design process. It will therefore be difficult to apply deterministic approaches to modelling the cost of design activities.

The design process in the construction industry is similar to that of general design although the number of parties involved in the process and the variety of relationships which can exist between these parties will influence the nature of the design work associated with each stage of the process. This adds further complexity to the interpretation of data on design resource requirements. Furthermore, there has been a fundamental shift in the way in which design teams are appointed, and there are reservations that some recent methods of appointment may result in a reduction in the levels of service that are provided by designers. This will introduce a barrier to the effective utilisation of historic cost data for future cost estimating, and will introduce further variability in recently acquired data.

Models of the design process in the construction industry are readily available but the potential uses of these models to the planning and estimating the cost of new design projects have not been investigated. The literature suggests that design management is dominated by the application of cost control systems which monitor costs against estimates that have been derived in a simplistic manner. The potential opportunity for the establishment of a data base for future cost estimation, using cost control information on current projects is largely overlooked, being identified in only one of the publications, and there is no mention of such an approach in papers which deal with current practice. Cost estimation is generally driven by experience, is intuitive and is loosely supported by non-specific records of previous projects. However, possible forms of cost estimating models have been identified that might be applied to construction industry. These models were either based on; non-linear functions, relating predominantly to the size of a project adjusted by other cost significant factors or, reflecting the probabilistic nature of design cost estimation, computer simulation.

The literature review has contributed to the first two aims of the research which were:

- the identification, and quantification of the use of, design cost estimation approaches that are currently applied by design managers; and
- the evaluation of the extent to which current cost estimation practice would facilitate the application of a more rational approach to design cost estimating.

In relation to the first aim, the literature review has identified a limited number of cost estimation approaches and it can be reasonably concluded that current fee estimation approaches are not sufficiently precise to generate accurate estimates for specific levels of service. The literature review did not produce evidence of either; the extent of the application of each of the approaches in industry, or on the availability within organisations of a data base of historic cost information which might be used for improved fee estimation.

In relation to the second aim, there was a scarcity of published material which dealt in any detail with design cost modelling in the construction industry. Therefore, before any final conclusion can be drawn on the potential for the application of the cost modelling approaches that were identified in the review can be made, it is essential that a fuller understanding of costs estimating practice in construction industry design organisations is gained. This investigation is described in Chapter 5.

# CHAPTER 4
# METHODOLOGY

## 4.1 INTRODUCTION

The background to the research programme was given in Chapter 1. Initial work on the literature review presented in Chapters 2 established the novel nature of the work and this confirmed that a a grounded theory approach would be appropriate. Oppenheim (1992) identified a fourteen stage methodology for research work that appeared to be appropriate for this study because it encompassed the search the project hypothesis, which is a central feature of the grounded theory approach. The stages were:

1. deciding the aims of the study;
2. reviewing the relevant literature;
3. conceptualisation of the study;
4. deciding on the research design and its feasibility;
5. deciding the hypothesis to investigate and identifying the variables which must be measured in its appraisal;
6. designing the research instruments;
7. doing the necessary pilot work;
8. designing the samples;
9. selecting the people to be approached;
10. doing the field work;
11. processing the data;
12. doing the statistical analysis;
13. testing the hypothesis; and
14. writing the research report.

The first stage of Oppenheim's methodology involved the selection of the aims of the study. In terms of the grounded theory approach it is more appropriate to describe this stage as the definition of the area of study and this was established as being concerned with a study cost estimation and cost control within construction industry design organisations.

The literature review, which constituted the second stage of Oppenheim's methodological framework, was structured to provide the following:

- an analysis of the nature of the design activity and of the design process to be made;
- an understanding of the way in which this process is integrated into overall construction industry procedures to be developed;
- the identification and evaluation of the management approaches that are currently being used by designers; and
- the identification and evaluation of approaches which might be successfully applied to more effectively manage design work.

The literature review identified a limited number of cost estimation approaches that are currently used by design managers (Rutter and Martin, 1991; Hudgins and Lavelle, 1995). It also provided sufficient evidence on the nature of the design process in the construction industry to reasonably conclude that these approaches are not sufficiently precise to generate accurate estimates for specific levels of service.

The literature review did not produce evidence of either the extent of the application of each of the above approaches in industry, or on the availability of a data base of historic cost information within organisations which might be used for improved fee estimation. There was also a scarcity of published material which dealt in any detail with design cost modelling in the construction industry, although some examples of cost modelling applied to other professional services such as software development and accountant's auditing services were found. It was now evident that a fuller understanding of cost estimating practice in design organisations would have to be gained before any useful conclusions could be drawn on the potential application of the identified cost modelling approaches.

A study of organisations and their behaviour is a common requirement in social science research programmes for which Miller (1991) identified seven models of research design:
- descriptive surveys - aiming at a 100 per cent enumeration of the population under study, either "cross-sectional" as in a census, or "longitudinal" studying changes over a period of time;
- sample surveys - using an appropriate sampling approach to ensure that a sample which is representative of the entire population is obtained;
- field studies - investigations of processes and patterns within a group or organisations;
- case studies of persons - intensive analysis of a single instance of the topic of study;

- combined survey and case study - general patterns are identified during the survey and greater interpretation is provided by the case studies;
- prediction studies - where an estimate of the prediction of the outcome of an experiment is made in advance as a test on an underlying hypothesis; and
- controlled experiments - where the phenomenon is investigated under controlled conditions by the manipulation of one or more variables.

A descriptive survey was not considered to be appropriate for this study for two reasons. Firstly, the magnitude of a survey of all organisations involved in design would be impracticable, and secondly this would place an unnecessary burden on designers in the construction industry. Some form of sample survey was judged to be more appropriate. Controlled experiments and predictive studies would also be inappropriate because this would involve experimentation on the commercial activities of practising designers and this would clearly be unattractive to potential collaborators. More detailed consideration was given at this stage to the use of sample surveys, field studies and case studies. Oppenheim (1992) described this exploratory work as the second activity of the conceptualisation stage of research and recommended in depth interviews as being an appropriate approach. Hoinville et al. (1978) also suggested the use of in-depth interviews for this type of work, which they described as "unstructured design work". They did, however, recommend that the scope of this work should also include the preliminary development of any quantitative data collection instruments such as structured questionnaires for interviews or postal surveys.

It was now apparent that Oppenheim's (1992) model of research had provided a useful framework for the research methodology but was somewhat simplistic, because it suggested a linear, uni-directional approach. Some inter-relationship between the stages of the research work was required, together with a bifurcation in the research design in order that an assessment could be made of the feasibility of: collecting more detailed data; developing a cost model; and verifying the cost model. A more iterative, flexible approach to the research design was required and the methodology, shown diagramatically in Figure 4.1 was devised based on Oppenheim's fourteen stage methodology.

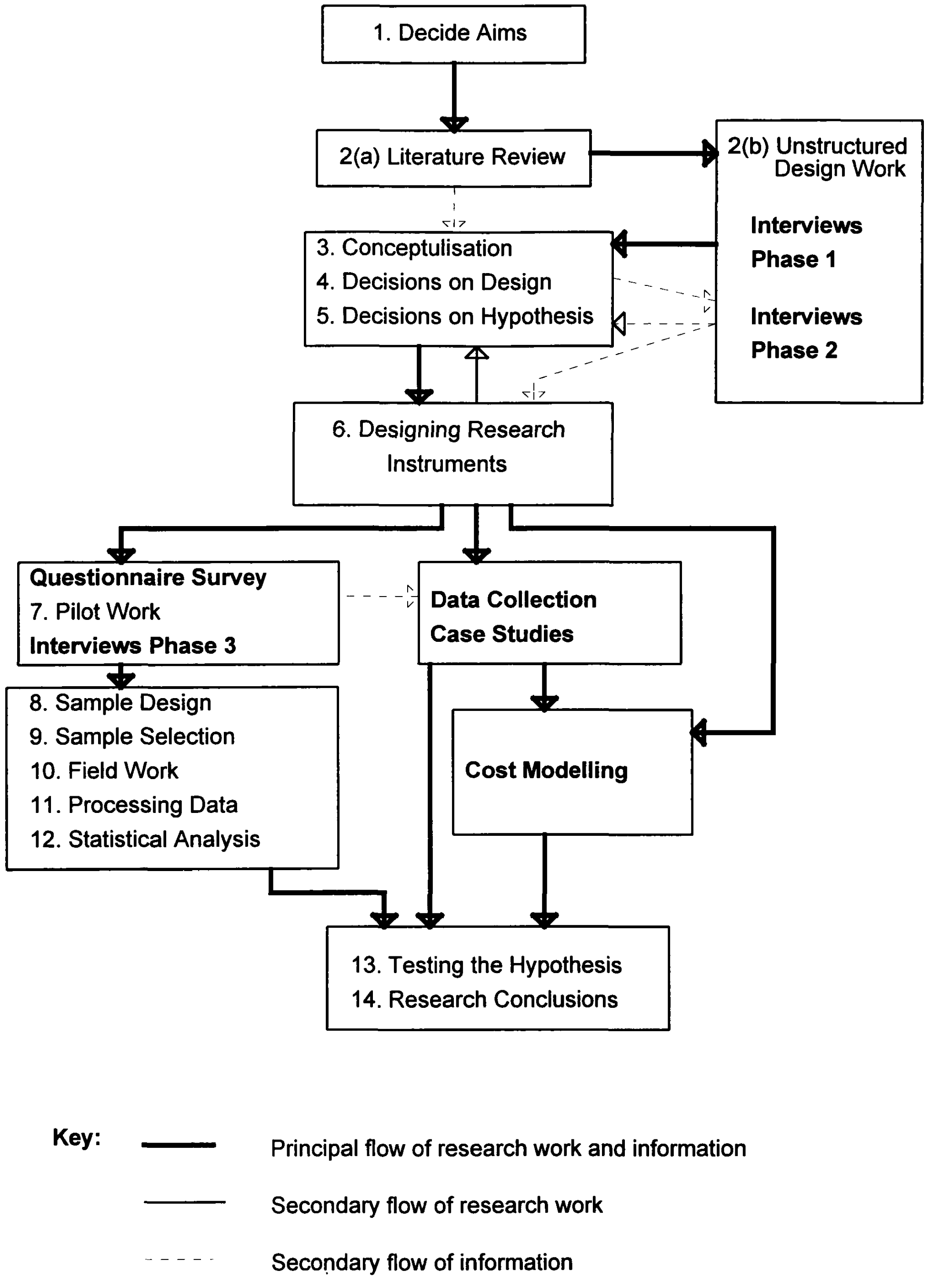



**Figure 4.1: - Research methodology**

## 4.2 IN-DEPTH INTERVIEWS WITH DESIGNERS

Having completed stages 1 and 2(a) of the research, a number of in-depth interviews with design organisations were performed in order to enable stages 2(b) to 7 to be completed. In total, eleven design offices were selected at random for the interviews to give a representative range of construction industry design organisations. The sample comprised:

- the head office of a large firm of consulting engineers (800 staff);
- five regional offices of a consulting engineering practice (staff numbers within each office varied between 20 and 100);
- the head office of a multi-disciplinary design organisation (100 staff);
- the regional office of a medium sized architectural practice (20 staff);
- the office of a small architectural practice (10 staff);
- a local authority water services department design section (80 staff); and
- the design section of a large organisation which provides, internationally, large design and construct energy related projects (100 staff).

The programme of interviews was divided into three phases each with a distinct purpose:

- Phase 1 - exploratory work, using an unstructured interview;
- Phase 2 - development of the research instrument using semi-structured interviews; and
- Phase 3 - piloting the research instrument, by structured interviews using the draft questionnaire.

### 4.2.1 Phase 1- exploratory interview

The head office of a large civil engineering consultancy was selected as being an appropriate organisation for the exploratory study. The organisation was known to be involved in a wide range of civil engineering projects. Oppenheim (1992) described the purpose of the exploratory interview as being concerned with ideas collection rather than data collection and suggested that the primary objective of such an interview is to maintain spontaneity and to allow the interviewee the maximum opportunity to identify the important concepts. This minimises the risk of the discussions being led by the interviewer. Hoinville at al. (1978) suggested a more structured approach with the areas of investigation and key questions being pre-prepared by the interviewer to guide the discussions. The former approach was adopted for the first interview with the latter being adopted for the second semi-structured phase.

Initial telephone contact was made with the senior partner, followed by a letter that outlined the purpose of the research work and highlighted the following areas for discussion during the interview:

- the planning and estimating approaches adopted;
- the influence of fee competition on planning and estimating practice; and
- the extent to which historic design cost data is available and is used in cost estimation.

During the interview notes of the meeting were taken, with the consent of the interviewee, for subsequent analysis.

The outcome of the explaratory interview is described in Chapter 5, but for the purpose of the development of the methodology the findings from the interview and the literature review allowed stages 3 to 5 of the methodology as shown in Figure 4.2 to take place.

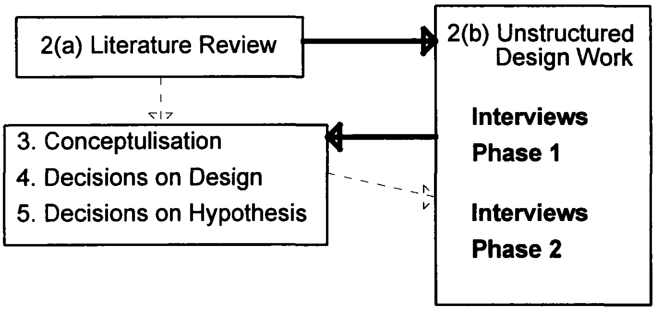



**Figure 4.2: - Stages 3 to 5 of the methodology**

To facilitate the development of the aims, the following general hypothesis was established:

> "there exists the potential for the development of a rational approach to the estimation of construction industry design costs by the application of cost modelling, based on historic cost data".

In order that the hypothesis could be tested, the following specific aims were developed:

- the identification and quantification of the use of the design cost estimation approaches that are currently applied by designers;
- the evaluation of the extent to which current cost estimation practice would facilitate the application of a cost modelling approach to design cost estimating;

- the evaluation of the practicality of enhanced data collection to support cost modelling;
- the selection and development of a form of model that is appropriate for the available data; and
- the verification of the performance of the cost model.

### 4.2.2 Phase 2 -development of research instruments

The purpose of the second phase of interviews was: to extend the scope of the study to a wider range of organisations; to test the conclusions drawn from the explaratory work; and to begin to develop the research instrument for a more comprehensive survey of design organisations. A more structured approach than that for phase 1 was adopted for this round of interviews using a semi-structured interview approach (Oppenheim, 1992). An outline list of questions was developed for consideration by the interviewee with key questions developed to reflect the issues identified during the exploratory interview. The questionnaire contained four sections:

- Section 1, where information on the nature of the organisation could be noted;
- Section 2, which listed the planning and estimating techniques that were identified in the literature review; and
- Sections 3 and 4, included open questions on the influence on cost estimation practice of the growth in the use of fee competition by clients.

A senior member of staff was interviewed in each of seven design organisations, typically for about three hours. During the interviews, the question list was used by the interviewer to stimulate discussion and to record notes of the discussions. In addition many of the interviewees provided examples of their standard cost estimation or cost reporting forms. A summary report on each of the interviews was compiled and these were compared using a simplified qualitative version of the content analysis approach adopted by Wallace in a study of design team communication patterns (Wallace 1987). Qualitative content analysis involved a subjective appraisal of the recorded information and this proved to be successful as it enabled commonly recurring themes to be identified and any inconsistencies in individual interviews to be highlighted.

The results of the second round of interviews are given in Chapter 5, but with regard to the methodology the first of the aims listed in section 4.2.1 above had been partially achieved; the identification of the design cost estimation approaches that are currently applied by designers. The interviews also identified that a surprisingly consistent approach to estimating design cost and planning design work was adopted by the organisations. However, the sample was too small to enable meaningful conclusions on the nature of estimating and planning in the construction industry at large. In order to fully achieve the first aim, there was a need for a more comprehensive survey of design organisations to enable a wider evaluation to be made of the extent of usage of the various cost estimation approaches by designers. The interviews also suggested that detailed historic cost data would not be readily available in design organisations and that this would clearly influence the potential for rational cost modelling. The survey was extended to ascertain, with greater certainty, the types of data that would be available within design organisations. The output from this stage of the work was the pilot version of the questionnaire, which was tested in the next phase of interviews.

### 4.2.3 Phase 3 - piloting the research instrument

Section 4.3 below describes the design and implementation of the questionnaire survey. The importance of testing the research instrument through pilot studies has been highlighted in a number of publications (Hoinville et al 1978, Miller 1991, Oppenheim 1992) and this was achieved during later stages of the interviews where the draft questionnaire was completed by the interviewee in the presence of the interviewer. In this way, a fuller understanding of the thought process of respondents during the completion of the questionnaire was developed. This enabled a final version of the questionnaire to be produced that would be expected to be readily understood by future respondents.

## 4.3 QUESTIONNAIRE SURVEY DESIGN AND ADMINISTRATION

The role of the questionnaire survey in the overall research methodology is shown in Figure 4.3.

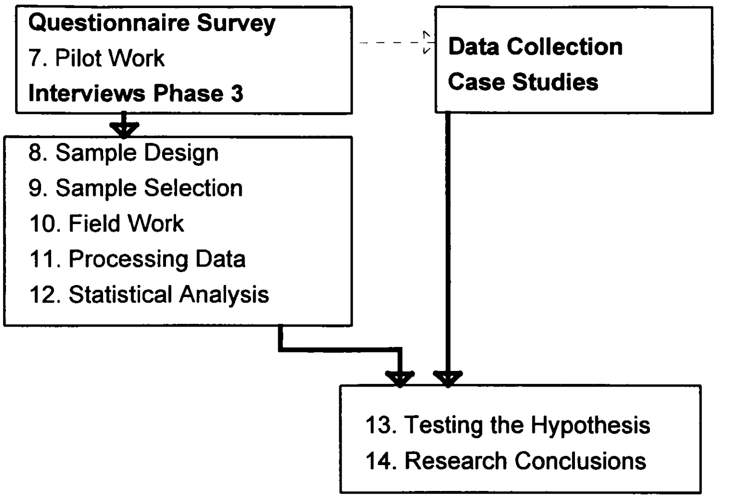



**Figure 4.3: - Role of the questionnaire survey**

### 4.3.1 Approaches to data collection for the extended survey

Two approaches for data collection were considered for the extended survey, namely interviews and a postal survey. Mangione (1995) identified nine criteria that would support the choice of postal surveys:

- the research sample is widely distributed geographically;
- the research budget is modest;
- there is limited person-power to help conduct the study;
- research subjects require time to consider their responses;
- questions can be written in a closed end style;
- the sample are likely to have an investment in the topic;
- the list of research objectives is modest in length;
- research subjects require privacy in formulating the response; and
- questions are more appropriate in the visual rather than oral mode.

The proposed survey met all the above criteria, with the possible exception of the last two, and therefore a postal survey was an attractive option. The interviews completed to date demonstrated the cost and time limitations of a widespread survey using interviews. The total time requirement, including travel, ranged from one half to two days, and costs of between £30 and £150 including travel and subsistence expenses were incurred. If the cost of the researcher's time was included the average cost of an interview would be in excess of £250 giving a total cost of £75,000 for a sample of 300, and duration in excess of a year if only one interviewer was involved. It should be noted that the total cost of the survey to the construction industry would be much higher. The completion of a questionnaire during the interview of a senior member of staff would cost each organisation some £100 (allowing 2 hours for completion of the form) increasing the total cost of the survey by £30,000 to in excess of £100,000. In contrast, the estimated cost of a postal survey to a sample of 300 was: initial telephone contact with potential recipients £150, stationery £20; postage (Out and Return) £130; printing costs £200. Researcher time was estimated at 10 days preparation of questionnaire, 10 days preparing mailing lists including making telephone contact with each organisation, 2 days issuing questionnaire, 5 days administering follow up surveys giving a total staff cost of £4500 and a total cost to the researchers of some £5,000. Assuming that completion of the questionnaire would involve the respondent for a similar time as the interview then the cost to industry of the postal survey would again be approximately £30,000 giving a total cost for the postal survey of approximately £35,000 and a total duration of some three months. It was apparent that postal surveys would be the most effective means of data collection although due consideration had to be given to the major disadvantage of this form of survey, the problem of non-respondents (Miller, 1991).

### 4.3.2 Questionnaire contents

Stage 5 of the research methodolgy, (decisions on hypothesis) involved the identification of the variables which must be measured in order to draw meaningful conclusions in support of the research objectives. This was an appropriate first stage in the determination of the contents of the questionnaire. The project aims which have yet to be realised include part of the first aim and the second aim which were concerned with:

- the quantification of the use of the design cost estimation approaches that are currently applied by designers; and
- the evaluation of the extent to which current cost estimation practice would facilitate the application of a more rational approach to design cost estimating.

Miller (1991) described this form of survey as a descriptive enquiry where the primary function is to enumerate or count responses in the various categories. However, in order that a more comprehensive understanding of cost estimating practice could be developed, the style of the survey was extended to encapsulate elements of an analytic design where some trend or relationship between the variables was investigated. In this case, the enumeration was concerned with ascertaining the frequency of usage of the techniques and the availability of historic cost data. The analysis was concerned with, firstly, the development and testing of hypotheses on the use of the various techniques and, secondly, with an investigation of the relationships between the usage of the techniques with both the nature of the design organisation and the stages of the design process. To facilitate this analysis, questions were devised to enable the responses to be entered and processed using the Statistical Package for Social Sciences software (SPSS) (Norusis, 1988).

The questionnaire comprised four sections:

- Section A, provided information of the nature of the respondent's organisation to allow an analytical comparison to be made between organisations;
- Section B, provided enumeration of the frequency of usage of estimating planning and cost control techniques at each stage of the design process, thereby allowing an analytical comparison to be made between the stages;
- Section C, obtained information on any links between planning and estimating and quality management; and,
- Section D, tested the applicability of a model of the cost estimating process which was developed following the exploratory interviews.

Having identified the coverage and general content of the questionnaire, decisions had to be made on the most appropriate form of question for each item of required information. Oppenheim (1992) identified two forms of questions, open or closed. Closed questions involved the respondent being offered a choice of alternative replies and being invited to tick or circle, or provide a single response to each question, whereas open questions required the respondent to write answers, unguided, in a given space on the questionnaire. Open questions were not considered to be appropriate because the primary function of the questionnaire was enumeration and analysis and therefore some standardised scale of measurement was required which would be common to all respondents and would be amenable to statistical analysis. Furthermore, Mangione (1995) noted a reluctance amongst respondents in postal surveys to answer open questions and, in order to enhance the response rate, priority was given in the questionnaire design to minimise the effort of the respondents in its completion. The questionnaire is included as Appendix B and the closed nature of the majority of the questions can be seen. Three open questions were included where more general information was required: question 11 which invited respondents to describe any estimating techniques not listed, question 14 which invited respondents to list any software used in their planning and estimating work, and question 16 which invited respondents to explain how cost control data were used. Space was also provided after each closed question for comments and an additional page allowed for any further comments.

Consideration had to be given to the nature of the information required from the questions in each of the sections. Closed questions were devised for Section A which enabled organisations to provide information on the nature of their principal activities. Section B was included to provide information for enumeration and analysis. It was apparent from the interviews that four estimating techniques ranging from intuitive approaches to those supported by data were used by designers, with intuitive approaches being the most commonly used. Some statistical comparison of the frequency of use of the various techniques was required in order that conclusions could be drawn about the extent to which intuitive cost estimating approaches predominate in design management. The interviews also suggested that most organisations did not possess a detailed data base of historic design costs some measure of the availability of data for cost modelling was also required in this section.

To facilitate the enumeration and analysis of the responses some measurement scales were required. Oppenheim (1992) identified three forms of scales:

- Nominal measures - where responses consist of a number of discrete categories which have no numerical value nor is there any assumed continuum;
- Ordinal - where the respondents are invited to assess the parameters in sequence or rank order; and
- Linear - where the respondents position is measured against some fixed, interchangeable unit.

Nominal measures were not appropriate for enumeration and analysis because they are not amenable to any statistical analysis. Ordinal scales would be appropriate but would limit the statistical analysis to the use of non-parametric techniques (Miller, 1991). Linear scales offered the possibility of the application of a full range of statistical analysis techniques and these were used in most cases. Ordinal scales were used to measure the organisation's degree of involvement in the various sectors of the construction industry. Linear scales were described by Mangione (1995) simply as:

> *"a list a list of alternatives that range from not much of a particular attribute to a great deal of the same attribute"* (p 11).

Miller (1991) provided detailed guidance in the construction of a rating scale as follows:

- the continuum to be measured is divided to an optimal number of scale divisions (approximately five to seven);
- the continuum should have no breaks or divisions;
- descriptive phrases are used to define different points on the continuum;
- only universally understood descriptive terms should be used;
- the end phrases should not be so extreme as to be avoided by respondents; and
- to score, the assigned numerical values are used.

Three rating scales were devised for the questionnaire. The first was used in Section B and was concerned with the frequency of use of the various planning and estimating techniques. A five point scale from "Always" to "Never" devised with the intermediate values of "Often", "Sometimes" and "Seldom" being chosen to guide the respondent to interpret the distance between scales points as being equal. The second scale, also in Section B, was included to assess the availability of historic data and this was constructed to assess the respondents agreement with the statement that data were available. The third scale was used to test a model of the cost estimation process and a scale of agreement with the applicability of the model was devised.

### 4.3.3 Sampling strategy

A sample frame was assembled which comprised all organisations involved in the provision of design services for construction industry related projects, including:

- civil engineering consultants, drawn from a listing of 250 organisations in the New Civil Engineer Consultants File (New Civil Engineer, 1991);
- architectural practices drawn from a list of the 100 largest architectural practices provided by the RIBA;
- national and local government departments and water authorities, drawn from the organisations listed in the Municipal Year Book (Clements, 1991); and,
- building services engineering consultants and multi-disciplinary design organisations drawn from the organisations listed in the New Builder Professional Services File (New Builder, 1991).

In view of the large number of organisations involved, some form of sampling from the overall population was required. Miller (1991) produced a table to guide in the selection of sampling strategies. These included:

- simple random, where each item in the sample frame was given a unique number and selections were drawn from the whole sample frame by the use of random numbers;

- multi-stage random, where items are selected following a two or more stage random selection;
- systematic, where the items in the sample frame were arranged in some rank order and then every $n^{th}$ item selected;
- stratified proportionate, where the population was arranged into known grouping and then a number of items selected at random from each strata in proportion to its relative size within the sample;
- stratified disproportionate, which was similar to the above except the size of the sample from each strata was selected on the basis of analytical considerations; and
- judgement, where items were selected which, in the opinion of the researcher on the basis of available information, were considered to be representative.

In this case, there was a considerable amount of information available in the publications on the nature of the sample, and thus a combination of some form of stratified proportionate and two stage random sampling was appropriate. Consideration was also given at this stage to the knowledge gained on design management from the interviews to assist in the stratification process. Firstly, in very small practices (less than six people) sophisticated planning and cost estimation systems were not considered to be necessary as the organisations tended to be more amenable to close personal control by the senior partner who would have a reasonable understanding of the costs involved in, typically, small design projects. A stratum of these small practices was established and this was removed from the sample frame. The interviews also revealed a difference in the sophistication of cost control systems between private organisations and those in, or more recently in, the public sector. A sub-division of the sample frame was introduced to reflect this. In total three general groupings were established:

- Consulting Engineers;
- Architectural practices;
- Miscellaneous, with sub-sets of public sector bodies, water authorities and building services engineers.

Having identified the population and established the groupings, stratified proportionate sampling was used to select target organisations with the stratification being based on the number of employees in the organisation. Two stage random sampling was required to select from each stratum because it was established during the interviews that the cost estimation function was devolved from head offices to regional offices in large organisation. Consequently, the first stage involved the random selection of an organisation followed by the random selection of a regional office (where this was necessary). In each case, the organisations and offices were given a unique number and selection was made using random numbers.

The overall sample size was chosen to generate a sufficient number of responses to allow the maximum opportunity for the application of as wide a range of statistical analysis approaches as possible. A total target sample size of 300, evenly split between the three groupings, was chosen in order to generate sub-sample for the three categories of greater than 30 responses assuming a response rate of 40 per cent (Miller 1991).

### 4.3.4 Administration of the questionnaire survey

Oppenheim (1992) stated that the main disadvantage of a postal questionnaire was that it generally results in a low response rate, leading to the possibility of sample bias due to the high proportion of non-respondents. There are a variety of techniques that can be used to maximise the response rates from postal surveys and these are outlined by a number of authors (Hoinville, 1978; Oppenheim, 1992; Mangione, 1995). Additionally, Miller (1991), provided a detailed analysis of response rates to postal questionnaire studies and quantified the anticipated improvement that can arise when due regard is given to a number of aspects of the questionnaire design. The following aspects were considered in this survey:

- The questionnaire design was an important aspect and this was described in Section 4.3.2 above. The appearance was deemed to be particularly important and therefore the questionnaire was typeset and printed by the University of Abertay Dundee Media Centre.
- Advanced warning was given to respondents. Each organisation was contacted by telephone in advance of the issue of the questionnaire and the name and designation of the most appropriate recipient determined. The organisations were asked whether or not they would wish to participate in the survey.
- A personalised covering letter was prepared using a word processor merge facility and therefore, using the information gained from the telephone calls, each respondent received a properly addressed letter and envelope with each letter being individually signed.
- A return envelope bearing a University address label and a postage stamp was used in preference to business reply envelope.

- Respondents were offered an incentive in the form of a summary report of the findings of the survey. It was noted that all respondents indicated that they wished to receive such a report.
- Respondents were assured of confidentiality with each form being identified by a code number rather than by the name of the respondents.
- The possibility of drawing to the attention of respondents that the work was being sponsored by Tayside Regional Council, a major client, was considered but discounted because it was pointed out during the interviews that they could be perceived by organisations as competitors as providers of engineering services.
- The rate of responses were monitored and reminders were issued to non-respondents when the response rate appeared to have levelled off. Reminders were not sent to the entire sample but to selected organisations as part of the strategy of dealing with non-respondents.

### 4.3.5 Dealing with non-respondents

Whilst a target response rate of 40 per cent would produce a sufficiently large sample for statistical analysis, the high proportion of non-respondents would give rise to some concerns that sample bias may exist, i.e. that organisations who have responded have chosen to do so because they have a particular view on cost estimation that is not shared by non-respondents. It was necessary to devise a strategy for investigating the nature of the non-respondent organisations. Firstly, the response rates were analysed to see if there was any significant variation in response rates between different design organisations. Secondly, telephone contact was made with 30 per cent of non-respondents who were asked if they would be willing to either:

- receive another opportunity to complete the questionnaire; or
- answer briefly during the telephone call some of the key questions on the questionnaire: or
- identify their reasons for not responding.

Finally the results obtained from this follow up exercise were taken as a separate group to represent the population of non-respondents and the results of this group compared with those of the initial respondents.

### 4.3.6 Outline conclusions from questionnaire survey

The results of the questionnaire survey are reported fully in Chapter 5, but for the purposes of the development of the methodology, the main conclusion was that design cost estimation in the construction industry relied predominately on the application of intuitive approaches, and that historic cost data were not available in a form which would enable detailed cost models to be constructed. This conclusion supports the observation by Rowdon and Mansfield (1989) that designers believe that the nature of design work is such that it is not amenable to prescriptive planning and rigorous cost control. Whilst this finding suggested that currently the potential for the development of a rational approach to design cost estimation was limited, no firm conclusions could be drawn until alternative approaches to data collection and cost modelling had been fully investigated.

## 4.4 DATA COLLECTION CASE STUDIES

The role of the data collection case studies in the overall research methodolgy is shown in Figure 4.4.

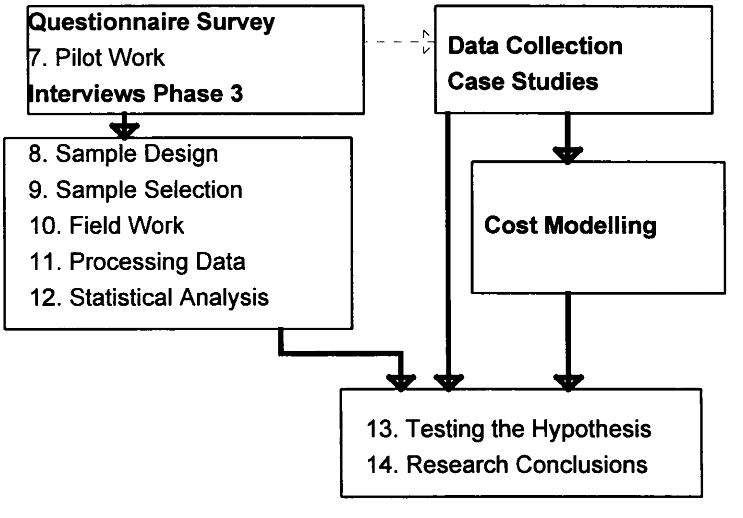



**Figure 4.4: - Role of the data collection case studies**

It was apparent from the empirical surveys, that, although design cost data were available in design organisations, this lacked detail. The data had been collected from staff time sheets that had been devised to support the organisations cost control systems. These only required projects to be broken down into a small number of broad work packages. This would restrict any potential cost modelling approaches to the use of parametric cost models which predict, to a low degree of accuracy (Boehm

1981), total project costs using methods similar to those developed by Boehm (1981) and O'Keefe et al. (1994) for other professional services.

If other cost modelling approaches were to be considered it would be necessary to compile a database of design costs comprising a larger number of smaller work packages for each project. Thus, the data collection phase of the research design served two purposes:

- to provide some detailed cost data for the model development and, more importantly in the context of testing the overall research hypothesis,
- to allow an evaluation to be made of the practicality of the collection in industry of a substantial volume of detailed cost data for estimation purposes.

There were two possible strategies for this stage of the work. One strategy would involve data collection from a number of projects across a number of organisations which would give rise to a large volume of cost data. However, there were two major drawbacks to this approach, namely:

- it would rely heavily on the involvement of a large number of employees in the participating organisations and discussions with possible collaborators during the interviews indicated that they would be unable to commit the necessary resources; and
- the collaborators would be unwilling to provide a large volume of commercially sensitive cost information.

The second strategy was to adopt a case study approach to data collection and this was deemed to be appropriate because:

- the case study provides an opportunity for intensive analysis of a single instance of the topic of study. In this case it allowed the researcher to become involved in the data collection process within each of the collaborating organisation which provided an in depth understanding of the problems associated with the process and thereby enabled meaningful conclusions to be drawn on the practicalities of widespread application of the data collection methodology; and
- a more limited trail of the data collection methodology was attractive to the collaborators.

It was decided that the case study should involve projects with a range of durations in different organisations, but it was realised that the number of projects and organisations would have to be restricted to enable the data collection to be effectively managed and monitored. A total of four projects with durations of two to sixteen months were selected from three organisations.

The results of the case studies are reported fully in Chapter 6, but for the purposes of the development of the methodology, the main conclusion was that it was possible to collect detailed cost data, although the traditional approach of using staff time sheets to collect the data presented a considerable barrier to the development, within an entire organisation, of a detailed data base of historic costs. The case studies provided detailed cost data for a limited range of projects and it was possible to proceed to the final stage of the research, which was to investigate the potential for application of such data to the development and verification of a cost model.

## 4.5 MODEL DEVELOPMENT AND VERIFICATION

### 4.5.1 The Role of the model in the research design

The role of the cost modelling the overall research methodolgy was shown in Figure 4.4.

Miller (1991) described the purpose of a model in research design as being to:

> "*assist in identifying significant variables in such a way that tests of hypothesis can be defined more sharply*" (p 51).

Furthermore, in producing guidance on their usage he noted that:

> *The modelling exercise and resultant simulations are regarded as tools to be used to further our understanding of how the system works*" (p 52).

These statements are particularly appropriate in the context of this study where the purpose of modelling stage is not to produce a model which can be universally applied to design cost estimation by practising engineers, but to provide evidence on the practicality of cost modelling, to the extent that data either is currently available, or might reasonably be expected to be available in the near future.

### 4.5.2 Selection of a form of model

Figure 4.5 shows how the previous work contributed to the model selection process.

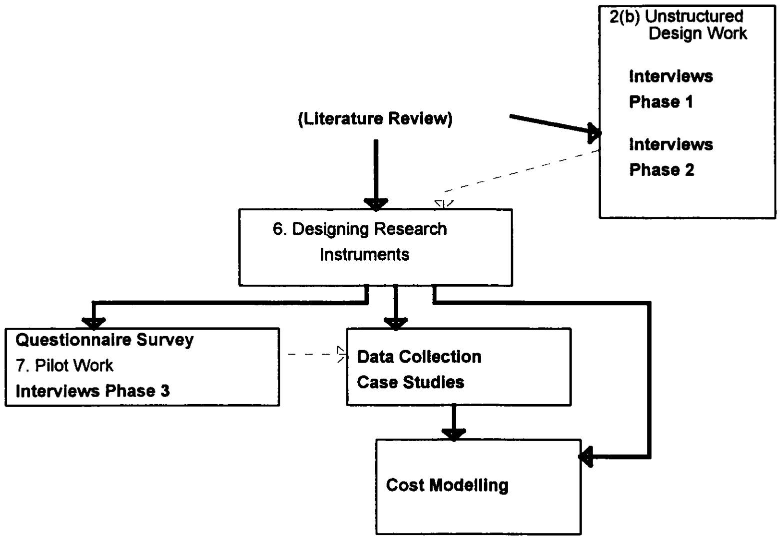



**Figure 4.5: - Information supporting the model selection process**

The literature review identified the following possible cost modelling approaches:

- parametric cost models (Boehm, 1981; O'Keefe, 1994);
- simulation models (Davis and Cochrane, 1987; Cornwell and Modianos 1990);
- risk analysis approaches (Hudson, 1992; Touran and Bolster, 1994; Uher, 1996); and
- fuzzy logic (Ock, 1996).

Each approach was critically appraised and due consideration had to be given to the model's input, output and to the context in which it would be applied.

Considering firstly the input data, the data collection case studies demonstrated that it should be possible for organisations to produce historic cost data for cost modelling at two levels of detail. Whole project costs could be readily provided and these could be subdivided, if this was appropriate into costs for major stages such as feasibility studies, detailed design and site supervision. It would be feasible to provide detailed data to the first level of a work breakdown structure for the individual projects or for major elements of larger projects. It would not be possible, however, to provide detailed data to the second level, the level at which projects are generally broken down to at the cost estimating stage.

The questionnaire survey and interviews with designers enabled a specification for the form of the model and its output to be devised. The output should be such that it could be readily used by designers in the estimating process which consisted of the developing the project cost in a bottom up manner and then reviewing the overall costs in an intuitive manner in the light of their experience of the nature of the project, the client, and the prevailing market condition. The most valuable cost output from the model would be an independent estimate of the overall project cost or of the costs of the work packages at the first level of WBS. There was evidence from the interviews to support the view that designers consider that design work is not amenable to prescriptive planning and cost estimation and therefore would be sceptical about the practical use of any cost model. Consequently "black box approaches" would be less attractive than those where the underlying principles of the modelling approach are more transparent and more readily understood. Finally, there was evidence from the data collection case studies that any cost model would have to be supported on hardware and software systems that are readily available to, and within the computer competency of designers.

### 4.5.3 Model development, testing and verification.

The selection process is reported fully in chapter 7 and resulted in the choice of a risk analysis modelling approach supported by the @risk package. A model was developed and tested using the data from the data collection case study projects and the performance of the model was verified through its application to a further project for which data were made available on the initial estimates to a level 2 WBS and final costs to level 1 WBS. The model development, testing and verification are also described fully in Chapter 7.

# CHAPTER 5

# SURVEY OF DESIGN MANAGEMENT PRACTICE

## 5.1 INTRODUCTION

The literature review presented in Chapters 2 and 3 has provided information on the cost estimation and control approaches that are adopted by construction industry designers, but a more comprehensive understanding of the extent of the application of these approaches is required. This chapter presents the results of a comprehensive survey of design management practice which, as previously shown in Figure 4.3, was structured to contribute to:

- the finalisation of the research aims and hypothesis;
- the development and refinement of the research instruments; and
- hypothesis testing through the provision of qualitative and quantitative analysis.

## 5.2 INTERVIEWS WITH DESIGN ORGANISATIONS

### 5.2.1 Exploratory interview

The exploratory interview with two senior members of a large civil engineering consultancy was conducted within the conceptualisation stage of the research design. The strategy for the interview was to engage the interviewees in a wide-ranging discussion of their planning and cost estimating and control approaches. In order to eliminate interviewer bias, no information was given to the interviewees on the conclusions drawn from the literature review. They were however sent a letter in advance of the meeting which outlined the purpose and scope of the research programme and identified three key areas for discussion:

- the planning and estimating approaches used within the organisation;
- the influence of fee competition on planning and estimating practice; and
- the extent to which historic design cost data were available and used in cost estimating.

The interviewees initially focused on the "unique" nature of design projects. They were of the opinion that this resulted in a very limited potential for the creation of a historic costs database and consequently cost estimates had to be derived by senior designer's who possessed a great deal of experience in a particular field. Broad comparisons were usually made with previously completed projects once an overall estimate had been established. Estimates were developed by breaking the projects down into a number of work packages and then, on the basis of the experience of the estimator, an estimate was made of the man-hours requirements for several grades of staff. The resulting total cost was derived by multiplying the man-hours by the various standard "charge-out rates" and summing the costs of the individual work packages. The charge-out rates were derived on the basis of the number of productive hours per employee multiplied by a factor to cover all overheads as follows:

$$\frac{\text{Total cost of employment of staff member} \times \text{overhead factor}}{1800 \text{ hrs}}$$

Overhead factors would ideally be 2.4, in line with previous practice when fee scales were widely used, but in recent years the factor is often adjusted on the basis of a commercial decision. Overhead factors as low as 1.8 were not unknown but a factor of 1.5 was considered to be the minimum level at which projects could be undertaken without incurring a financial loss. The overall design cost derived using an overhead factor of 2.4 are then compared with:

- figures obtained by taking a set percentage, based loosely on ACE fee scales, of the estimated capital cost of the project; and
- the overall design cost of previously completed projects of a similar nature.

Final bids for projects were decided at partner level where a commercial decision would be made to increase or decrease the estimated cost, typically giving consideration to the market value of individual projects or to any special relationship with the client. Once an estimate was complete this formed the project design budget and the design team appointed to a project would be expected to complete the project within this budget. The overall expenditure on each project was closely and continuously monitored by the project manager and by the senior management using a centrally organised cost reporting system which collected cost data via staff time-sheets. The cost information was provided to the project manager on a monthly basis with the information providing a summary of total expenditure to date on each project but not a breakdown of expenditure on each work package. Cost control data were therefore not readily available for cost estimating purposes, its use being limited to the provision of a total cost figure for the completed project. The importance of making a profit was highlighted several times by the interviewees who explained that all staff were aware of the need to adhere to budgets.

The impact of fee competition on the cost estimating process was discussed and the respondents were of the opinion that this did not influence the way in which cost estimates were devised but would probably affect the final level of the quotation through the decision on the commercial value of the project. They were of the opinion that fee competition had reduced margins on design fees which increased the importance of ensuring that the initial cost estimate was realistic. The interviewees noted the possibility that the reduction in design fees arising from fee competition might adversely effect the levels of service that were provided. The iterative nature of the design process was discussed and it was suggested that the number of iterations at any stage of the design would be limited by the available budget: a design would always be developed which met the design criteria but the extent to which it was refined would be dictated by the budget. They suggested that clients should be aware that this was an inevitable consequence of a reduction in fees for design services and that they should specify their requirements for level of service more precisely in the design brief.

Finally, the organisation's Quality Assurance (QA) system was discussed. The interviewee's organisation was accredited to BS5750 part 1 and they were of the opinion that the accreditation had resulted in efficiency gains but that these were difficult to quantify. They did not perceive any direct links between the QA system and cost estimation.

The interview supported the general conclusions from the literature review that design management is dominated by the application of cost control systems which monitored costs against estimates that have been derived in an intuitive manner. The potential for the establishment of a database using cost control information from current and previous projects and the application of database to cost modelling for future cost estimation had not been considered by the organisation. Cost estimation was driven by experience, loosely supported by non-specific records of previous projects.

### 5.2.2 Second round of interviews

The purpose of the second round of interviews was:

- to determine the extent to which the organisation above was representative of current construction industry practice; and

- to allow the development of an appropriate research instrument for a wider study of design management approaches.

A semi-structured approach was adopted for these interviews to ensure that all the key areas which emerged from the literature review and the exploratory interview were fully examined. The organisations were contacted in advance and were provided with a list of fairly general open questions to focus the discussions. The list of questions, included as Appendix A, was devised as the first stage in the development of the postal questionnaire. As was the case in the exploratory interview, care was taken to avoid interviewer bias and therefore the interviewer's involvement in the dialogue was restricted to introducing each question, providing expansion or clarification as necessary, and taking notes of the responses. No indication was given to the interviewees on the conclusions drawn from the literature review or on the information gained from the exploratory interview. The information received from each of the interviewees was remarkably consistent with that of the exploratory interview, as summarised above, but a number of specific additional items were raised by some of the organisations as described below.

**Organisation A (Civil Engineering Consultant)**

Organisation A had already experimented in the development of a database of information relating to specific design activities that can be used for estimating future projects. This database had to be updated regularly by a manual appraisal of costs and performance on completion of each project. The system was seldom used and reviews were not often carried out. The interviewee described an additional cost estimating technique which was to estimate the number of drawings required for a project and to determine the resource requirements from this on the basis of a standard number of man-hours per drawing.

**Organisation B (Civil Engineering Consultant)**

The interviewee considered that design cost estimating was a "*seat of the pants*" activity based on experience, therefore the time sheet system was used solely to collect data for cost control purposes and not for future estimates. The cost monitoring system reported cost on a whole project basis with no sub-division into work packages or stages of design nevertheless, the data collection process was still time consuming and expensive. Fee bids were normally adjusted downwards to reflect market conditions but there was a lower limit to the level of fees which could be charged, i.e. this organisation would not bid for a job unless they were certain that the bid would enable an adequate professional service to be offered.

**Organisation C (Civil Engineering Consultant)**

The interviewee from organisation C considered that time spent on site supervision should be viewed separately from design work, as it is normally paid for by clients on a cost reimbursement basis. Design Engineers allocated to a project would agree the project programme and resource requirements with a director of the organisation during the development of the fee bid. The organisation's cost reporting system was managed centrally by head office and divided projects into three stages, feasibility, detailed design and site supervision. The interviewee was of the opinion that if the work breakdown was more complicated, (i.e. too many codes) then doubts must arise as to the accuracy of the completion of the time sheets by the engineers. The designation of work packages used in each project were at the discretion of the project engineer and the estimating function was fully devolved to each office in the group. Consequently, no group wide cost data were available.

**Organisation D (Civil Engineering Consultant)**

The interviewee considered that planning became easier as the design process proceeds, i.e. detailed design was easier to estimate than conceptual design and feasibility studies, because of greater certainty about the requisite design activities at the detailed design stage.

**Organisation E (Multi-disciplinary Design Consultant)**

Organisation E was committed to QA and operated a QA system. They perceived a strong link between QA and planning design work. The Project Engineer was required to prepare a Quality Plan as well as a programme for the design. This quality plan should identify the necessary procedures for a project which was beneficial in preparing the estimate and should provide a library of standard work packages against which cost data could be, but currently were not, collected. The process of bidding for a project is allocated a job code in the same way as any other activity and therefore costs involved in bid preparation could be identified and controlled.

**Organisation F (Local Authority Civil Engineering Capital Works Design Office)**

Organisation F was involved in in-house design of capital projects and their approach to design management was quite different from that of the consultants. The main objective of the design groups was to produce designs and contract documentation in accordance with a predetermined capital expenditure programme and therefore the main management criterion was to ensure that design work was completed in time and to a satisfactory quality. The design teams operated with a fixed staffing compliment and traditionally costs had not been attributed to individual projects, nor had there been any need to produce cost estimates or budgets. However, with the possibility of an extension of compulsory competitive tendering into the provision of professional services, the organisation was beginning to develop with some urgency a cost reporting system for individual projects with the data being collected from engineer's time sheets.

**Organisation G (Small Architectural Practice)**

The problems of cost estimation were compounded for this organisation by having to deal with clients with no professional expertise or little experience of the construction industry. The costs of conceptual design work was especially difficult to quantify, particularly where creative or novel solutions were required by the clients. Little cost data were collected on individual project as the most appropriate measure of performance for a small practice was whether sufficient turnover was being generated to cover costs that were generally constant from year to year.

**Organisation H (Large Architectural Practice)**

Organisation H was involved in a number of large design projects. The interview described an estimating process involving project architects and partners which was similar to that described by civil engineering practices and identified the same cost estimating techniques. The interviewee was of the opinion that "good design" was not compatible with detailed planning, therefore, no detailed planning was performed for individual projects. The progress would be assessed by comparing an estimate of overall completion of the design work with a cost report which was provided on a monthly basis from time sheet data.

**Organisation I (Design Section of an International Energy Consultant)**

Organisation I specialised in the design of civil, electrical and mechanical engineering components of power generation projects world-wide. They had developed a database of man-hours for repetitive items of design such as pumps and generators. Statistical analysis had been performed on the probability of requiring various levels of design input in terms of man-hours for each of the components and this information was used as a guide in cost estimation but intuitive interpretation of the data was necessary to allow for varying degrees of complexity. Cost data were updated through a post project audit on completion of each project.

**Organisation J (Civil Engineering Consultant)**

Organisation J used similar cost estimating approaches to the other organisations but had, in response to the tighter profit margins on projects resulting from fee competition, recently undertaken a comprehensive review of their cost reporting system. The revised system was administered centrally at head office and produced cost reports on a weekly basis. Time-sheet data were collected every Monday and input by a secretary via an on-line computer link to the headquarters, and cost reports were issued the following week. No consideration was given during the development of the system to linking it to the cost estimation function, and although standard codes had been adopted for six stages of design, the selection of work packages was left to the individual project engineers. This means that, although comprehensive cost data were being collected, the form of the data were such that it could only be used for the production of up to date cost monitoring reports. The lack of uniformity in the determination of work packages for individual projects prevented the establishment of a database of costs categorised by design activities.

### 5.2.3 Summary of information obtained from the interviews

The second round of interviews demonstrated that, despite the diverse nature of the design organisations, a remarkably consistent approach was adopted by the organisations to planning and estimating design work. The findings of the exploratory interview was confirmed and additional information was gained which enabled conclusions on the following aspects of design cost estimating and control to be drawn.

**Planning and estimating process**

The model presented in Figure 5.1 was consistently adopted by all the organisations interviewed. The responsibility for deriving the nett cost estimate usually rested with the project engineer, who was also responsible for defining the constituent work packages, but the final bid was decided at director level. Only one consultant used standard work packages across the organisation with the design programme being developed in this case from the project quality plan.

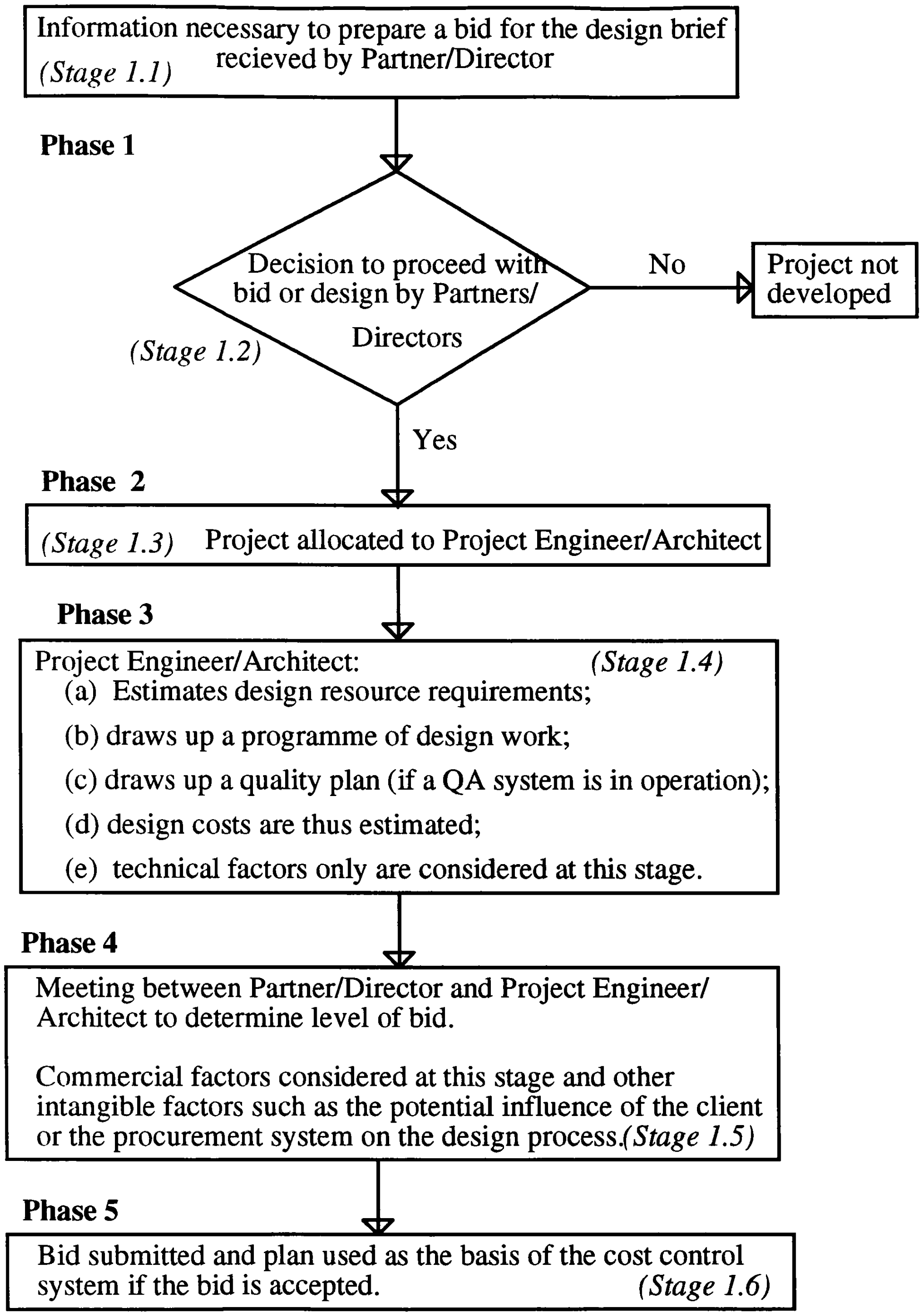



**Figure 5.1: - Model of the design fee estimating process**

### Cost estimating techniques

Four techniques, which had been highlighted in the literature review (Rutter & Martin, 1994), were constantly identified during the interviews. There was also considerable evidence of a general acceptance of the opinion that design work can not be estimated more scientifically. The techniques described were:

- using previous projects of a similar nature for a broad comparison with the estimates of the necessary person-hour contributions from the various grades of engineer being derived by the engineer on the basis of experience rather than from "hard data";
- developing an estimate, based on experience of projects of a similar nature, of the number of drawings required for a project and the man-hours associated with the drawings;
- making a broad estimate of the cost of the completed works and relating this, through consideration of the ICE scale of fees (with suitable adjustment), to required man-hours of the various grades; and
- by reference to a central database of costs which would give data on the necessary resources for specific activities. It is significant that only one consultant claimed to have such a system and said that the database was compiled using a post contract appraisal of the project. The consultant explained that the database was not widely used and that appraisals of completed projects were seldom carried out. In every organisation time sheets were completed by staff and the data were used for cost monitoring purposes but not for estimating future resource requirements.

**Impact of fee competition**

All consultants currently develop fee bids in line with the procedures shown in Figure 5.1 above. This had not altered as a result of fee competition. The initial estimate of the cost of design work was based on an estimate of the necessary resources required to design adequately the project in a professional manner, but the final level of fee bid was increasingly determined by consideration of commercial criteria, such as the relationship with the client, past experience of the degree of involvement of the client in the design process, the impact of a the general state of the market and the desirable or achievable profit margin. The advent of fee competition had significantly increased the importance of the commercial element of the fee bidding process which, together with the relatively poor state of the market at the time of the study, had resulted in a large reduction in achievable profit margins. In a number of cases fees were being set at a break even level in order that some income could be achieved from the project to contribute to the companies employment costs and overheads. Consultants were of the opinion that there was a minimum threshold below which they could not reduce their fees and maintain a professional level of service but that there were occasions when fee bids at that level had been significantly undercut by other bidders. Most of the organisation were responding to fee competition by improving their cost monitoring systems rather than giving serious consideration to improved cost estimation.

**The role of quality management systems**

All the organisations were developing formal Quality Assurance Systems but only one of the organisations perceived a link between the QA and planning and estimating. It was clear that the opportunity to standardise the selection of work packages for project cost estimating and monitoring through reference to QA procedures was not being taken.

## 5.3 DESIGN OF THE RESEARCH INSTRUMENTS.

Figure 4.1 showed that the purpose of the interviews was two fold: firstly, the provision of qualitative data for the conceptualisation stage of the research design in order that decisions could be made on the research hypothesis and on the variables which must be measured in order to draw meaningful conclusions in support of the research objectives, and secondly, to contribute to the development of the appropriate research instruments.

### 5.3.1 Decisions on research hypothesis

The overall aim of the project was to investigate the hypothesis that:

> there exists the potential for the development of a rational approach to the estimation of construction industry design costs by the application of cost modelling using historic cost data.

The information gained from the interviews supports the proposition from the literature review that intuitive approaches were universally used by design managers to estimate design costs and that the predominant design management tool was the organisation's cost monitoring system. Considerable time and effort were being put into the collection of cost data via staff time-sheets but these data were not collected in a form suitable for the cost estimation process. This qualitative research does not support the hypothesis because it can be reasonably assumed that, in the competitive environment in which design organisations operate, practising design managers would apply what they consider to be the most appropriate cost estimating approaches. This suggests that potential for the practical application of cost modelling approach within design organisations is limited. This qualitative research alone, whilst raising doubts about the validity of the hypothesis, does not provide sufficient grounds for its rejection but it does contribute to the first two project aims, which were to:

- identify, and quantify the use of, design cost estimation approaches that are currently applied by design managers; and
- evaluate the extent to which current cost estimating practice would facilitate the application of a more rational approach to design cost estimating.

In order that these aims can be fully realised, the above conclusions must be tested on a quantitative basis on a wider sample of design organisations; this was achieved using the postal questionnaire survey. As previously described in the methodology chapter, the questionnaire design encompassed two forms of enquiry. Firstly, enumeration where the attribute "frequency of use" was used to quantify the extent to which design managers apply intuitive rather than rational cost estimating approaches and secondly, analysis where relationships between the application of the various techniques and both the nature of the design process and the nature of the design organisations were explored. The purpose of the latter form of enquiry was to measure design manager's perception of the potential for the application of rational cost estimating approaches. No single simple attribute could be devised to measure this perception and therefore a number of sub-hypothesis were developed as described below.

The literature review has identified the features of the design process which make design costs difficult to quantify and has established that these features are present to varying degrees in different design problems and during the various stages of the design process. It can be assumed therefore that design activities that are more mechanistic, or which are undertaken a number of times within an organisation, should be more amenable to the application of rational cost estimating approaches. It can be reasonably concluded that if design managers consider that the potential to apply a rational cost estimating approach exists then it should be applied more often:

- at the detailed design stage;
- by organisations which are more involved in design projects that are repetitive by nature; or,
- by larger organisations who might have access to significant volumes of data on each activity.

The following sub-hypotheses were developed in such a way that their rejection would support the proposition that design managers do not consider that the potential exists for the application of rational cost estimating approaches:

- that there are relationships between use of cost estimating techniques and both the size of the organisation and the nature of their design work;
- that there are relationships between the use of cost estimating techniques and the stages of the design process;
- that computer based techniques are equally applied for planning and cost control; and
- that detailed cost control data is frequently used for cost estimation purposes.

### 5.3.2 Structure of the postal questionnaire

The interviews proved to be invaluable in the development of the questionnaire. The respondent's reaction to the sections in the question lists were noted during the interviews and due regard was given to the following five aspects in the design of the postal questionnaire.

**Questions 1 to 4 - The nature of the organisations**

The organisations were happy to provide information on: their number of employees, the magnitude of projects being undertaken, and their areas of specialism but it transpired that they were involved to varying degrees in a number of different types of project. The questionnaire would require to give respondents the opportunity to indicate their degree of involvement in each type of project rather than asking respondents simply to list there areas of specialism.

**Question 5 - Responsibility for Estimating Fees**

Discussions of this question led to the development of the model shown in Figure 5.1 and this question was replaced with a section containing the model with respondents being invited to indicate their degree of agreement with each stage of the model in order to test its validity.

**Question 6, 7 & 8 - Planning & Estimating Techniques**

This section was intended to determine how the Project Engineers estimate the resources required to design the project. In response to question 7, all the organisations claimed to use the range of estimating techniques identified above and both manual and computer assisted planning approaches. Question 8 revealed that the usage of the planning and estimating techniques varied during the different stages of the design process. It was therefore necessary to devise some form of matrix structure for questions of this nature in the final questionnaire to enable respondents to indicate the frequency of use of the techniques at various stages of the project's development.

**Question 9 to 13 - Influence of Fee Competition.**
Questions 10 to 13 were not well received because they were perceived as challenging the organisations professional integrity and it was clear from the interviews that the issues to be investigated here had already come to light and had been explored under the discussion of Question 9. With hindsight this reaction was predictable and therefore this area of questioning was removed and replaced with a statement which investigates the extent to which the organisations consider that the data currently used for cost control could, or should, be utilised further for estimating future projects.

**Questions 14 - 17 - Quality Management System.**
The respondents reaction to this section suggested that the use of these questions in a postal survey may have an adverse effect on the overall response rate as their inclusion would unduly lengthen the questionnaire and the relevance of this set of questions would not be readily evident to the respondents. It was therefore decided that these questions should be removed and replaced with two simple questions: one investigating whether organisations are considering a formal Quality Assurance (QA) system, and the other exploring the perceived link between the QA and planning and estimating systems.

The revisions described above were incorporated in the final version of the postal questionnaire. A copy of the final questionnaire that was issued to design organisations is included as Appendix B.

## 5.4 QUESTIONNAIRE SURVEY RESULTS

### 5.4.1 The Nature of the Respondents

In total, on completion of the follow up exercise, 119 valid responses were received which is 45 per cent of the 266 questionnaires that successfully reached their destinations. This response rate was considered to be adequate and was in line with expectations for this form of survey (Miller, 1991). Despite care being taken in the preparation of the mailing list 9 of the 275 questionnaires issued were returned unopened by the post office as the respondents had moved away from their known address. Table 5.1 summarises the response rates from the different groups of organisations and the response rate from each is consistent with the population structure. A Chi-squared goodness of fit test was carried out as shown in Table 5.2.

**Table 5.1: - Summary of response rates**

| Nature of Organisation | Number of Questionnaires issued | Number of Responses | % of Total Respondents | % Response Rate for Sub-sample |
|---|---|---|---|---|
| Civil Engineering Consultant | 92 | 42 | 35 | 46 |
| Architectural Practice | 87 | 35 | 29 | 40 |
| Local Authority | 29 | 15 | 13 | 52 |
| Water Company/ Department | 19 | 9 | 8 | 47 |
| Building Services Consultant | 39 | 18 | 15 | 46 |

**Table 5.2: - Goodness of fit test on response rates**

| OBSERVED (O) | EXPECTED (E) | $(O - E)^2 / E$ |
|---|---|---|
| 42 | 41.16 | 0.017 |
| 35 | 39.82 | 0.395 |
| 15 | 12.97 | 0.316 |
| 9 | 8.50 | 0.029 |
| 18 | 17.45 | 0.017 |

$$\chi^2 = 0.774$$

$$\chi^2(4) = 0.774, p > 0.05.$$

This demonstrates that there is no evidence of sample bias between the sub-groups of the sample.

The responses to questions 1 and 5 demonstrated that respondents had been drawn from an appropriately wide range of sizes of organisations. Table 5.3 gives information on the number of employees and Table 5.4 on the sizes of contract being undertaken.

**Table 5.3: - Number of employees**

| Category | Minimum Number | Maximum Number | Mean | Standard Deviation |
|---|---|---|---|---|
| **Chartered Engineers** | 1 | 150 | 16 | 22 |
| **Chartered Architects** | 2 | 30 | 11 | 7 |
| **Engineering Technicians** | 0 | 230 | 19 | 30 |
| **Architectural Technicians** | 1 | 30 | 9 | 7 |

**Table 5.4: - Size of projects**

| Size of Project (estimated capital cost) | Minimum Number | Maximum Number | Mean | Standard Deviation |
|---|---|---|---|---|
| **Less than £250,000** | 1 | 1931 | 49 | 200 |
| **£250,000 t0 £500,000** | 1 | 508 | 17 | 58 |
| **£500,000 to £1M** | 1 | 435 | 13 | 46 |
| **£1M to £5M** | 1 | 350 | 13 | 40 |
| **£5M to £10M** | 0 | 43 | 5 | 7 |
| **Greater Than £10M** | 0 | 26 | 4 | 5 |

The questionnaires were targeted mainly at area offices of organisations, where, it was believed, the senior managers were given a high degree of autonomy in cost estimating. Question 6 was included to test this assumption using a scale from 1 to 6 to represent high to low degrees of autonomy respectively. The mean response rate of 1.6 confirms that cost estimation was the responsibility of each individual office.

Question 2 was included to enable information on the percentage of staff who were substantially involved in the management of the organisations. Mean responses of 30 and 25 per cent for chartered engineers and chartered architects respectively and 7 and 12 per cent for civil engineering and architectural technicians respectively were obtained. In all cases a wide range of percentages were given, from 0 to 90 per cent which suggests that respondents interpretation of the term "substantially" varied considerably and therefore no meaningful conclusions can be drawn from this question.

Question 5 was included to determine the range of design services that were being provided by the respondents and the results are summarised in Table 5.5.

**Table 5.5: - Nature of design services**

| Design Stage | Relationship with Client: Employed Direct (%) | Joint Venture with Contractor (%) | Sub-contract to Consultant (%) | Total (%) |
|---|---|---|---|---|
| Advisory Work | 9 | 3 | 4 | 16 |
| Feasibility Studies | 10 | 5 | 3 | 18 |
| Detailed Design | 13 | 7 | 4 | 24 |
| Contract Documents | 10 | 4 | 4 | 18 |
| Supervision of Construction | 11 | 4 | 3 | 18 |
| Post Contract | 3 | 3 | - | 6 |
| Total | 56 | 26 | 18 | 100 |

Table 5.5 shows that the largest percentage of respondents time is spent on projects where they are employed directly by the client but that a significant amount of work is gained in joint ventures and as sub-contractors to other clients. The detailed design stage is the predominant activity with work on the other stages being evenly distributed. The influence of the nature of the design work and of the client on design cost estimation has been explored in the literature review and in the interviews with design managers and it is clear that the spread of design commissions shown in Table 5.5 will introduce considerable variability in historic design cost data.

### 5.4.2 The validity of the model of the cost estimating process

Section D of the questionnaire gave respondents the opportunity to express their agreement, based on the scale of 1 from strongly agree to 5 strongly disagree, with the model of the design cost estimating process shown in the figure. There is evidence of differences in the degree of agreement with the various stages of the model and this can be assessed by investigating the hypothesis that, in the population at large, there is no consistency of agreement with each of the stages of the model and therefore a mean response of 3 would be anticipated. The central limits theorem shows that for samples of the size obtained in the survey (n = 119) sample means will be normally distributed. Hence, the t test can be used to test hypothesis concerning the population mean. (Hines and Montgommery 1990). Using standard notation, the null hypotheses and alternative hypothesis may be expressed as:

$$H_0: \mu = 3$$
$$H_1: \mu \neq 3$$

The test procedure is based on the statistic

$$t = \frac{\bar{x} - \mu_o}{S/\sqrt{n}} \quad \text{where:} \quad S/\sqrt{n} = \text{Standard Error of the sample mean.}$$

Table 5.6 shows the results of the analysis of the data from the whole sample.

**Table 5.6: - Validity of the model of the cost estimating process (whole sample)**

| Stage+ | Mean Score | n | Standard Error | t | Significance |
|---|---|---|---|---|---|
| 1.1 | 1.55 | 102 | .10 | -14.50 | ***Reject Ho |
| 1.2 | 1.58 | 102 | .11 | -12.90 | ***Reject Ho |
| 1.3 | 2.16 | 101 | .14 | -6.00 | ***Reject Ho |
| 1.4A | 2.14 | 101 | .13 | -13.46 | ***Reject Ho |
| 1.4B | 2.09 | 99 | .12 | -7.58 | ***Reject Ho |
| 1.4C | 3.46 | 96 | .16 | 2.87 | **Reject Ho |
| 1.4D | 2.31 | 96 | .14 | -4.59 | ***Reject Ho |
| 1.4E | 3.01 | 96 | .14 | 0.07 | *Can not reject Ho |
| 1.5 | 2.12 | 99 | .14 | -6.28 | ***Reject Ho |
| 1.6 | 1.88 | 99 | .12 | -9.33 | ***Reject Ho |

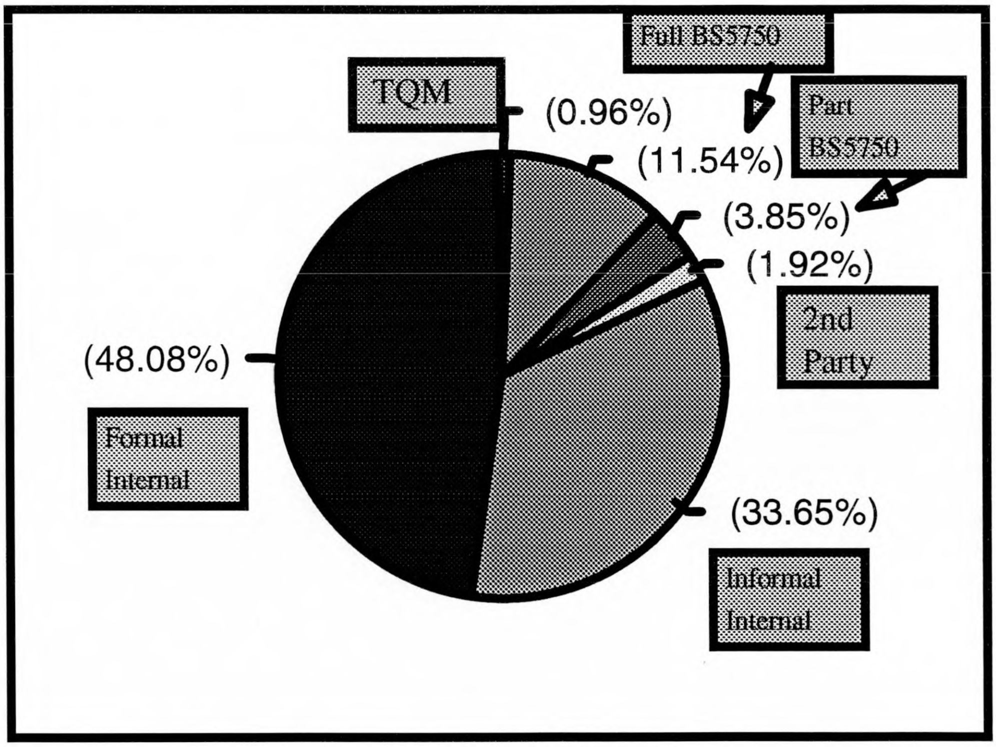
probability of type 1 error: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

+ See Figure 5.1 (p93) for details of stages. These can be summarised as follows:

Stage 1.1 Information on project received;
Stage 1.2 Decision whether or not to proceed;
Stage 1.3 Project Engineer/architect allocated;
Stage 1.4A Design resources estimated;
Stage 1.4B Programme drawn up;
Stage 1.4C QE plan drawn up;
Stage 1.4D Design costs estimated;
Stage 1.4E Technical factor only considered in estimate;
Stage 1.5 Commercial and intangible factors considered by partners;
Stage 1.6 Bid submitted and used for cost control.

Table 5.6 demonstrates that in every case, with the exception of stage 1.4E the hypothesis that there is no consistency of agreement with the stages of the model can be rejected. Stage 1.4E stated that only technical factors were considered during the initial estimating stage and it can be concluded that estimates were not consistently prepared in this way.

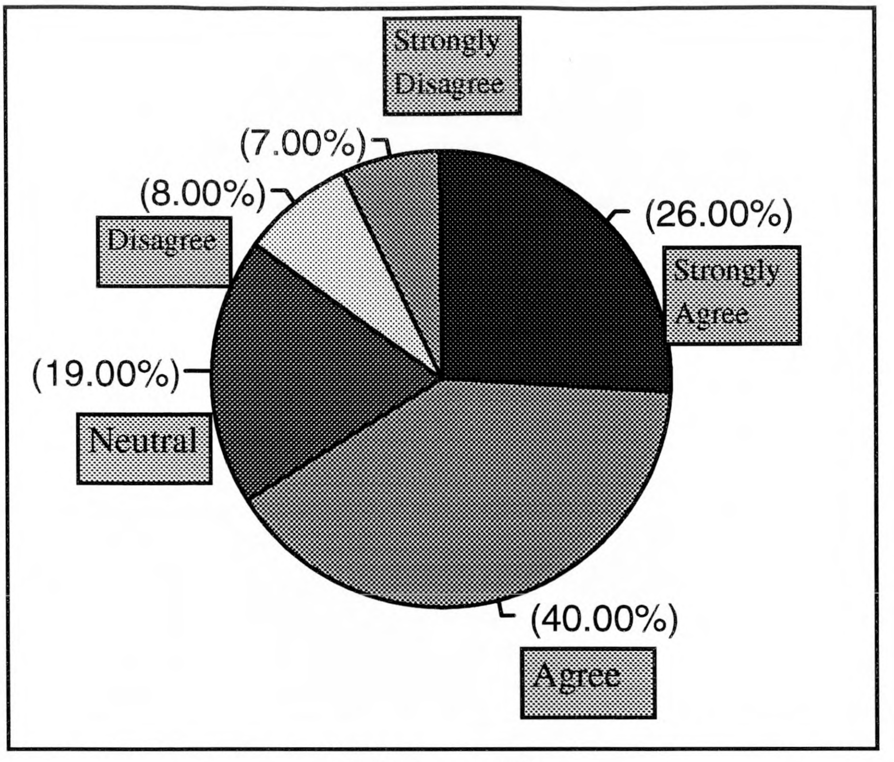
The mean scores of between 1.55 and 2.31 for all stages except 1.4C and 1.4E indicate agreement that the model is applicable whilst the mean score for stage 1.4C of 3.46 demonstrates that the use of a QA plan in the development of the cost estimate is not generally adopted. Questions 18 to 20 in the questionnaire were included to investigate further the relationship between Quality Management and cost estimation and control. Questions 18 and 19 ascertained the companies' current and future positions with regard to quality management. Question 20 investigated the perception amongst design managers that there could be a link between the quality assurance and design planning and cost estimation systems. The responses to Question 18 are summarised in Figure 5.2.




**(Note n = 104)**

**Figure 5.2: - Quality management systems**

Less than 15 per cent of the organisations operate externally accredited Quality Assurance systems although, in response to Question 19, 87 per cent of organisations indicated that they were developing their Quality Management systems. Question 20 invited respondents to express their agreement with the statement that there was a definite link between formal QA systems and cost estimating and control procedures and the responses are summarised in Figure 5.3.




**(Note n = 100)**

**Figure 5.3: - Perception of link between quality management and cost estimating and control system.**

The rejection of the null hypothesis for stage 1.4C can be explained by the relatively small proportion of companies that had developed externally accredited QA systems. However, the evidence that most organisations were developing their QA systems, together with the recognition by design managers of the potential link between their QA and cost estimation systems, suggests that this stage may be included in future design planning and estimating practice. This may lead to the use of standard work packages across organisations which would increase the value of historic cost data.

A comparative analysis of the levels of agreement within the sub-groups of organisations in Table 5.1 was carried out to investigate the extent to which their cost estimating process are influenced by the nature of the design work in these organisations. The average scores are shown in Table 5.7.

**Table 5.7: - Validity of the model of the cost estimating process (mean response scores by sub-sample)**

| Stage* | Civil Engineering Consultants | Architectural Practices | Local Authorities | Water Authorities | Building Services Consultants |
|---|---|---|---|---|---|
| 1.1 | 1.10 | 1.41 | 2.85 | 3.75 | 1.27 |
| 1.2 | 1.23 | 1.26 | 2.62 | 4.50 | 1.54 |
| 1.3 | 1.97 | 2.41 | 2.31 | 3.25 | 1.45 |
| 1.4A | 2.24 | 2.15 | 2.00 | 3.75 | 1.63 |
| 1.4B | 2.24 | 1.97 | 1.85 | 3.00 | 1.91 |
| 1.4C | 3.67 | 3.42 | 3.08 | - | 2.60 |
| 1.4D | 2.31 | 2.19 | 2.25 | 3.75 | 2.18 |
| 1.4E | 3.07 | 3.17 | 2.17 | 4.25 | 2.82 |
| 1.5 | 1.61 | 2.36 | 2.75 | - | 1.45 |
| 1.6 | 1.60 | 1.63 | 2.75 | 4.75 | 1.63 |

* See Figure 5.1 (p93) and Table 5.6 for details of stages.

The mean scores of the sub-sample of civil engineering consultants were taken as a bench mark to test the hypothesis that a similar degree of agreement on the applicability of the stages of the model exists in the other sub-samples. The rational for the selection of this group as a benchmark was to reflect the overall focus of the later part of the research programme, which was concerned particularly with civil engineering design for the water industry. The sample of water industry was not appropriate for this purpose due to its relatively small size but could, along with the local authority sample, enable a comparison between private sector consultants and (what were then) public sector design organisations. Using the benchmark approach a comparison could also be made between organisations involved in different design sectors, i.e. between civil engineering and both architecture and building services engineering. It was decided that the comparison would be made using a test of hypothesis on the means of two normal distributions, variances unknown (Hines and Montgomery 1990).

The null hypotheses and alternative hypothesis may be expressed as:

$H_0$: $\mu_1 = \mu_2$ for both sub-samples, and for each stage of the estimating process respectively;

$H_1$: : $\mu_1 \neq \mu_2$ for both sub-samples, and for each stage of the estimating process respectively.

The test statistic t can be derived from:

$$\frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{S_1^2}{n_1} + \frac{S_2^2}{n_2}}}$$

where $\overline{X}_1$, $S_1$ and $n_1$ relate to the sub-sample of civil engineers, and $\overline{X}_2$, $S_2$ and $n_2$ relate to the other sub-samples

The results of the analysis are shown in Table 5.8.

**Table 5.8: Comparative analysis of sub-samples**

| **Stage+** | **Architects** | | **Local Authorities** | | **Water Authorities*** | | **Building Services Engineers** | |
|---|---|---|---|---|---|---|---|---|
| | t | Prob.≠ | t | Prob.≠ | t | Prob.≠ | t | Prob.≠ |
| **1.1** | **-2.55** | **0.013** | **-6.57** | **0.000** | **13.00** | **0.000** | 1.27 | 0.209 |
| **1.2** | -0.33 | 0.745 | **-5.04** | **0.000** | **10.83** | **0.000** | 1.41 | 0.164 |
| **1.3** | -1.36 | 0.178 | -0.74 | 0.465 | -1.72 | 0.093 | 1.20 | 0.237 |
| **1.4A** | 0.02 | 0.984 | 0.35 | 0.726 | **-2.13** | **0.040** | 1.15 | 0.256 |
| **1.4B** | 0.85 | 0.397 | 0.91 | 0.365 | -0.99 | 0.330 | 0.70 | 0.487 |
| **1.4C** | 0.70 | 0.489 | 1.14 | 0.260 | - | - | 1.98 | 0.054 |
| **1.4D** | 0.36 | 0.723 | 0.13 | 0.896 | -1.83 | 0.075 | 0.27 | 0.792 |
| **1.4E** | -0.29 | 0.776 | **2.05** | **0.046** | -1.67 | 0.099 | 0.58 | 0.563 |
| **1.5** | **-2.64** | **0.010** | **-2.67** | **0.010** | - | - | 0.47 | 0.640 |
| **1.6** | 0.17 | 0.846 | **-2.96** | **0.005** | **6.89** | **0.00** | 0.12 | 0.902 |

+ see Figure 5.1 (p91) and Table 5.6 for details of stages.

* sub-sample small and for some stages cases no responses were recorded

≠ probabilty of a type one error.

Tables 5.7 and 5.8 demonstrate a high degree of consistency of agreement with the model of the estimating process between the different groups of organisations. The greatest consistency existed among the three groups of consultants and, in view of this consistency, it was not considered to be necessary to perform a more comprehensive analysis of the data in Table 5.7 using a one way ANOVA analysis, which would have allowed the Local Authorities and Water Authorities group to be compared individually against the other groups of consultants.

The null hypothesis that the group means are equal can not be rejected at any part of the model when comparing the civil engineering and building services consultants and can only be rejected for stages 1.1 and 1.5 in the comparison of the civil engineering and architectural consultants. In the case of stage 1.1, which simply stated that the information required for a fee bid was accepted by their partner/director, the actual mean scores of 1.10 and 1.41 respectively for the civil engineer and architects indicate a high degree of acceptance of the model. The null hypothesis is rejected because of the extremely low standard error of 0.04 for the civil engineering group. In this case the rejection of the null hypothesis is not considered to be of any practical significance with respect to the validity of the model. In the case of stage 1.5, which deals with the consideration of commercial issues in the determination of the fee bid, the difference between the actual mean scores is greater which indicates that this stage of the cost estimation process is deemed to be less applicable to architectural practices. This suggests that architectural practices may be less commercially aware than civil engineering consultants. However, no evidence to support this proposition was found elsewhere in the research and further research, out with the scope of this programme, would be required before any firm conclusion could be drawn on this issue.

There is significantly less agreement on the applicability of the model between consultants and the local authorities and water authorities. The Null hypothesis is rejected by both groups in the case of stage 1.1 and stage 1.2 which deal with the receipt of the design brief and the decision to prepare a bid which is not unexpected as the majority of the design work in these organisations is on the basis of a provision of in-house professional services. This would also explain the rejection of the null hypothesis for stage 1.5. The hypothesis is also rejected for stage 1.6 which deals with the cost control system and this supports the conclusions from the interviews that time rather than cost was the predominant issue in design management in this sector.

In general it can be concluded that the planning and estimating model was accepted by private sector organisations but that the cost estimation and cost control systems were less well developed in the public sector (Water Authority and Local Authority organisations).

### 5.4.3 Estimating, planning and cost control techniques

**1. Analysis of the usage of the various techniques at each stage of the design process.**

Questions 7 to 10 of the questionnaire gave respondents the opportunity to indicate their frequency of use of each of the cost estimating techniques, based on the scale of 1 for always to 5 never. There is evidence of differences in the degree of application of the various techniques and this can be assessed by investigating the hypothesis that, in the population at large, there is no tendency to consistently apply, or not to apply each technique, in which case a mean response rate of 3 would be anticipated. The test procedure was similar to that adopted for Table 5.6 and the results of the analysis are shown in Table 5.9.

**Table 5.9: - Degree of application of cost estimating techniques at each stage of the design process**

| TECHNIQUE | Mean Score | Standard Error | t | Significance |
|---|---|---|---|---|
| **Advisory Stage** | | | | |
| Broad Estimate | 2.18 | 0.11 | -7.45 | ***Reject Ho |
| Number of Drawings | 3.18 | 0.13 | 1.38 | *Can Not Reject Ho |
| Scale of Fees | 2.87 | 0.13 | -1.00 | *Can Not Reject Ho |
| Detailed Data | 4.23 | 0.09 | 13.66 | ***Reject Ho |
| **Feasibility Stage** | | | | |
| Broad Estimate | 2.15 | 0.08 | -10.63 | ***Reject Ho |
| Number of Drawings | 2.80 | 0.11 | -1.82 | *Can Not Reject Ho |
| Scale of Fees | 2.53 | 0.12 | -4.59 | ***Reject Ho |
| Detailed Data | 4.07 | 0.10 | 10.70 | ***Reject Ho |
| **Detailed Design Stage** | | | | |
| Broad Estimate | 2.05 | 0.09 | -10.55 | ***Reject Ho |
| Number of Drawings | 2.23 | 0.10 | -7.70 | ***Reject Ho |
| Scale of Fees | 2.10 | 0.10 | -9.00 | ***Reject Ho |
| Detailed Data | 3.88 | 0.12 | 7.33 | ***Reject Ho |
| **Contract Documents** | | | | |
| Broad Estimate | 2.25 | 0.10 | -7.50 | ***Reject Ho |
| Number of Drawings | 2.54 | 0.12 | -3.83 | ***Reject Ho |
| Scale of Fees | 2.28 | 0.11 | -6.54 | ***Reject Ho |
| Detailed Data | 4.07 | 0.10 | 10.70 | ***Reject Ho |
| **Supervision** | | | | |
| Broad Estimate | 2.20 | 0.10 | -8.00 | *Reject Ho |
| Number of Drawings | 3.08 | 0.14 | 0.57 | *Can Not Reject Ho |
| Scale of Fees | 2.46 | 0.12 | -4.50 | ***Reject Ho |
| Detailed Data | 4.15 | 0.10 | 11.50 | ***Reject Ho |

**Table 5.9 (Continued)**

| TECHNIQUE | Mean Score | Standard Error | t | Significance |
|---|---|---|---|---|
| **Post Contract** | | | | |
| Broad Estimate | 2.56 | 0.12 | -3.66 | ***Reject Ho |
| Number of Drawings | 3.52 | 0.14 | 3.71 | ***Reject Ho |
| Scale of Fees | 2.87 | 0.13 | -1.00 | *Can Not Reject Ho |
| Detailed Data | 4.32 | 0.09 | 14.67 | ***Reject Ho |

probability of type 1 error * $p < 0.05$

*** $p < 0.001$

(n varies between 103 and 111)

The null hypothesis can be rejected for the majority of the techniques at each of the stages of the design process which demonstrates consistency in the application of the techniques. The hypothesis was however not rejected in the following areas where consistent use of the techniques has not been established.

- estimates based on the number of drawings for advisory work, feasibility and supervision which is consistent with the nature of work in these activities; and
- estimates based on fee scales for advisory work or post contract work, which can be explained by the absence of fee scales in the standard forms of engagement for this type of work.

In all the other cases the techniques are either consistently applied or not applied and the polarisation between the application of the intuitive techniques, (broad estimate, using the number of drawing and fee scales) and using a detailed data base is clearly evident with mean scores of approximately 2 and 4 respectively at every stage of the process.

**2. Comparison of the application of the techniques by different categories of Organisation.**

A comparative analysis of the usage of design cost estimating techniques within the sub-groups in Table 5.1 was carried out to investigate the extent to which their cost estimating process are influenced by the nature of the design work in these organisations. The average scores (from a scale of usage form 1 = Always to 5 = Never) are shown in Table 5.10.

**Table 5.10: - Use of Cost Estimating Techniques (Mean response scores by sub-sample)**

| Technique | Civil Engin. Consultants | Architects Practice | Local Auth. | Water Auth. | Building Services Consultants |
|---|---|---|---|---|---|
| **Advisory Stage** | | | | | |
| Broad Estimate | 2.00 | 2.11 | 2.47 | 2.30 | 2.55 |
| No. of Drawings | 3.23 | 3.03 | 3.33 | 3.56 | 3.00 |
| Scale of Fees | 2.90 | 2.47 | 3.60 | 3.56 | 2.45 |
| Detailed Data | 4.42 | 4.06 | 4.47 | 4.11 | 3.82 |
| **Feasibility Stage** | | | | | |
| Broad Estimate | 1.93 | 2.25 | 2.27 | 2.22 | 2.50 |
| No. of Drawings | 2.62 | 2.74 | 3.13 | 3.33 | 2.82 |
| Scale of Fees | 2.48 | 1.97 | 3.60 | 3.56 | 2.18 |
| Detailed Data | 4.24 | 3.94 | 4.20 | 3.89 | 3.82 |
| **Detailed Design** | | | | | |
| Broad Estimate | 1.83 | 3.28 | 1.93 | 2.33 | 1.83 |
| No. of Drawings | 2.02 | 2.21 | 2.47 | 3.11 | 2.00 |
| Scale of Fees | 2.00 | 1.65 | 2.87 | 3.56 | 1.67 |
| Detailed Data | 4.09 | 3.66 | 3.93 | 3.78 | 3.83 |
| **Contract Docs.** | | | | | |
| Broad Estimate | 2.09 | 2.68 | 1.87 | 2.11 | 2.17 |
| No. of Drawings | 2.51 | 2.45 | 2.47 | 3.11 | 2.50 |
| Scale of Fees | 2.29 | 1.70 | 2.89 | 3.56 | 2.00 |
| Detailed Data | 4.39 | 3.85 | 3.93 | 4.00 | 3.82 |
| **Supervision** | | | | | |
| Broad Estimate | 1.90 | 2.44 | 2.07 | 2.33 | 2.58 |
| No. of Drawings | 3.11 | 2.94 | 3.43 | 3.22 | 2.80 |
| Scale of Fees | 2.56 | 1.86 | 3.14 | 3.56 | 2.18 |
| Detailed Data | 4.54 | 3.94 | 4.07 | 3.78 | 3.82 |
| **Post Contract** | | | | | |
| Broad Estimate | 2.23 | 2.70 | 2.79 | 2.56 | 2.92 |
| No. of Drawings | 3.41 | 3.16 | 3.46 | 3.67 | 3.00 |
| Scale of Fees | 3.11 | 2.27 | 3.64 | 3.56 | 2.36 |
| Detailed Data | 4.60 | 4.18 | 4.43 | 4.11 | 3.82 |

The mean scores of the sub-sample of civil engineering consultants were taken as a benchmark to test the hypothesis that a similar degree of usage of the techniques existed in the other sub-samples. This was achieved using a two sample test using the same procedure as that adopted for Table 5.8. The results of the analysis are presented in Table 5.11.

**Table 5.11: - Use of cost estimating techniques - a comparative analysis of sub-samples**

| Technique | Architects | | Local Authorities | | Water Authorities | | Bldg. Services Engineers | |
|---|---|---|---|---|---|---|---|---|
| | t | Prob. | t | Prob. | t | Prob. | t | Prob. |
| **Advisory stage** | | | | | | | | |
| Broad Estimate | -0.54 | 0.588 | -1.52 | 0.134 | -0.89 | 0.379 | -1.62 | 0.111 |
| No.of Drawings | -0.62 | 0.535 | -0.27 | 0.787 | -0.61 | 0.544 | 0.46 | 0.645 |
| Fee Scales | 1.39 | 0.167 | -1.72 | 0.091 | -1.24 | 0.220 | 0.96 | 0.342 |
| Detailed Data | 1.72 | 0.089 | -0.14 | 0.890 | -0.92 | 0.362 | 1.86 | 0.069 |
| **Feasibility Stage** | | | | | | | | |
| Broad Estimate | -1.75 | 0.085 | -1.36 | 0.180 | -0.98 | 0.330 | -2.17 | **0.035** |
| No.of Drawings | -0.44 | 0.666 | -1.46 | 0.151 | -0.15 | 0.134 | -0.49 | 0.627 |
| Fee Scales | 2.02 | **0.047** | -3.22 | **0.002** | -2.38 | **0.021** | 0.76 | 0.444 |
| Detailed Data | 1.20 | 0.235 | 0.20 | 0.905 | 0.86 | 0.396 | 1.11 | 0.271 |
| **Detailed Design** | | | | | | | | |
| Broad Estimate | -2.49 | **0.015** | -0.39 | 0.701 | -1.44 | 0.156 | 0.00 | 1.000 |
| No.of Drawings | -0.83 | 0.408 | -1.56 | 0.123 | -2.68 | **0.010** | 0.08 | 0.939 |
| Fee Scales | 1.90 | 0.061 | -3.09 | **0.003** | -4.27 | **0.000** | 1.15 | 0.255 |
| Detailed Data | 1.67 | 0.099 | 0.44 | 0.622 | 0.71 | 0.483 | 0.67 | 0.503 |
| **Contract Docs.** | | | | | | | | |
| Broad Estimate | -2.27 | **0.028** | 0.77 | 0.444 | -0.04 | 0.967 | -0.21 | 0.833 |
| No. of Drawings | 0.21 | 0.832 | 0.13 | 0.901 | -1.22 | 0.228 | 0.03 | 0.978 |
| Fee Scales | 2.25 | **0.027** | -1.83 | 0.072 | -3.05 | **0.004** | 0.84 | 0.404 |
| Detailed Data | 2.30 | **0.024** | 1.45 | 0.152 | 1.09 | 0.283 | 1.70 | 0.096 |
| **Supervision** | | | | | | | | |
| Broad Estimate | -2.34 | **0.022** | -0.60 | 0.554 | -1.23 | 0.225 | -2.08 | **0.042** |
| No. of Drawings | 0.50 | 0.619 | -0.73 | 0.470 | -0.21 | 0.836 | 0.60 | 0.533 |
| Fee Scales | 2.89 | **0.005** | -1.62 | 0.112 | -2.21 | **0.032** | 0.99 | 0.326 |
| Detailed Data | 2.65 | **0.010** | 1.57 | 0.123 | 2.12 | **0.039** | 2.22 | **0.031** |
| **Post Contract** | | | | | | | | |
| Broad Estimate | -1.72 | 0.089 | -1.53 | 0.133 | -0.67 | 0.506 | -1.65 | 0.106 |
| No.of Drawings | 0.78 | 0.439 | -0.10 | 0.922 | -0.43 | 0.666 | 0.82 | 0.416 |
| Fee Scales | -2.81 | **0.006** | -1.34 | 0.188 | -0.87 | 0.398 | 1.16 | 0.104 |
| Detailed Data | 2.07 | **0.042** | -0.68 | 0.499 | 1.58 | 0.121 | 2.602 | **0.012** |

As might have been anticipated from Table 5.10 which demonstrated reasonably consistent mean scores across the subgroups, Table 5.11 shows that the null hypothesis can not be rejected in the majority of cases, which implies that the selection of design cost estimating techniques by public sector design organisations and by architectural and building services engineering designers is not significantly different to that of private sector civil engineering designers. This suggests that the nature of the design work and the nature of the design organisations do not influence to any large degree the cost estimating approaches that are adopted. However, there are cases where the null hypothesis can be rejected at less than a 0.05 probability of a type 1 error, and these are shown in bold in the Table 5.11.

Considering Tables 5.10 and 5.11 together the following patterns of results emerge.

- Architects are less likely than civil engineering practices to use broad estimates of fees at the detailed design, preparation of contract documents and supervision stages but are more likely to use fee scales for preparation of documents, supervision and post contract stage. This is consistent with the conclusion from Table 5.6 that commercial decision stage of the estimating process was deemed to be less applicable to architectural practices.
- Local Authorities and Water Authorities are less likely to apply fee scales to the feasibility, detailed design, preparation of contract documents and supervision stages of the design process and this can be accounted for by the predominantly in-house nature of their professional services as discussed above.
- Water authorities are also less likely to base a cost estimate on the number of drawings for the detailed design and preparation of contract documents stages.

## 3. Comparison of the application of techniques by different categories of organisation

The sub-division of the design process into six stages introduced a large number of possible permutations of category and design stage which would have required a large volume of processing and reporting. The analysis reported above has shown that there is little variability in the application of each of the techniques to the various stages of the design process and it was decided to limit the comparative analysis to the stage to which the techniques were most often applied; the detailed design stage.

**(a) Comparison by the nature of the design problem**

To investigate further the possibility that design cost estimating practice might be influenced by the nature of design work a comparative analysis was undertaken of the responses to question 3 which dealt with market sectors and questions 7 to 10 inclusive which dealt with the application of the cost estimating techniques. The procedures adopted for the analysis was as follows:

- the largest sub-samples (civil engineering consultants and architectural practices) which would provide an adequate number of responses for cross tabulation, were selected;
- a qualitative assessment of the relationship was undertaken by the inspection of the cross-tabulation of market sector against frequency of application of the technique; and,
- a quantitative analysis was provided by the determination of the test statistic gamma (Agresti, 1985) for ordinal measures for each cross tabulation.

As an example of the qualitative assessment, Tables 5.12 to 5.15 show the cross tabulation for two market sectors for each of the sub-samples against the use of detailed data in cost estimation.

**Table 5.12: - Involvement in water engineering vs use of detailed data in cost estimation for the sub-set of civil engineering consultants**

| | Use of Detailed Data | | | | | |
|---|---|---|---|---|---|---|
| **Involvement in Water Engineering** | Always | Often | Sometimes | Seldom | Never | **Total** |
| 1 (most involved) | | | 1 | 1 | 5 | 7 |
| 2 | | 1 | | 1 | 1 | 3 |
| 3 | | | 1 | 2 | 4 | 7 |
| 4 | 1 | 2 | 1 | 4 | 2 | 10 |
| 5 | 1 | 1 | 1 | 1 | 3 | 7 |
| 6 (least involved) | | | | | 6 | 6 |
| **Total** | 2 | 4 | 4 | 9 | 21 | 40 |

**Table 5.13: - Involvement in structural engineering vs use of detailed data in cost estimation for the sub-set of civil engineering consultants**

| | Use of Detailed Data | | | | | |
|---|---|---|---|---|---|---|
| **Involvement in Structural Engineering** | Always | Often | Sometimes | Seldom | Never | **Total** |
| 1 (most involved) | 1 | 2 | 2 | 6 | 13 | 24 |
| 2 | | 2 | 1 | | 3 | 6 |
| 3 | 1 | | | 2 | 4 | 7 |
| 4 | | | | | | 0 |
| 5 | | | 1 | | | 1 |
| 6 (least involved) | | | | 2 | 1 | 3 |
| **Total** | 2 | 4 | 4 | 10 | 21 | 41 |

**Table 5.14: - Involvement in office design vs use of detailed data in cost estimation for the sub-set of architectural practices**

| | Use of Detailed Data | | | | | |
|---|---|---|---|---|---|---|
| **Involvement in Office Design** | Always | Often | Sometimes | Seldom | Never | **Total** |
| 1 (most involved) | | 1 | 4 | 2 | 3 | 10 |
| 2 | | 5 | 1 | 4 | 4 | 14 |
| 3 | 1 | 1 | | | 3 | 5 |
| 4 | | | 1 | | 1 | 2 |
| 5 | | 1 | | 1 | 1 | 3 |
| 6 (least Involved) | | | | | | 0 |
| **Total** | 1 | 8 | 6 | 7 | 12 | 34 |

**Table 5.15: - Involvement in industrial projects vs use of the number of drawings in cost estimation for the sub-set of architectural practices**

| | Use of Detailed Data | | | | | |
|---|---|---|---|---|---|---|
| **Involvement in Industrial Projects** | Always | Often | Sometimes | Seldom | Never | **Total** |
| 1 (most involved) | 4 | 3 | | | | 7 |
| 2 | | 7 | | | | 7 |
| 3 | 1 | 2 | 4 | | | 7 |
| 4 | 2 | 4 | 1 | | | 7 |
| 5 | | | 2 | | | 2 |
| 6 (least Involved) | | 1 | | 2 | 1 | 4 |
| **Total** | 7 | 17 | 7 | 2 | 1 | 34 |

There is no evidence of any significant relationship between the degree of involvement in a market sector and the application of a cost estimation approach, except possibly in the case of Table 5.15. If a strong positive correlation exists observations would tend to be concentrated on the upper left to lower right diagonal of the table or on the upper right to lower left if a strong negative correlation exists. A comparison of Tables 5.13 and 5.14 demonstrates again the polarisation between the use of intuitive estimating techniques and detailed data.

A similar pattern was observed for each of the market sectors and for each technique, and the apparent lack of correlation can be further investigated using the statistic gamma. Gamma is a measure of association for a table of two ordered variables based on the comparison of the values of both variables for all possible pairs of cases or observations. The numbers of concordant, discordant and tied pairs are identified and the value of gamma is determined. Gamma lies between -1 (perfect negative correlation) and +1 (perfect positive correlation) with 0 indicating no association. Table 5.16 presents the values of gamma which were consistently low, except as had been anticipated in the case of Table 5.15 where a value of 0.6142 occurred. However, the values are not significant in any case which demonstrates that the degree of usage of each of the techniques is independent of the market sector of the design organisation. This provides further support for the earlier conclusion that the nature of the design problem does not influence degree of application of the cost estimating techniques. The relatively high, but not significant, value of gamma for

Table 5.15 is due to the concentration of responses in the top left corner rather than a clear tendency for the results to lie along the diagonal.

**Table 5.16: - Values of gamma for use of technique by market sector**

**5.16a: - Gamma - Sub-sample of civil engineering consultants**

| | TECHNIQUE | | | |
|---|---|---|---|---|
| **Market Sector** | Broad Estimate | No. of Drawings | Fee Scales | Detailed Data |
| Water and Sewerage | -0.1768 | 0.3496 | 0.0604 | 0.0137 |
| Transportation | 0.1784 | 0.3320 | 0.0547 | -0.1695 |
| Marine Works | 0.2197 | 0.1492 | 0.1070 | 0.0728 |
| Structural Engineering | 0.0877 | 0.2429 | 0.0565 | -0.1045 |
| Geotechnics | 0.0801 | 0.0367 | 0.2410 | 0.2706 |

**5.16b Gamma- Sub Sample of Architectural Practices**

| | TECHNIQUE | | | |
|---|---|---|---|---|
| **Market Sector** | Broad Estimate | No. of Drawings | Fee Scales | Detailed Data |
| Industrial | 0.0086 | 0.6142 | 0.1890 | 0.0696 |
| Offices | -0.2393 | 0.1470 | 0.1583 | 0.0253 |
| Retail | -0.2653 | 0.1428 | -0.0071 | 0.0728 |
| Hotel and Leisure | -0.1210 | 0.0796 | -0.2593 | 0.1928 |
| Residential | 0.0947 | 0.0256 | 0.0758 | 0.1670 |

**(b) Comparison by size of organisation**

The possibility that larger organisations would have access to a larger data set and would therefore use the three intuitive approaches that were identified in section 5.2.3 less often, and the rational data supported approach more often, than smaller organisations was investigated. The number of chartered architects and chartered engineers was selected as a suitable indicator of an organisation's size. The frequency distributions for Questions 1 and 2 of the questionnaire for the largest sub-sets, consulting engineers and architects, were examined and in both cases the 75 percentile value was approximately 15 employees. This was used to sub-divide the sub-sets into large and smaller organisations. Once again, the analysis was restricted to the detailed design stage of the design process. As was the case in the analysis for table 5.8, the two sample test was used to examine differences between sub-sets. The results of the analysis are shown in Table 5.17.

**Table 5.17: - Comparison of frequency of use of technique by size of organisation**

**5.17a: - Civil engineering consultants**

| | Large Organisation | | Small Organisation | | | |
|---|---|---|---|---|---|---|
| **Technique** | **Mean Score** | **Standard Error** | **Mean Score** | **Standard Error** | **t** | **Significance*** |
| Broad Estimate | 1.89 | 0.14 | 1.82 | 0.23 | 0.27 | Can not Reject Ho |
| No. Of Drawings | 2.22 | 0.15 | 1.94 | 0.22 | 1.05 | Can not Reject Ho |
| Fee Scales | 2.22 | 0.13 | 1.94 | 0.23 | 1.05 | Can not Reject Ho |
| Cost Data-Base | 3.56 | 0.19 | 4.24 | 0.19 | -2.00 | Can not Reject Ho |

* probability of type 1 error = 0.05, $t_{0.05,41} = \pm 2.02$.

**5.17b Architectural practices**

| | Large Organisation | | Small Organisation | | | |
|---|---|---|---|---|---|---|
| **Technique** | **Mean Score** | **Standard Error** | **Mean Score** | **Standard Error** | **t** | **Significance*** |
| Broad Estimate | 2.69 | 0.24 | 2.19 | 0.25 | 1.44 | Can not Reject Ho |
| No. Of Drawings | 2.46 | 0.31 | 2.05 | 0.18 | 1.14 | Can not Reject Ho |
| Fee Scales | 1.62 | 0.21 | 1.67 | 0.16 | 0.19 | Can not Reject Ho |
| Cost Data-Base | 3.54 | 0.29 | 4.24 | 3.67 | -0.31 | Can not Reject Ho |

* probability of type 1 error = 0.05, $t_{0.05,35} = \pm 2.03$.

Table 5.17 shows that in each case the null hypotheses can not be rejected and therefore it can be concluded that there is no evidence that the frequency of application of the various techniques is influenced by the size of the organisation, which confirms the conclusions from the interviews that, even in the largest organisations, cost control data were not being retained and processed for cost estimation purposes. The t value for the cost data base for civil engineering consultants is close to the confidence level which suggests that larger organisations may more frequently use the technique. However the location of the mean score is between "sometimes" and "seldom" for the large practices indicating a low level of use of this approach. Furthermore, as discussed in section 5.3.5, the qualitative evidence suggests that cost data is in fact not available, even in the larger organisations.

### 5.4.4 The planning and estimating process

The interviews had suggested that design management was dominated by the application of cost control rather than planning techniques, and this was tested by initially comparing, for the whole sample, the relative sophistication of the organisation's planning and cost control systems. It was decided that the use of computer based techniques would be a useful measure of the degree of sophistication of the systems and Questions 12 to 14 were included in the questionnaire to enable such an assessment to be made. The respondents were invited to indicate the frequency of use of manual and computer techniques for planning and cost control at each stage of the design process and a null hypothesis developed that:

> there would be no difference in the average response values on the use of manual and computer systems for each stage of the design process.

The null hypotheses and alternative hypothesis may be expressed as:

$H_0$ $\mu_1 = \mu_2$ for each stage of the design process;
$H_1$: $\mu_1 \neq \mu_2$ for each stage of the design process.

where: $\mu_1$ relates to responses relating to the use of manual techniques and, $\mu_2$ relates to the use of computer assisted techniques

In this case, where the samples are drawn from one source, it was appropriate to use a paired t test (Kennedy and Neville, 1986). The results of the analysis are shown in Tables 5.18 and 5.19.

**Table 5.18: - Comparison of the use of manual and computer assisted planning approaches**

| | Mean Score - Frequency of Use | | | | |
|---|---|---|---|---|---|
| **Design Stage** | **Manual** | **Computer Application** | **t** | **Prob.** | **Significance** |
| Advisory | 2.88 | 4.32 | -8.08 | 0.00 | Reject Ho |
| Feasibility | 2.47 | 4.05 | -7.99 | 0.00 | Reject Ho |
| Detailed Design | 2.21 | 3.63 | -6.25 | 0.00 | Reject Ho |
| Preparation of Docs. | 2.41 | 3.81 | -6.31 | 0.00 | Reject Ho |
| Supervision | 2.45 | 3.96 | -7.50 | 0.00 | Reject Ho |
| Post Contract | 3.00 | 4.28 | -6.11 | 0.00 | Reject Ho |

**Table 5.19: - Comparison of the use of manual and computer assisted cost control approaches**

| Design Stage | Manual | Mean Score<br>Computer Application | t | Prob. | Significance |
|---|---|---|---|---|---|
| Advisory | 3.61 | 3.42 | 0.57 | 0.57 | Can not reject Ho |
| Feasibility | 3.41 | 3.30 | 0.36 | 0.72 | Can not reject Ho |
| Detailed Design | 3.33 | 3.15 | 0.53 | 0.60 | Can not reject Ho |
| Preparation of Docs. | 3.42 | 3.19 | 0.69 | 0.49 | Can not reject Ho |
| Supervision | 3.53 | 3.32 | 0.59 | 0.56 | Can not reject Ho |
| Post Contract | 3.57 | 3.40 | 0.51 | 0.61 | Can not reject Ho |

Table 5.18 shows that the hypothesis can be rejected in the case of planning approaches with manual planning techniques being used "often" whilst computer assisted planning was "seldom" used.

In contrast, Table 5.19 shows that it was not possible to reject the hypothesis in the case of the cost control approaches with both manual and computer cost control systems being used "sometimes". The mean scores in the region of 3 does not provide any further evidence to support or refute the initial conclusion from the interviews that cost control was the dominant design management tool, but suggests that the cost control systems which are used by design managers are, in general, not sophisticated. This concurs with comments received during the interviews (which were confirmed after the questionnaire survey by follow up interviews) that the organisations, in response to the development of fee competition, identified a need to improve their cost control systems. The lack of sophistication of the cost control systems would lead to a lack of suitable data for cost estimation which supports the conclusions from previous sections above.

A comparative analysis which again focused on the detailed design stage was performed to investigate the consistency of the findings across the different design organisations, classified by the sub-samples in Table 5.1. As before the mean scores of the sub-sample of civil engineering consultants were taken as a datum to test the hypothesis that a similar degree of application of manual and computer techniques exists in the other sub-samples. This was achieved using a two sample test using the same procedure as that adopted for Table 5.8. The results of the analysis are shown in Table 5.20b.

**Table 5.20:- Comparative analysis of the use of planning and estimating systems by sub-samples**

**Table 5.20a: - Mean response scores by sub-sample**

| Technique | Civil Engin. Consultants | Architects Practices | Local Auth. | Water Auth. | Building Services Consultants |
|---|---|---|---|---|---|
| Manual Planning | 1.97 | 2.00 | 2.23 | 2.00 | 2.33 |
| Computer Assisted Planning | 3.61 | 3.30 | 3.73 | 2.83 | 3.26 |
| Manual Cost Control | 2.93 | 2.88 | 3.55 | 3.38 | 2.63 |
| Computer Assisted Cost Control | 2.19 | 2.50 | 3.15 | 3.42 | 2.78 |

**Table 5.20b: - Comparative analysis of sub-samples.**

| Technique | Architects Practices | | Local Authority | | Water Authority | | Building Services Consultants | |
|---|---|---|---|---|---|---|---|---|
| | t | Prob. | t | Prob. | t | Prob. | t | Prob. |
| Manual Planning | -0.11 | 0.915 | -0.69 | 0.496 | -0.05 | 0.963 | -0.80 | 0.438 |
| Computer Assisted Planning | 0.92 | 0.361 | -0.23 | 0.824 | 1.21 | 0.268 | 0.51 | 0.619 |
| Manual Cost Control | 0.11 | 0.915 | -1.30 | 0.207 | -0.62 | 0.550 | 0.52 | 0.612 |
| Computer Assisted Cost Control | -0.80 | 0.430 | -1.58 | 0.132 | -1.54 | 0.162 | -1.13 | 0.274 |

Tables 5.20a and 5.20b show that the application of the planning and cost control techniques is not a function of the nature of the design organisation. This is consistent with the earlier conclusions on the application of design cost estimating approaches.

Question 14 was included in the questionnaire to gather qualitative information on the nature of the organisations computer assisted planning cost control systems, Respondents were given the opportunity to state the name of their software package if a commercial package was used. The responses relating to planning were evenly spread among in house, proprietary systems and spreadsheets whereas the majority of cost control software was either provided by the organisation's in-house accounting system or had been developed using standard spreadsheet packages. Proprietary systems were only mentioned by three of the 119 respondents. The absence of any dominant off the shelf software and the tendency to develop in house systems using standard spreadsheets supports the conclusion that design management cost control systems lack sophistication and have not traditionally been able to provide detailed data for future cost estimating purposes.

### 5.4.5 Use of cost control data for planning and estimating

Questions 15 to 18 were included to ascertain the current availability of data for cost estimating purpose. Questions 15 and 16 investigated the current usage of cost control data and the mean scores for each category of organisation for question 15 is given in Table 5.21.

**Table 5.21: - Use of cost data (mean response scores by sub-sample)**

| Design Stage | Civil Engin. Consultants | Architects Practices | Local Auth. | Water Auth. | Building Services Consultants |
|---|---|---|---|---|---|
| Advisory | 3.02 | 3.38 | 3.80 | 4.22 | 3.27 |
| Feasibility | 2.90 | 3.17 | 3.60 | 3.77 | 3.00 |
| Detailed Design | 2.76 | 2.76 | 3.33 | 3.78 | 2.82 |
| Preparation of Documents | 2.98 | 2.71 | 3.33 | 3.78 | 3.09 |
| Supervision | 3.18 | 2.82 | 3.57 | 3.78 | 3.09 |
| Post Contract | 3.26 | 3.12 | 4.07 | 4.22 | 3.18 |

Table 5.21 shows that the mean score is generally around 3 which indicates that, on average, cost control data was only "sometimes" used to estimate costs. Furthermore, an assessment of the frequency distribution reveals that approximately 40% of respondents "seldom" or "never" use cost control data to estimate design costs which supports the earlier conclusions that design cost estimation is predominated by intuitive approaches. However, more careful consideration is required for the 60% of organisations who had indicated "always", "often" or "sometimes" in response to question 15. This was achieved by a qualitative assessment of the written responses to Question 16, which asked those organisations describe briefly the way in which cost data are applied to cost estimating.

The comments on the use of data can generally be grouped into organisations in the following three categories:

- 20 organisations who used the total man-hour requirements of previous projects as a check on a current cost estimate, having derived the estimate using the methods identified in the study. A further 8 organisations used data in a similar way but their cost data were subdivided into a number of broad work packages which related to the RIBA plan of work or the ACE forms of engagement;
- 18 organisations who used cost control data to monitor expenditure during a project and then taking corrective action if the cost of the project deviated from the estimate; and
- 16 organisations who chose not to respond, with the majority of these indicating a response of 3 to question 15 which suggest that their use of cost data were limited.

Other responses included:

- 3 organisations who used the overall costs of previous projects to justify costs in negotiated contracts;
- 3 organisations who collected data to assist in the determination of the necessary man-hour requirements for drawings; and
- 1 organisation who compared total costs for their office against total income to check that the office was operating profitably.

The general conclusion which was drawn from the comments was that the organisations who indicated, in response to question 15, that they used cost data did not use detailed data to produce cost estimates, but used the data to allow a broad comparison to be made between the cost of previously completed projects and estimates developed using intuitive approaches.

For further analysis the mean scores of the sub-sample of civil engineering consultants were taken as a benchmark to test the hypothesis that a similar degree of use of cost control data exists in each of the other sub-samples. This was achieved using a two sample test using the same procedure as that adopted for Table 5.8. The results of the analysis are shown in Table 5.22.

**Table 5.22: - Use of cost data - comparative analysis of sub-samples**

| Design Stage | Architects | | Local Authorities | | Water Authorities | | Building Services Engineers | |
|---|---|---|---|---|---|---|---|---|
| | **t** | **Prob.** | **t** | **Prob.** | **t** | **Prob.** | **t** | **Prob.** |
| Advisory | -1.39 | 0.170 | **-2.36** | **0.025** | **-2.57** | **0.028** | -0.61 | 0.553 |
| Feasibility | -1.04 | 0.303 | -1.88 | 0.070 | -1.49 | 0.105 | -0.22 | 0.829 |
| Detailed Design | -0.01 | 0.992 | -1.37 | 0.182 | -1.74 | 0.112 | -0.12 | 0.906 |
| Preparation of Documents | 0.94 | 0.350 | -0.87 | 0.394 | -1.38 | 0.198 | -0.25 | 0.806 |
| Supervision | 1.22 | 0.226 | -1.00 | 0.327 | -1.04 | 0.323 | 0.17 | 0.865 |
| Post Contract | 0.44 | 0.665 | **-2.21** | **0.036** | -2.01 | 0.067 | -0.14 | 0.891 |

Table 5.21 and 5.22 show a high degree of consistency in the use of cost data across the categories of organisations as the null hypothesis can only be rejected at a 5% level on three occasion; the application by local authorities and water authorities to the advisory stage of the design process and the application by local authorities to post contract work. There was also evidence, although not statistically significant, of a lower level of usage of cost control data by the local authority and water authority sub-samples across each of the design stages, confirming the conclusion from the interview stages that the cost of the design services was not the most critical management consideration in these sectors.

Question 17 was included to investigate the suitability of the current form of the cost control data for cost estimating purposes. Respondents were invited to indicate their agreement with statement regarding whether cost control data *were* or *should be* available in a suitable form for cost estimation, and a null hypothesis was developed that:

> if the organisations were satisfied with the links between their cost control and cost estimating systems there would be no difference in the average responses values to the two statements above.

A paired t test which used the same procedure as that for Tables 5.18 and 5.19 was carried out and the results of the analysis are as follows:

Mean response to Statement 1, cost control data are available = 2.99;
Mean response to Statement 2, cost control data should be available = 1.71;
t = 11.07, probability of a type 1 error = 0.000

The null hypothesis can be therefore rejected and it can be concluded that the difference in mean scores is significant.

With a mean response to statement 1 of 3, there would appear to be no consistency of agreement with the statement that cost control data were available and this corresponds with the conclusion above. However there is stronger, but not unanimous agreement, with the statement that cost control should be available for cost estimating purposes, indicating that design managers are not satisfied with the current links between their cost control and estimating systems

As before, for further analysis, the mean scores of the sub-sample of civil engineering consultants were taken as a datum to test the hypothesis that a similar degree of use of cost control data exists in each of the other sub-samples. This was achieved using a two sample test using the same procedure as that adopted for Table 5.8. The results of the analysis are shown in Tables 5.23 and 5.24.

**Table 5.23: - Availability of cost data (mean response scores by sub-sample)**

| Statement | Civil Engin. Consultants | Architects Practices | Local Auth. | Water Auth. | Building Services Consultants |
|---|---|---|---|---|---|
| Cost control data are available | 2.80 | 2.85 | 3.27 | 3.22 | 3.09 |
| Cost control data should be available | 1.71 | 1.67 | 1.47 | 1.89 | 1.91 |

**Table 5.24: - Availability of cost data - comparative analysis of sub-samples**

| Statement | Architects | | Local Authorities | | Water Authorities | | Building Services Engineers | |
|---|---|---|---|---|---|---|---|---|
| | t | Prob. | t | Prob. | t | Prob. | t | Prob. |
| Cost Control data are available | 0.19 | 0.854 | -1.29 | 0.243 | -0.90 | 0.388 | 0.80 | 0.433 |
| Cost control data should be available | 0.22 | 0.826 | -1.07 | 0.296 | 0.38 | 0.714 | 0.71 | 0.489 |

Table 5.24 shows that the null hypothesis can not be rejected in every case with the consistency across the various sub-samples being once again evident.

## 5.5 DEALING WITH NON-RESPONDENTS

Although the response rate to the questionnaire survey was reasonable, a further study of the organisations who had not responded was necessary to investigate the possibility of sample bias. Firstly, the analysis of the response rates from the different categories of design organisation rate in Table 5.1 demonstrated consistency between sectors, with a level of response that might have been anticipated for a postal survey, which suggests that the respondents were a representative sample of the population.

Secondly, telephone contact was made with a random sample of 60 non-respondent organisations (40% of total number of non respondents) who were asked if they would be willing to either:

- receive another opportunity to complete the questionnaire;
- answer briefly during the telephone call some of the key questions on the questionnaire: or,
- identify their reasons for not responding.

Of the 60 organisations, 8 said that they were unable to respond due to pressure of work, but were prepared to provide outline answers to some questions during the telephone conversation. In every case the information provided on estimating approaches and the use of cost control data in cost estimation was similar to that provided by the initial respondents to the survey. 52 additional questionnaires were issued and this resulted in 23 returns bringing the total number to 119.

Finally, the results from the 23 questionnaires received from the follow up exercise were taken as a separate group to represent the population of non-respondents and the results of this group compared with those of the 96 initial respondents in the key areas of :

- use of design cost estimating techniques; and
- use of cost control data in cost estimating.

This comparison was made using a test of hypothesis on the means of two normal distributions. The results of the analysis are shown in Tables 5.25 and 5.26.

**Table 5.25: - Comparison of the use of cost estimating techniques by the initial and follow up samples**

| Technique | Mean Response Scores: Initial Respondents | Late Respondents | t | Probability |
|---|---|---|---|---|
| **Advisory Stage** | | | | |
| Broad Estimate | 2.17 | 2.22 | -0.24 | 0.812 |
| No. of Drawings | 3.12 | 3.37 | -0.81 | 0.418 |
| Scale of Fees | 2.77 | 3.21 | -1.38 | 0.171 |
| Detailed Data | 4.19 | 4.37 | -0.80 | 0.425 |
| **Feasibility Stage** | | | | |
| Broad Estimate | 2.12 | 2.26 | -0.68 | 0.498 |
| No. of Drawings | 2.85 | 2.62 | 0.82 | 0.416 |
| Scale of Fees | 2.49 | 2.67 | -0.60 | 0.552 |
| Detailed Data | 4.05 | 4.12 | -0.27 | 0.785 |
| **Detailed Design** | | | | |
| Broad Estimate | 1.96 | 2.43 | **-2.20** | **0.030** |
| No. of Drawings | 2.15 | 2.50 | -1.48 | 0.142 |
| Scale of Fees | 2.01 | 2.41 | -1.63 | 0.107 |
| Detailed Data | 3.85 | 3.95 | -0.37 | 0.710 |
| **Contract Docs.** | | | | |
| Broad Estimate | 2.19 | 2.47 | -1.13 | 0.260 |
| No. of Drawings | 2.52 | 2.58 | -0.21 | 0.831 |
| Scale of Fees | 2.21 | 2.54 | -1.24 | 0.291 |
| Detailed Data | 4.05 | 4.12 | -0.27 | 0.790 |
| **Supervision** | | | | |
| Broad Estimate | 2.14 | 2.45 | -1.26 | 0.212 |
| No. of Drawings | 3.00 | 3.34 | -1.06 | 0.293 |
| Scale of Fees | 2.39 | 2.69 | -1.06 | 0.292 |
| Detailed Data | 4.16 | 4.08 | 0.32 | 0.751 |
| **Post Contract** | | | | |
| Broad Estimate | 2.61 | 2.36 | 0.81 | 0.421 |
| No. of Drawings | 3.36 | 3.17 | 0.58 | 0.561 |
| Scale of Fees | 2.78 | 3.17 | -1.26 | 0.212 |
| Detailed Data | 4.30 | 4.39 | -0.40 | 0.690 |

**Table 5.26: - Comparison of the availability of cost data in the initial and follow up samples**

| Statement | Mean Response Scores Initial Respondents | Late Respondents | t | Probability |
|---|---|---|---|---|
| Cost control data are available | 3.08 | 2.69 | 1.17 | 0.249 |
| Cost control data should be available | 1.72 | 1.59 | 0.65 | 0.516 |

In almost every case the null hypothesis can not be rejected and therefore there is no significant evidence that the non-respondents, as represented by the late respondents, adopt different planning and estimating approaches to the initial respondents. This conclusion provided increased confidence that the results from the questionnaire survey reported above are representative of design management practice in the United Kingdom.

## 5.6 SUMMARY OF CONCLUSIONS FROM THE SURVEY OF DESIGN MANAGEMENT PRACTICE

In Chapter 4 the purpose of the survey of design management practice was established as being to provide qualitative and quantitative information which could be used to facilitate the achievement of the first two of the project aims. These were:

1. the identification and quantification of the design cost estimation approaches that are currently applied by design managers;
2. the evaluation of the extent to which current cost estimation practice would facilitate the application of a more rational approach to design cost estimating;

With regard to the first objective, the interviews enabled the model of the cost estimation process shown in Figure 5.1 to be developed, with the validity of the model being tested by a larger sample of design organisations in the questionnaire survey. The questionnaire survey provided quantitative data (Tables 5.6 and 5.7) on the applicability of this process to design organisations in various sectors. A detailed analysis of those data (Table 5.8) demonstrated that the predominant management approach in design offices offering in-house services was to monitor progress on their projects against a predetermined design programmes, whereas civil engineering, architectural and building services consultants used cost control system as the predominant management tool.

Within the cost estimating process, four cost estimating techniques were identified during the interviews and the extent of the usage of each technique at each stage of the design process was determined in the questionnaire survey (Table 5.9). In general there was clear evidence of a polarisation in the use of two forms of cost estimation, with the intuitive approaches being used frequently and rational data driven approach being seldom used.

In addition to the enumeration aspects described above, which allowed the first project aim to be achieved, the questionnaire design allowed further analysis of the data in order that conclusions could be drawn on the second aim; the evaluation of the extent to which current cost estimation practice would facilitate the application of a more rational approach to design cost estimation. It can be reasonably presumed that, if design managers consider that the potential to apply rational cost estimating approaches exists they would be applied more often:

- at the detailed design stage;
- by organisations which are more involved in design projects that are repetitive by nature; or,
- by larger organisations who might have access to significant volumes of data on each activity.

The following sub-hypotheses were developed in such a way that their rejection would support the proposition that design managers do not consider that the potential exists for the application of rational cost estimating approaches:

- that there are relationships between the use of cost estimating techniques and the stages of the design process;
- that there are relationships between use of cost estimating techniques and both the size of the organisation and the nature of their design work;
- that computer based techniques are equally applied for planning and cost control; and
- that detailed cost control data is frequently used for cost estimation purposes.

Table 5.9 highlighted the polarisation between the use of intuitive and traditional cost estimating approaches and demonstrated that, in almost every case, the techniques are either consistently applied or not applied to the various stages of the design process. Consequently, there is sufficient evidence to reject the first sub-hypothesis.

The second sub-hypothesis can also be rejected. Tables 5.10 and 5.11 demonstrated consistent agreement, in almost every case, with the results in Table 5.9 for each of the group of design organisations whilst Tables 5.12 to 5.16 demonstrated that no relationship existed between the nature of the design problem and the application of the planning techniques. Finally, Table 5.17 demonstrated that there was no evidence that the frequency of application of the various techniques was influenced by the size of the organisation.

Tables 5.18 and 5.19 allowed an assessment to be made of the use of manual and computer assisted approaches to cost control and planning. The results in the tables are rather inconclusive when considered against the third hypothesis above but nevertheless the clear conclusion that there was a significant difference in the application of computer assisted and manual planning approaches was not repeated in the case of the cost control approaches. The average response scores of approximately 3 suggest equal usage of the approaches which suggests that the cost control systems which are used by design managers are, in general, not sophisticated. This concurs with comments received during the interviews (which were confirmed after the questionnaire survey by follow up interviews) that the organisations, in response to the development of fee competition, identified a need to improve their cost control systems. The lack of sophistication of the cost control systems would contribute significantly to a lack of suitable data for cost estimation.

There is sufficient evidence to reject the fourth sub-hypothesis. Table 5.21, the qualitative evidence collected in the questionnaire survey, and the information received in the interviews demonstrated that the design organisations do not use detailed cost data to produce cost estimates, but use the data to allow a broad comparison to be made of the a cost estimate developed using the intuitive approaches with previously completed projects. Table 5.22 shows a high degree of consistency in the use of cost data across the categories of organisations, although there is evidence of a lower level of usage of cost control data by the local authority and water authority sub-samples across each of the design stages. This confirms the conclusion from the interview stages that the cost of the design services was not the most critical management consideration in these sectors. Finally Table 23 shows that there was no consistency of agreement with the statement that cost control data is available and that there was stronger agreement with the statement that cost control should be available for cost estimating purposes. This indicates that design managers are not satisfied with the current links between their cost control and estimating systems.

The rejection of three of the four sub-hypothesis, and the conclusions drawn against the other, provide sufficient evidence to support, with a high degree of confidence the proposition that design managers do not consider that the potential exists for the application of rational approaches to design cost estimation. In the context of the overall thesis the first two aims had been realised, which were:

1. the identification and quantification of the design cost estimation approaches that are currently applied by design managers;
2. the evaluation of the extent to which current cost estimation practice would facilitate the application of a more rational approach to design cost estimating;

In the context of the overall objective of the project, which was to investigate the hypothesis that: there exists the potential for the development of a rational approach to the estimation of construction industry design costs by the application of cost modelling using historic cost data, the evidence collected provided strong evidence that the hypothesis can be rejected, but no final conclusions could be substantiated until the final project aims were realised. These were:

3. the evaluation of the practicality of enhanced data collection to support a more rational approach;
4. the selection and development of a form of model that is appropriate for the available data;
5. the verification of the performance of the cost model.

Chapter 4 has identified that the final aims were realised through the case study and modelling work as described in Chapters 6 and 7 respectively.

# CHAPTER 6

# DATA COLLECTION CASE STUDIES

## 6.1 INTRODUCTION

This chapter describes the data collection case studies that were developed to satisfy the third aim, and to contribute towards the achievement of the fourth aim of the project which are:

- to evaluate the practicality of enhanced data collection to support a more rational cost estimating approach; and
- to select and develop a form of model that is appropriate for the available data.

The justification for the selection of a case study approach to data collection has been presented in section 4.4. In view of the collaborative nature of the project, the case studies were focused on one sector of the construction industry, the water industry within Scotland. Four organisations were involved in the case studies, these were: Tayside Regional Council, Water Services Department (now part of North of Scotland Water Authority); Fife Regional Council, Water Services Department (now part of East of Scotland Water); and the Waste Water Technology Centre, a research and development unit of the School of Construction and Environment of the University of Abertay Dundee.

The survey of design management presented in Chapter 5 revealed some significant features of this sector that must be considered when extrapolating the findings from the case study to the construction industry at large. The main objective of the design groups in this sector was to produce designs and contract documentation in accordance with a predetermined capital expenditure programme. The main management criterion were to ensure that design work was completed on time and to a satisfactory quality and in such a way that the capital costs of the projects was within budget. The design teams operated with a fixed staffing compliment and costs had traditionally not been attributed to individual projects, nor had there been any need to produce cost estimates or budgets for the design work. This approach was evident in the results of the questionnaire survey where it was shown that, when compared to the other design organisations in the survey, Local Authorities and Water Authorities were less likely to apply fee scales to feasibility studies, detailed design preparation of contract documents and supervision stages of the design process. This can be accounted for by the predominantly in-house nature of their professional services. Water authorities were also less likely to base a cost estimate on the number of drawings for the detailed design and preparation of contract documents stages. Finally, there was evidence of a low use of cost control data in design cost estimation by the local authority and water authority sub-samples across each of the design stages.

The case studies were thus based on the sector of the construction industry which would, relative to other sectors of construction industry design, have the least experience in producing cost estimates and the least well developed costs control systems.

## 6.2 THE DATA COLLECTION SYSTEM

### 6.2.1 The system parameters

A specification for the data collection system was developed by giving consideration to information gained from three sources:

- the wide-ranging literature review (Chapters 2 and 3);
- the survey of design management practice (Chapter 5); and
- a focused literature review of relevant publications on data collection methodologies used in professional offices which is presented in Section 6.2.2.

The following common themes emerged from the literature and were supported by the findings of the survey. It was essential that personnel appointed to the design team should be made fully aware of the design brief and of their role and responsibilities in the fulfilment of the brief. To achieve this, these duties should be recorded in writing and the records must include target inputs and completion dates (Institution of Structural Engineers, 1991). Other authors (Diekmann and Thrush 1986) identified the importance of design teams having "ownership" of the design cost estimate and programme which would increase their motivation to adhere to budget and meet critical dates. Shared ownership of the cost control data would be equally important. The necessity of providing feedback on actual costs in a structured form to cost estimators was identified by Ogunlana (1991).

Several authors (Institution of Structural Engineers, 1991; Rowdon and Mansfield, 1989; Dowling 1990) described the use of design team programmes for all the activities of analysis, design and detailing. This approach required the use of the smallest practicable work packages for planning and estimating. The overall progress on the project was determined by aggregating the progress on each of the constituent work packages and this information was presented graphically. Other authors (Suarez and Green, 1988; Buckthorp, 1990; Coles, 1992) suggested the use of indices for measuring and reporting but these would appear to lack the ease of interpretation of the graphical output.

Diekmann and Thrush (1986) described design management systems in the United States of America and highlighted some features of the systems which matched the conclusions drawn from the interviews. Projects were broken down using work packages to an appropriate level of detail for planning and cost estimation. However, in order to keep management information to manageable levels, actual person-hours were not allocated to specific individual work packages but to groups of work packages. Progress was measured using a count of physical production of documents and by comparing "earned value" with predetermined project milestones. The authors concluded that small computers would offer enhanced prospects for project control.

With regard to programming techniques most authors (Gray et al, 1994; Diekmann and Thrush, 1986; Dowling, 1990) considered that network analysis was inappropriate for design process programming because of the need for the exchange of information during the process. The dependencies between activities were neither clearly identifiable nor fixed. It was concluded that, even in a small project, the volume of interactions and their complexity would swamp a network. Consequently, the degree of representation of dependencies that was possible in a simple bar chart was more appropriate. This was confirmed in the conclusions from the survey of design practice.

Sawzuk (1992), in common with the other authors, noted the need for planning followed by cost control during the design process but did not highlight the need for a link between cost control and planning systems (see Figure 3.2). Without this link, project review information can not be used in the cost estimation stages of new projects. The absence of such a link was also confirmed in the survey of design management. A prime function of the data collection methodology was to create such a link between the organisations cost control and estimating systems.

To summarise from the above, a specification would have to be devised for the data collection system for the case study which gave due regard to the following aspects:

- the cost estimate and the cost control data should be the "property" of the design team;

- the cost estimate should be derived by breaking the project down to the smallest practicable work packages;
- the cost control data should be collected against the smallest practicable work packages to enable useful data to be produced for future cost estimating;
- a bar chart approach to programming the work should be adopted; and
- a graphical output system which is readily assessable by the design team should be provided.

### 6.2.2 Data collection methodology

All organisations interviewed operated some form of cost monitoring system, although these were generally not sophisticated and often relied on the abstraction of data from hand prepared time sheets. This function was performed centrally in all of the organisations and often in a location remote from the design teams. Feedback to the design teams was normally provided on a monthly basis in the form of a printout of budgeted and actual hours expended. The level of detail of the cost reports varied; in some cases the costs related only to the whole project; in others the projects were broken down to a limited number of major work packages. Most cost control systems were developed in house using standard spreadsheet and database software packages. The literature described above did not provide details of the nature of data collection systems except in one case (Rowdon and Mansfield, 1989) where a manual time sheet system was described. The literature review was extended to seek examples of time monitoring in professional practice in other sectors.

Schie (1990) described a system similar to the above for the management of small construction projects, although the initial project programme was developed using a critical path method and was then converted into a bar chart. The use of the critical path approach conflicts with opinions of other authors (see section 6.2.1) and Schie does not produce any convincing arguments to justify the need for the more advanced planning technique. The system described by Schie used a spreadsheet to produce a graphical comparison of planned progress with actual cost and actual progress. Schie's cost monitoring system was similar to that shown in Figure 3.1 in section 3.1 except that planned cost and planned progress are represented in percentile terms by a single line which is described as the "baseline". The justification for this approach was that rate of expenditure and rate of production should be equivalent, *"spending 35 per cent of the dollars will result in 35 per cent of the product completed"* (p 43). This baseline was then used to compare *"actual costs"*, derived from time sheets, and *"production"* based on the projects manager's estimate of the degree of completion of the project.

Postula (1991), in the context of software engineering development projects: agreed with the previous authors that effective project management requires the identification and clear definition of tasks that need to be accomplished; and recommended the development of an appropriate work breakdown structure (WBS) approach which could be applied across an organisation to identify and define the standard tasks that need to be accomplished in each project. He identified three features of the WBS approach that are particularly pertinent to design management:

- Each WBS element should be defined by a "dictionary" that describes the cost content and the technical content, and provides a statement of the work to be performed. This becomes a central communication tool to convey to all involved in the project the requirements of each package and their relationship with other packages.
- This definition enables the design manager to determine the resource requirements for each element.
- The WBS framework can be applied consistently across the organisation and thereby can become a means of accumulating a database of actual costs against well defined packages of work.

There was no evidence from the survey of design practice that organisations had developed a standard WBS that was applied across the organisation, although current developments in construction management research would suggest that such a development would be timely. These developments are:

- the concepts of concurrent engineering and business re-engineering and the process mapping that is associated with the re-engineering process;
- the promotion of the use of Co-ordinated Project Information (CPI); and
- the increasing interest in construction productivity and the use of benchmarking.

Jaffari (1997) describes concurrent construction (CC) as being derived from concurrent engineering and defines it as;

> *"... an integrated approach to the planning and execution of all project activities, from the conceptualisation stage through to the handover of the facility"* (p 427)

He further notes that the development of an integrated work breakdown structure is a key requirement of the CC approach. Having identified the packages, activities with a high affinity to each other must be grouped on a process map and then managed as an integrated whole in order to ensure efficiency in the operation of the project. He suggests that successful implementation of the CC approach may lead to:

*".... a revolution in the industry as the entrenched approaches to procurement, contracting, on-site work organisation and so on will be challenged and remodelled."*

Although he did not use the term, Jaffari was describing the Business Process Re-engineering (BPR) approach which was reviewed by Betts and Wood-Harper (1994). In this paper the authors propose the use of process maps as an alternative to simply mapping the current work breakdown structure. They argue that a process view is concerned with a customer-driven view of the appropriateness of tasks rather than examining the way in which current tasks are undertaken. BPR also considers the application of information technology, but not in the context of automation of existing systems but in the context of its contribution to process improvement.

Regardless of whether a task driven or process driven approach to the identification of work packages were adopted the key issue in the design of an appropriate data collection methodology is to ensure that consistent data is collected across the organisation. Kang and Paulson (1997) suggest that the adoption of a standard information classification system;

*".... enables management of similar projects by a standardised method and facilitates applications of a computer system for information management."* (p 419)

The authors review a number of standard information systems and note that a Unified Classification for the Construction Industry (Uniclass) is currently under development (National Building Specification Service, 1996) which overcomes problems of complexity and impracticability of previous classification systems.

McKim (1990) supported the use of WBS in securing effective project control and stated that total project control can theoretically be established by setting up control cycles, similar to that shown in Figure 3.5, for each work package. He noted that this is often impossible because the organisation's WBS is too incomplete, or inappropriate, to allow its application to individual projects or that the reporting systems are too slow to permit effective action to be taken. Furthermore, the identification of a high number of work packages (as would be required in the estimation of design fees) would result in a cost control system of such complexity that it would be unmanageable or excessively expensive to operate. McKim suggested that adequate cost control can be achieved by identifying the key cost components of the project and concentrating the cost control system on these items. Kharbanda, Stallworthy and Williams (1987) supported this view and stated that an effective cost control system should comprise *"simple controls applied early not sophisticated controls applied late"* (p 22).

Smith (1989), in the context of accountancy practices in the United States, identified three possible approaches to the time management problem:

- to identify tasks, set priorities and mentally analyse compliance with schedules without keeping records; or
- to occasionally keep a time log for one or two weeks and to repeat this on an infrequent basis and then analyse the results for any trends; or
- to keep a continuous record of times spent on all activities.

Smith concluded that the first approach suffered the major disadvantage that employee's recollections of how time has been spent is rarely accurate, and whilst the second approach could provide representative data to illustrate the extent of productive (billable) time against non-productive time, only a continuous record of time would allow any meaningful analysis to be made. He identified two problems with continuous data collection, firstly the cost in terms of time and effort of each employee recording time spent on each task and secondly the tendency for professional staff to *"feel that keeping track of and analysing specific use of time is more time-consuming than it is worth"* (p 17) which introduces great uncertainty in the validity and accuracy of the data produced. Similar reservations on the potential value of adopting rigorous project monitoring systems to the provision of professional services have been identified earlier in the context of civil engineering design (Rowdon and Mansfield 1989); and were also evident in a study of design management practice in electrical engineering design during the product development process by Albano and Keska (1990). Ellwood (1991) presented a study of the relative costs of treatment in the national health service and concluded that the large variances in unit costs were likely to be more a result of the crude nature of the costing approaches than to real differences in treatment patterns and the cost of the resource inputs.

Smith (1989) suggested that the problem of encouraging commitment to an accurate data collection process could be partially overcome by implementing a straightforward data collection system utilising spreadsheets which involved direct entry of time data by each employee at the end of each day. This, he argued, would address concerns of employees by reducing the time required to collect continuous data and the direct input of data daily by staff would reinforce the importance of daily time management and give ownership of the data to the staff. In a subsequent paper (Smith and Albright, 1989), the authors described the operation of the spreadsheet system in parallel with a standard database package in which the data collected by the spreadsheet system were input monthly to the database for analysis and the production of management accounting information. They concluded that this system provided a number of benefits:

- feedback was provided directly to employees;
- patterns of employee time-use were identified; and
- a database is assembled which can enable managers to monitor and compare the relative performance of individuals.

Leonard (1990) reviewed the development of time monitoring systems in accountancy practices in the United States and noted that early systems operated on a continuous data collection basis with manual time sheets data being input centrally. However, several organisations have recently been considering the expansion of their systems to encompass the analysis of the effective use of time and the provision of planning data to allow target budgets to be set. Leonard argued that more frequent data entry, perhaps on a daily basis, would increase the usefulness of the system and improve the accuracy of the data collected by reducing the tendency for employees to complete time sheets on an infrequent basis, estimating time spent on each activity on the basis of their recollection of the actual time spent on during the reporting period. This, she argued, could be achieved by the regular entry of time data by each employee directly into the cost control system via a networked personal computer on their desk.

The tendency towards daily data entry was also noted by Levi (1989) in his paper on the requirements of a good time management system for accountancy practices in the United States. He suggested that data capture from time sheets by central operators may be acceptable, provided that the layout of the data entry screen of the data collection system was similar to that of the time sheets. This would speed up data capture times, reduce necessary staff training and lead to reduced possibilities of erroneous data entry. Levi also stated that the retrospective correction of data entry errors and of changes in charge out rates should be readily accommodated in the system.

The literature from providers of professional services described a range of approaches to time management which was consistent with that identified by the interviews and questionnaire survey of design organisations. This has confirmed that the specification for the data collection system given at the end of the previous section were appropriate. In addition, further guidance was obtained on the nature of the data collection methodology. To summarise, the essential features of the methodology were that:

- a WBS approach should be used and applied across the organisation to facilitate the use of common definitions of work packages;
- the level of development of the WBS for cost control must be such that the system is manageable but it could be less well developed than that required for cost estimation;
- simple control mechanisms should be developed which can be applied early;
- there was a need for more frequent data entry which was best facilitated by direct entry of data by employees; and
- retrospective correction of erroneous data, data entry updates of missing data, or changes in charge out rates should be readily accommodated.

It was concluded that a spreadsheet based system similar to those described in the papers reviewed above would be most appropriate for two reasons. Firstly, it enables a simple system to be developed and supported by the computer facilities now available within most design organisations. Secondly, it is capable of being operated by the design team which would enable frequent data input and permit ease of access to feedback on levels of performance.

### 6.2.3 The system design

Mathews (1987) considered that the prime consideration in the design of any project management system was the way in which it would be applied by an organisations and, in providing a conceptual framework for project management software stated that:

> *"the use of software is bounded by the needs experience and cognition of the user, along with the processes and procedures* (necessary) *to produce a product"* (p 71).

He also identified areas of concern with respect to the interface between the software and user which included:

- the way in which the system interrelates with those who it serves with particular reference to job design and job productivity;
- the way in which the data are collected, stored and maintained; and

- the extent to which the software is well structured, consistent and comprehensible to the user.

Consideration was first given to the interaction between the user and the system and, by addressing the specification for the data collection methodology which was presented in Sections 6.2.1 and 6.2.2., the data inputs and outputs for the system were developed by the author as follows.
The input to the system involved three components:

- the development of the project programme which enabled planned progress to be determined, and associated with this;
- the build up of the fee estimate to enable planned costs to be determined; and
- the cost monitoring system which enabled actual costs and overall actual progress to be determined.

The components of the input system involve a project bar chart (Appendix C), spreadsheets for building up the cost estimate (Appendix D) and spreadsheets to permit the direct entry of weekly time sheet data and the project managers estimate of actual physical progress on each work package (Appendix E).

The output from the system served the two purposes as shown in Figure 3.2 namely: the provision of monitoring information for the project under consideration, and the provision of planned and actual cost data for a database of historic costs. The most appropriate output for monitoring a project was deemed to be a record of planned progress (which would also represent planned cost), actual progress and actual cost and this could either be viewed on screen or printed on hard copy in tabular or graphical form. The output system consisted of a master spreadsheet (Appendix F) to collate and process the input data and produce tabular and graphical output (Appendix F and Figure 6.2). The interaction between the various components of the system is shown in Figure 6.1.

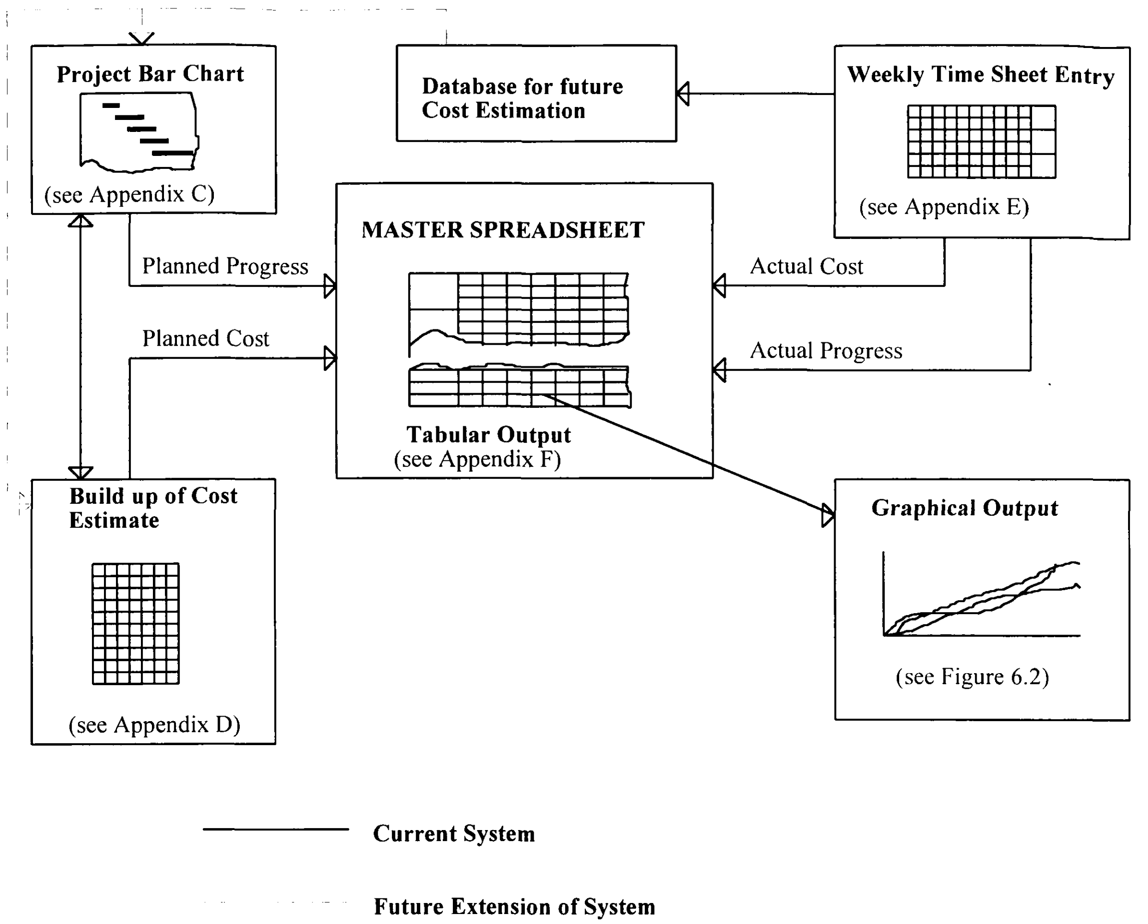



**Figure 6.1: - Diagrammatic representation of the data collection and cost monitoring spreadsheet system**

### 6.2.4 Project bar chart and cost estimation system

The cost estimation spreadsheet was designed by the author to assist in the arithmetic process of building up the initial cost estimate. The spreadsheet (see Appendix D for examples) allowed the project managers to use a two level work breakdown structure (see Figures 6.3 and 6.4) in the cost estimate, and at the second level to input their estimate numbers of the person-hour requirements of the various grades of staff. The spreadsheet then calculated the costs, using standard charge out rates for staff grades, for each of the level two work packages and the total costs for each level one work package. The level one work package totals were then transferred to the master spreadsheet for further analysis. In parallel with the development of the estimate the project managers developed a programme in the form of a bar chart (see appendix C). This allowed planned progress to be entered manually to the master spreadsheet, in terms of the weekly percentage completion of each level one work package. The spreadsheet was configured in such a way that no further data entry for planned progress was required when a work package was 100 per cent complete.

### 6.2.5 Time sheet entry spreadsheet

The time sheet entry spreadsheet (see Appendix E for examples) enabled the project managers to input, on a weekly basis, the actual person-hours expended by the various grades of staff on each level one work package. It was decided by the author, following consultation with the engineers involved in the case study and in light of the information from the literature review, that it would not be practicable to collect cost data against each level two work package as this would have made the completion of time sheets complicated and time consuming. This would have reduced the likelihood of the supply of accurate and continuous data from all design staff involved in the project. The spreadsheet then calculated, using the appropriate charge out rates, the actual cost of each work package (ACTCOST). The project managers were also required to input, on a weekly basis and in percentage terms, their estimate of actual progress on each level one work package (PERCOMP).

### 6.2.6 Master spreadsheet

**Project Planning Stage**

The master spreadsheet (see Appendix F for examples) read the appropriate cells of the cost estimation spreadsheet, and using the estimated weekly planned progress figures which had been input as described above, performed calculations of:

- the total cost estimate for the project;
- the percentage that each work package contributes to the total cost (PERCONT); and
- the weekly overall planned progress for the project which was given by

$$\sum_{i=1}^{n}(PERPLAN \times PERCONT)$$

where, n = number of work packages.

The weekly overall planned progress appears on a cumulative basis on the first row of the project totals section at the foot of the master spreadsheet.

**Project Monitoring Stage**

The master spreadsheet read the appropriate cells of the time sheet entry system and placed the values of:

PERCOMP; and

(ACTCOST/Estimated total cost of work package x 100)

in the second and third rows respectively of each work package to give in percentage terms the actual cost and actual progress. The spreadsheet also performed calculations of:

- the total weekly overall progress on the project which was given by

  $$\sum_{i=1}^{n}(\text{PERCOMP} \times \text{PERCONT})\text{; and}$$

- the total weekly overall cost on the project which was given by

  $$\sum_{i=1}^{n}(\text{ACTCOST})/\text{Estimated total cost of the work package);}$$

  where n = number of work packages.

The weekly overall actual progress and actual cost appears on a cumulative basis on the second and third rows of the project totals section at the foot of the master spreadsheet.

The project manager was then able to gain immediate access, on a weekly basis, to the outcome of the project monitoring exercise and could view the data either in tabular form on the master spreadsheet or in graphical form as shown in Figure 6.2 with the three rows of project totals on the table forming the three lines on the graph.

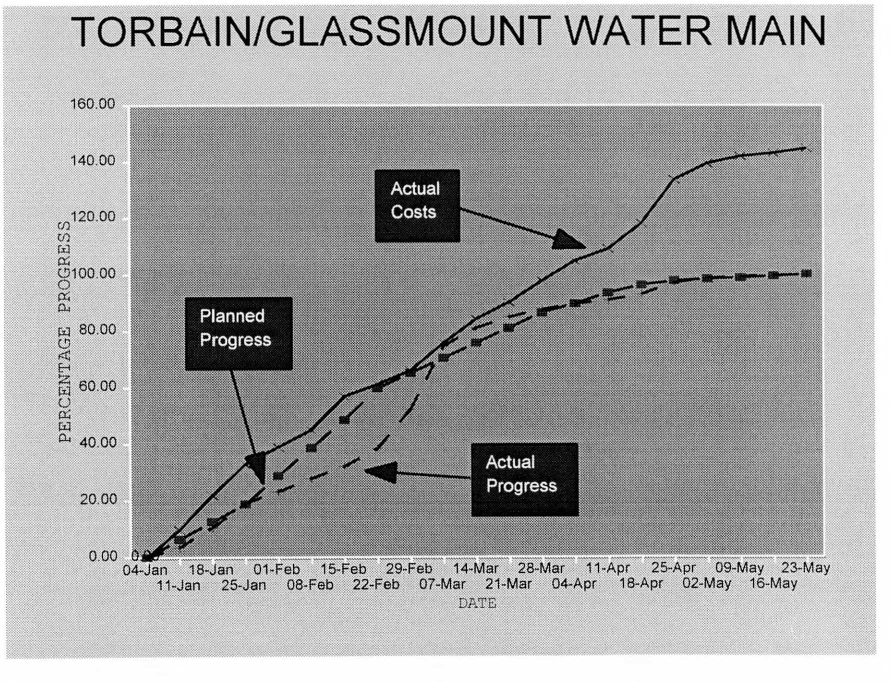



**Figure 6.2 : Graphical output from data collection system**

## 6.3 IMPLEMENTATION AND OPERATION OF THE SYSTEM

### 6.3.1 Selection of the case study organisations

Section 4.4 presented the justification for a case study approach to data collection that would involve a limited number of organisations. In view of the focus of the research and collaborative nature of the project, the North of Scotland Water Authority (who were at the time of the study Tayside Regional Council Water Services Department) was identified as being appropriate. It was, however, considered prudent to involve other similar organisation to provide some evidence on the wider applicability of the system whilst producing data that might be expected to be reasonably consistent. It was clear that the installation and monitoring of the performance of the data collection system would involve considerable input from the researcher and therefore organisations that were in reasonably close proximity to the University deemed to be most appropriate. Two were selected: the Glenrothes office of East of Scotland Water (who were at the time of the study Fife Regional Council Water Services Department) and the Waste Water Technology Centre at the University of Abertay Dundee.

### 6.3.2 Integration with the organisations existing systems

The two water departments' current design management systems were very similar. In both cases, the key objective in managing design work in the department had traditionally been to ensure that: the departments' capital expenditure programme was adhered to; and the engineers used available staff to ensure that tender documents for the various projects were issued on time to ensure the appropriate rates of expenditure on the new projects. The cost of the design services had not been a specific issue, and whilst design managers would strive to ensure the most efficient use of staff, no formal system of measuring efficiency existed.

In one local authority, employees were required to complete a four weekly time sheet and this was passed to the administration section for transfer to a computerised control system which produced a quarterly summary of expenditure on each project. Filling in time sheets for a complete four week period was found to be laborious by staff, and the information produced was of little interest to staff because of the delay in the production of the cost reports and the lack of relevance of their contents. Consequently they were completed without any particular care which made the information collected of limited value. The quarterly reporting system produced feedback which was too late for corrective action, and there was no cost target for each scheme to enable a comparison of actual and planned costs to be made. However, in response to a perceived need to demonstrate their ability to provide cost effective services, and in order that the department prepare itself for the possible introduction of compulsory competitive tendering for local authority professional service, a weekly time sheet system was being introduced at the time of the case study and target costs were being established for each project. Initially, these were set at eighty per cent of the ACE fee scales and design managers were also required to produce an estimate of their perceived design resource requirements inputs for projects as a further comparison.

In the second local authority, the overall cost of the in-house design services had been measured as a percentage overhead on the capital budget and the effectiveness could be monitored on a year on year basis. They had, for about two years prior to the case study, instituted a weekly time-sheet system with the data being abstracted by administrative staff for input to a dedicated software system. Actual costs were provided on an infrequent basis and at one point there was a significant backlog of time sheets to be input to the system. Again, there was no target cost figure for each project and the cost reports on projects were a matter of interest only. At the time of the case study the authority were reviewing their data collection strategy to identify ways of producing more regular and more useful feedback from the cost reporting system.

The Waste Water Technology Centre was established at the time of the case study and had devised a time sheet and cost reporting system, but had little experience of the operation of the system or of cost estimation for project fees.

In each case, the organisations had limited data and limited experience in developing cost estimates for design services. None of the organisations had devised a standardised WBS for projects so cost data was not available for assisting the engineers in the build up of the cost estimate. However, in the case of the second local authority, a quality assurance system had been developed and the various procedures could serve as a useful alternative to a formal WBS.

None of the organisations' cost monitoring systems were sufficiently developed to collect costs to the WBS level required in the case study (the first level) and therefore the design teams involved were required to use the weekly time sheet entry spreadsheet to collect cost data.

### 6.3.3 The case study projects

It was decided that the case study should involve projects with a range of durations in the different organisations, but it was realised that the number of projects would have to be restricted to enable the data collection to be effectively managed and monitored. A total of four projects with durations of between two to sixteen months, and estimated resource input requirements of between 300 and 1000 person-hours, were selected from the three organisations. The capital costs of the projects were estimated to range between £200,000 and £750,000. The questionnaire survey demonstrated that the majority of design projects were in this cost range. (see Table 5.4).

**Project A.**

Project A comprised the full range of services for the in-house design of a water main extension, with an initial total fee estimate of approximately £7,500. The project was managed by an experienced Civil Engineer who had recently joined the authority from a firm of consulting engineers and had therefore had some ten years of experience of fee cost estimation practice in the private sector. The project was broken down into six work packages at level one of the WBS with up to ten sub-packages at the second level as shown in Figure 6.3. Having identified the level 2 work-packages the engineer considered that he was able to estimate, based on intuition and experience un-supported by historic cost data, the required input from the various grades of staff for each work package.

**Project B.**

Project B comprised the full range of professional services for the design a sewage treatment plant with an initial total fee estimate of £20,000. The project was managed by an experienced engineer whose career had substantially been in local government. It was initially envisaged that Project B would comprise ten work packages at level one of the WBS with up to four sub-packages at the second level as shown in Figure 6.4. On developing the estimate the estimator decided not to use work package 3 and this has been omitted from the figure and from subsequent cost models. Again the engineer estimated the staff input in an intuitive manner.

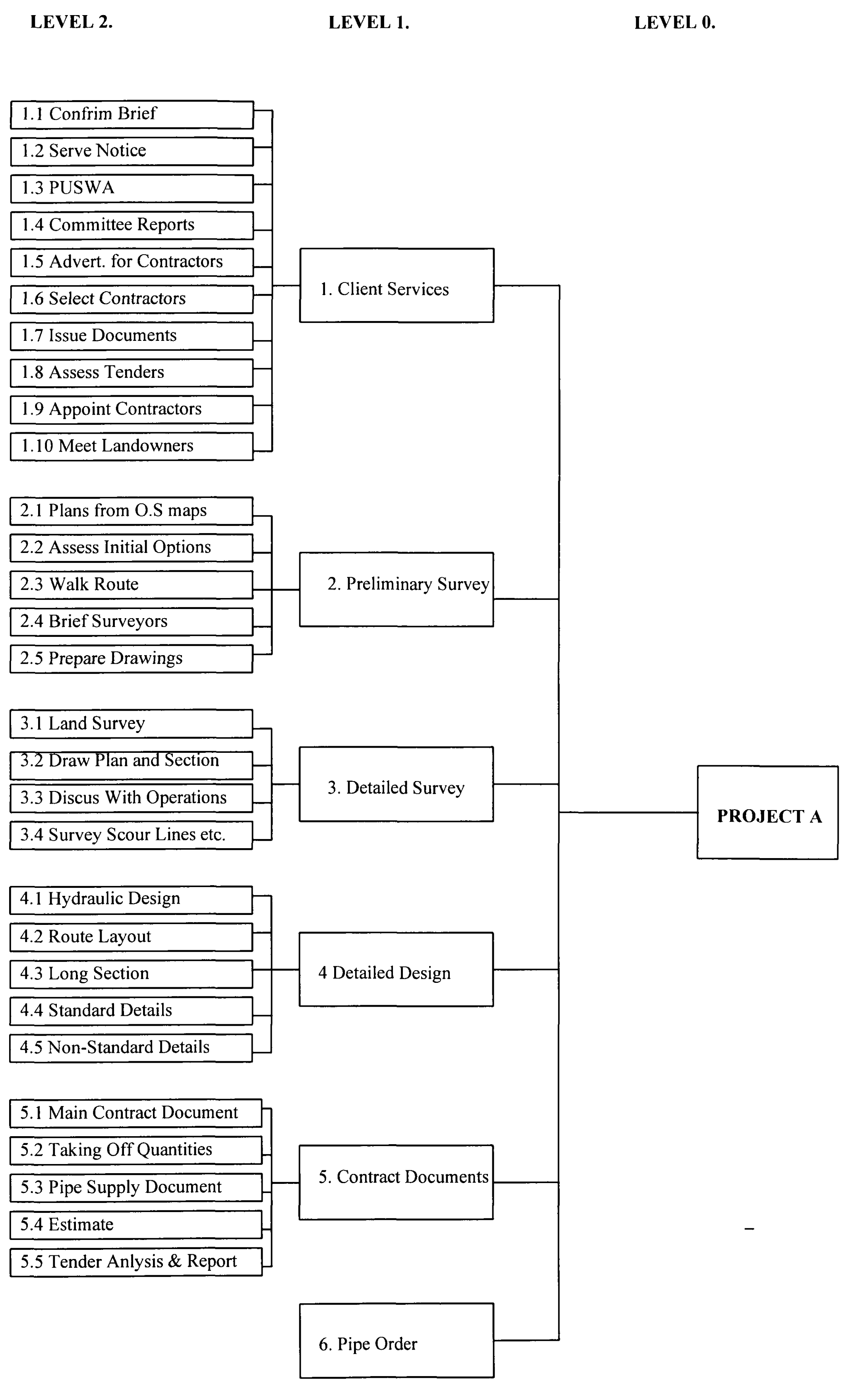



**Figure 6.3: - Project A work packages**

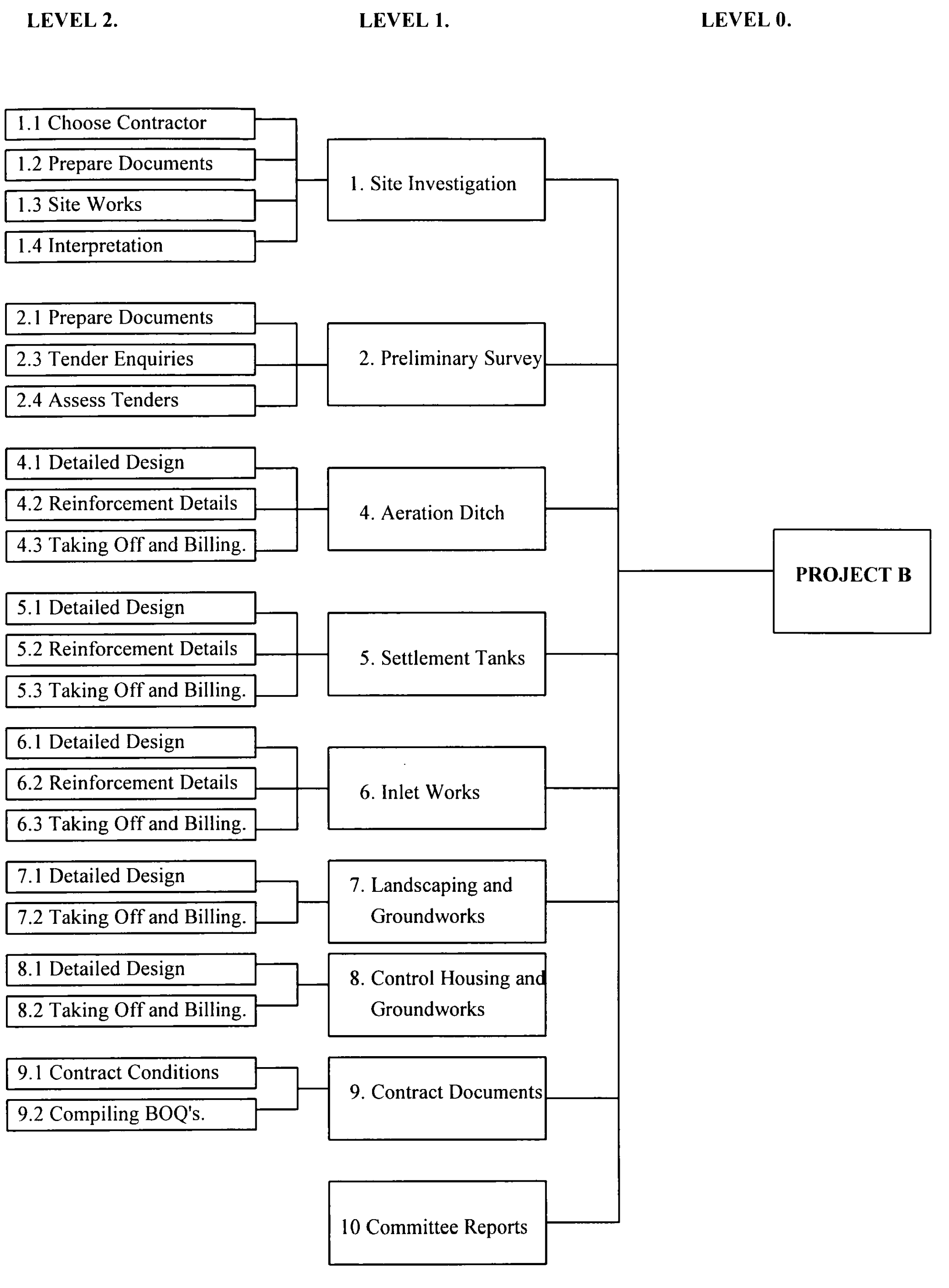



**Figure 6.4: - Project B work packages**

**Project C.**

Project C comprised the detailed design and preparation of contract drawings for a sewer replacement project with an initial fee estimate of £16,000 to be carried out over a short period. The project was managed by an experienced engineer whose career had been entirely within the department and who identified difficulties in the preparation of the cost estimate due to his inexperience in costing and quantifying design resource input to projects. Project C was broken down to seven work packages at level 1, and it was decided that this provided sufficient detail for the cost estimate with the required staff input being estimated intuitively. During the project design work packages 6 and 7 were passed to members of another team and no actual cost data was collected. The work breakdown structure for cost modelling is shown in Figure 6.5. The reference number prefixed by QP for each work package relates to Quality Assurance procedures in the organisations quality manual.

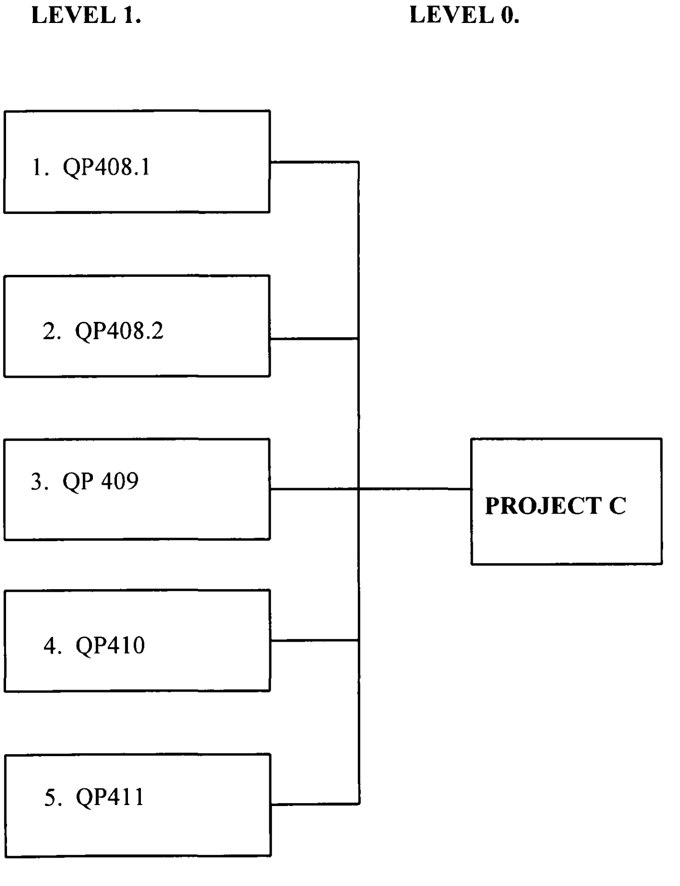



**Figure 6.5: - Project C work packages**

**Project D**

Project D comprised the construction and verification of a hydraulic model of the sewerage system for a very large urban catchment and had an initial fee estimate of £57,000. The project was managed by a team which had experience of hydraulic modelling but no cost estimation experience. This was the first occasion in which the organisation had submitted a competitive fee bid for such a large project. The list of work packages identified for this project were as follows:

- Assess existing data;
- Upgrade manhole records;
- Inspect principal overflows;
- Set up wallrus model;
- Test model;
- Flow survey (short term);
- Model Verification;
- Assess overflows;
- Develop upgrading measures;
- Consultation/liaison; and
- Project Management

In this project the variances between the cost estimates and the actual costs for the first two work packages became very large in the early stages of the project, partially due to the inexperience of the estimators who had to determine the required resource input in an intuitive basis, but also due to major changes in the clients requirement for the level of detail of the model. The total project costs were re-negotiated and the costs monitored using the spreadsheet system, but on a whole project rather than work packages basis. Consequently, no useful data was available from this project. It was interesting to note that payments for the additional work as a result of the changes required by the client, partially compensated for the degree of underestimation of the initial costs and enabled the project to produce a cash surplus on a direct costs cost multiplier of 1.2 instead of the desirable 2.4 (see Section 5.2.1).

### 6.3.4 Data collected

The following data were available from projects A, B and C for the cost model:

- estimated person-hours and costs broken down to the level 2 work packages, as shown in Appendix D; and
- actual person-hour and cost data for level 1 work packages.

The data can be applied to the cost model in three forms (O'Keefe 1994):

- disaggregated person-hours, i.e. total person-hours grouped by grade of employee;
- aggregated person-hours i.e. total person-hours on the work packages; and
- total cost which will be a cost weighted equivalent of aggregated hours.

An analysis of the accuracy of the estimates of disaggregated person-hours, aggregated person-hours and cost was undertaken and the results are presented in Tables 6.1, 6.2 and 6.3 below. A scale was devised to represent estimating accuracy in terms of the inaccuracy of the initial estimate when compared to the actual person hour requirements as follows:

$$\text{Estimating Inaccuracy}(\%) = \frac{\text{Actual Value}}{\text{Estimated Value}} \text{ X } 100$$

This scale ranges between 0 per cent and $+\infty$ percent and with 100 percent representing total accuracy. The magnitude of the inaccuracy is represented by the distance from the 100 per cent point of the scale.

**Table 6.1: - Estimated and actual disaggregated person-hour data for level 1 work packages**

| | Estimated Person-hours | | | | Actual Person-hours | | | | Inaccuracy (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Project A** | | | | | | | | | | | | |
| **Grade** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| **WP1** | 33 | | 7 | | 82 | | 60 | | 248 | | 857 | |
| **WP2** | 44 | | 16 | | 71 | | 10 | | 161 | | 63 | |
| **WP3** | 7 | | 10 | 0 | 19 | | 6 | 9 | 271 | | 60 | n/a |
| **WP4** | 13 | | 29 | | 28 | | 139 | | 215 | | 479 | |
| **WP5** | 42 | | 66 | | 47 | | 132 | | 112 | | 200 | |
| **WP6** | 17 | 10 | 10 | | 19 | 36 | 37 | | 112 | 300 | 360 | |
| **Project B** | | | | | | | | | | | | |
| **WP1** | 14 | 42 | 7 | | 0 | 1 | 0 | | n/a | 2 | n/a | |
| **WP2** | 42 | 71 | 0 | | 22 | 157 | 1 | | 52 | 221 | n/a | |
| **WP4** | | 84 | 63 | | | 51 | 32 | | | 61 | 51 | |
| **WP5** | | 70 | 35 | | | 55 | 65 | | | 78 | 185 | |
| **WP6** | | 136 | 105 | | | 83 | 65 | | | 61 | 62 | |
| **WP7** | | 56 | 49 | | | 23 | 36 | | | 41 | 73 | |
| **WP8** | | 56 | 49 | | | 10 | 18 | | | 18 | 37 | |
| **WP9** | | 42 | 0 | | | 41 | 3 | | | 98 | n/a | |
| **WP10** | | 54 | 72 | | | 91 | 111 | | | 168 | 154 | |
| **Project C** | | | | | | | | | | | | |
| **WP1** | | 0 | 15 | 54 | | 5 | 1 | 62 | | n/a | 7 | 115 |
| **WP2** | | 0 | 0 | 290 | | 20 | 38 | 370 | | n/a | n/a | 127 |
| **WP3** | | 54 | 54 | 145 | | 19 | 38 | 182 | | 35 | 70 | 126 |
| **WP4** | 36 | 36 | 73 | 0 | 22 | 26 | 23 | 58 | 61 | 72 | 31 | n/a |
| **WP5** | | | 40 | | | | 11 | | | | 28 | |

**Table 6.2: - Estimated and actual aggregated person-hours and costs for level 1 work packages**

| | Aggregated Person-hours | | | Cost (£) | | |
|---|---|---|---|---|---|---|
| **Project A** | | | | | | |
| | **Estimated** | **Actual** | **Inaccuracy** | **Estimated** | **Actual** | **Inaccuracy** |
| **WP1** | 40 | 142 | 355 | 1216 | 4001 | 329 |
| **WP2** | 60 | 81 | 135 | 1609 | 2774 | 172 |
| **WP3** | 17 | 34 | 200 | 487 | 893 | 183 |
| **WP4** | 42 | 167 | 398 | 867 | 3081 | 356 |
| **WP5** | 108 | 179 | 166 | 2353 | 3567 | 152 |
| **WP6** | 37 | 85 | 229 | 901 | 1798 | 200 |
| **Project B** | | | | | | |
| **WP1** | 63 | 1 | 2 | 1457 | 31 | 2 |
| **WP2** | 113 | 180 | 159 | 2834 | 4108 | 145 |
| **WP4** | 147 | 83 | 56 | 2666 | 1618 | 61 |
| **WP5** | 105 | 120 | 114 | 2052 | 2245 | 109 |
| **WP6** | 241 | 147 | 61 | 4367 | 2835 | 65 |
| **WP7** | 105 | 59 | 56 | 1866 | 1081 | 58 |
| **WP8** | 105 | 28 | 27 | 1831 | 507 | 28 |
| **WP9** | 42 | 44 | 105 | 914 | 989 | 108 |
| **WP10** | 126 | 202 | 160 | 2153 | 3265 | 151 |
| **Project C** | | | | | | |
| **WP1** | 69 | 68 | 98 | 996 | 900 | 90 |
| **WP2** | 290 | 428 | 147 | 3480 | 5824 | 168 |
| **WP3** | 253 | 239 | 94 | 4425 | 3562 | 80 |
| **WP4** | 145 | 128 | 88 | 3679 | 2516 | 68 |
| **WP5** | 40 | 11 | 28 | 920 | 253 | 28 |

**Table 6.3: - Estimated and actual aggregated person-hours and costs for projects**

| | Aggregated Person-hours | | | Cost (£) | | |
|---|---|---|---|---|---|---|
| | **Estimated** | **Actual** | **Inaccuracy** | **Estimated** | **Actual** | **Inaccuracy** |
| **PROJECT A** | 304 | 688 | 226 | 7432 | 16115 | 217 |
| **PROJECT B** | 1047 | 864 | 82 | 20139 | 16945 | 84 |
| **PROJECT C** | 797 | 874 | 110 | 13500 | 13054 | 97 |

Table 6.1 shows extremely large discrepancies between the estimates of the dis-aggregated person-hours and the values which range from 2 to 857 per cent of the initial estimate. This provides clear evidence that the planned usage of the various grades of engineers is significantly altered during the execution of the project and suggests that an estimate of the dis-aggregated hours may not be a useful indicator of actual resource requirements. In fact, in a number of cases an allowance has been made for a grade of engineer that has subsequently not been used, and in others a grade of engineer has been used when no allowance had been made. In these cases (shown as n/a in the inaccuracy column) it is not possible to indicate an inaccuracy value.

Tables 6.2 and 6.3 show that the difference between the actual and estimated values decrease as the estimate is accumulated, firstly to aggregated hours and work package costs then to whole project hours and costs. Table 6.2 shows that the actual aggregated person-hours were within a range of 2 to 398 per cent of the estimated values whilst Table 6.3 shows that the accuracy of estimates for the project total ranged between 82 to 226 per cent of the estimated value. The levels of accuracy in terms of cost and person-hours are not identical as costs represent a weighted aggregate of person-hours, but they are sufficiently similar to suggest that there is little to be gained from developing separate cost and person-hour models.

The results above are consistent with studies of the accuracy of consultants' estimates of project construction costs at the design stage. Ogunlana (1991) presented the results of a survey of estimators' accuracy when compared with contractors lowest bids for work packages and used;

$$\frac{(\text{Estimated value- Lowest Bid value}) \times 100}{\text{Loweast Bid value}}$$

as a measure of estimating accuracy. He stated that the mean accuracy of the contractors bids for a number of work packages ranged between -151 and + 301 per cent (although it is inconceivable that the relationship above could produce a figure of less than -100% accuracy) which would equate, using the measure of inaccuracy used in Tables 6.1, 6.2, and 6.3, to approximately 0 to per cent to 400 per cent of the estimated value. Notwithstanding the above, the mean inaccuracy of the estimate of the overall value of the project was approximately 88 per cent of the lowest bid (or 12.77 per cent using Ogunlana's measure) which demonstrated the overestimation and underestimation of work packages tended to compensate when combined to produce the overall cost estimate. Table 6.3 shows that only Project C showed a similar level of accuracy (i.e. ±12 percent).

There is evidence in each of the tables of a tendency for the estimator in project A significantly to under-estimate the person-hour requirements, whilst the estimators in project B tended significantly to over-estimate. The estimator in project C demonstrated tendencies significantly to both over-estimate and under-estimate certain work packages. These tendencies, or biases, are indicative of the attitudes of the estimators towards risk which will arise as combination of their personal attitudes and professional backgrounds. The estimator for project A recently joined the authority from a private practice and was accustomed to producing competitive fee bids which would involve seeking the lowest possible costs which is likely to produce the tendency to underestimate. It is also possible that the estimator would not have had the opportunity to gain experience of the productivity rates in the local authority office compared to the private practice and this might explain the magnitude of the variance between actual and estimated person hour requirements in certain work packages. The estimators for projects B and C had no experience of cost estimation and acknowledged their difficulty in producing a cost estimate, but in each case had considerable experience of design work in the local authority environment. It is also significant that in the local authority environment there was no incentive to estimate on a lowest cost basis because the projects were not let on a competitive basis and the estimates were required only for the purposes of the research project. They were therefore likely to produce a more conservative estimate of the resource requirements. Clearly a detailed study of the influence of attitude towards risk during the estimating process is out with the context of this study, but some allowance must be made for this in the cost model. Other factors which must be allowed for in the cost model are:

- the need to relate the variability in the accuracy of the cost estimates to the levels of uncertainty within the individual work packages; and
- the potential impact of the organisations cost control system on the actual activity times, particularly those occurring later in the process.

These factors are considered more fully in the development and application of the cost model in Sections 7.2 and 7.3 of this thesis.

## 6.4 DISCUSSION OF THE FINDINGS OF THE CASE STUDY

Meetings with all engineering staff involved in the case studies were held regularly throughout the data collection experiment, to provide training and assistance in the operation of the system and to enable the performance of the system to be monitored.

### 6.4.1 The operation of the planning and cost estimation system

None of the organisations had developed a standard WBS and their current cost control systems restricted the sub-divisions of projects to main stages such as; feasibility, detailed design, site supervision and client services (which were generally local government administration requirements). The case study projects each constituted one of the above stages, three being concerned with detailed design and one with a feasibility study, therefore a suitable WBS had to be identified for each project. The WBS was extended until the engineers considered that they could "reasonably" estimate the required resource requirements for the work packages and in three cases the level two WBS incorporated in the estimating spreadsheet proved to be sufficient with one being developed only to level one. The work packages at each level were readily identified by the individual project managers who expressed a preference for devising their own project specific packages rather than attempting to develop work package definitions which could be applied across the organisations.

Three out of the four project managers experienced difficulty in the preparation of the project bar chart and project cost estimate, due to inexperience of this approach to design management and the lack of availability of data from previous project to assist their deliberations. The exception was the project manager who had joined recently from a firm of consulting engineers who had been previously involved in estimating design fees. The bar chart was generally developed first, working back from the date at which the contract documents would have to issued to contractors as dictated by the department's capital expenditure programme. In every case, the project engineers considered that a bar chart of level activities of the WBS produced a sufficiently detailed project programme.

The second step involved the estimate of the necessary resources to complete to the work packages in the time available and this proved to be the most difficult stage. In one case, a top down approach was adopted where a team had previously identified to work on the project and the team members available time was distributed across the activities on the basis of the relative magnitude and complexity of the activities.

in the others, a bottom up approach was used with the resource inputs to the level two work packages being selected intuitively by the project manager.

Having identified the resource requirements, the project engineers found the cost estimating spreadsheet to be a useful tool and found the task of transferring the programme from bar chart format to percentage estimate of planned progress for each level one work package straightforward. It was noted that two of the four project managers required considerable assistance in the use of the system because of their low level of expertise in the use of spread sheet packages.

### 6.4.2 Operation of the cost monitoring/data collection system

The following procedure was devised for the operation of the cost monitoring/data collection system:

- each engineer involved in the project would complete, on a weekly basis, a manual time sheet recording times spent on each level one work package (it was envisaged that it would not be practicable to collect data against level two packages); and
- these would be passed each Monday to the project engineer who would input the composite data to the weekly data input spreadsheet and then by opening the master spreadsheet and refreshing the links with the input spreadsheet would be able to instantaneously produce and access the weekly progress reports.

Three major problems were encountered in the operation of the system. Firstly, the engineers found the task of completing the time sheets time consuming and onerous, even when the data were restricted to level one work packages, as the level of detail required was greater than the rest of the organisations cost control system. This was perceived as being a particular problem for staff who were involved in more than one project during any given time period. It was suggested that problem would severely restrict the potential for the extension of the system to cover all projects within the organisations. Secondly, the project engineer's abilities in the use of standard spreadsheet packages proved to be insufficient for the task of operating the time sheet entry spreadsheet and more particularly, the master spreadsheet. The third problem related to the hardware support. The physical size of the master spreadsheet on a long duration project, together with the number of links required to the time sheet entry spread sheets caused problems with the operation of the spreadsheets due to limitations in the available memory capacity and processing speed of the personal computers. In order to resolve the second and third problems the manual time sheets were sent weekly to the University of Abertay Dundee for input and processing, which introduced a substantial delay to the feedback loop.

A further meeting was held with the project teams on each project on its completion, to enable further feedback to be obtained once staff had an opportunity to reflect on the operation of the system. The key points emerging from these meetings were:

- that the system had provided a useful vehicle to ensure that staff were involved in the cost estimation and control and in doing so had been effective in motivating staff to "beat targets that they had themselves set";
- that the two level work package breakdown structure adopted for the project estimating spreadsheet had been useful and would be used to try to develop a standard work package breakdown structure across the organisation;
- that the graphical output of progress was particularly useful as it "provides an easy to read indication of progress and performance on the project and allows for a rapid response times in any rapid re-resourcing"; and
- that some refinement to the system would be required to "ensure that it is user friendly and caters for the involvement of a sizeable design team working on a fair number of schemes".

## 6.5 SUMMARY OF CONCLUSIONS FROM THE CASE STUDY

The data collection case study enabled the third project aim to be achieved; i.e. the evaluation of the practicality of enhanced data collection to support a more rational cost estimating approach.

The positive conclusions that can be drawn against this aim were that the case study demonstrated that it was possible to set up a cost monitoring system for single projects which would produce historic cost data, but not to the level of detail that was required for the cost estimating system. The integration between the cost estimating and cost monitoring systems encouraged the design teams to take ownership of the data which enhanced the benefits obtained from the system and which should improve the accuracy of the data collected, and through the provision of feedback improve the estimators' appreciation of their levels of accuracy.

However, the cost monitoring aspects of the spread sheet system would prove to be too cumbersome to be applied to all projects within an organisation. Some improvements in the operation of the integrated system could be achieved through the establishment of appropriate programme of staff training on the system and on the supporting spreadsheet packages and the provision of high specification personal computers. Alternatively, the planning and cost estimation aspects of the spreadsheet system could be maintained with cost monitoring data provided by the organisations current cost control system. In either case a work breakdown structure would have to be established to provide uniformity of data across an organisation and a decision would have to be made about the level of detail of data that could be provided. The case study has suggested that data against the first level of the work breakdown structure could be provided, but further work would be required to establish whether this was sustainable across an entire organisation. It would not be practicable using current time sheet approaches to provide historic cost data against the second level of the work breakdown structure.

In terms of the potential for cost modelling in the context of the case study organisations there are two scenarios which must be considered. Firstly, the current situation where the available data would be limited to historic data on whole project design costs, or on detailed data as described in section 6.3.3 above. Secondly, should the organisations choose to adopt a cost reporting system linked to an organisation wide WBS, data would become available through time from an increasing number of projects for each work package at the first level of the WBS, and cost and time frequency distributions could be developed. The potential for rational cost estimation in both of the scenarios above is considered fully in Chapter 7.

# CHAPTER 7

# COST MODELLING

This chapter describes the process of development and testing of the cost model which was required in order that the fourth and fifth aims of the project could be achieved. These were to:

- select and develop an appropriate form of model; and,
- verify the performance of the model.

This chapter describes the appraisal of the potential modelling approaches that were identified in Chapter 3, justifies the modelling approach adopted and reports on, and critically evaluates, the development, testing and verification of the model using the data provided from the case study presented in Chapter 6.

## 7.1 THE PURPOSE OF THE MODEL

In the overall context of the study, the purpose of the modelling stage was not to produce a model which could be universally applied to design cost estimation by practising engineers, but to provide evidence on the practicality of cost modelling by:

- using data which were either currently available, or might have been reasonably expected to be available in the near future; and
- using modelling approaches that are transparent, readily understood and readily applicable by design managers.

## 7.2 THE FORM OF THE MODEL

In arriving at the appropriate form of model, due consideration had to be given to the model's input, output and to the context of its application.

### 7.2.1 Model Input

The previous chapter demonstrated that it should be possible for organisations to produce historic data for cost modelling at two levels of detail:

- whole project costs could be readily provided, and this could be subdivided for larger projects into the costs of major stages such as feasibility studies, detailed design, site supervision etc.; and
- it would be feasible to provide detailed data to the first level of a WBS for the individual projects, or for the major stages of larger projects, but data of this nature were not readily available within organisations.

It was also concluded that it would not be possible to provide detailed data to the second level of a WBS, the level at which projects are generally broken down to at the cost estimating stage.

### 7.2.2 Model output and the context of its application

The questionnaire survey and interviews with design managers enabled a specification for the form of the model and its output to be devised.

Firstly, the output should be in a form that is readily applicable by design managers to an estimating process which comprised the development of an overall project cost in a bottom up manner from work packages at level two of a WBS. This overall cost was reviewed by the design managers in an intuitive manner in the light of their experience of the nature of the project, the client and the prevailing market conditions. The most valuable output from the model would be to provide an independent estimate of the overall project cost, or of the costs of the work packages at the first level or second level of WBS.

Secondly, there was strong evidence from the interviews to support the view that design managers believe that design work is not amenable to prescriptive planning and cost estimation and consequently would be sceptical about the practical use of any cost model. "Black box approaches" would be significantly less attractive than those where the underlying principles of the modelling approach are transparent and readily understood.

Finally, there was evidence from the data collection case studies that any cost model would have to be supported by hardware and software systems that are readily available to, and within the computer competency of, design managers.

## 7.3 CRITICAL REVIEW OF MODELLING APPROACHES

The literature review identified three possible cost modelling approaches and each was critically appraised against the criteria given above. The approaches were:

- parametric cost models (e.g. Boehm, 1981; O'Keefe, 1994);
- simulation models (e.g. Davis and Cochrane, 1987; Cornwell and Modianos 1990), including those used in risk analysis (e.g. Kidd, 1991; Thomson and Perry 1992; Hudson, 1992; Touran and Bolster, 1994; Uher, 1996); and
- fuzzy logic (e.g. Kangari and Bakheet, 1994; Ock 1996).

### 7.3.1 Parametric cost models

The literature review provided no evidence of the use of parametric cost models for design fee estimation. An evaluation of the potential for the practical application of this technique in the context of design work was achieved by reviewing models in other sectors against the criteria given in Section 7.2.

**Model Input**

Boehm (1981) used data collected from 63 software projects over a 15 year period (1964-79), covering a range of customer types, computer systems and programming languages, and, not surprisingly, produced a model with low reliability. The difficulty in producing such data is illustrated by the absence of the assembly of a more useful (i.e. more consistent) data set. Recent researchers in software cost estimation have used Boehm's 1979 data to investigate the application of fuzzy set theory (Fei and Lui, 1992) and neural networks (Samson, Ellison and Dugard, 1997). O'Keefe, Simunic and Stein (1994) used a larger data set based on 249 audits carried out by an international accountancy practice to examine the empirical relationships between client characteristics and both the amount and mix of labour resources. Unfortunately, whilst this paper identified the most significant parameters which affect labour requirements, no attempt was made to quantify the predictive ability of the parametric model.

The empirical models above evaluated project costs in terms of the relationship between the necessary person-hour input for a project (as an indicator of cost) and the size of a project using a single parameter to define project size. An estimated required number of computer instructions was used to represent size for software projects and the turnover of the audited organisation for the accountants models. O'Keefe makes the valid observation that it would not be possible to investigate the relationship between fees charged and project size as this would be heavily contaminated by pricing policy. In each case, the basic relationship was modified by the application of factors which allowed for specific features of individual projects.

A parametric design cost estimating model would require the following information:
- historic data on design costs measured as resource input in terms of person-hours;
- the derivation of a reliable parameter to represent the magnitude of the project; and
- the derivation of reliable parameters to represent specific characteristics of individual projects.

The in-depth interviews and questionnaire survey demonstrated that, whilst a database of historic information on the total cost of previous projects did not exist within design organisations, it would be possible for most organisations to assemble data from recently completed projects. This could comprise the total design resources that were required and the capital cost of the completed projects, which could be used as a measure of the project magnitude. The data could enable a parametric model, similar to that of Boehm, to be developed which utilised the basic relationship between design resource input and the capital cost of a project. There are, however, inherent difficulties in the application of such an approach to construction industry design work.

Firstly, a parameter would have to be established to define the magnitude of the task. Traditionally, using fee scales, an estimate of the capital cost of a project was used. As this would be produced before or during the conceptual design stage it would be an extremely unreliable indicator (Ogunlana 1991). Furthermore, the technical requirements of the design would significantly influence any relationship between capital cost and the design resource requirements, as identified in the case study projects (see Chapter 6). It would thus be necessary to produce individual cost-resource relationships for specific project types which would severely restrict the volume of available data.

Secondly, the literature review presented in Chapter 2 identified the following project specific factors which would have to be allowed for in the model:
- the extent to which the problem was previously defined by the client;
- the extent to which optimal rather than satisfactory decisions are made during the design process;

- the extent of the application of intuitive approaches rather than logical deduction to decision making;
- the necessity for creativity in the development of the solution;
- the personal attributes of the designers;
- the existence of the different procurement systems;
- the fundamental shift in recent years in the way in which design teams are appointed which has resulted in uncertainty in level of service that are provided by designers and will introduce of further variability in acquired data; and
- the change in the relative importance the above factors throughout the stages of the design process;

The development of adjustment factors for these eight categories in the design cost model would present the following serious difficulties:

- many, if not all of the factors are intangible and are not likely to be amenable to quantification by the development of a scale; and
- even if they could be quantified, data from a large number of projects would be required to allow the relationship between each factor and design costs to be fully established before assigning any coefficients (O'Keefe 1992).

It is clear that a large data set would be required for each type of design problem to allow the development of a rigorous parametric design cost model. The data would have to be drawn from recent commissions to avoid contamination resulting from changes in design practice due to factors such as: changes in procurement systems, changes in the application of information technology and the effects of fee competition on the levels of services provided. The interviews and survey have identified a lack of detailed and reliable historic data on design resource input within design organisations, and the case studies have demonstrated the difficulty in assembling such information.

**Model output and the context of its application**

A parametric model, developed as described above, might produce a single estimate of design resource requirement but with a low level of accuracy and reliability (Boehm 1982). Whilst this would provide a benchmark against which intuitive estimates could be compared, the deterministic basis of the model would limit the value of the output, although the robustness of the parametric estimate could be assessed by performing a sensitivity analysis on the key variables. However, this output would not assist the design manager in the build up of the estimate from the constituent work packages nor would it provide any indication of the relative probabilities of completing the project to a given budget.

The computational process in determining a cost estimate would comprise a simple arithmetic procedure and this would be readily understood by design managers. The calculations, and any sensitivity analysis, could be performed by a simple spreadsheet and little training would be required. Design managers would be provided with the relationships and parameter values for specific design types, together with an explanation of their derivation to ensure the transparency of the system.

The literature review has demonstrated that the design process is highly uncertain, which will reduce the likelihood that reliable algorithms can be developed. Boehm and O'Keefe have shown that it is feasible to develop a parametric model for the costs of professional services, but the results are inaccurate and unreliable. It is therefore concluded that parametric cost models could only be developed and tested if a sufficiently large data-base of recent and reliable information is assembled, however this data collection approach was discounted in Section 4.4.

### 7.3.2 Simulation and risk analysis approaches

Pidd (1992) classified systems which might be simulated as either: deterministic, where the behaviour is entirely predictable, or stochastic, where the behaviour can not be entirely predicted but where some assessment can be made about the probability of occurrence of certain events. The literature review revealed that the design process is stochastic in nature and that the process comprises a series of iterative stages. The required input to the process is greatly affected by the extent to which optimal rather than satisfactory decisions are made and, in addition Section 7.3.1 listed a number of factors that would give rise to further uncertainty in the determination of a cost estimate for a design project.

Three forms of stochastic models were identified in the literature review and these can be classified with respect to their form of logical representation of the system. The forms of model were:

- models in which "*...the real performance of the system is mimicked by unfolding the model through time.*" (Pidd, 1994, p 9) where the performance of the system is evaluated by modelling the transformation in the state of the system induced by each of the constituent activities (Davis and Cochrane, 1987; Dawson, 1988; Cornwell and Modianos, 1990);

- models which represented the programme for the project in the form of a network of activities (Marston and Skitmore, 1990; Kidd, 1991; Thomson and Perry, 1992); and
- models which represented the project in the from of a work breakdown structure (Hudson, 1992; Touran and Bolster, 1994; Uher, 1996).

The second and third approaches in the list above were described in the literature as risk analysis techniques and can be further classified in this way. The use of risk analysis is timely because this has been a developing area of construction management research (Raftery 1994).

**Model input**

Regardless of the form of the simulation model, the characteristics of the input data would be similar. Law and McComas (1990) described the stages in the development of simulation studies and stated that each source of randomness should be represented by appropriate input probability distributions. Additionally, they suggested that data should be collected on the performance of the existing system to assist in the validation of the model.

Marston and Skitmore (1990) concurred with the conclusions from the data collection case studies that empirically derived data for the definition of the probability distributions would be scarce and that the model user would often have to resort to subjective judgement. Dingle (1991, p. 30), in the context of risk analysis considered that assigning probabilities to events was *"very largely a matter of subjective judgement"*, and stated that *"There is nothing inherently problematic about using subjective probabilities provided that those who are informed about the situation being considered agree on what the values mean"*.

There are a number of examples in the literature survey of the subjective development of input distributions. Dawson et al (1990) used a panel of experts to assign the probabilities that cost estimates for civil engineering construction work were high or low, against six cost bands, and represented the input distribution using a step rectangular distribution (histogram). Hudson (1988) also produced step rectangular distributions following interviews with estimators but warned of the need to allow for the bias of the estimator in the determination of the true shapes of the distributions. Uher (1996) adopted the fractile method of eliciting probabilities (Raffia 1968) through interviews and the distributions were represented in triangular form whilst Catling and Westwood (1985) used a questionnaire survey of estimators to produce Beta distributions. Beta distributions were also used by Kidd (1991).

There were also examples of step rectangular probability distributions being developed using empirical data (Selia and Banks, 1990; Cornwell and Modianous, 1990; Davis & Cochrane, 1995). In each case this was possible because the models were of the first form identified above (as defined by Pidd, 1994) and represented a sequential process that was continuously repeated in an existing system. Thus appropriate parameters to describe the constituent activities could be easily defined and measured over a significant period of time.

The information requirements for the second and third forms of simulation model (risk analysis) are more likely to require subjective judgement to supplement empirical data. Raftery (1994) stated that:

> *"The choice of input distribution* (for risk modelling) *is not based upon the search for the true distribution for the variable in question but on the objective of modelling the estimators' perception of the range and probability of the outcomes. We are in the realm, not of repeatable statistical assessment, but of subjective definitions of probability."*

The design process is not sequential and nor does it consist of a fixed combination of activities that are consistently applied across a large number of projects. It was demonstrated in Chapter 6 that it would extremely difficult to collect a sufficient volume of empirical data to allow probability distributions for the cost of individual design activities to be constructed. This would be a significant barrier in the development of simulation models which mimic the performance of the system with respect to both cost and time.

The models which represent the project by a network of activities would require the identification of distributions for both time and cost for each of the constituent activities and the definition of any relationship between the two distributions. The cost estimation risk analysis models which represent the project using a WBS will be simpler to construct requiring only probability distributions of work package costs only.

The potential does exist to synthesise information from the following sources to produce probability distributions for the risk analysis forms of simulation modelling:

- the interviews with design managers;
- the data collection case studies;
- literature on design cost estimation (e.g. Nicolson and Popovic, 1994; Hudgins and Lavelle, 1995); and
- literature on cost estimation in other areas (e.g. Catling and Westwood 1985; Uher 1996).

The abstraction and application of this data are described in section 7.4.

**Model output and the context of its application.**

Pidd (1992) indicated that simulation modelling required the creation of a logical representation of the problem to be solved. Chapter 3 of the literature review identified models of the design process which could provide such a representation. Markus (1972), French (1975) and Gergas (1988) provided flow diagrams which represented the design process as a series of sequential decisions with feedback loops between the processes in recognition of their iterative nature. This type of model, in the form of a critical path diagram, has been used in the simulation of time and costs in construction and other projects by a number of authors (Marston and Skitmore, 1990; Kidd, 1991; Thomson and Perry, 1992). These models operated by the repetitive generation of costs and times for the constituent activities using Monte Carlo simulation followed in each case by a critical path analysis of the project network. In this way, the frequency distributions of possible overall times, costs and rates of returns of the project were determined.

There was, however, evidence that critical path methods were inappropriate for planning and estimating design work (Diekmann and Thrush, 1986; Gray et al, 1994) because the dependencies between activities were neither clearly identifiable nor fixed due to the iterative nature of the process, and because of the need to transfer information between parties as the design develops. This latter point was particularly significant because it highlights the need in design planning and estimating to distinguish between determining the times for activities, which are dictated by external factors, and the costs which are determined by the required design resource input (RIBA, 1976).

The interviews, survey and the literature review (Diekmann and Thrush, 1986; Hudgins and Lavelle, 1995) revealed that: cost estimates were developed by design managers separately from the project programmes, and in the preparation of the cost estimate, projects were broken down using work packages to an appropriate level of detail. This suggests that the WBS models of the design process (Austin et al 1993; Kim, Popescu and Hamilton, 1994) would provide a more useful logical representation for simulation modelling. The construction and operation of risk analysis models using a WBS representation and a simple additive simulation model was described by a number of authors (e.g. Dawson et al 1990, Hudson 1988, Uher 1996) and appear appropriate for this study.

The simulation models would produce a more useful form of output than a deterministic model. Instead of providing a single estimate of design costs (based on resource requirements) as a benchmark, these methods could assist the design manager further by: providing information on the probabilities of completing the project to a given budget; and on the probability distributions of the costs of each of the constituent work packages.

The computational process involved in the application of each of the simulation approaches would vary. Pidd (1994) reviewed a number of simulation software approaches including:

- writing software using programming languages such as FORTRAN, C, C++;
- using simulation programming languages such as SIMSCRIPT and SIMULA; and
- using flow diagram systems such as GPSS, HOCUS.

Selia and Banks (1990) noted that simulation languages and simulation packages would be required for developing sophisticated models of complex systems because these models provide the necessary mechanisms for advancing time in discrete event simulation, but demonstrated that it would be possible to develop a decision support simulation model using standard spreadsheet. The majority of the simulation models reviewed in Section 3.4.1 were also based on spreadsheets, with more recent papers describing the use of the @RISK package which can be used with the EXCEL spreadsheet package.

This use of @RISK and EXCEL would be particularly attractive for this study since it would satisfy the ease of application criteria since spreadsheet packages are readily accessible to design managers and generally within their computer competency, although some training would have to be given, particularly on the use of @RISK. Furthermore, to further ensure the transparency of this form of model, it would be necessary to involve design managers in the development of the constituent distributions (Dingle 1991), but this involvement is essential in the development of any design cost estimate (Diekmann and Thrush, 1986).

### 7.3.3 Fuzzy Set approach

Fuzzy set theory is attributed by most authors to Zadeh (1965) and provides a conceptual framework and a mathematical tool to solve real physical problems which are often obscure or indistinct, and involve a high degree of uncertainty. Kruse, Geberhardt and Klawonn (1994) describe the philosophy behind the fuzzy set approach as being to simplify complex systems by the toleration of a reasonable amount of imprecision, vagueness and uncertainty during the modelling process. The authors gave particular emphasis to its application to "approximate reasoning" in the context of knowledge-based expert systems. Klir and Folger (1988) provided a useful overview of fuzzy sets as a broad conceptual framework for dealing with uncertainty and distinguished between the concept of a fuzzy sets and a fuzzy measures which indicate the degree of evidence that an elements belongs within a subset, and are expressed in terms of a membership function. They note that analytical tools in the form of fuzzy arithmetic and fuzzy calculus have been developed by others.

There would appear to be two possible applications for fuzzy set theory to design cost estimation:

- through the provision of an analytical tool (e.g. Ock, 1996); or
- through the development of a knowledge based expert system (e.g. Kangari and Bakheet, 1994);

**Input data.**

Ock (1996) stated that often in construction industry planning and programming:

> *"... directly applicable historic cost data is inadequate or unavailable, so the subjective judgement of experts who have relevant knowledge and experience is used instead"* (p 26)

and suggested that a fuzzy set approach could be used in the analysis of activity duration's where probabilistic data were not available. Kangari and Bakheet (1994) also suggested that in the construction industry quantitative and detailed information to evaluate uncertainty is often unavailable and that the factors describing uncertainty can be expressed in qualitative or linguistic terms such as "bad weather" or "poor design". This suggested that a direct analysis of these linguistic factors could be achieved through the use of fuzzy set theory.

Ock (1996) used a fuzzy mean method to produce a single "crisp" estimate of the total risk associated duration for a hypothetical activity using estimates from five engineers on the risk associated duration of the activity. He considered that a most-likely and largest-likely intervals of the estimates of the duration could be determined on the basis of historical or published data, or from the judgement of experts, which suggests that the sources of information for simulation modelling of cost risks (listed in section 7.3.2) would be equally appropriate to the application of fuzzy set theory.

Kangari and Bakheet (1994) suggested that the practical application of fuzzy set theory could be best achieved through a knowledge based expert system. The user would respond to a query by the expert system by the input of a response such as "high", "medium" or low", thus avoiding the need to input numerical data. Unfortunately, the authors did not provide any information on the operation of the expert system but stated that research is underway and that the necessary data-base and knowledge base had been established through literature and expert interviews, and that algorithmic models which include fuzzy sets were being developed. The use of algorithms in Knowledge Based Systems is consistent with that proposed by Miles, Moore and Price (1995) in Section 3.4.1.

**Model output and context of its application**

The application fuzzy set theory using the fuzzy mean method should produce a single estimate of cost, or required resource input, and the use and limitations of this output would be the same as those described for the parametric model in Section 7.3.1. However, unlike the parametric model, fuzzy set approaches would be judged by the majority of design managers to be a "black box approach" and the potential for its practical application would be limited.

Kangari and Bakheet (1994) noted that the practical application of fuzzy set theory in construction risk analysis was still at the research stage and that more work would be required before a practical risk assessment model could be developed. The two major problems which would have to be investigated were:

- the assignment of membership values of the fuzzy set, which are a measure of the degree of belonging within the set: and,
- the lack of an established method of performing arithmetic operations.

Ock (1996) used a fuzzy mean method which produced a differential equation which allowed the risk associated duration of an activity to be determined from the following:

- the upper and lower bound values of the activity duration at membership degree of 0, i.e. the largest-likely interval between the estimates of the activities duration, (this is the difference between the most optimistic and most pessimistic estimate of the activities duration); and

- the upper and lower bound values of the activity duration at membership degree of 1 i.e. the most-likely interval between the estimates of the activities duration (this is the difference between the two estimates that were closest to each side of the mean value of the estimate).

Unfortunately, he provided no evidence to support his selection of the arithmetic approach, nor could he support the validity of the crisp estimate of the activity duration produced by the analysis. The lack of an established methodology for the practical application of fuzzy set theory would be a significant barrier to its practical application to design cost estimation now and in the near future.

### 7.3.4 Summary of the appraisal

The appraisal above has shown that it should be theoretically possible, with varying degrees of additional work, to develop and test a design cost estimation model based on each of the modelling approaches reviewed above. However, it would not be possible within the available time scale of this study to fully investigate all of the approaches and it will be necessary to select the approach which can best contribute to the overall aim of the project which was:

> "to investigate the extent to which there exists the potential for the development of a rational approach to the estimation of construction industry design costs by the application of cost modelling, based on historic cost data".

The potential for the application of each of the estimating approaches can be quantified by the evaluation of their degree of conformance with the criteria described in Section 7.2, which were:

- that the necessary input data should be available or accessible within design organisations;
- that the output data from the cost model is readily applicable to the cost estimating process;
- that the basis of the technique is transparent so as to instil confidence in the user and thereby ensure its use; and
- that the software support is available within design organisations.

To facilitate the analysis a simple scale of conformance of either High, Moderate or Low was developed and the results are presented in Table 7.1.

**Table 7.1: - Evaluation of the alternative modelling approaches**

| | CRITERIA | | | |
|---|---|---|---|---|
| **MODELLING APPROACH** | **Availability of appropriate input Data** | **Suitability of output data** | **Transparency** | **Potential for practical application.** |
| **Parametric cost modelling** | Low | Moderate | High | High |
| **Simulation** | Moderate | High | High | Low |
| **Risk analysis** | Moderate | High | High | High |
| **Fuzzy set theory** | Moderate | Moderate | Low | Low |

The table demonstrates that the risk analysis approach is the most appropriate form of model. The reasons for the elimination of the other forms of model are summarised below.

- Parametric cost modelling has been eliminated principally because of the impracticality of the assembly of an appropriate data set and the limited value of the output data.
- Simulation approaches which mimic the performance of the system on a time-slicing basis have been eliminated principally because it is not appropriate to model the design process as a series of linked activities represented in the form of a process flow diagram.
- Fuzzy set theory has been eliminated principally because the technique lacks transparency and the methodology has not been sufficiently developed to be readily adopted by design managers. This is particularly true in the context of its application to knowledge based decision support systems.

## 7.4 DEVELOPMENT, TESTING AND VALIDATION OF THE COST MODEL

A useful guide to the development and application of management science models was provided by Markland (1989). An amended extract from this methodological process, which covers the model building, testing, and application stages is shown in Figure 7.1.

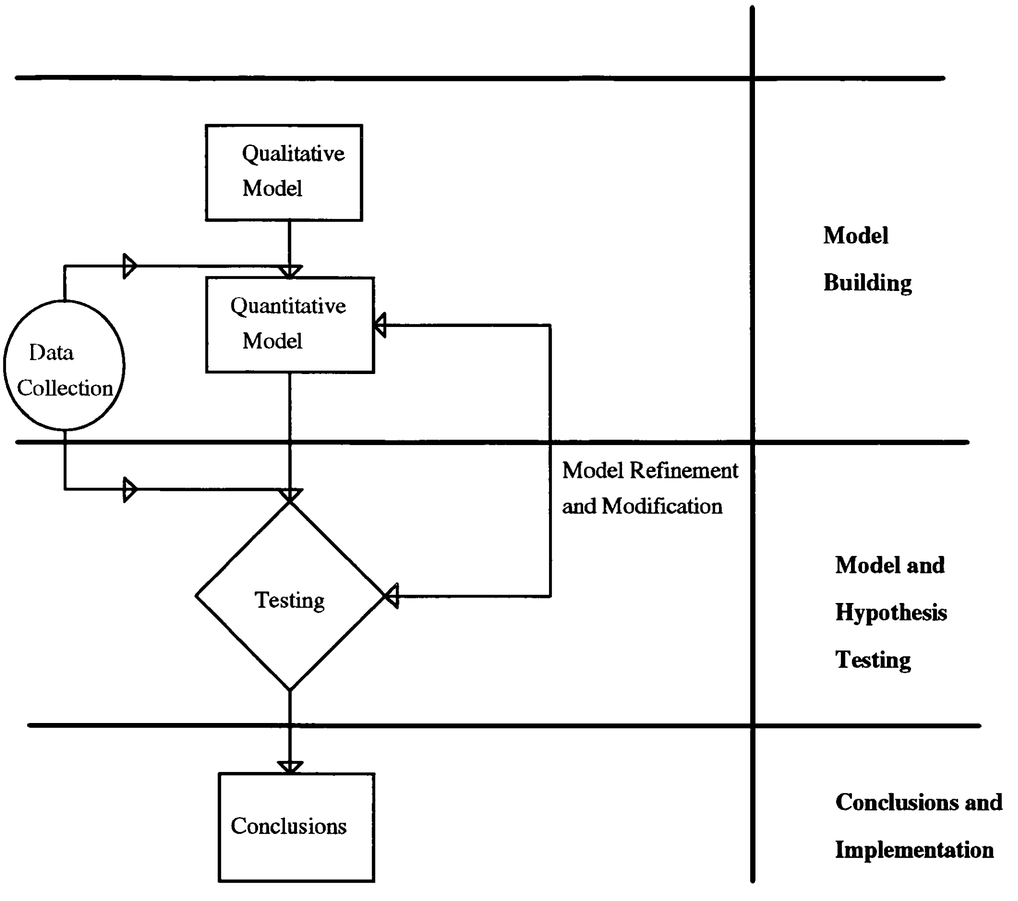



**Figure 7.1: - The modelling methodology.**

Markland also stated that two forms of experiment are required during the testing stage.

- Manipulation of the model to produce relevant data which can be used to assess its performance against previously collected data. This experimentation will lead to refinements and modification of the model and this process is repeated until the analyst is satisfied with the models validity.
- Experimentation using the validated model to test the stated hypothesis.

Pidd (1994) provided more detailed guidance on model validation and identified two forms. Firstly, "black-box" in which the inner working of both the model and the real world are assumed to be unknown, but where it is possible to observe the results of both. Secondly, "white-box" validation where the validation is focused on the internal workings of the model and it is assumed that a satisfactory performance is assured if the validity of the input distributions can be established. Pidd noted that there would be some overlap between the typologies and suggested that a complete black box approach to simulation modelling was unlikely as the modellor should have some appreciation of the operation of the system. The concept of testing the model by reference to both its output and its internal operation can be usefully adopted in the context of this study.

A strategy was devised for the development, validation and application of the model which comprised the following stages:

- the development of a qualitative model;
- the development of a quantitative model which would involve the synthesis and testing of input probability distribution to provide an element of white box validation, followed by experimentation using the case study projects to refine the model and to provide an element of black box validation; and
- the application of the validated model to an additional design project to evaluate its performance and hence to allow the hypothesis, "that there exists the potential for the development of a rational approach to the estimation of construction industry design costs by the application of cost modelling, based on historic cost data", to be tested.

### 7.4.1 Development of the qualitative model

The qualitative model comprised a WBS representation of the design process and project specific structures were created during the production of the "bottom-up" cost estimate for the projects in the case study (Chapter 6). The qualitative models for the three case study projects that were successfully completed were shown in Figures 6.3, 6.4 and 6.5.

### 7.4.2 Development of the quantitative model

The qualitative models allowed two forms of estimating model to be devised:

- models which used input probability distributions of the dis-aggregated person-hour estimates at level 2 of the work breakdown structure for Projects A and B; and
- models which used input probability distributions for the aggregated person-hour estimates at level 1 of the work breakdown structure for Projects A, B and C.

The level 2 models were developed and tested initially, prior to the development testing and validation of the level 1 models.

**Dis-aggregated person-hour models at level 2 of WBS**

The source of data was the data collection case studies which were presented in Chapter 6. No information on actual expenditure was available for the level 2 WBS packages and the estimates of inaccuracy in the work packages at this level had to be based on evidence from the dis-aggregated totals for the level 1 work packages as shown in Table 6.1.

The lack of useful feedback for estimators involved in predicting the capital cost of projects at the conceptual design stage was identified by Ogunlana (1991) who concluded that estimators were unaware of the magnitude of their estimating inaccuracies and consequently were overconfident in the precision of their estimates. This lack of feedback on estimating accuracy was more evident in the water services departments where the cost control systems were, at the time of the survey significantly less well developed than those of private design practices. It was expected that the levels of accuracy of the estimates particularly at level 2 of the WBS would be particularly low. As had been anticipated, there was a particularly wide range of inaccuracy of the estimates of dis-aggregated person hours, from 2 to 847 per cent which was similar to the reported accuracy of estimates the construction costs of work package estimates by design teams (Ogunlana, 1991).

In addition to the selection of the appropriate range of estimating inaccuracy, a decision had to be made on the most appropriate form of input distributions. Perry and Hayes (1985) suggested that cost distributions should be skewed to represent a greater probability of cost over-run. The use of unsymmetrical distributions was universally adopted by other authors (see section 7.3.2 above) with the use of a range of distributions including: Step Rectangular (Histogram), Triangular, Beta, and Log normal being reported. The @Risk package contained the following unsymmetrical distributions: Histogram, Triangular, Beta, Beta Subjective, Beta Pert, Gamma, Log normal, Pearson and Rayliegh, and each were considered using the RiskView sub-package which enables a graphical representation of the probability distribution to be created before their inclusion in the cost model. The distributions were put in three categories in terms of their potential value as follows.

**Category One**

These distributions could be immediately discounted as, in each case, there was either insufficient data to make a meaningful assessment of the necessary parameters, or the domain of the distribution was inappropriate. Histograms and Beta Subjective distributions were discounted because of insufficient data whilst the Beta distribution was discounted because of it's domain ($0 \le x \le 1$).

**Category Two**

These distributions were capable of representing the input distributions but required to be specified using parameters of the distributions, for example, $\alpha$ and $\beta$ in case of a Gamma distribution. In many cases the parameters were not transparent, and their selection would present a degree of difficulty that would make their use unattractive to practising design managers.

However, since the relationship between the parameters and the mean and mode of the distributions are known it was possible to infer reasonable values for the parameters that would produce appropriate input distributions for each work package. The Riskview software proved to be invaluable in this because it provided a visual representation of the input distribution for user specified values of the parameters, and allowed the values of any given percentile point in the distribution to be established simply by moving a pointer across the image of the distribution.

The use of category two distribution cannot be discounted, but they would be used only if they were demonstrably more appropriate than the category three distributions. The category two distributions were: Gamma, Invgauss, Log normal, and Pearson.

**Category Three**

These distributions were capable of representing the distributions and, in addition, their parameters were transparent and sufficient data existed from the case study to allow the synthesis of the parameters. The category three distributions were Triangular, Beta Pert and Rayliegh.

A modelling strategy was devised such that category three distributions were used initially and where necessary, depending on the validity of performance of the models, category two distributions were used as required until satisfactory results were obtained. Level 2 models were constructed for Projects A and B and the input distributions that were ultimately required are listed in Table 7.2. Each model enabled output distributions of aggregated person-hours to be produced for each level 1 work package and for the project total person-hours requirement and these were compared with the actual requirements. Typical models are included as Appendix G.

**Table 7.2: - Input distributions used in the Level 2 models**

**Project A**

| | Distribution | Parameters of distribution |
|---|---|---|
| Model 1 | Triangular | Minimum: 0,<br>Most Likely: Estimated Value,<br>Maximum: 8.5 x Estimated Value |
| Model 2 | Triangular | Minimum: 0,<br>Most Likely: Estimated Value,<br>Maximum: 4.5 x Estimate Value |
| Model 3 | Beta pert | Minimum: 0,<br>Most Likely: Estimated Value,<br>Maximum: 4.5 x Estimated Value. |
| Model 4 | Raleigh | b (mode): Estimated Value. |
| Model 5 | Log normal | $\mu$, $\sigma$: Parameters determined to give:<br>Mode = Estimated Value,<br>Maximum (99.5 percentile value) approximately 4.5 x Estimated Value |

**Project B**

| | Distribution | Parameters |
|---|---|---|
| Model 1 | Triangular | Minimum: 0,<br>Most Likely: Estimated Value,<br>Maximum: 8.5 x Estimated Value. |
| Model 2 | Triangular | Minimum: 0,<br>Most Likely: 0.8 x Estimated Value,<br>Maximum: 3.5 x Estimated Value. |
| Model 3 | Log normal | $\mu$: Estimated Value,<br>$\sigma$: selected to produce a maximum (99.5 percentile value) approximately 4.5 x Estimated Value. |

The input distributions for Model 1 of Projects A and B were constructed using the simplest form of category one distribution (triangular) and utilised the maximum variation between the estimated and actual values of person-hours that was evident in Table 6.1, a range of 0 to approximately 850 per cent of the estimated values. The results of this simulation are presented in Table 7.3.

**Table 7.3: - Results of simulation for Model 1 of Projects A and B**

**Project A, Model 1**

| | Simulated Hours | | | | Simulation Inaccuracy | | |
|---|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | Mode | Actual Hours | Mean (%) | Mode (%) |
| WP1 | 53 | 125 | 217 | 140 | 142 | 88 | 98 |
| WP2 | 55 | 200 | 389 | 197 | 81 | 247 | 243 |
| WP3 | 14 | 85 | 185 | 61 | 34 | 250 | 179 |
| WP4 | 51 | 132 | 231 | 125 | 167 | 79 | 74 |
| WP5 | 106 | 342 | 710 | 303 | 179 | 191 | 169 |
| Project Total | 574 | 928 | 1307 | 940 | 688 | 134 | 137 |

**Project B, Model 1**

| | Simulated Hours | | | | Simulation Inaccuracy | | |
|---|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | Mode | Actual Hours | Mean (%) | Mode (%) |
| WP1 | 68 | 199 | 419 | 177 | 1 | 19900 | 17700 |
| WP2 | 127 | 358 | 717 | 316 | 180 | 198 | 176 |
| WP4 | 133 | 465 | 854 | 442 | 83 | 560 | 533 |
| WP5 | 91 | 332 | 659 | 328 | 120 | 276 | 273 |
| WP6 | 228 | 668 | 1362 | 609 | 147 | 454 | 609 |
| WP7 | 120 | 332 | 681 | 352 | 59 | 562 | 597 |
| WP8 | 60 | 332 | 668 | 340 | 28 | 1185 | 1213 |
| WP9 | 6 | 133 | 318 | 95 | 44 | 302 | 216 |
| Project Total | 2233 | 3061 | 4063 | 3111 | 864 | 354 | 360 |

For Project A, the actual values fell within the predicted range for each level one work package and for the project total, although the mean and mode predicted values for work packages were significantly higher than the actual values in most cases. Furthermore, the predicted project totals were some 35 per cent higher than the actual values. However for Project B, only work packages 2 and 9 were within the predicted range and the minimum predicted value of the project total was some 250 per cent of the actual value.

In view of this extreme over-prediction adjustments were made to create Model 2 for both projects. As before, to simplify the modelling process in order to enhance its potential for practical application, a consistent shape of distribution was used for each work package. For Project A, the extreme value of 857 per cent inaccuracy was ignored and the maximum value of the distribution reduced to 450 per cent of the estimated value which was considered to be more representative of the levels of inaccuracy exhibited in Table 6.1. For Project B, the most likely and maximum values were further adjusted by a factor of 0.8 to allow for the general level of over-estimation that was evident in this project. The results of the simulation are shown in Table 7.4.

**Table 7.4: - Results of simulation for Model 2 of Projects A and B**

**Project A, Model 2**

| | Simulated Hours | | | | Simulation Inaccuracy | | |
|---|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | Mode | Actual Hours | Mean (%) | Mode (%) |
| WP1 | 27 | 71 | 121 | 73 | 142 | 50 | 51 |
| WP2 | 43 | 110 | 191 | 99 | 81 | 135 | 122 |
| WP3 | 11 | 49 | 106 | 51 | 34 | 144 | 150 |
| WP4 | 38 | 75 | 135 | 71 | 167 | 45 | 43 |
| WP5 | 65 | 197 | 362 | 196 | 179 | 110 | 109 |
| Project Total | 340 | 545 | 753 | 582 | 688 | 79 | 84 |

**Table 7.4 (Continued)**

**Project B, Model 2**

| | Simulated Hours | | | | Simulation Inaccuracy | | |
|---|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | Mode | Actual Hours | Mean (%) | Mode (%) |
| WP1 | 39 | 115 | 201 | 118 | 1 | 11500 | 11800 |
| WP2 | 76 | 207 | 367 | 230 | 180 | 115 | 127 |
| WP4 | 120 | 269 | 447 | 268 | 83 | 323 | 324 |
| WP5 | 77 | 192 | 341 | 200 | 120 | 160 | 167 |
| WP6 | 175 | 445 | 791 | 361 | 148 | 303 | 246 |
| WP7 | 73 | 192 | 367 | 191 | 59 | 325 | 323 |
| WP8 | 65 | 192 | 333 | 166 | 28 | 685 | 592 |
| WP9 | 10 | 76 | 160 | 77 | 44 | 173 | 175 |
| Project Total | 1354 | 1834 | 2433 | 1799 | 864 | 212 | 208 |

As might have been anticipated in Project A, the maximum predicted values for work packages 1 and 4 were less than the actual by some 20 per cent reflecting the magnitude of the underestimate of these work packages, but the other work packages and the project totals were within the predicted range. The predicted mean and mode of these work packages were now within 50 per cent of the actual value and the total project estimates were now within 21 per cent. For Project B a pattern of over-prediction emerged similar to that of Model 1, and although the magnitude of the over-prediction was reduced, the predicted minimum value was still in excess of the actual hours in most cases. It was therefore concluded that triangular distributions could produce realistic results for Project A total hours, and for three of the work packages (2, 3 and 5), provided that an "average maximum" of 450 per cent of the estimated value was adopted for the input distributions.

It was now evident from Models 1 and 2 that the differing risk attitudes of the estimators in Projects A and B, which were identified in Chapter 6, were having a significant effect on the applicability of the models. It was concluded that, because of the risk adverse tendency (resulting in over-estimation) in Project B, this project could not be realistically modelled using the estimated value as the mode in unsymmetrical distributions where the mean exceeded the mode. This was because skewed nature of these input distribution would increase the probability of sampling, during the simulation exercise, cost values that were greater than the estimated value for each level 2 work package. Consequently the mean and mode simulated costs of the level one work packages and the project totals would invariably be greater than the estimated values. The other category three distributions, Beta-Pert and Rayliegh, were similarly skewed and therefore could not be usefully considered for this project.

Model 3 for Project A was constructed utilising Beta-Pert input distributions using similar parameters to Model 2. The results of this simulation are presented in Table 7.5. This mean predicted value for this model provided a satisfactory representation of actual values (within ± 15 per cent) in three work package, but as before could not predict the large actual values in work packages 1 and 4. The mean and mode predictions underestimated the project total by some 40 per cent but this can be largely explained by the exceptionally large estimating errors in work packages 1 and 4 where the actual aggregated costs in each case were some 400 per cent of the estimated values. Model 4 for Project A used Rayliegh input distributions and the results of this simulation are also presented in Table 7.5. This model predicted lower mean and mode hours for each work package than the Beta-Pert model, with actual values for work packages 2, 3 and 5 under predicted by up to 25 per cent. The accuracy of prediction of the total project cost was also less than the previous model.

**Table 7.5: - Results of simulation for Models 3 and 4 of Project A**

**Project A, Model 3**

| **Simulated Hours** | | | | | **Simulation Inaccuracy** | | |
|---|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | Mode | Actual Hours | Mean (%) | Mode (%) |
| WP1 | 21 | 55 | 86 | 63 | 142 | 39 | 44 |
| WP2 | 48 | 84 | 141 | 85 | 81 | 104 | 105 |
| WP3 | 11 | 38 | 73 | 41 | 34 | 112 | 121 |
| WP4 | 31 | 59 | 95 | 58 | 167 | 35 | 35 |
| WP5 | 54 | 152 | 268 | 178 | 179 | 85 | 99 |
| Project Total | 304 | 432 | 597 | 459 | 688 | 63 | 67 |

**Project A, Model 4**

| Simulated Hours | | | | | Simulation Inaccuracy | | |
|---|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | Mode | Actual Hours | Mean (%) | Mode (%) |
| WP1 | 25 | 48 | 86 | 43 | 142 | 34 | 30 |
| WP2 | 32 | 75 | 141 | 75 | 81 | 93 | 93 |
| WP3 | 8 | 33 | 67 | 31 | 34 | 97 | 91 |
| WP4 | 22 | 52 | 87 | 52 | 167 | 31 | 31 |
| WP5 | 52 | 135 | 270 | 135 | 179 | 75 | 75 |
| Project Total | 248 | 391 | 548 | 391 | 688 | 57 | 57 |

Finally, the use of category two distributions were considered. The potential for the application of each of the category two distributions was evaluated prior to time consuming modelling and it was concluded that the Log normal distribution parameters were the most transparent. This form was used in Model 5 for Project A and Model 3 for Project B. The parameters that were necessary to define the distribution for each model were $\mu$ and $\sigma$, but, because of the contrasting risk attitudes of the estimators, different approaches were adopted in the production of the input distributions for the two projects. For Project A, where risk seeking behaviour was evident, the estimated value was assumed to be representative of the mode of the required hours distribution, and an appropriate value of $\mu$ determined to produce this mode for each input distribution using the following equations:

$$\text{Mode} = \exp(\mu_1 - \sigma_1^2)$$

where $\mu_1 = \ln\left(\frac{\mu^2}{\sqrt{\sigma^2+\mu^2}}\right)$

and $\sigma_1 = \ln\left(\frac{\sigma^2+\mu^2}{\mu^2}\right)$

The value of $\sigma$ was selected pragmatically with the aid of the RiskView package in such a way that the tail of the distribution approached the X axis (99.5 percentile value) at approximately 4.5 x the estimated hours value. This was considered to be a reasonable representation of the maximum levels of estimating inaccuracy.

As discussed above, it was apparent that this approach could not model the actual costs for Project B where risk adverse behaviour was evident, but it was assumed that an unsymmetrical distribution could still be appropriate. It was decided that the risk adverse behaviour of the estimators may be better represented by taking the estimators values for the level 2 work package as being representative of the mean rather than the mode of the distribution of hours. Having established the values for $\mu$ for the input distributions, $\sigma$ was determined as for Project A. The results of this simulation are presented an Table 7.6 and Figures 7.2 and 7.3.

**Table 7.6: - Results of simulation for Model 5 of Project A and Model 3 of Project B**

**Project A, Model 5**

| | Simulated Hours | | | | Simulation Inaccuracy | | |
|---|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | Mode | Actual Hours | Mean (%) | Mode (%) |
| WP1 | 29 | 54 | 98 | 50 | 142 | 38 | 35 |
| WP2 | 47 | 80 | 151 | 79 | 81 | 99 | 98 |
| WP3 | 16 | 37 | 102 | 39 | 34 | 109 | 115 |
| WP4 | 33 | 58 | 110 | 55 | 167 | 35 | 33 |
| WP5 | 72 | 146 | 281 | 152 | 179 | 82 | 85 |
| Project Total | 314 | 418 | 595 | 438 | 688 | 61 | 64 |
| Total WP 2,3 & 5 | 203 | 306 | 446 | 298 | 294 | 104 | 101 |

**Project B, Model 3**

| | Simulated Hours | | | | Simulation Inaccuracy | | |
|---|---|---|---|---|---|---|---|
| | Minimum | Mean | Maximum | Mode | Actual Hours | Mean (%) | Mode (%) |
| WP1 | 25 | 63 | 144 | 63 | 1 | 6300 | 6200 |
| WP2 | 50 | 112 | 245 | 102 | 180 | 62 | 57 |
| WP4 | 70 | 147 | 297 | 141 | 83 | 177 | 170 |
| WP5 | 48 | 105 | 314 | 102 | 120 | 88 | 85 |
| WP6 | 127 | 240 | 558 | 213 | 147 | 163 | 144 |
| WP7 | 48 | 104 | 265 | 98 | 59 | 176 | 166 |
| WP8 | 44 | 105 | 253 | 83 | 28 | 375 | 296 |
| WP9 | 12 | 42 | 107 | 40 | 44 | 95 | 91 |
| Project Total | 786 | 1063 | 1577 | 1057 | 864 | 123 | 122 |
| Total WP2 to 9 | 713 | 1000 | 1429 | 957 | 863 | 116 | 111 |

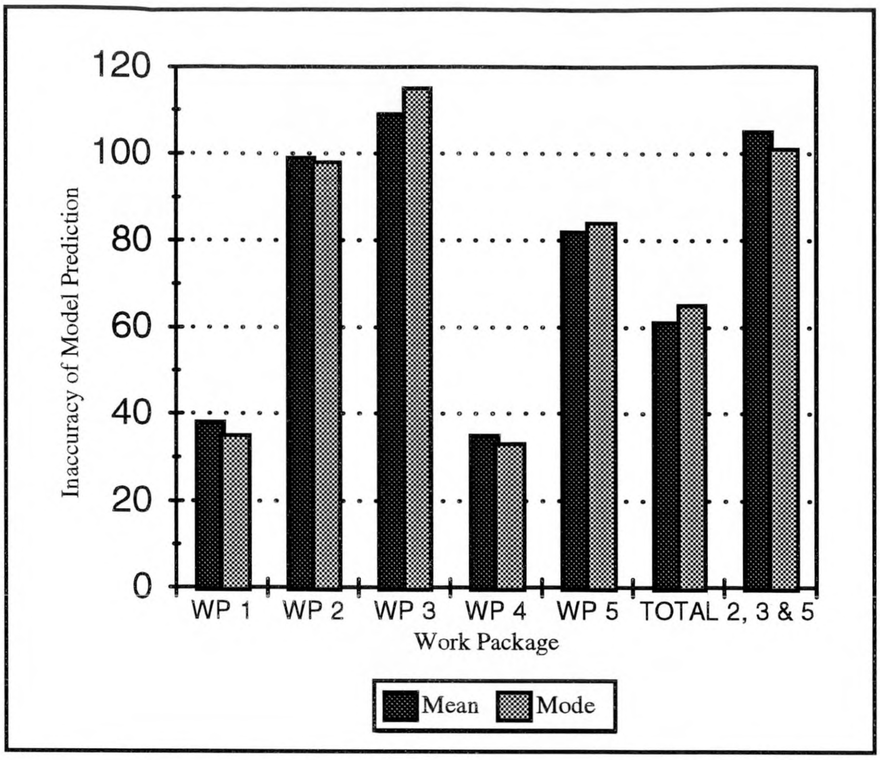



**Figure 7.2:- Results of simulation for Model 5 of Project A**

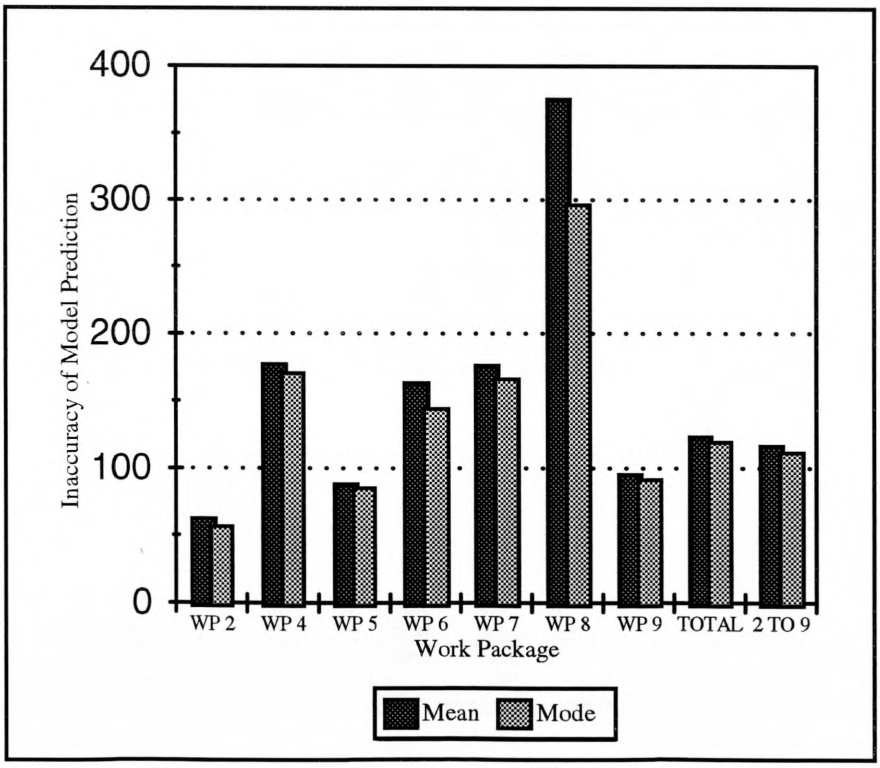



**Figure 7.3:- Results of simulation for Model 3 of Project B**
(WP 1 omitted for clarity)

The results of the simulation for Project A showed a similar degree of accuracy to the Beta-Pert distributions in Model 3. Once again the inaccuracy of the project total is influenced by work packages 1 and 4 and an additional simulation which neglected these was undertaken and this produced simulated mean and mode values that were within 5 per cent of the actual values. Bradley, Powell and Soulsby (1990) stated that experience of simulation modelling has shown that the results for construction projects tend to be influenced more by the range of variation in each component than by the selected shape of the probability distribution and this is supported in the results of the various models. No further modelling work was undertaken using other category three distributions.

The simulation results for Project B show a considerable improvement over the previous models which used triangular distributions. With the exception of work packages 1 (extreme case) and 8 (inaccurate, but not to a level that can be discounted) the simulated mode values give a reasonable representation of the actual hours for the work packages and, even including work package 1, the predicted mode value is within 20 per cent of the actual value. A further simulation was undertaken to predict the project total neglecting work package 1 and this increased the accuracy of the mode prediction to within 11 per cent of the actual value.

The validity of the range of estimates produced by the various models was further tested by comparing the cost ranges predicted by the models against actual and estimated values. Table 7.7 presents the simulated ranges of estimating inaccuracy for the various models and Table 7.8 presents a comparison between actual and simulated data. In each case the maximum and minimum estimates have been expressed as:

$$\frac{\text{Minimum (or Maximum Estimate)}}{\text{Mode Estimate}} \times 100$$

**Table 7.7: - Modelled person-hour ranges**

**Project A**

| | **Model 1** | | **Model 2** | | **Model 3** | | **Model 4** | | **Model 5** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. |
| WP1 | 38 | 155 | 37 | 166 | 33 | 162 | 68 | 200 | 58 | 196 |
| WP2 | 28 | 197 | 44 | 192 | 56 | 167 | 42 | 188 | 59 | 191 |
| WP3 | 23 | 303 | 22 | 208 | 27 | 192 | 26 | 216 | 41 | 262 |
| WP4 | 41 | 185 | 54 | 190 | 53 | 161 | 42 | 167 | 60 | 200 |
| WP5 | 35 | 234 | 33 | 185 | 30 | 176 | 38 | 200 | 47 | 185 |
| Average WP | 33 | 215 | 38 | 188 | 40 | 171 | 43 | 194 | 53 | 207 |
| Project Total | 61 | 139 | 58 | 129 | 66 | 138 | 63 | 141 | 72 | 136 |

**Project B**

| | **Model 1** | | **Model 2** | | **Model 3** | |
|---|---|---|---|---|---|---|
| | Min. | Max. | Min. | Max. | Min. | Max. |
| WP1 | 34 | 210 | 33 | 174 | 39 | 228 |
| WP2 | 35 | 200 | 37 | 177 | 49 | 240 |
| WP4 | 29 | 184 | 45 | 166 | 49 | 211 |
| WP5 | 27 | 188 | 40 | 177 | 47 | 307 |
| WP6 | 34 | 198 | 39 | 178 | 59 | 261 |
| WP7 | 36 | 205 | 38 | 191 | 46 | 254 |
| WP8 | 18 | 201 | 33 | 173 | 45 | 264 |
| WP9 | 15 | 240 | 13 | 211 | 42 | 267 |
| Average WP | 29 | 203 | 35 | 181 | 47 | 254 |
| Project Total | 72 | 133 | 73 | 132 | 73 | 147 |

Table 7.7 shows a fairly consistent range of average simulated level one work package person-hours of approximately 40 to 210 per cent of the mode value, for the more representative models of Project A (2 to 5). In every case for Project A, a consistent range of project total hours was produced between 60 per cent and 150 per cent of the mode value. The most representative model of Project B (Model 3) exhibited a slightly wider range of estimates for both the level one work packages and for the project total with upper boundaries being 253 and 147 per cent respectively for work packages and project totals. Table 7.8 allows a comparison to be made between the estimated and actual values of aggregated person hours and the simulated range from Model 5 for Project A and Model 3 for Project B. With the exception of the work

packages mentioned earlier, where extreme estimating inaccuracy was noted, the actual hours fall within the simulated range giving some confidence in applicability of the input distributions.

**Table 7.8: - Comparison of estimated and actual hours to the range of simulated hours**

| | Project A | | | | Project B | | | |
|---|---|---|---|---|---|---|---|---|
| | Estimated Hours | Actual Hours Required | Simulated Hours Min. | Simulated Hours Max. | Estimated Hours | Actual Hours Required | Simulated Hours Min. | Simulated Hours Max. |
| WP1 | 40 | 142 | 29 | 98 | 63 | 1 | 25 | 144 |
| WP2 | 60 | 81 | 47 | 151 | 113 | 180 | 50 | 245 |
| WP3 | 17 | 34 | 16 | 172 | - | - | - | - |
| WP4 | 42 | 168 | 33 | 110 | 147 | 83 | 70 | 297 |
| WP5 | 108 | 179 | 72 | 281 | 105 | 120 | 48 | 314 |
| WP6 | | | | | 241 | 147 | 127 | 528 |
| WP7 | | | | | 105 | 59 | 48 | 265 |
| WP8 | | | | | 105 | 28 | 44 | 259 |
| WP9 | | | | | 42 | 44 | 12 | 157 |
| Project Total | 304 | 688 | 314 | 595 | 1047 | 864 | 761 | 1737 |

The simulated total project costs were also compared with the range of project cost estimates suggested by other authors as shown in Table 7.9.

**Table 7.9: - Suggested ranges of estimating inaccuracy**

| Source | Minimum Estimate (%) | Maximum Estimate (%) | Comments |
|---|---|---|---|
| Hudgins and Lavelle (1995) | 50 | 250 | Total project estimate for rough concept design work |
| | 70 | 160 | Total project estimate for general concept design work |
| | 80 | 130 | Total project estimate for detailed design work |
| Nicolson and Popovic (1994) | 60 | 180 | Total project estimate using "scale method" |
| | 60 | 180 | Total Project Costs using "bench mark method" |
| | 50 | 210 | Total project estimate using "analytical method" |
| Kidd (1991) | 50 | 200 | Time for tasks in software development |
| Hudson (1992) | 60 | 150 | Total design costs on a project |

The most useful direct comparison between the simulated results and those from other sources can be made using the data from Nicolson and Popovic's (1994) survey for "analytical estimating", where the estimates were also prepared using a work package breakdown approach. This survey produced fee bids between 60 per cent and 210 per cent of the mode value. The difference in the simulated range of fee estimates and those observed by Nicolson and Popovic can be explained by the existence of the following two components to the level of accuracy of bids submitted.

- A component resulting from the inherent inaccuracy of the estimator, which would explain 60 to 150 per cent of the range of estimates.
- A component arising from the involvement of a number of separate organisations in the bidding process in Nicolson and Popovic's survey which would result in the introduction of different perceptions of the true cost and value of the project. This would be due to differing levels of efficiency within the organisations and to differing attitudes toward risk, which would influence the adjustment to the estimate during the commercial decision stage of the development of the fee bid (See figure 5.1). This would explain the remainder of the observed range of estimates.

It can be concluded from the above discussion that the range of estimates provided by simulation models are reasonably realistic. Having established that the selected levels of variance in the input distributions were appropriate, a decision had to be made on the most appropriate form of input distribution for further modelling. Triangular and other positively skewed distributions had been demonstrated to be ineffective in modelling risk adverse cost estimates, but it was possible to use Log normal distributions for such estimates provided that the estimated value was taken as being representative of the mean of the distribution of actual hours. The Log normal distribution has been shown to be equally appropriate for risk seeking behaviour when the estimate was taken as being representative of the mode. This form of input distribution was adopted for subsequent modelling because it appeared to be universally applicable.

**Dis-aggregated person-hour models at level 1 of WBS**

The final stage of the model development involved the creation of models for projects A, B and C based on the aggregated hours for level 1 work packages. There are a number of reasons why these models would prove to be more attractive in practice which are:

- the models would be easier to create and operate because they would involve significantly fewer work packages; and
- data on variance between actual and estimated person-hours would be more likely to be available in practice enabling a more sophisticated selection of the appropriate range of the input distributions to be made.

The latter reason is particularly significant in the light of the results of the survey by Hudgins and Lavelle (1995). The survey concluded that estimating accuracy would be influenced by the degree of certainty in the design input requirements with a wider range of estimates being expected for rough concept work than for detailed design. Fellows (1996), in a review of risk management approaches suggested that an objective evaluation of statistical probabilities of the components of risk was seldom possible in business situations but proposed a subjective method of risk quantification whereby risks were categorised on a simple scale of low, medium or high. The possibility of different levels of risk being associated with the various work packages was excluded from the simulation at level 2 of the WBS, due to a lack of data on estimating accuracy, but was introduced to the level 1 model.

Initially, however, standard forms of distribution were devised for all work packages in each project but these had to be selected to provide an accurate representation of the risk attitudes or personal biases of the estimators in each project (Hudson, 1992; Uher, 1996) These were identified in section 6.3.3 as being:

- risk seeking in the case of project A;
- risk adverse in the case of Project B; and
- risk neutral in the case of Project C.

The input distributions were again represented for each project by Log normal distributions. In the case of Project A, to reflect the risk seeking behaviour, and in view of the levels of inaccuracy revealed in the data, mean values were chosen for each distribution to produce a mode equal to the estimated value and the spread of the distribution established such that the 99.5 percentile value was 400 per cent of the mode value. The estimated values were also taken to represent the mode for the Project C input distributions but the 99.5 percentile values restricted to 200 per cent of the mode. This should reflect the risk neutral behaviour of the estimator, which would be likely to result in lower levels of over-estimate or underestimate than those exhibited in Project A and B. In the model for Project B the estimated values were used as the mean to reflect the risk adverse tendencies of the estimators and the 99.5 percentile values were again arranged to be 400 per cent of the mode. The results of this analysis are shown in Table 7.10

**Table 7.10: - Level 1 work package model, comparison of actual and simulated project total hours**

| Simulated Hours | | | | | | | Simulation Inaccuracy | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min. | Mean | Max. | Mode | 5%ile | 95%ile | Actual Hours | Mean (%) | Mode (%) |
| Proj. A | 220 | 414 | 875 | 351 | 284 | 593 | 688 | 60 | 51 |
| Proj. B | 522 | 1047 | 2234 | 1095 | 713 | 1526 | 864 | 121 | 127 |
| Proj. C | 595 | 868 | 1274 | 874 | 706 | 1055 | 873 | 99 | 100 |

The simulation outputs from the level 1 and level 2 models exhibit similar mean and mode values, but the values of the maximum and minimum hours differ significantly. Repeated simulations of the level one model showed that these maximum and minimum values were unstable due to the reduced number of input distributions in the level 1 models, The data can be more usefully interpreted by reference to the mean, mode, and 5 and 95 percentile values of the output distributions.

The difficulty in predicting actual hours that had been encountered with the level 2 models, where risk seeking or risk adverse behaviour was combined with high levels of estimating inaccuracy, remains (Projects A and B). Nevertheless, the actual total project hours for each project is contained within the simulated range of the output distribution, albeit close to the 95 and 5 percentile values of the distributions. The selection of Log normal distributions to represent the risk neutral estimating behaviour in Project C seems to be vindicated with the simulated mode and mean values being very close to the actual total hours. The position of the actual hours at the extremities of the output distributions for Projects A and B suggests that the range of inaccuracy of the work package estimates could have been understated in some work packages in the models. The assumption that a standard work input distribution should be used for each work package must be questioned and the possibility of identifying, and allowing for, higher risk work packages was investigated. An attempt was made to differentiate between the levels of risk that were inherent in the work packages.

The sources of risk which would influence estimating accuracy were identified in the literature review (Chapter 2) and can be summarised as follows:

- the extent to which the problem can be defined;
- the degree of influence of non-technical criteria;
- the extent of the application of intuitive approaches rather than logical deduction to decision making;
- the necessity for creativity in the development of the solution;
- the degree of interaction with other parties (which would itself be affected by the procurement system); and
- the personal attributes of the designers.

A qualitative risk evaluation was carried out for the level one work packages for each project and the results are summarised in Table 7.11. The last risk source, the personal attributes of the design personnel, has been omitted from the analysis because it could not be properly assessed by the writer. In arriving at an overall risk rating, scores of 1, 2, and 3 have been allocated to low medium and high risks respectively.

**Table 7.11: - Qualitative risk assessment**

**Project A**

| | Risk Category | | | | | |
|---|---|---|---|---|---|---|
| **Risk Source** | **WP 1** | **WP2** | **WP3** | **WP4** | **WP5** | **WP6** |
| Problem Definition | High | Low | Low | Low | Low | Low |
| Non-technical Criteria | High | Low | Low | Medium | Low | High |
| Intuitive approaches | Low | Medium | Low | Medium | Low | Low |
| Creativity | Low | High | Low | Medium | Low | Low |
| Interaction with others | High | High | Low | Low | Low | Low |
| Overall Risk Rating | 11 | 10 | 5 | 8 | 5 | 7 |

**Project B**

| | Risk Category | | | | | |
|---|---|---|---|---|---|---|
| **Risk Source** | **WP 1** | **WP2** | **WP4** | **WP5** | **WP6** | **WP7** |
| Problem Definition | Low | Low | Low | Low | Low | Low |
| Non-technical Criteria | Low | High | Low | Low | Low | Low |
| Intuitive approaches | Low | Low | Low | Low | Low | Low |
| Creativity | Low | Low | Low | Low | Low | Low |
| Interaction with others | High | High | Low | Low | Low | Low |
| Overall Risk Rating | 6 | 9 | 5 | 5 | 5 | 5 |

**Project B (Continued)**

| | Risk Category | | |
|---|---|---|---|
| **Risk Source** | **WP8** | **WP9** | **WP10** |
| Problem Definition | Low | Low | Low |
| Non-technical Criteria | Low | Low | High |
| Intuitive approaches | Low | Low | Low |
| Creativity | Low | Low | Low |
| Interaction with others | Low | Low | High |
| Overall Risk Rating | 5 | 5 | 9 |

**Project C**

| | Risk Category | | | | |
|---|---|---|---|---|---|
| **Risk Source** | **WP 1** | **WP2** | **WP3** | **WP4** | **WP5** |
| Problem Definition | Low | Low | Low | Low | Low |
| Non-technical Criteria | Low | Medium | Low | Low | Medium |
| Intuitive approaches | Low | Medium | Low | Low | Medium |
| Creativity | Low | Medium | Low | Low | Low |
| Interaction with others | Low | Low | Low | Low | High |
| Overall Risk Rating | 5 | 8 | 5 | 5 | 9 |

The overall risk ratings were compared with the levels of inaccuracy of the initial estimate for each work package. A parameter had to be devised for estimating inaccuracy that would take into account the overall risk attitude and estimating expertise of the individual estimators to allow the three projects to be compared on an equivalent basis. This was achieved by measuring the relative estimating inaccuracy of each work package against the inaccuracy of the estimate of the person-hour requirements for the whole project as follows (See Table 6.2 and 6.3 for details):

$$\text{Relative Estimating accuracy (\%)} = \frac{|\text{Work package accuracy - project total accuracy}|}{\text{project total accuracy}} \times 100$$

where work package and project total inaccuracy's were determined from:

$$\frac{\text{Actual hours} \times 100}{\text{Estimated hours}}$$

The results of this analysis are presented in Table 7.12 and in Figure 7.4.

**Table 7.12: - Overall risk assessment and relative estimating inaccuracy for each work package**

| | PROJECT A | | PROJECT B | | PROJECT C | |
|---|---|---|---|---|---|---|
| | Risk Rating | Estimating Inaccuracy | Risk Rating | Estimating Inaccuracy | Risk Rating | Estimating Inaccuracy |
| WP1 | 11 | 57 | 6 | n/a | 5 | 11 |
| WP2 | 10 | 59 | 9 | 94 | 8 | 33 |
| WP3 | 5 | 13 | | | 5 | 15 |
| WP4 | 9 | 76 | 5 | 32 | 5 | 20 |
| WP5 | 5 | 38 | 5 | 39 | 9 | 74 |
| WP6 | 7 | 1 | 5 | 26 | | |
| WP7 | | | 5 | 32 | | |
| WP8 | | | 5 | 67 | | |
| WP9 | | | 5 | 28 | | |
| WP10 | | | 9 | 29 | | |

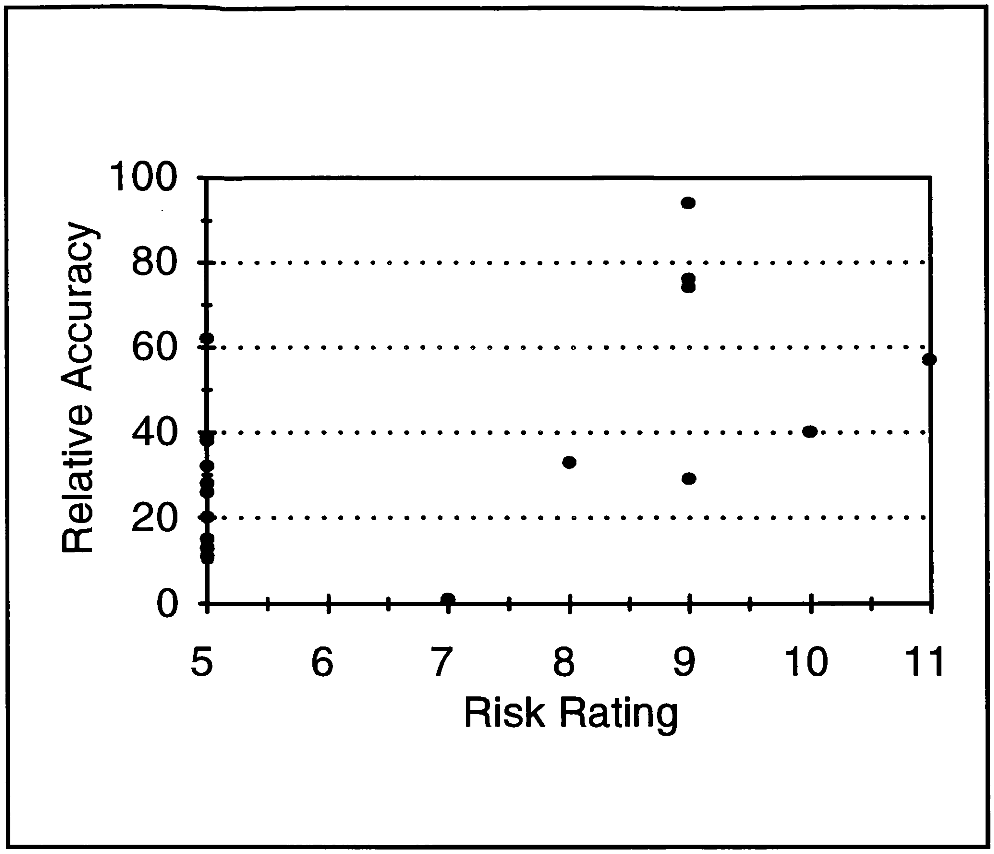



**Figure 7.4: - Scatter plot of aggregated risk rating v relative inaccuracy for all work packages**

Figure 7.4 shows that there is some correlation between the risk rating and the relative inaccuracy of the work package estimates but suggests that the correlation is not strong. This was confirmed by a regression analysis which produced a regression coefficient r of 0.55. Figure 7.4 does, however, provide evidence of grouping of data in two areas: between risk rating 5 and 7 and between risk ratings 8 and 11. These could be described as being representative of work packages with overall risk ratings of Low and Medium respectively. Note that the maximum possible risk rating (high) on this scale would correspond with ratings of between 12 and 15, but no data was available for work packages in this range. The presence of these groupings suggests that input distributions which comprised different ranges of estimating inaccuracy should be included in the model for the level one work packages to represent the low and medium risk work packages. Unfortunately, whilst Figure 7.4 indicates that a relationship between the risk rating and relative inaccuracy exists, the relationship is not sufficiently strong to permit a quantitative assessment of the necessary adjustment to the variance in the input distributions. An arbitrary increase of 50 per cent in the 99.5 percentile value of the input distributions for the medium risk category activities was made in order that some assessment of the potential effects of differential risk assessment could be made. The results of this analysis are presented in Table 7.13 and Figures 7.5 and 7.6.

**Table 7.13: - Revised Level 1 work package model, actual and simulated project total hours**

| Simulated Hours | | | | | | | Simulation Inaccuracy | | |
|---|---|---|---|---|---|---|---|---|---|
| | Min. | Mean | Max. | Mode | 5%ile | 95%ile | Actual Hours | Mean (%) | Mode (%) |
| Proj. A | 210 | 438 | 1080 | 360 | 296 | 630 | 688 | 63 | 52 |
| Proj. B | 470 | 1046 | 2563 | 948 | 670 | 1540 | 864 | 121 | 110 |
| Proj. C | 576 | 917 | 1687 | 870 | 695 | 1205 | 873 | 105 | 100 |

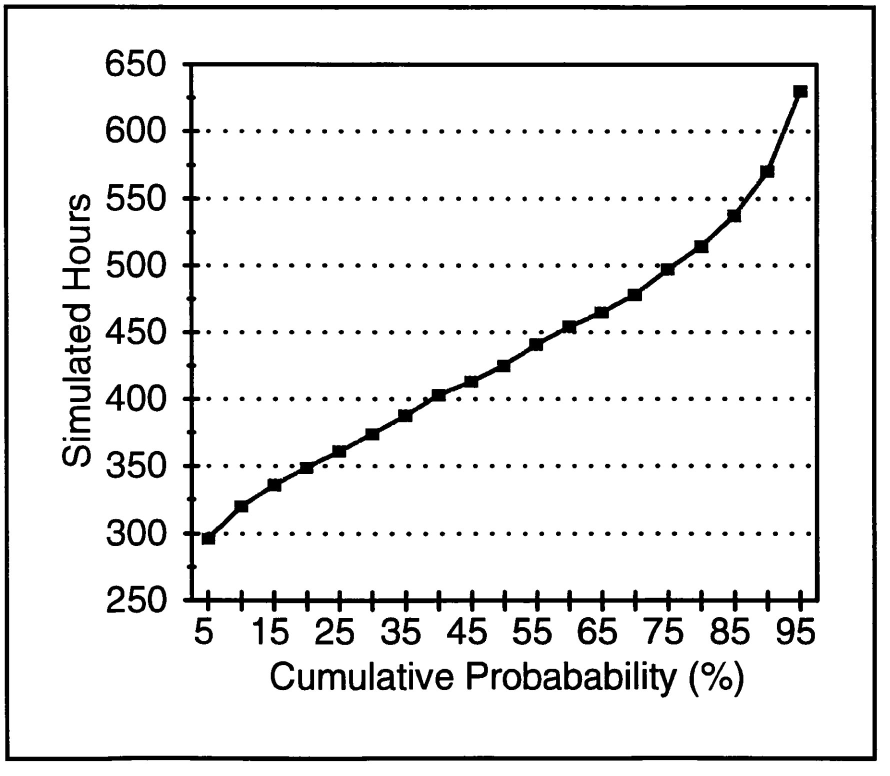



**Figure 7.5: - Revised Level 1 work package model Project A - simulated project total hours**

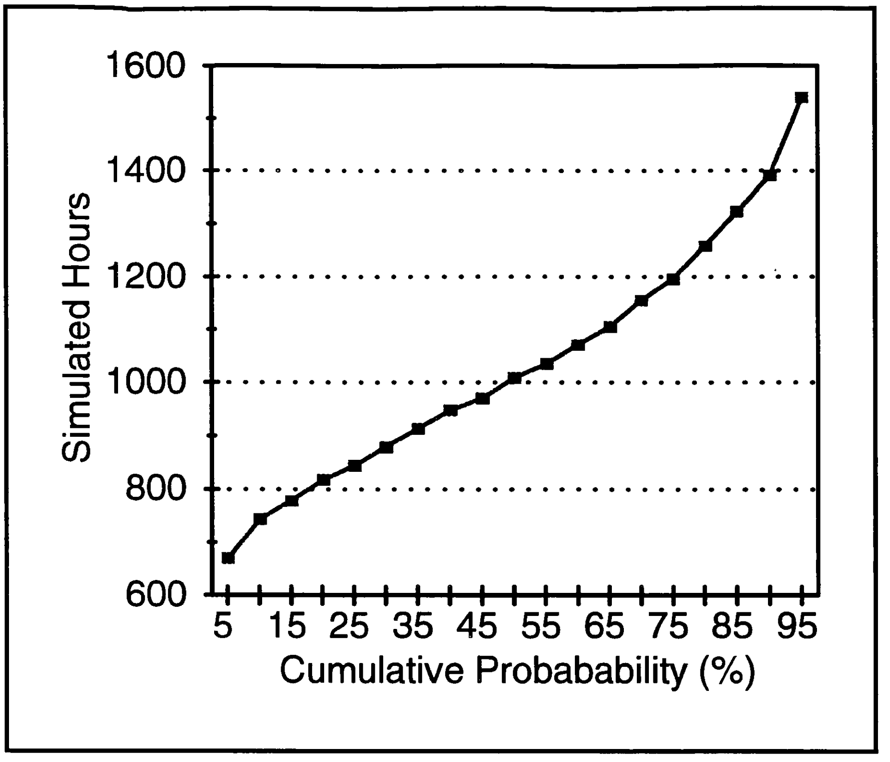



**Figure 7.6:- Revised Level 1 work package model Project B - simulated project total hours**

Table 7.13 demonstrates that the incorporation in the model of an assessment of the risk associated with the individual work packages has not significantly affected the results of the simulation, although Figures 7.5 and 7.6 show that the actual hours occupy less extreme positions in the distribution which would give more confidence in the use of the output distributions. In Project A the actual hours are closer to the 95 percentile value and in Project B these correspond with the 27 percentile value.

The simulation models had now taken account of the risk attitudes of the estimators and the relative levels of inaccuracy of their estimates but no allowance had been made in the model for interdependence between the variables. Uher (1996), stated that the correct assessment of dependence or correlation amongst variables was more critical in terms of the accuracy of the results than the choice of probability distributions and then, paradoxically, produced a model which assumed independence. Hudson (1992) explained that a cost model could be effected because overspend in early work packages would lead to management action which would result in closer control of the later work packages which would alter the shape of the probability distribution functions for these activities. The literature review and survey of design managers revealed that cost control systems were the predominant design management technique and Hudgins and Lavelle (1995) stated that their survey demonstrated that internal management controls force actual costs to self correct towards the original project estimate. The writer considered that an allowance should be made for interdependence between activities but examination of the data in Tables 6.1 to 6.3 revealed no evidence of the impact of a cost control system on the actual work package hours. The work packages for each project are listed in chronological order and there is no real evidence of a reduction in the variance between estimated and actual hours in the later work packages. Thus the assumption of independence between variables would appear to be valid for the three models. This could have been anticipated due to the delay in the processing of data and the late provision of feedback during the data collection stage (see section 6.4.1).

## 7.5 APPLICATION OF THE MODEL

Figure 7.1 showed that the final stages of the modelling process comprised model and hypothesis testing. This work can be divided into two categories:

- experimentation on the effects of differing levels of estimating accuracy on the overall estimate for a project; and
- experimentation by the application of the general model to a further project to validate it's performance and thereby to test the hypothesis "that there exists the potential for the development of a rational approach to the estimation of construction industry design costs by the application of cost modelling, based on historic cost data."

### 7.5.1 Estimating accuracy

The model development stages have provided a useful insight into the effect of levels of estimating accuracy of work packages on project total estimates. The effects of differing levels of estimating accuracy can be examined by considering their influence on the range of possible outcomes for the required project total hours. The initial assumption in Model 1 of the level 2 WBS was that design cost estimating at this level was typified by the widest range of inaccuracy exhibited in the case studies (i.e. between 0 and 850 per cent of the estimated value). Tables 7.3 and 7.7 showed that this would result in a range of project total person hours of approximately ±40 per cent of the mode value. However, if design cost estimation at level 2 was typified by Models 2 to 5 (Log normal distribution with a 99.5 percentile value of 450 per cent of the mode) then a range of hours of approximately ±30 per cent of the mode would arise (Tables 7.4 to 7.7).

The effects of changes in the level of estimating accuracy on the probable range of outcomes were explored further using the level one model for risk seeking behaviour, which can be assumed more realistically to represent estimating practice in a competitive environment. Two further level one models were created for Project A to simulate improved levels of estimating accuracy using Log normal distributions with 99.5 percentile values of 300 and 200 per cent of the mode respectively. Whilst these levels of inaccuracy may appear to be higher than those suggested by the data in Table 6.2, it must be appreciated that the 99.5 percentile point was selected because it was deemed to be sufficiently representative of the maximum level of inaccuracy that might be expected to occur. Furthermore, the Log normal distribution is typified by a positive skew with a long tail containing values which represent project total hours that might arise when the project was significantly underestimated. A range of percentile values of the input distributions for the three models are shown in Table 7.14 and the results of the analysis are presented in Table 7.15. In Table 7.15 the range of estimating inaccuracy has been based on the relative values of the mean, 5 and 95 percentile values to give a consistently stable measure of improving accuracy. This was necessary because the mode, maximum and minimum simulated values were much more unstable in the level 1 model than in the level 2 model due to the reduced number of input distributions.

**Table 7.14: - Percentile points of the input distributions as a percentage of the mode value**

| | **Value of 99.5 percentile as a percentage of the Mode** | | |
|---|---|---|---|
| **Percentile Point** | **400%** | **300%** | **200%** |
| 5 | 60 | 60 | 72 |
| 25 | 90 | 88 | 92 |
| 50 | 123 | 115 | 108 |
| 75 | 165 | 145 | 128 |
| 95 | 257 | 210 | 162 |

**Table 7.15: - Effects of estimating inaccuracy of level 1 work packages on predicted range of project total hours**

| Estimating Inaccuracy (% of mode of 99.5% percentile value of input distribution) | Simulated Hours<br>5% percentile | Mean | 95% percentile | Range (% of Mean) |
|---|---|---|---|---|
| 400 | 285 | 413 | 593 | 69 to 143 |
| 300 | 278 | 372 | 497 | 75 to 134 |
| 200 | 274 | 332 | 394 | 82 to 118 |

Table 7.15 shows that it is possible for design estimators to produce estimates of project total hours with a range of accuracy of ±18 per cent. However, Table 7.14 shows that, in order to reach this level of accuracy, design estimators would have to regularly produce estimates of level 1 work package hours that were within 72 per cent and 162 per cent of their estimated value. Evidence in the literature and from the case study leads the writer to conclude that this is currently not possible.

The impact of estimating accuracy can also be examined with reference to the adequacy of the estimators single point prediction of total project hours when this is compared with the mean of the distribution of probable resource requirements. Table 7.13 contained simulated mean values of 438 and 917 hours respectively for the risk seeking estimators in Projects A and C which, when compared with the estimators total predictions of 303 and 688 hours respectively, demonstrates the inherent inaccuracy resulting from using a simple summation of the modes for the individual work packages. The use of a simple summation by estimators could only produce a reliable estimate of the mean and mode outcomes when the estimator was risk neutral and equally likely to overestimate or underestimate hours, as was the case in Project C.

It can therefore be concluded that there are two components to the levels of inaccuracy that were observed in the case study projects. These arise from:

- the risk attitude of the estimator which results in inaccuracy in the prediction of the mean resource requirements: and,
- the general levels of inaccuracy in estimating the work packages which results in the spread of probable resource requirement from the predicted mean resource requirements.

The use of Log normal distributions in the estimating models has been shown to be appropriate in simulating the effects of the former (Tables 7.6) except in cases of extreme risk seeking (under-estimation) or risk adverse (over-estimation) behaviour. The selection of appropriate 99.5 percentile values of the distributions has been shown to be appropriate in simulating the effects of the latter with 99.5 percentiles value of 400 per cent of the mode (or estimated value) being appropriate for low risk activities, adjusted to 600 per cent for higher risk activities in model of the project estimate from level 1 of the work breakdown structure (Tables 7.13).

### 7.5.2 Model application and hypothesis testing

A simulation model which incorporated the standard input distributions developed in Section 7.4.2 was applied to an additional project to allow the performance of the model to be further evaluated and the overall hypothesis tested. For consistency, another water industry project was selected and, in order that the robustness of the modelling procedure could be analysed, a decision was made to apply the model in a different type of organisation.

The project identified had been recently completed by a firm of Consulting Engineers and actual and estimated cost and person hour data were available. The project estimate had been prepared using a bottom up approach for a WBS to level 2 and examples of the initial estimate are included as Appendix I. The project comprised a technical appraisal of the performance of a major urban wastewater system and included the creation of a hydraulic model of the catchment (which was sub-contracted), the evaluation of the performance of the existing system, and the identification of a strategy to alleviate any problems that had been identified. The WBS for the project was as shown in Figure 7.7.

The model testing consisted of the following stages:

- data on the cost estimate was obtained from the consulting engineers and a meeting was held to review the estimating process and to establish the project estimators views on the accuracy of the estimate of the individual components;
- a general procedure for the application of the model to any design project was devised to enable the selection of the most appropriate standard form of input distribution and to give guidance on the interpretation of the output distribution;
- the model was built and the analysis performed; and finally

- a meeting was held which allowed the model output to be presented to the consulting engineers, a comparison to be made between the actual and simulated person hours, and discussion to be held on the potential for the practical application of the model.

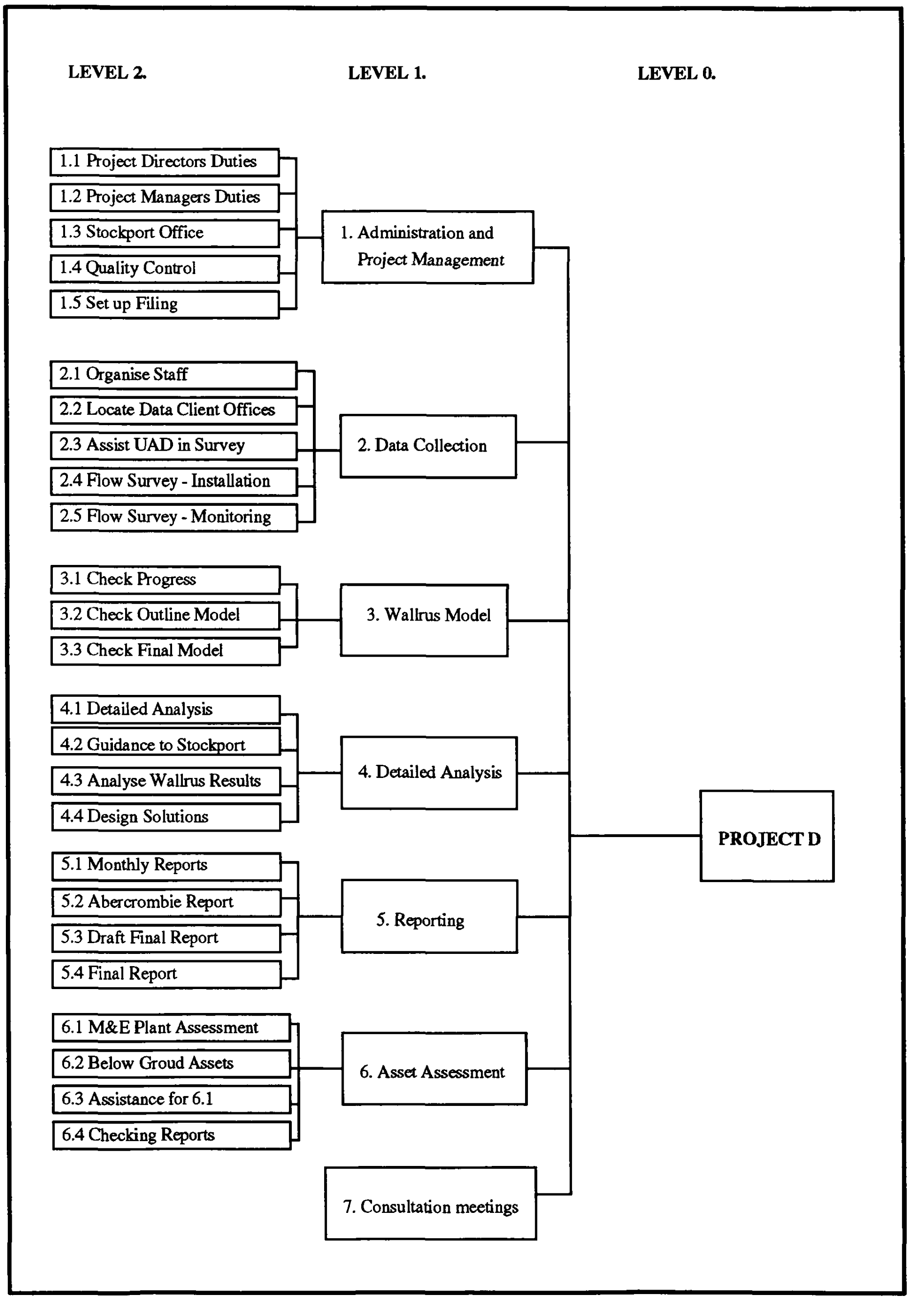



**Figure 7.7: - WBS for Project D**

**Preparation of the Estimate.**

The project estimator described the process of producing cost estimate using the WBS shown in Figure 7.7. He explained that the estimated hours for each work package were based on his perception of the minimum time that would be required by a competent engineer to execute the tasks because risks, contingencies and market conditions would be considered when the cost estimate was converted to a tender (see also Figure 5.1) The estimator was invited to comment on his perceived levels of estimating accuracy for the level 1 work packages and these were as follows.

**Work Package 1.** This can often go over budget by up to 25 per cent because it is often used by staff as a "dump" code for recording times for a variety of tasks on their time sheets. Whilst this item increases it should lead to a reduction in the hours recorded against other work packages.

**Work Package 2.** This was difficult to estimate because of uncertainty about the available data and their current form, and because the data retrieval involved an interface with staff from another organisation. The estimate was assumed to be within ±20 per cent.

**Work Package 3.** This stage would be difficult to estimate because it involves work that was sub-contracted to another consultant, therefore the person hour input from the estimators organisation would be influenced by the performance of the sub-contractor. The estimate was assumed to be within ±20 per cent.

**Work Packages 4 to 7.** Having completed the hydraulic model, the remaining task should be fairly well defined and the estimate for each of these work packages was assumed to be within ±10 per cent.

**General Procedure for the Application of the Model to a Design Project**

The general procedure shown in Figure 7.8 was developed to include the elements of the model development that have been described in the previous sections and this procedures was applied to Project D. Stages 1 to 5 of the modelling procedure would be incorporated in Phase 3a of the general design estimation process (which was shown in Figure 5.1) and Stage 6 would provide additional information to support the final decision on the level of the fee bid in Phase 4 of the process.

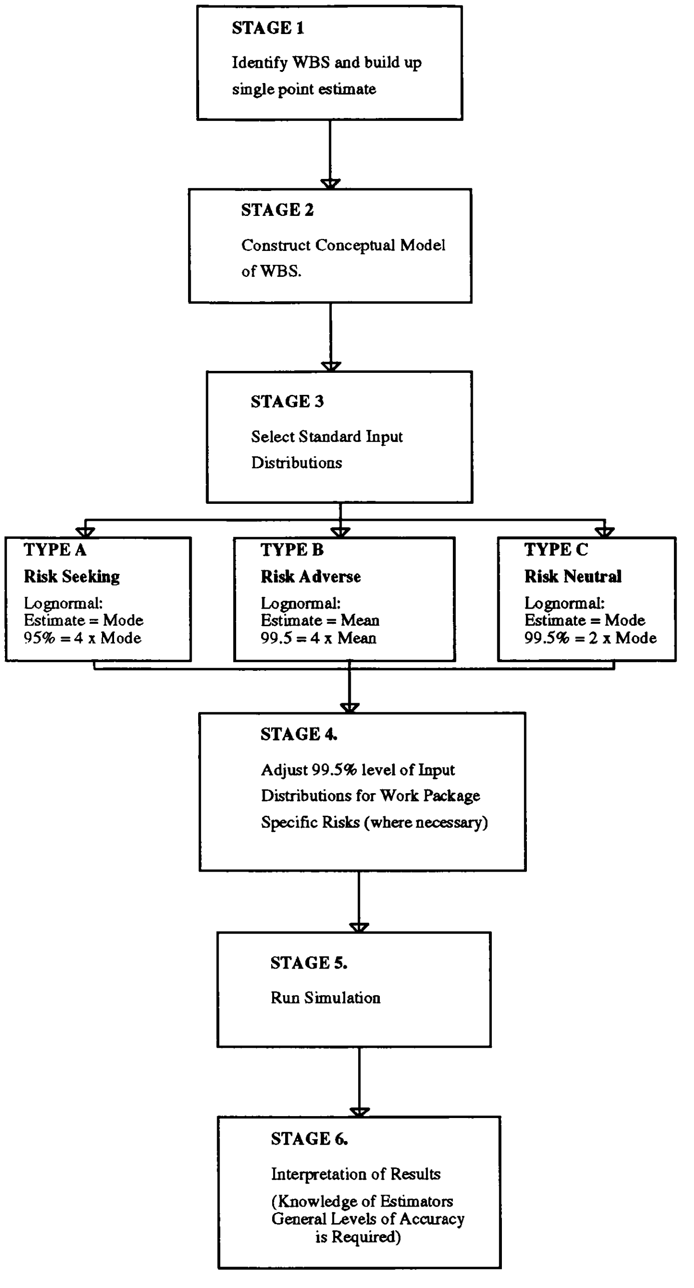



**Figure 7.8: - General procedure for cost modelling**

**Model Building and Analysis.**

**Stages 1 and 2.** The qualitative conceptual model was set up on the spreadsheet to represent the WBS to level 1 as shown in Figure 7.7. Two quantitative models were developed: the first being a general model which utilised the distributions that had been selected in the model development work, and the second which utilised distribution which reflected the estimator's perception of his estimating accuracy. Each comprised six input distributions to represent the level 1 work packages, and produced an output distribution that represented the total project person hour requirements.

**Stage 3.** This involved the selection of the appropriate input distributions. It was apparent from the initial meeting with the project estimator that a risk seeking attitude had been adopted in the preparation of the estimate and therefore Type A distributions were selected for the general model. Revised Type A distributions were selected for the perceived model with the spread of the distributions being reduced so that the 95 percentile points of the distribution corresponded with the estimator's evaluation of the upper bound of his estimating accuracy.

**Stage 4.** This stage enabled an adjustment to be made to the selected input distributions for the general model to reflect different levels of risk inherent in the work packages. The initial meeting with the estimator identified two categories of risk: low levels of risk for work packages 4 to 7 inclusive and moderate levels of risk for work packages 1 to 3 inclusive. As was the case with the previous level 1 models the position of the 95 percentile point of the distributions for the higher risk work packages was adjusted to be 600 per cent of the estimated value.

**Stage 5.** The simulation analysis was carried out. The results of the analysis are summarised in Table 7.16 and Figures 7.9 and 7.10.

**Table 7.16: - Summary of analysis of Project D**

| **Simulated Project Total Hours. (Actual Project Total Hours = 1928)** | | | | | | | **Simulation Inaccuracy** | |
|---|---|---|---|---|---|---|---|---|
| | Min. | Mean | Max. | Mode | 5 percentile | 95 percentile | Mean (%) | Mode (%) |
| General Model | 986 | 1916 | 4047 | 1754 | 1260 | 2810 | 99 | 91 |
| Model of Perceived Accuracy | 1272 | 1301 | 1328 | 1299 | 1287 | 1313 | 67 | 67 |

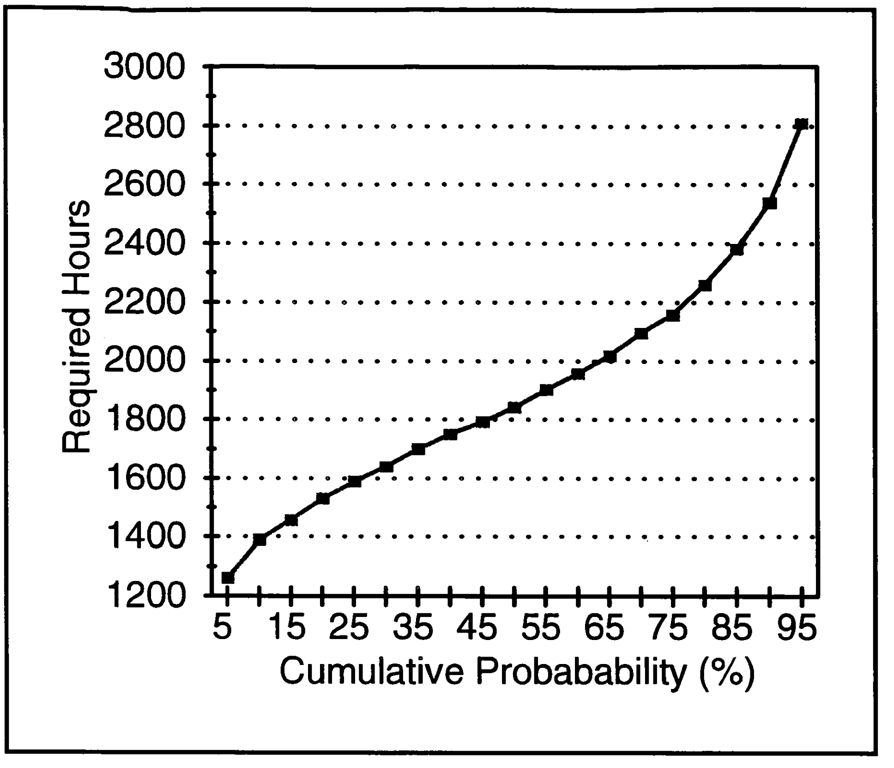



**Figure 7.9: - Cumulative probability distribution - general model**

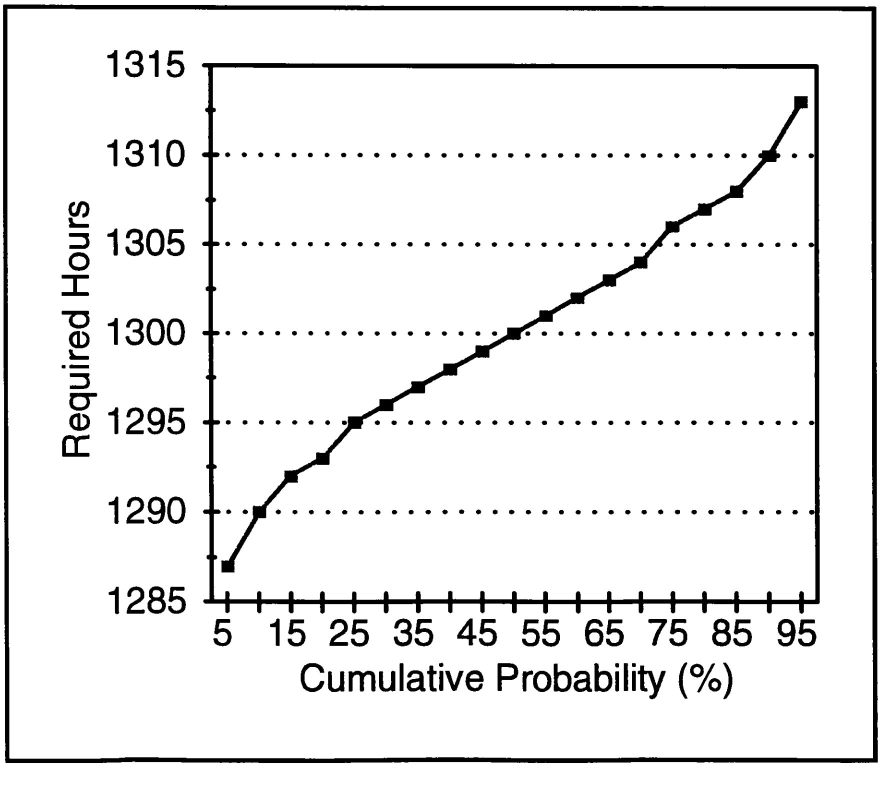



**Figure 7.10: - Cumulative probability distribution - perceived estimating accuracy**

**Stage 6 Interpretation of Results.**

It was initially envisaged that the results of the simulation would enable the project manager to assess the probabilities of the single point intuitive estimate being exceeded. This would allow the estimator to reflect upon the adequacy of the single point estimate developed during Phase 3 of the estimating process, shown in Figure 5.1, before presenting this estimate to the organisations Directors for Phase 4, the conversion of the estimate into a tender. The procedure for the interpretation of the results would be as follows:

- a confidence level would have to be established based on the perceived levels of accuracy of the estimator;
- the probability of exceeding the single point estimate should be determined from Figure 7.9; and
- a decision would be made on the adequacy of the single point estimate.

There is insufficient data to allow the desired confidence levels to be established with any certainty but a qualitative assessment can be made in this case based on the model development work. Table 7.13 showed that actual hours required for Project A were at the 95 percentile point of the output distribution. The estimator for Project A can be described as inexperienced in terms of his current employment and it might be reasonable to suggest that a 95 per cent confidence level might be appropriate for an inexperienced estimator exhibiting risk seeking behaviour. Consequently, it could be argued that a lower confidence level would be appropriate for Project D where the estimator was risk seeking but highly experienced within the organisation and in the field of the estimate.

Table 7.16 showed that the mean of the output distribution for the general model of Project D (which used the standard Log normal input distributions) was virtually identical to the total hours that were required for the project. It could be argued therefore that the standard model has been demonstrated to be valid and that the mean predicted by the general model is a useful indicator of required person hours for a project in a risk seeking environment. However, before concluding on the validity of the model, it is also necessary to consider the significance of cumulative probability distributions for the model output which was shown in Figure 7.9. This demonstrated that the actual hours correspond with the 57 percentile point of the distribution which suggests that there was a 43 per cent chance that the project person hour requirements could exceed this value. The validity of the general model can only be established if it could reasonably be concluded that the project estimators personal

risk attitude and levels of accuracy were such that the mean prediction of actual hours could be accepted with confidence.
In the absence of other data, the estimators attitude and levels of accuracy can only be measured using the data that was available from this project. The estimator's inaccuracy in predicting each of the work packages is shown in Table 7.14, where inaccuracy is expressed as:

$$\frac{\text{Actual Hours}}{\text{Estimated Hours}} \times 100$$

**Table 7.17: - Analysis of estimating inaccuracy for Project D**

| Work Package | Estimated Hours | Actual Hours | Inaccuracy |
|---|---|---|---|
| 1 | 167 | 201 | 120 |
| 2 | 292 | 367 | 126 |
| 3 | 37 | 57 | 154 |
| 4 | 315 | 531 | 169 |
| 5 | 320 | 553 | 173 |
| 6 | 70 | 97 | 139 |
| 7 | 100 | 122 | 122 |

**Average Inaccuracy = 143 per cent**

Table 7.17 demonstrates that the estimator is risk seeking and it could be argued that this risk attitude has contributed 143 per cent of the overall inaccuracy in the estimate. Against this benchmark the estimators performance with respect to general inaccuracy within work packages (see section 7.5.1) is extremely good, with inaccuracy in the individual work packages being within -23 and +30 per cent of the bench mark figure. Table 7.15 has shown that work package estimation at this level of accuracy would produce predictions of total actual hours that were within a very narrow band of the mean prediction. In the context of prediction of the general model it would be reasonable to accept the mean predicted value when the estimator was known to be risk seeking but was otherwise consistently accurate. It can therefore be concluded that the general model has been shown to be robust in it's application to Project D.

Table 7.17 also provides additional information on other assumptions within the general model. Firstly, the risk categorisation of the individual work packages has been unsuccessful. Work packages 1 to 3 were identified as being higher risk but this has not been reflected in the accuracy of the estimates, with work packages 4 and 5 exhibiting the greatest inaccuracies. Secondly the assumption of no interdependence between the input distributions has been shown to be valid. The sequence of activities for the project were;

> the project commenced with activities 1, 2, 3 and 6 which were carried out in parallel, followed by activity 4, and then, finally, activity 5. Activity 7 took place throughout the project.

As was the case in the case study projects there is no evidence of a restriction in the resource input in the later work packages as feedback on the overall performance on the project became apparent which suggests that the assumption of independence was appropriate.

**Practical Application of the Model Output.**

A meeting to discuss the analysis and the results described above was held with the project estimator and the following key points arose.

Estimators are now familiar with producing a single point estimate of total required hours for a project in a competitive environment and this is built up from a summation of single point estimates of the minimum anticipated resource requirements for the constituent work packages. They would have difficulty in applying a probabilistic estimating approach at this stage because they would consider that the utilisation of the information in Figure 7.9 to adjust their estimate prior to a decision on the final tender values would significantly reduce the chance of winning a project.

Simulation analysis would, however, be a valuable tool for Phase 4 of the estimating process because it is at this stage that a decision is taken on the cost multiplier to be adopted (see Section 5.1.1). The factors that are taken into account at this stage include, the levels of risk associated with the work packages, the nature of the client, the number and nature of the competitors, the prevailing market conditions, and the possibility of negotiating additional work at favourable terms during the currency of the project. The impact of inaccuracy in the estimate was not considered directly because of overconfidence by the estimators in the accuracy of their estimates and the extent of this overconfidence can be gauged from a comparison on Figure 7.9 which is believed to represent the true design cost estimating risk profile with Figure 7.10 which represents the risk profile based on the estimators perception of work package accuracy.

The estimator explained that, in arriving at the tender value for Project D a cost multiplier of 1.8 on the single point estimate of 1301 hours was agreed. The estimator considered that Figure 7.9 would be more useful if it could be adjusted to show the probability of actually achieving the selected mark as a result of estimating inaccuracy. For each 5 percentile point the predicted cost was converted to a predicted mark up as follows:

$$\text{Actual Multiplier} = 1.8 \times \frac{\text{Predicted hours}}{\text{Estimated Hours}}$$

Figure 7.11 shows the results of the simulation analysis in terms of the cost multipliers for the general and perceived models.

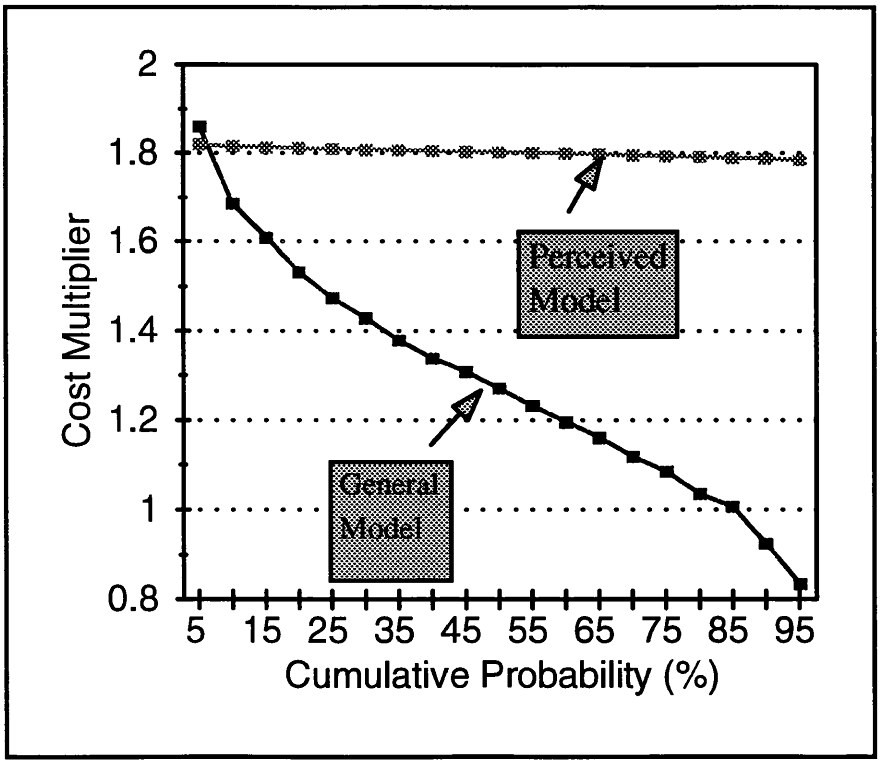



**Figure 7.11: - Cumulative frequency distribution based on cost multipliers**

The risk profile from the general model shows that the probability of achieving the desired 1.8 multiplier was very low which suggests that the organisation should have increased the multiplier used in the tender to achieve such a level of profitability. In contrast the risk profile from the model of perceived estimating accuracy showed that the organisation appeared to be certain to achieve a cost multiplier of approximately 1.8.

The estimator agreed that Figure 7.11 was useful in two ways. Firstly, it allowed some quantification of the risk associated with the cost estimate. Normally, no information of this nature was available during Phase 4 of the estimating process and decisions on the multiplier to be applied are based purely on the combined judgement of the panel. Secondly, the figure demonstrated that current perceptions of estimating accuracy were likely to result in an erosion in the profitability of projects and that consequently it would be extremely useful to establish a realistic risk profile for projects.

The discussion then focused on the other issues which affected the decision on the level of the multiplier at the tender stage. This project was strategically important to the organisation because it was believed that securing this project would provide the opportunity to establish an office in the city being studied and that there would be a high probability of securing follow up work. Furthermore, there was considered to be a high probability of additional work being required by the Client in this project with the possibility of being able to negotiate more favourable rates for this work, thereby recovering additional overheads. Consequently, notwithstanding the risks inherent in the work it was decided that a relatively low multiplier of 1.8 would be appropriate at the tender stage. (In fact, the final outcome of the project was that a significant amount of additional work was required and, as a result of this work, that the project broke even as a multiplier of 1.37 achieved but the project contributed little to company overheads. In view if the strategic importance of the project being studied to the organisation this was deemed to be a satisfactory outcome.)

Unfortunately, it is impossible to speculate whether or not the knowledge from Figure 7.11 would have resulted in the selection of a different multiplier at the tender stage. It could be argued that the risk model accurately identified the low probability of achieving the desired multiplier, and that had a increased multiplier been applied at the tender stage then the project would have been more profitable. Alternatively it could be argued that the market conditions would not allow the application of a higher multiplier if the project were to be secured. It can however be concluded that Figure 7.11 allowed the estimator to understand more fully the likely outcome of bidding for the project on a 1.8 multiplier and the risk could be considered against the strategic importance of the project and the probability of additional work being required in the project.

## 7.5 SUMMARY OF CHAPTER 7

This chapter has described the cost model which was developed in order that the fourth and fifth aims of the project could be achieved. These were:

- the selection and development of an appropriate form of model; and
- the verification of the performance of the cost model.

With regard to the fourth project aim, a number of potentially useful cost modelling approaches were identified and reviewed. It was concluded that, in view of the limited availability of cost data within design organisations and, having given due consideration to the practicalities of utilising the various techniques, simulation modelling using a risk analysis approach was the most appropriate form of instrument. A general model of design cost estimation was developed using data from the case studies which enabled the selection of the appropriate forms of input distributions. Finally, a procedure for the application of the model to other projects was devised.

With regard to the fifth project aim, the cost modelling procedure was applied to a further project and it was concluded that the model gave a prediction of the required resource input for the project that was realistic when considered in the context of the estimating accuracy exhibited by the project estimator.

In addition, the model development and testing has also provided useful insight into the components of estimating inaccuracy which were identified as arising from:

- the estimators attitude toward risk; and
- the estimators level of accuracy within each work package.

Finally, the model development and testing have also provided information on the effects of different levels of estimating inaccuracy on the predicted overall project cost.

The successful development of the model tends to supports the hypothesis; "that there exists the potential for the development of a rational approach to the estimation of construction industry design costs by the application of cost modelling, based on historic cost data".

# CHAPTER 8

# CONCLUSIONS

## 8.1 INTRODUCTION

The conclusions were developed in the following manner. A critical review of the extent to which the aims had been achieved was undertaken and, consequently, the extent to which the overall hypothesis was supported or rejected by this investigation was determined. The results of this appraisal are presented in sections 8.2, 8.3, 8.4, and 8.5. Then recommendations for future work were developed in response to any limitations of the current study that had been identified and these are presented in section 8.6.

The project aims were:

- to identify, and quantify the use of, design cost estimating and cost control approaches that are currently applied by design managers;
- to evaluate the extent to which current practice could facilitate the application of a more rational approach to cost estimating;
- to evaluate of the practicality of enhanced data collection to support a more rational approach;
- to select and develop a form of model that is appropriate for the available data; and
- to verify the performance of the cost model.

The overall hypothesis was:

> *that there exists the potential for the development of a rational approach to the estimation of construction industry design costs by the application of cost modelling, based on historic cost data.*

## 8.2 REVIEW OF CURRENT COST ESTIMATING AND COST CONTROL TECHNIQUES

The work undertaken to achieve the first two project aims was presented in Chapters two, three and five and the conclusions drawn from this investigation are given in sections 8.2.1 and 8.2.2.

### 8.2.1 Current cost estimating and cost control practice in construction industry design

The literature review demonstrated that design cost management was dominated by the application of cost control systems which monitor costs against estimates that had been derived in a simplistic, intuitive manner. The survey of design practices enabled a model of the cost estimation process (Figure 5.1) to be developed and the validity of this model was positively tested by applying it to a large sample of design organisations. The interviews identified four cost estimating techniques that were used during the cost estimation process and the extent of the usage of the techniques at each stage of the design process was determined in the questionnaire survey. There was clear evidence of a polarisation in the use of two forms of cost estimation, with the intuitive approaches being used frequently and the rational data driven approach being seldom, if ever, used.

It can be concluded that the first project aim has been fully achieved and it has been shown that design cost estimation is driven by experience, is intuitive, and is loosely supported by non-specific records of previous projects. With regard to the overall hypothesis, there was strong evidence that rational cost estimating approaches were not being adopted by designers, which indicates that currently the potential for their application is limited.

### 8.2.2 The impact of existing practice on the potential for rational design cost estimation

The potential for the application of more rational approaches to cost estimation was more fully evaluated by considering three factors:

- the nature of the design activity and the design process,
- the perception amongst designers that the design process was not amenable to the application of rigorous cost estimation and control systems; and
- the nature of cost data that was available within design organisations.

The literature review demonstrated that the general design process is essentially a decision making process which comprised a series of iterative stages. The required input to this process will be greatly affected by the extent to which optimal rather than satisfactory decisions are made at each stage of the process. The degree of rationality of these decisions will be influenced by: the extent to which the problem can be defined; the degree of influence of non-technical criteria; the extent of the application of intuitive approaches rather than logical deduction to decision making; the necessity for creativity in the development of the solution; and the personal attributes of the designers. Furthermore, the extent to which each of these factors influence the design resource requirements will vary throughout the stages of the design process.

The integration of the design process within the construction industry was considered and the number of parties involved in the process and the variety of relationships that can exist between these parties was identified. It was concluded that the existence of this range of procurement systems did not alter the fundamental nature of the design process, but would influence the nature of the design work associated with each stage of the process, thereby adding further complexity to the problem of cost estimation.

Overall, it can be concluded from the evidence in the literature review that the nature of the design activity and the design process are such that the potential for the application of rational cost estimation to the constituent components of this process would be limited due to the high degree of variability in the required design input. Evidence to support this conclusion emerged in the analysis of the case study project data and was present in reports by others on cost variability in design fee estimates in practice.

There was also evidence in the literature review that there was a widely held view amongst designers that, by its very nature, design work was not suited to accurate cost estimation and rigorous cost control. The questionnaire survey produced data that enabled hypotheses to be developed and tested, and it can be concluded with a high degree of certainty that design manager do not consider that the potential exists for the application of rational cost estimating approaches.

Finally, the nature of the cost information that was currently available within design organisations was examined. The literature review suggested that the availability of appropriate data for cost estimation would be limited. The authors reviewed treated organisations cost control and cost estimating functions as unrelated activities and the potential opportunity for the establishment of a cost database for future estimating using cost control information from current projects was overlooked. These conclusions were confirmed in the questionnaire survey.

It can be concluded that the second project aim has been fully achieved. In achieving this aim the following overall conclusion can be drawn. The nature of the design process and the design activity has resulted in the development, amongst designers, of a perception that design work was not suited to accurate cost estimation and rigorous cost control. Consequently, cost estimating and cost control functions were seen as being separate and cost data were not available in a form that would facilitate the application of a more rational approach to cost estimating.

## 8.3 POTENTIAL FOR ENHANCED DATA COLLECTION

The third aim, to evaluate the practicality of enhanced data collection to support a more rational cost estimating approach, was addressed through the data collection case study presented in Chapter 6. The positive conclusions from this part of the research were that the case studies demonstrated that it was possible to set up a cost monitoring system for single projects which would produce historic cost data, but not to the level of detail that was required for the cost estimating system. The case study also demonstrated that the integration between the cost estimating and cost monitoring systems encouraged the design teams to take ownership of the data which enhanced the benefits obtained from the system. These were the provision of more accurate data and, through the provision of feedback, the opportunity to enhance estimator's accuracy.

However, the cost monitoring aspects of the spread sheet system proved to be too cumbersome to be applied to all projects within an organisation. Delays were encountered in the provision of feedback due to the time required for data processing because the system proved to be inappropriate, in some instances, for direct entry of data by the engineers involved in the project.

It can be concluded that the third project aim has been fully achieved. Conflicting evidence emerged on the validity of the hypothesis. It can be concluded that it is possible to develop an integrated cost estimation and cost control system that would contribute to the creation of a database of historic design costs with the proviso that, in order to generate a sufficiently large database, the system would have to be applied across an entire organisation. There are a number of serious, but probably not insurmountable, barriers to this including:

- the establishment of an appropriate programme of staff training on the system;
- the establishment of a standard work breakdown structure to provide uniformity of data across an organisation; and
- the impracticality of using current time sheet approaches to provide historic cost data against the second level of the work breakdown structure.

## 8.4 MODEL DEVELOPMENT AND TESTING

The work undertaken to achieve the fourth and fifth project aims was presented in Chapter 7. Simulation modelling using a risk analysis approach was identified as being the most appropriate form of model. A general simulation model of design cost estimation was developed using data from the case studies which enabled the selection of appropriate forms of input distributions. A procedure for the application of the model to other projects was devised and it was applied to a further project. It was concluded that the model prediction of the required resource input for the project was realistic.

The cost modelling also suggested that there were two components of inaccuracy in design cost estimating: the estimator's attitude toward risk; and the estimator's level of accuracy within each work package. It also provided information on the effects of different levels of estimating accuracy on the predicted overall project cost.

It can therefore be concluded that the fourth and fifth aims of the project have been fully achieved. It has been shown that it was possible to select and develop a form of cost model that was appropriate for the available data, and to verify its performance. The experimentation with the model enabled a greater understanding to be gained of the sources of estimating inaccuracy and the impact of these on the accuracy of total project design costs.

## 8.5 CONCLUSIONS ON THE VALIDITY OF THE HYPOTHESIS

The Grounded Theory approach which was adopted for the study has enabled an appropriate hypothesis to be developed, and tested, through systematic data collection and analysis. Qualitative and quantitative procedures have been brought to bear on the research, but the overall conclusion on the validity of the research hypothesis can only be reached by a qualitative analysis of the findings that emerged from the realisation of each of the research aims.

As would have been expected there were conflicting indications as to the validity of the overall hypothesis. It appears that the overall hypothesis "*that there exists the potential for the development of a rational approach to the estimation of* *construction industry design costs by the application of cost modelling, based on historic cost data"*, can not be sustained based on the following findings.

- There was strong qualitative evidence from the literature review which demonstrated clearly that the nature of the design activity and the design process are such that the potential for the application of rational cost estimation approaches to this process is limited.
- This finding was supported by strong quantitative evidence from the literature review, the data collection case studies and the cost modelling work which demonstrated, and explained, the high degree of variability that exists between cost estimates from different organisations, and within the levels of accuracy of estimates at work package level for individual estimators.
- The qualitative evidence from the interviews that designers do not believe that design work is suited to rational cost estimation. This was supported by the quantitative findings of the questionnaire survey.

However, the partial success of the data collection case studies provided a contrasting dimension to the evidence which comprised:

- quantitative evidence that it had been possible to produce data that were appropriate for cost modelling purpose, albeit on a limited scale;
- qualitative evidence on the benefits of the implementation of an integrated cost estimating and cost control system; and
- qualitative evidence on the problems that would have to be resolved in the wider implementation of an integrated cost estimation and cost control system.

On balance, these findings appear to support the hypothesis, but the limitations of the data collection case study must be acknowledged. This was necessary for a number of reasons. Firstly, data collection was restricted to a small number of organisations to ensure that the implementation of the system could be effectively managed and monitored. Secondly, over-sophistication in the system design had to be avoided to minimise intrusion in the normal working practices of the case study organisations in order that the ongoing co-operation of the design teams could be ensured. Similarly, only tools that were readily available to the designers within these organisations could be used in the system in order that the need for staff training could be minimised.

Finally, the following findings emerging from the successful development of the cost model tend to support the hypothesis. The evidence comprised:

- qualitative evidence that led to selection of an appropriate form of cost model;

- quantitative evidence that it was possible to develop a cost model which was appropriate for the available data, and to verify its performance; and
- qualitative and quantitative evidence that the model could contribute to a greater understanding being gained of the sources of estimating inaccuracy and the impact of these on the accuracy of total project design costs.

The limitations of the model development and validation must be acknowledged. Limited data were available to support the model development. Model verification was also limited because it was not possible to acquire data from a number of estimators to establish whether the model could consistently provide realistic cost estimates.

Notwithstanding the reservations on the findings relating to the data collection and cost modelling aspects of the work, there is sufficient evidence to draw a final conclusion on the overall hypothesis.

*It can be concluded that, in the context of current design cost estimation and cost control practice, the hypothesis "that there exists the potential for the development of a rational approach to the estimation of construction industry design costs by the application of cost modelling, based on historic cost data" can be accepted as being valid provided that a means of widespread collection of detailed cost data against standard design packages was developed, and that this data were used to further verify the performance of the cost model.*

## 8.6 SECONDARY CONCLUSION

It should be noted that, whilst the main thrust of the research work was concerned with the estimating process, there were a number of areas in the study where there was evidence that the influence of the culture in design management restricted the potential for rational design cost estimation. These included:

- evidence in the literature review (e.g. Rowdon and Mansfield, 1989; Hudgins and Lavelle, 1995);
- evidence in the interviews and surveys of a lack of appreciation of the need for the use of standard work packages:
- the levels of estimating accuracy exhibited by the design engineers in the case study which contrasted with the unrealistic perceptions of estimating accuracy exhibited by designers during the application of the cost model

## 8.7 RECOMMENDATIONS FOR FUTURE WORK.

This study has been described in Chapter 1 as being principally "exploratory" in nature, i.e. research that was concerned with tackling a new problem, although the work was extended to include a developmental stage in the production and verification of the simulation model. The purpose of any exploratory study is allow general conclusions to be drawn on the phenomenon under investigation and these can usefully identify the future direction for "*testing-out*" research where the conclusions can be developed.

From the conclusions above, it is recommended that the following areas of research in this field should be usefully pursued.

- A programme of research should be undertaken to investigate the practicality of widespread collection of detailed data across a number of organisations using a standardised work breakdown system. This should lead towards a standard classification system similar in concept to Uniclass co-ordinated project information system or the Civil Engineering Standard Method of Measurement (CESMM) for construction works. This work would be timely because it parallels and complements other recent developments in construction management research including; bench marking, business re-engineering and process mapping. Process mapping should be investigated as a means of establishing, across organisations, a consistent set of work packages against which data can be recorded. In doing so, the potential for the opportunity to consider the effectiveness of the process identified using re-engineering approaches and bench marking could be assessed. Information flows within the organisation should be identified as part of this study and in keeping with the concepts of re-engineering the impact of the data flows on design times and costs should be identified.

- A programme of research work should be undertaken to develop and test more fully the implementation of the data collection methodology described in Chapter 6. Developments in data recognition technology and the availability of computer networks should be utilised as they provide for the first time an opportunity to collect a sufficient volume of detailed design cost data to allow cost modelling approaches to be fully developed

- Having compiled an appropriate data base of costs the assembled data should be used to allow a repetition and expansion of the cost modelling work to see if the risk analysis simulation approach could consistently produce reliable estimates for a range of estimators with differing risk attitudes and levels of estimating accuracy. Additionally the data should be used to re-assess the potential, for cost estimating purposes of the other estimating techniques identified in this study namely; parametric models, process simulation, fuzzy logic and neural networks.

- The creation of a reliable data set will also enable a full study to be undertaken on the assumptions made in this thesis that new methods procurement systems have little effect on the operation of the cost model of design services. Data from standard work packages for differing procurement systems could also be evaluated to facilitate a comparative analysis of the cost of design services under the various systems.

- A programme of research should be undertaken to establish whether the prevalent mind-set and culture in design organisations constitute a significant barrier to more rational design cost estimation.. This research should focus on both the influence of organisational culture on current design cost estimation practice and on ways in which this culture might be modified to facilitate the use of the tools and approaches outlined in the recommendations above.

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# Appendix A

## List of questions issued in advance of the second round of interviews

## SECTION A. General

(1) In total, how many chartered engineers and technicians do you employ (including trainees)?

(2) Please estimate the proportion of these that are substantially ( >33% of their time) involved in the management of your organisation as opposed to direct project work.

(3) Please estimate the approximate proportions of your organisation's workload in each of the following areas:
(i) Water & Sewerage;
(ii) Transportation (highways, rail, airports);
(iii) Marine works;
(iv) Building related structural engineering;
(v) Geotechnics and foundation engineering;
(vi) Other (please state).

(4) Please estimate the approximate proportions of your organisation's workload in each of the following categories:
(i) Report and advisory work, either engaged by the client or in conjunction with a contractor in design and construct contracts;
(ii) Design and supervision of construction, engaged directly by the client;
(iii) Design work in conjunction with a contractor in design and construct projects.

## SECTION B. Planning your design work.

(5) Who has the main responsibility for determining the resources required for design work on a particular project:
(i) senior managers alone;
(ii) senior managers in consultation with the project engineers;
(iii) project engineers in consultation with the senior managers.

(6) On what basis are the allocations of time and resources to design works made:
(i) a broad estimate based on experience, largely unsupported by specific data;
(ii) a broad estimate based on cost data from previous projects:
(iii) detailed programmes based on comprehensive data relating to design activities within previous project.
(iv) Any other method?

(7) Which the following techniques do you use in planning design work:
(i) Bar charts;
(ii) Micro-computer based programming packages;
(iii) Manual budgetary and cost control systems;
(iv) Computer based budgetary and cost control systems?

(8) Do you apply different techniques for different stages of the development of a project i.e.:
(i) Report and advisory work;
(ii) Detailed design work;
(iii) Supervision of construction?

(9) Which of the following factors is predominant in estimating the cost of design work:
(i) the likely level of income from the project;
(ii) the necessary resources required to design the project?

## PART C. Trends in planning design work

Please consider the following statements for questions 10 to 12.

(a) The allocation of design resources to a project is determined substantially by the design budget available.

(b) the design budget of a project is determined by the resources necessary to design the most economic solution for that project.

(10) Historically, which of these statements would be most applicable to your organisation's planning of design work:
(i) for the report and advisory stage;
(ii) for the detailed design stage?

(11) Considering clients increasing requirements for negotiation of design fees, which of the statements would be most applicable:
(i) for the report and advisory stage;
(ii) for the detailed design stage?

(12) Do you consider that your organisation possess sufficiently detailed information to programme work in accordance with statement (b) above:
(i) for the report and advisory stage;
(ii) for the detailed design stage?

(13) Does your organisation intend to collect more comprehensive details in future:
(i) for the report and advisory stage;
(ii) for the detailed design stage?

**PART D. Quality assurance**

(14) Does your organisation operate some form of formal Quality Assurance (QA) system?
(if "yes" please go to Q 17).

(15) Are you considering implementing some form of formal QA system?
(if "yes" please go to Q 17).

(16) Please outline your reasons for not considering the implementation of a formal QA system.

(17) Please consider and rate the following possible reasons for implementing a formal QA system.
(Scale: 1 Very important, 3 Quite important, 5 Not at all important
(a) to gain a commercial advantage over competitors;
(b) to improve efficiency;
(c) to improve the quality of your output;
(d) to facilitate more accurate estimation of future work.

# Appendix B

# Postal Questionnaire

Dundee Institute of Technology

# Questionnaire Survey of Design Offices

Thank you for taking part in this survey. The questionnaire has been designed to permit most responses to be made by a single entry to a box or grid which should minimise the time required to complete the form. In addition space has been allocated beside each question to give you the opportunity to add any comments which you consider to be appropriate. Such comments can be particularly useful and space has been allocated at the back of the questionnaire for general comments or for the continuation of previous comments.

As stated in the accompanying letter, any information provided will be treated in the strictest confidence with no organisation or individuals being identified in any reports or publications on the outcome of the survey. Nevertheless, the overall results of the survey will be published. Please put a tick in the box below if you would like me to send you a summary report on the results of the survey. This would be sent to the same addressee as the questionnaire unless otherwise indicated.

Please send me a summary report of the results of the survey. ☐

*This should be sent to:*

...................................................

...................................................

...................................................

...................................................

(name only required if different from addressee of accompanying letter)

**Reference Number** ............

## Section A – General

This part of questionnaire has been included to allow a comparison to be made of the planning and estimating approaches adopted by various offices, considering for example, their size, main discipline (i.e. architecture or engineering) or main sector of work. This questionnaire survey is being sent to selected individual offices of companies as opposed to company head offices and therefore the information requested relates to your particular office rather than to your organisation as a whole.

1. *How many of the following do you employ in your office?*

| | |
|---|---|
| Chartered Engineers | ☐ |
| Chartered Architects | ☐ |
| Engineering Technicians | ☐ |
| Architectural Technicians | ☐ |

Comments ........................................................................................

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2. *Please estimate the percentage of staff who are substantially involved with the management of your organisation as opposed to project work.*

| | % |
|---|---|
| Chartered Engineers | ☐ |
| Chartered Architects | ☐ |
| Engineering Technicians | ☐ |
| Architectural Technicians | ☐ |

Comments ........................................................................................

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3. *Please rank the following market sectors in order of your offices involvement. (please circle)*

| | *Most Involved* ◄ | | | | | ► *Least Involved* |
|---|---|---|---|---|---|---|
| **Civil Engineering** | | | | | | |
| Water and sewerage | 1 | 2 | 3 | 4 | 5 | 6 |
| Transportation (highways, rail airports) | 1 | 2 | 3 | 4 | 5 | 6 |
| Marine works | 1 | 2 | 3 | 4 | 5 | 6 |
| Building related structural engineering | 1 | 2 | 3 | 4 | 5 | 6 |
| Geotechnics and foundation engineering | 1 | 2 | 3 | 4 | 5 | 6 |
| Other (please specify) | 1 | 2 | 3 | 4 | 5 | 6 |

| **Architecture** | | | | | | |
|---|---|---|---|---|---|---|
| Industrial | 1 | 2 | 3 | 4 | 5 | 6 |
| Offices | 1 | 2 | 3 | 4 | 5 | 6 |
| Retail | 1 | 2 | 3 | 4 | 5 | 6 |
| Hotel and leisure | 1 | 2 | 3 | 4 | 5 | 6 |
| Residential | 1 | 2 | 3 | 4 | 5 | 6 |
| Other (please specify) | 1 | 2 | 3 | 4 | 5 | 6 |

Comments ..........................................................................................

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4. *Please estimate the approximate number of projects currently being undertaken by your offices in terms of the value of the project*

| | |
|---|---|
| Less than £250,000 | ☐ |
| £250,000 to £500,000 | ☐ |
| £500,000 to £1M | ☐ |
| £1M to £5M | ☐ |
| £5M to £10M | ☐ |
| Greater than £10M | ☐ |

5. *Please estimate the approximate percentage of your offices work load in each of the following categories: (the percentages should total to approximately 100)*

| **Stage of Project** | **Relationship with Client** | | |
|---|---|---|---|
| | Employed Directly % | Employed by/ joint venture with contractor % | Employed on sub-contract to other consultant % |
| (a) Advisory work | ☐ | ☐ | ☐ |
| (b) Feasibility studies/Outline design | ☐ | ☐ | ☐ |
| (c) Detailed design | ☐ | ☐ | ☐ |
| (d) Preparation of contract documents | ☐ | ☐ | ☐ |
| (e) Supervision of construction | ☐ | ☐ | ☐ |
| (f) Post contract work | ☐ | ☐ | ☐ |

Comments ..........................................................................................

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6. *Please indicate the extent to which the estimation of design staff resources is delegated from head office to your office (please circle)*

**Degree of Autonomy**

*High* ◄──────────────► *Low*

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|

Comments ..........................................................................................

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## Section B – Estimating, Planning and Cost Control Techniques

This section of the questionnaire has been included to determine the frequency of use, by design managers, of various techniques for estimating, planning and controlling the staff resources which are necessary to design construction projects. The techniques listed were identified during a series of interviews with design managers. However I would be most grateful if you could briefly describe any other techniques used in your office. If your office contains more than one discrete or semi-autonomous section and approaches to planning, estimating and cost control vary, then please relate your responses to the section which you consider to be most representative of the planning and estimating approaches adopted by your office.

### *Estimating Techniques*

7. *How often do you estimate design resources using a broad comparison with previous projects of a similar nature, with the estimates of the necessary manhour contributions from the various grades of staff being derived by the project engineer/architect on the basis of experience rather than from "hard data"? (please circle)*

| **Stage of Project** | | **Frequency of Use** | | | | |
|---|---|---|---|---|---|---|
| | | *Always* | *Often* | *Sometimes* | *Seldom* | *Never* |
| (a) | Advisory work | 1 | 2 | 3 | 4 | 5 |
| (b) | Feasibility studies/Outline design | 1 | 2 | 3 | 4 | 5 |
| (c) | Detailed design | 1 | 2 | 3 | 4 | 5 |
| (d) | Preparation of contract documents | 1 | 2 | 3 | 4 | 5 |
| (e) | Supervision of construction | 1 | 2 | 3 | 4 | 5 |
| (f) | Post contract work. | 1 | 2 | 3 | 4 | 5 |

Comments ..........................................................................................

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8. *How often do you use an estimate, based on experience of similar projects of a comparable nature, of the number of drawings required for a project and the manhours associated with the drawings? (please circle)*

| Stage of Project | | Frequency of Use | | | | |
|---|---|---|---|---|---|---|
| | | *Always* | *Often* | *Sometimes* | *Seldom* | *Never* |
| (a) | Advisory work | 1 | 2 | 3 | 4 | 5 |
| (b) | Feasibility studies/Outline design | 1 | 2 | 3 | 4 | 5 |
| (c) | Detailed design | 1 | 2 | 3 | 4 | 5 |
| (d) | Preparation of contract documents | 1 | 2 | 3 | 4 | 5 |
| (e) | Supervision of construction | 1 | 2 | 3 | 4 | 5 |
| (f) | Post contract work. | 1 | 2 | 3 | 4 | 5 |

Comments ....................................................................................

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9. *How often do you make a broad estimate of the cost of the completed works and relate this, through consideration of a scale of professional fees (with suitable adjustment), to the required manhours of the various grades of staff? (please circle)*

| Stage of Project | | Frequency of Use | | | | |
|---|---|---|---|---|---|---|
| | | *Always* | *Often* | *Sometimes* | *Seldom* | *Never* |
| (a) | Advisory work | 1 | 2 | 3 | 4 | 5 |
| (b) | Feasibility studies/Outline design | 1 | 2 | 3 | 4 | 5 |
| (c) | Detailed design | 1 | 2 | 3 | 4 | 5 |
| (d) | Preparation of contract documents | 1 | 2 | 3 | 4 | 5 |
| (e) | Supervision of construction | 1 | 2 | 3 | 4 | 5 |
| (f) | Post contract work. | 1 | 2 | 3 | 4 | 5 |

Comments ....................................................................................

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10. *How often do you estimate design resources by the application of a database of information which gives detailed information on the resources necessary for specific design activities? (please circle)*

| Stage of Project | | Frequency of Use | | | | |
|---|---|---|---|---|---|---|
| | | *Always* | *Often* | *Sometimes* | *Seldom* | *Never* |
| (a) | Advisory work | 1 | 2 | 3 | 4 | 5 |
| (b) | Feasibility studies/Outline design | 1 | 2 | 3 | 4 | 5 |
| (c) | Detailed design | 1 | 2 | 3 | 4 | 5 |
| (d) | Preparation of contract documents | 1 | 2 | 3 | 4 | 5 |
| (e) | Supervision of construction | 1 | 2 | 3 | 4 | 5 |
| (f) | Post contract work. | 1 | 2 | 3 | 4 | 5 |

Comments ....................................................................................

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11. *Do you use techniques other than those described in questions 7 to 10 inclusive for estimating the staff resources which are necessary for deign work? (please tick)*

Yes ☐

No ☐

If yes, please briefly describe the technique and indicate the frequency of use:

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*Planning and Cost Control Techniques*

For the following two questions, please enter the appropriate code in the boxes and, if applicable indicate an approximate value of completed project which would be the lower limit for the use of personal computers based methods.

*Codes*

1 = Always 2 = Often 3 = Sometimes 4 = Rarely 5 = Never

12. *How often does your office use manual planning techniques and personal computer based techniques for planning design work?*

| **Stage of Project** | | **Technique** | | |
|---|---|---|---|---|
| | | (i)Manually, using bar charts | (ii) Using personal computer based packages. | Cut off value for (ii) |
| (a) | Advisory work | ☐ | ☐ | .............. |
| (b) | Feasibility studies/Outline design | ☐ | ☐ | .............. |
| (c) | Detailed design | ☐ | ☐ | .............. |
| (d) | Preparation of contract documents | ☐ | ☐ | .............. |
| (e) | Supervision of construction | ☐ | ☐ | .............. |
| (f) | Post contract work | ☐ | ☐ | .............. |

Comments ..........................................................................................

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13. *How often does your office use manual cost control techniques and computer based cost control techniques for monitoring the resources required for design work?*

| Stage of Project | | Technique | | |
|---|---|---|---|---|
| | | (i) Manual, cost control | (ii) computer based system | Cut off value for (ii) |
| (a) | Advisory work | ☐ | ☐ | ☐ |
| (b) | Feasibility studies/Outline design | ☐ | ☐ | ☐ |
| (c) | Detailed design | ☐ | ☐ | ☐ |
| (d) | Preparation of contract documents | ☐ | ☐ | ☐ |
| (e) | Supervision of construction | ☐ | ☐ | ☐ |
| (f) | Post contract work | ☐ | ☐ | ☐ |

Comments ..........................................................................................

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14. *If a commercial software package is used for planning or cost control please state the name of the package. (eg Partmaster Advance, Syntech Manager.)*

Planning ..........................................................................................

Cost Control ..........................................................................................

15. *How often do you use cost control data for future planning of design work?( please circle)*

| Stage of Project | | Frequency of Use | | | | |
|---|---|---|---|---|---|---|
| | | *Always* | *Often* | *Sometimes* | *Seldom* | *Never* |
| (a) | Advisory work | 1 | 2 | 3 | 4 | 5 |
| (b) | Feasibility studies/Outline design | 1 | 2 | 3 | 4 | 5 |
| (c) | Detailed design | 1 | 2 | 3 | 4 | 5 |
| (d) | Preparation of contract documents | 1 | 2 | 3 | 4 | 5 |
| (e) | Supervision of construction | 1 | 2 | 3 | 4 | 5 |
| (f) | Post contract work | 1 | 2 | 3 | 4 | 5 |

Comments: ..........................................................................................

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16. *If you have circled 1, 2 or 3 in question 15 above, please describe briefly the way in which the cost control data is used for future planning.*

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17. *Please consider the following statements and indicate your opinion of their accuracy:*

"Cost control data in my organisation **is** available in a form which would enable it to be frequently used for planning design work"

*Strongly Agree* ◄————————————► *Strongly Disagree*

1 2 3 4 5

"Cost control data in my organisation **should be** available in a form which would enable it to be frequently used for planning design work"

*Strongly Agree* ◄————————————► *Strongly Disagree*

1 2 3 4 5

## Section C – Quality Management

This section of the questionnaire has been included to determine the way in which quality is managed in the design process and to investigate links between planning, estimating and cost control of design work and quality management.

18. *Does you office operate any of the following quality management systems? (please tick)*

Total Quality Management (TQM) ☐

Full Quality Assurance to BS 5750 Part 1 with third party certification ☐

Partial Quality assurance to BS 5750 (please describe briefly below) ☐

Quality Assurance with second party certification. (please describe briefly below) ☐

A formal internal Quality Assurance system ☐

An informal internal Quality Assurance system ☐

Others (please describe briefly below) ☐

Comments .................................................................................

.................................................................................

19. *Are you developing a Quality Management System? (please tick)*

*Yes* (please describe briefly below, indicating proposed date of implementation) ☐

*No* ☐

Comments ..........................................................................

..........................................................................

Comments:

20. *Do you agree that there is a definite link between a formal quality assurance system and design planning procedures? (please tick)*

Strongly agree ☐

Agree ☐

Neutral ☐

Disagree ☐

Strongly disagree ☐

**Section D – The Planning, Estimating and Cost Control Process**

This section has been included to seek confirmation of sequence of the processes of planning, estimating and cost control of design work. I should be grateful if you would consider the attached process flow diagram (figure 1), which was developed during a series of interviews with design managers, and indicate on the scale on the left hand side of the figure your opinion on the accuracy of each stage of the diagram as it relates to your office. Your comments on any inaccuracy within the diagram would be particularly valuable.

Comments ..........................................................................

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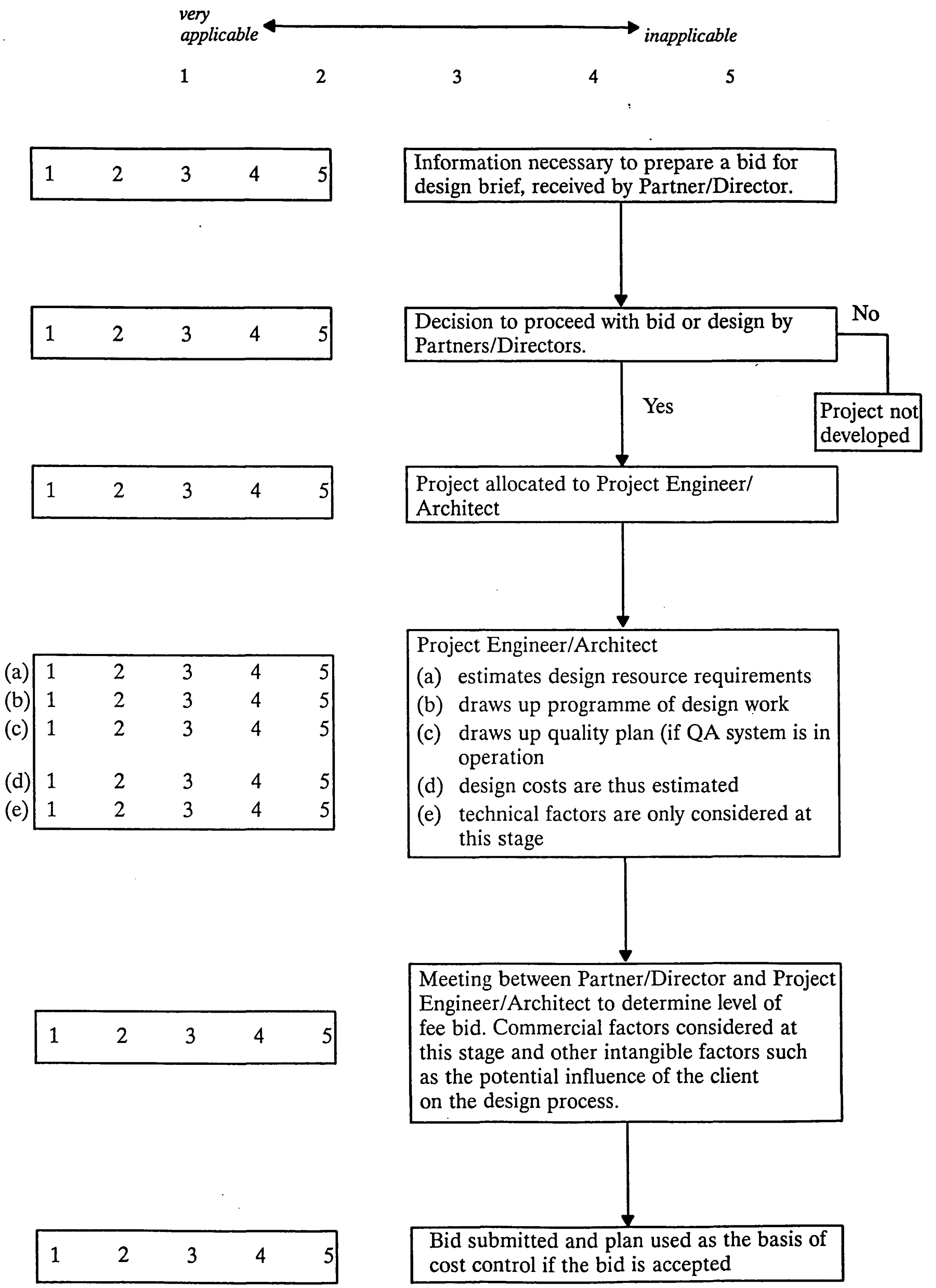
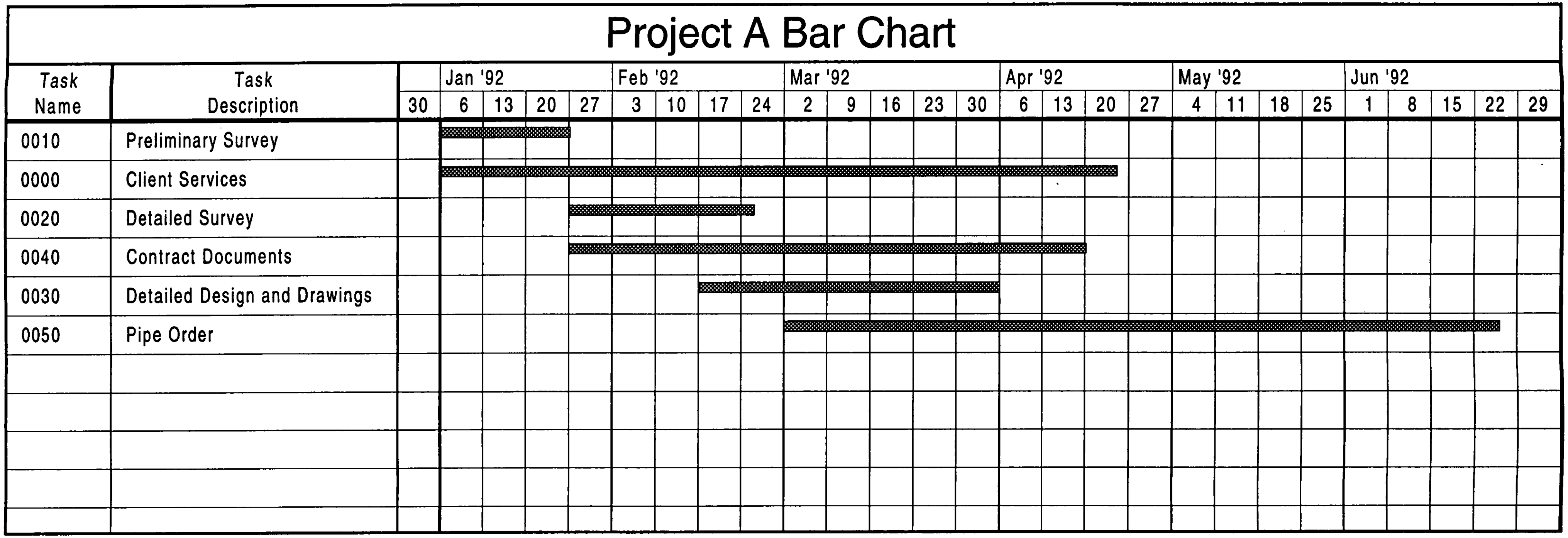
**Figure 1 : Model of the planning, estimating and cost control sequence for design work under competitive conditions.**



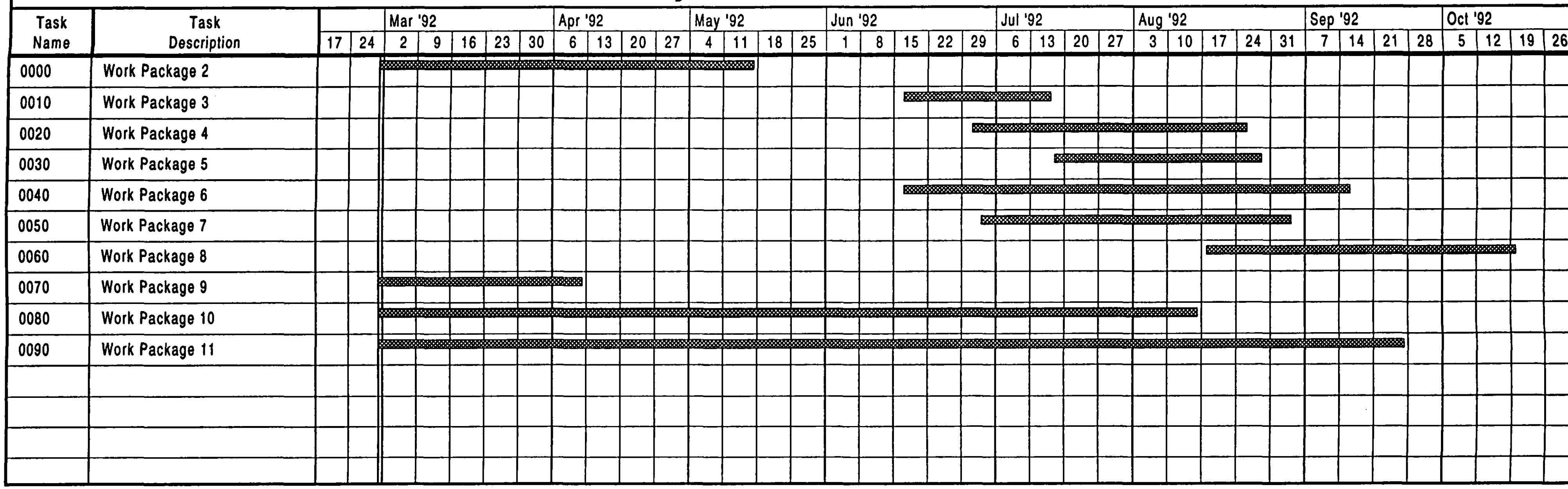
**Additional Comments**

# Appendix C

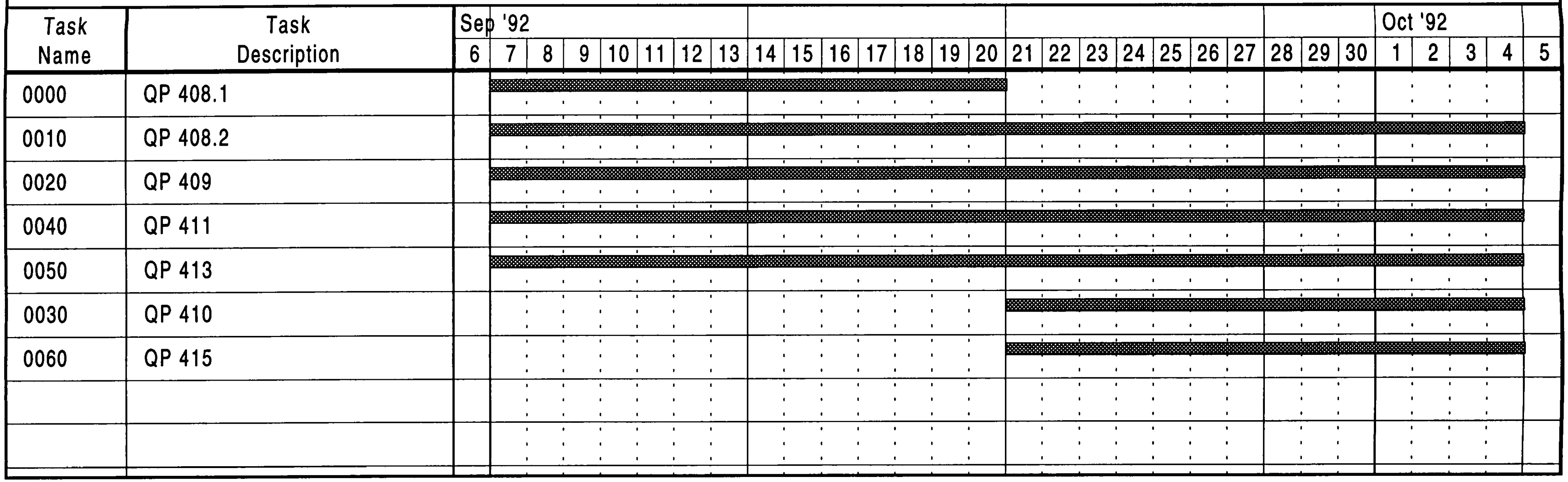
# Project bar charts


Project A Bar Chart
Task Name
Task Description
Jan '92
Feb '92
Mar '92
Apr '92
May '92
Jun '92
30
6
13
20
27
3
10
17
24
2
9
16
23
30
6
13
20
27
4
11
18
25
1
8
15
22
29
0010
Preliminary Survey
0000
Client Services
0020
Detailed Survey
0040
Contract Documents
0030
Detailed Design and Drawings
0050
Pipe Order

# Project B Bar Chart



# Project C Bar Chart



# Appendix D

## Example of cost estimation spreadsheet

| Project : PROJECT A | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | |
| **Work Package : TG/01 Client Services** | **Detailed list of steps required to complete this work package** | **Grade** | **No. of Employees** | **Chargeout Rate** | **Days** | **Manhours** | **Cost Estimate** | |
| | Confirm brief /meet Water Ops. | 1 | 1 | £30.70 | | 4 | £122.80 | |
| | | 1 | 1 | £30.70 | | 4 | £122.80 | |
| | Serve Notice plans | 1 | 1 | £30.70 | | 2 | £61.40 | |
| | | 3 | 1 | £16.12 | | 3 | £48.36 | |
| | PUSWA | 3 | 1 | £16.12 | | 2 | £32.24 | |
| | Advertise for Contractors | 3 | 1 | £16.12 | | 1 | £16.12 | |
| | Select Contractors | 1 | 1 | £30.70 | | 0.5 | £15.35 | |
| | Committee Report | 1 | 1 | £30.70 | | 1 | £30.70 | |
| | Issue Tender Document | 3 | 1 | £16.12 | | 1 | £16.12 | |
| | Assess Tenders | 1 | 1 | £30.70 | | 3 | £92.10 | |
| | | 1 | 1 | £30.70 | | 1 | £30.70 | |
| | Committee Report | 1 | 1 | £30.70 | | 1 | £30.70 | |
| | | | | | **Manhours** | 40 | | |
| | | | | | | **Total** | | |
| | | | | | | **Cost** | £1,125.94 | |
| | | | | | | | | |
| | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Project : PROJECT A** | | | | | | | | |
| | | | | | | | | |
| | | | | | | | | |
| **Work Package : Contract documents** | **Detailed list of steps required to complete this work package** | **Grade** | **No. of Employees** | **Chargeout Rate** | **Days** | **Manhours** | **Cost Estimate** | |
| | Main contract document | 1 | 1 | £30.70 | | 6 | £184.20 | |
| | | 3 | 1 | £16.12 | | 30 | £483.60 | |
| | | | | | | | | |
| | Taking off quantities | 1 | 1 | £30.70 | | 30 | £921.00 | |
| | | 3 | 1 | £16.12 | | 30 | £483.60 | |
| | | | | | | | | |
| | Pipe supply document, letter & B of Q | 3 | 1 | £16.12 | | 4 | £64.48 | |
| | | 1 | 1 | £30.70 | | 1 | £30.70 | |
| | | | | | | | | |
| | Estimate | 1 | 1 | £30.70 | | 2 | £61.40 | |
| | | 3 | 1 | £16.12 | | 2 | £32.24 | |
| | | | | | | | | |
| | Tender analysis & report | 1 | 1 | £30.70 | | 3 | £92.10 | |
| | | | | | **Total Planned Manhours** | 108 | | |
| | | | | | | **Total Cost** | £2,353.32 | |

# Appendix E

## Examples of weekly time sheets

Project: TORBAIN/GLASSMOUNT WATER MAIN

Project Engineer: R Wilson

Week No: ______

R Wilson GRADE 1

| Week No. | PROJECT | WORK CODE | ACTIVITY | Mon S | Mon O | Tue S | Tue O | Wed S | Wed O | Thu S | Thu O | Fri S | Fri O | Sat O | Sun O | Totals Std | Totals 1.5 X | Totals 2.0 X | Hours Worked | % Complete |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | | 01 | client services | 1.0 | | | | | | | | | | | | 1.00 | | | 1.00 | |
| | | 03 | DETAIL SURVEY | 0.30 | | | | 1.45 | | | | | | | | 2.15 | | | 2.15 | |
| | | 04 | DETAIL DESIGN/DRWGS | | | | | 1.45 | | 2.0 | | 2.0 | | | | 8.15 | | | 8.15 | |
| | | 05 | CONTRACT DOCUMENTS | 0.26 | | | | | | 2.0 | | | | | | 2.26 | | | 2.26 | |
| 50 | | 01 | CLIENT SERVICES | 2.0 | | 1.23 | | | | | | | 1.0 | | | 4.23 | | | 4.23 | |
| | | 04 | DETAIL/DESIGN/ DRAWINGS | | | 2.0 | | | | | | | | | | 2.00 | | | 2.00 | |
| 51 | | 03 | DETAIL SURVEY | 1.0 | | | | | | 1.30 | | | | | | 2.30 | | | 2.30 | |
| | | 04 | DETAIL/DESIGN/ DRAWINGS | 1.0 | | 1.30 | | | | 1.0 | | | | | | 3.30 | | | 3.30 | |
| | | 05 | CONTRACT DOCUMENTS | | | | | 0.30 | | | | | | | | 0.30 | | | 0.30 | |
| 52 | | 01 | client Services | | | 1.0 | | | | | | | | | | 1.00 | | | 1.00 | |
| | | 06 | PIPE order | | | 0.30 | | 1.0 | | 1.0 | | 0.30 | | | | 3.00 | | | 3.00 | |
| 1 | | 01 | client services | 1.0 | | 1.0 | | 0.30 | | | | | | | | 2.30 | | | 2.30 | |
| | | 06 | Pipe order | | | | | 1.30 | | | | 0.30 | | | | 2.00 | | | 2.00 | |
| 2 | | 03 | DETAIL survey | 1.19 | | | | | | | | | | | | 1.19 | | | 1.19 | |
| | | 04 | DETAIL DESIGN/ DRAWINGS | 2.0 | | | | | | | | | | | | 2.00 | | | 2.00 | |
| | | 06 | PIPE order | 0.30 | | 2.0 | | | | | | | | | | 2.30 | | | 2.30 | |
| 3 | | 01 | client services | 0.30 | | 3.0 | | | | | | | | | | 3.30 | | | 3.30 | |
| | | 03 | DETAIL SURVEY | | | 1.0 | | 1.0 | | | | | | | | 2.00 | | | 2.00 | |
| | | 05 | CONTRACT documents | 1.0 | | | | | | 4.23 | | 3.37 | | | | 9.00 | | | 9.00 | |

Project: TORRAIN/GLASSMOUNT WATER MAIN

Project Engineer: R. WILSON

Week No: 47 - 52

D. ANDERSON GRADE 2

| | PROJECT | WORK CODE | ACTIVITY | Mon | | Tue | | Wed | | Thu | | Fri | | Sat | Sun | Totals | | | Hours Worked | % Complete |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | S | O | S | O | S | O | S | O | S | O | O | O | Std | 1.5 X | 2.0 X | | |
| 47 | | 06 | PIPE ORDER | 1.0 | | 1.0 | | | | | | | | | | 2.0 | | | 2.00 | |
| | | | | | | | | | | | | | | | | | | | | |
| 48 | | 06 | PIPE ORDER | 2.0 | | 1.0 | | | | 1.30 | | 1.0 | | | | 5.30 | | | 5.30 | |
| | | | | | | | | | | | | | | | | | | | | |
| 49 | | 06 | PIPE ORDER | 2.0 | | 1.0 | | 1.0 | | | | 1.30 | | | | 5.30 | | | 5.30 | |
| | | | | | | | | | | | | | | | | | | | | |
| 50 | | 06 | PIPE ORDER | 3.30 | | 5.0 | | 1.30 | | 2.0 | | 3.0 | | | | 15.0 | | | 15.00 | |
| | | | | | | | | | | | | | | | | | | | | |
| 52 | | 06 | PIPE ORDER | 0.30 | | | | | | 0.30 | | 0.30 | | | | 1.30 | | | 1.30 | |
| | | | | | | | | | | | | | | | | | | | | |
| | (CONTRACTOR APPOINTED) | | | | | | | | | | | | | | | | | | | |
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Project: TORBAIN/GLASSMOUNT WATER MAIN

Project Engineer: R. WILSON

Week No: ____________________

I MATTHEW GRADE 3

| WEEK NO. | PROJECT | WORK CODE | ACTIVITY | HOURS Mon | | Tue | | Wed | | Thu | | Fri | | Sat | Sun | Totals | | | Hours Worked | % Complete |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | S | O | S | O | S | O | S | O | S | O | O | O | Std | 1.5 X | 2.0 X | | |
| 48 | | 01 | CLIENT SERVICES | | | 1.25 | | | | | | | | | | 1.25 | | | 1.25 | |
| | | 03 | DETAIL SURVEY | | | | | | | | | 2.30 | | | | 2.30 | | | 2.30 | |
| | | 04 | DETAIL DESIGN/DRAWING | 3.13 | | 1.10 | | 7.44 | | 3.38 | | | | | | 16.45 | | | 16.45 | |
| | | 05 | CONTRACT DOCUMENTS | | | 0.50 | | 0.58 | | | | | | | | 1.48 | | | 1.48 | |
| 49 | | 01 | CLIENT SERVICES | 2.34 | | 1.00 | | | | | | | | | | 3.34 | | | 3.34 | |
| | | 04 | DETAIL DESIGN/DRAWING | | | 1.57 | | 4.20 | | 4.52 | | 7.56 | | | | 19.05 | | | 19.05 | |
| | | 05 | CONTRACT DOCUMENTS | | 0.30 | | | | | | | | | | | 0.30 | | | 0.30 | |
| 50 | | 01 | CLIENT SERVICES | | | | | 3.40 | | 3.40 | | 1.44 | | | | 9.04 | | | 9.04 | |
| | | 03 | DETAIL SURVEY | 0.30 | | | | | | | | | | | | 0.30 | | | 0.30 | |
| | | 04 | DETAIL DESIGN/DRAWING | | | | | | | | | | | | | | | | | |
| | | 05 | CONTRACT DOCUMENTS | | | | | | | | | 4.16 | | | | 4.16 | | | 4.16 | |
| | | 06 | PIPE ORDER | 3.53 | | | | | | 1.38 | | | | | | 5.31 | | | 5.31 | |
| 51 | | 01 | CLIENT SERVICES | 2.19 | | 1.0 | | | | | | | | | | 3.19 | | | 3.19 | |
| | | 04 | DETAIL DESIGN/DRAWINGS | 2.30 | | | | 1.04 | | 2.25 | | | | | | 5.59 | | | 5.59 | |
| | | 05 | CONTRACT DOCUMENTS | 0.32 | | 1.29 | | | | | | | | | | 2.01 | | | 2.01 | |
| 52 | | 01 | CLIENT SERVICES | | | | | | | 0.15 | | 2.0 | | | | 2.15 | | | 2.15 | |
| | | 04 | DETAIL DESIGN/DRAWINGS | | | 3.30 | | 6.15 | | | | | | | | 9.45 | | | 9.45 | |
| | | 05 | CONTRACT DOCUMENTS | | | | | | | 0.30 | | 4.31 | | | | 5.01 | | | 5.01 | |
| | | 06 | PIPE ORDER | | | | | | | 4.38 | | | | | | 4.38 | | | 4.38 | |

Project: TORBAIN/GLASSMOUNT WATERMAIN

Project Engineer: R. WILSON

Week No: ______________________

I. MATTHEW GRADE 3

| PROJECT | WORK CODE | ACTIVITY | HOURS Mon | | Tue | | Wed | | Thu | | Fri | | Sat | Sun | Totals | | | Hours Worked | % Complete |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | S | O | S | O | S | O | S | O | S | O | O | O | Std | 1.5 X | 2.0 X | | |
| | 01 | CLIENT SERVICES | | | 0.20 | | 0.48 | | 8.37 | | 5.01 | | | | 14.46 | | | 14.46 | |
| | 04 | DETAIL DESIGN/DRAWINGS | 5.13 | | 4.19 | | 3.51 | | | | | | | | 13.23 | | | 13.23 | |
| | 06 | PIPE ORDER | 1.35 | | 1.00 | | 1.30 | | | | 1.54 | | | | 5.59 | | | 5.59 | |
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| Project : | Torbain/Glassmount Water Main | | | | | | | | | | | | | | | | | | | | | |
| Project Engineer : | | Robin Wilson | | | | | | | | | | | | | | | | | | | | |
| Week no. : | 48 | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | Hours | | | | | | | | | | | | | | |
| Package | | | Mon | | Tue | | Wed | | Thu | | Fri | | Sat | Sun | | Totals | | Hours | Hours | | % | |
| Number | Grade | Package Description | S | O | S | O | S | O | S | O | S | O | O | O | Std | 1.5 x | 2.0 x | Worked | Charged | Cost | Complete | |
| TG/01 | 1 | Client Services | | | | | | | | | | | | | | | | | | | 15.00 | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | 1.4 | | | | | | | | | | 1.4 | | | 1.4 | 1.4 | £22.57 | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| TG/02 | 1 | Preliminary Survey | | | | | | | | | | | | | | | | | | | 100.00 | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| TG/03 | 1 | Detailed Survey | | | | | | | | | | | | | | | | | | | 50.00 | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | 2.5 | | | | 2.5 | | | 2.5 | 2.5 | £40.30 | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| TG/04 | 1 | Detailed Design and Drawings | | | | | | | | | | | | | | | | | | | 30.00 | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | 3.2 | | 1.2 | | 7.7 | | 3.6 | | | | | | 15.7 | | | 15.7 | 15.7 | £253.41 | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| TG/05 | 1 | Contract Documents | | | | | | | | | | | | | | | | | | | 60.00 | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | 0.8 | | 1.0 | | | | | | | | 1.8 | | | 1.8 | 1.8 | £29.02 | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| TG/06 | 1 | Pipe Order | | | | | | | | | | | | | | | | | | | 20.00 | |
| | 2 | | 2.0 | | 1.0 | | | | 1.5 | | 1.0 | | | | 5.5 | | | 5.5 | 5.5 | £119.68 | | |
| | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
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| | 4 | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | Total Cost for Week | £464.97 | | |
| | | | | | | | | | | | | | | | | | | | | | | |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Project : | Torbain/Glassmount Water Main | | | | | | | | | | | | | | | | | | | | | |
| Project Engineer : | | Robin Wilson | | | | | | | | | | | | | | | | | | | | |
| Week no. : | 49 | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | Hours | | | | | | | | | | | | | | |
| Package | | | Mon | | Tue | | Wed | | Thu | | Fri | | Sat | Sun | | Totals | | Hours | Hours | | % | |
| Number | Grade | Package Description | S | O | S | O | S | O | S | O | S | O | O | O | Std | 1.5 x | 2.0 x | Worked | Charged | Cost | Complete | |
| TG/01 | 1 | Client Services | 1.0 | | | | | | | | | | | | 1.0 | | | 1.0 | 1.0 | £30.70 | 20.00 | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | 2.6 | | 1.0 | | | | | | | | | | 3.6 | | | 3.6 | 3.6 | £57.55 | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| TG/02 | 1 | Preliminary Survey | | | | | | | | | | | | | | | | | | | 100.00 | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| TG/03 | 1 | Detailed Survey | 0.5 | | | | 1.8 | | | | | | | | 2.3 | | | 2.3 | 2.3 | £69.08 | 90.00 | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| TG/04 | 1 | Detailed Design and Drawings | | | | | 4.3 | | 2.0 | | 2.0 | | | | 8.3 | | | 8.3 | 8.3 | £253.28 | 70.00 | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | 2.0 | | 4.3 | | 4.9 | | 7.9 | | | | 19.1 | | | 19.1 | 19.1 | £307.57 | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| TG/05 | 1 | Contract Documents | 0.4 | | | | | | 2.0 | | | | | | 2.4 | | | 2.4 | 2.4 | £74.60 | 80.00 | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | 0.5 | | | | | | | | | | | | 0.5 | | 0.5 | 0.8 | £12.09 | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| | 1 | Pipe Order | | | | | | | | | | | | | | | | | | | 40.00 | |
| | 2 | | 2.0 | | 1.0 | | 1.0 | | | | 1.5 | | | | 5.5 | | | 5.5 | 5.5 | £119.68 | | |
| | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| | 1 | | | | | | | | | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| | 1 | | | | | | | | | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| | 1 | | | | | | | | | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| | 1 | | | | | | | | | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| | 1 | | | | | | | | | | | | | | | | | | | | | |
| | 2 | | | | | | | | | | | | | | | | | | | | | |
| | 3 | | | | | | | | | | | | | | | | | | | | | |
| | 4 | | | | | | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | | | | Total Cost for Week | £924.54 | | |

# Appendix F

# Example of master spreadsheet output

PROJECT CONTROL SHEET

| Project title & code:<br>*Responsibility :*<br>Package Number | Description | Torbain/Glassmount Water Main<br>Robin Wilson<br>Estimated Cost | % of project | | 11<br>04-Jan | 2<br>11-Jan | 3<br>18-Jan | 4<br>25-Jan | 12<br>01-Feb | 2<br>08-Feb | 3<br>15-Feb | 4<br>22-Feb | 13<br>29-Feb | 2<br>07-Mar | 3<br>14-Mar | 4<br>21-Mar | 14<br>28-Mar | 2<br>04-Apr | 3<br>11-Apr | 4<br>18-Apr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TG/01 | Client Services | £1,126 | 11.8001 | Planned Progress(%) | 0.00 | 5.30 | 10.55 | 15.80 | 21.05 | 26.30 | 31.55 | 36.80 | 42.05 | 47.30 | 52.55 | 57.80 | 63.00 | 67.5 | 72 | 76.5 |
| | | | | Actual Progress(%) | | 5.00 | 10.00 | 12.00 | 15.00 | | | | | 20.00 | 30.00 | 40.00 | 50.00 | 60.00 | | |
| | | | | Actual Cost(%) | | 31.08 | 47.44 | 59.71 | 76.07 | 77.44 | 85.62 | 92.98 | 94.99 | 102.82 | 126.51 | 131.26 | 137.21 | 164.93 | | 174.47 |
| TG/02 | Preliminary Survey | £1,609 | 16.8598 | Planned Progress(%) | 0.00 | 33.33 | 66.67 | 100.00 | | | | | | | | | | | | |
| | | | | Actual Progress(%) | | 10.00 | 40.00 | 75.00 | 80.00 | 90.00 | 99.00 | 100.00 | | | | | | | | |
| | | | | Actual Cost(%) | | 28.63 | 74.88 | 103.38 | 111.01 | 118.17 | 122.58 | 123.71 | | | | | | | | |
| TG/03 | Detailed Survey | £2,687 | 28.1552 | Planned Progress(%) | 0.00 | | | | 25.00 | 50.00 | 75.00 | 100.00 | | | | | | | | |
| | | | | Actual Progress(%) | | | | | | | 10.00 | 20.00 | 50.00 | 90.00 | 92.00 | 96.00 | | | 98.00 | 100.00 |
| | | | | Actual Cost(%) | | | | | | | 12.18 | | 13.68 | 16.25 | 16.55 | 19.41 | | | 20.78 | 23.07 |
| TG/04 | Detailed Design and Drawings | £867 | 9.08197 | Planned Progress(%) | 0.00 | | | | | | | 14.29 | 28.57 | 42.86 | 57.14 | 71.43 | 85.71 | 92.5 | 100 | |
| | | | | Actual Progress(%) | | | | | 5.00 | 10.00 | | 20.00 | 30.00 | 70.00 | 75.00 | 80.00 | 85.00 | 90.00 | | 91.00 |
| | | | | Actual Cost(%) | | | | | 9.06 | 9.99 | 22.01 | | 51.25 | 115.97 | 123.06 | 159.99 | 204.92 | 228.73 | 235.81 | 242.90 |
| TG/05 | Contract Documents | £2,353 | 24.6634 | Planned Progress(%) | 0.00 | | | | 9.09 | 18.18 | 27.27 | 36.36 | 45.45 | 54.55 | 63.64 | 72.73 | 81.82 | 87.00 | 94.00 | 100.00 |
| | | | | Actual Progress(%) | | 5.00 | 10.00 | 20.00 | 30.00 | 40.00 | | 50.00 | 60.00 | 80.00 | 82.00 | 85.00 | 88.00 | | 91.00 | 96.00 |
| | | | | Actual Cost(%) | | 4.45 | 14.60 | 33.40 | 41.60 | 60.12 | 83.00 | 94.69 | 95.92 | 99.61 | 102.53 | 104.56 | 108.00 | | 111.08 | 132.69 |
| TG/06 | Pipe Order | £901 | 9.43956 | Planned Progress(%) | 0.00 | | | | | | | | 12.50 | 25.00 | 37.50 | 50.00 | 62.50 | 71.5 | 81 | 90 |
| | | | | Actual Progress(%) | | | | | | | | | 20.00 | 40.00 | 80.00 | 85.00 | 88.00 | 91.50 | 92.00 | 93.00 |
| | | | | Actual Cost(%) | | | | | | | | 4.83 | 18.12 | 31.41 | 77.09 | 83.91 | 106.05 | 122.35 | 149.48 | 162.74 |
| | Project Total | £9,541.76 | | | | | | | | | | | | | | | | | | |
| | PROJECT REPORT | | Planned Progress(%) | | 0.00 | 6.24 | 12.49 | 18.72 | 28.62 | 38.53 | 48.43 | 59.62 | 64.96 | 70.30 | 75.64 | 80.98 | 86.31 | 89.59 | 93.42 | 96.28 |
| | | | Actual Progress(%) | | 0.00 | 3.51 | 10.39 | 18.99 | 23.11 | 27.72 | 32.05 | 38.41 | 52.12 | 74.42 | 80.89 | 84.86 | 87.52 | 89.48 | 90.83 | 92.82 |
| | | | Actual Cost(%) | | 0.00 | 9.59 | 21.83 | 32.71 | 38.78 | 44.79 | 56.67 | 61.07 | 65.94 | 75.63 | 84.19 | 90.05 | 97.77 | 104.74 | 109.09 | 118.09 |

# Appendix G

# Dis-aggregated models of Level 2 of the WBS

| | | | | | |
|---|---|---|---|---|---|
| Disaggregated Model Level 1 | | | | | |
| Project A Model 3 | | | | | |
| | | | | | |
| Work Package 1 | | | | | |
| Sub-package | Risk Category | Grade 1 | Grade 2 | Grade 3 | Grade 4 |
| 1.1 | | =RiskRayleigh(8) | | | |
| 1.2 | | =RiskRayleigh(2) | | =RiskRayleigh(3) | |
| 1.3 | | | | =RiskRayleigh(2) | |
| 1.4 | | =RiskRayleigh(1) | | | |
| 1.5 | | | | =RiskRayleigh(1) | |
| 1.6 | | 1 | | | |
| 1.7 | | | | 1 | |
| 1.8 | | =RiskRayleigh(4) | | | |
| 1.9 | | =RiskRayleigh(4) | | | |
| 1.1 | | =RiskRayleigh(12) | | | |
| | | | | | |
| Total Work package 1 | | =SUM(C6:F15) | | | |
| | | | | | |
| Work Package 2 | | | | | |
| Sub-Package | Risk Category | Grade 1 | Grade 2 | Grade 3 | Grade 4 |
| 2.1 | | =RiskRayleigh(6) | | =RiskRayleigh(9) | |
| 2.2 | | =RiskRayleigh(6) | | =RiskRayleigh(3) | |
| 2.3 | | =RiskRayleigh(19) | | | |
| 2.4 | | =RiskRayleigh(13) | | | |
| 2.5 | | | | =RiskRayleigh(4) | |
| | | | | | |
| Total Work Package 2 | | =SUM(C21:F25) | | | |
| | | | | | |
| Work Package 3 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 3.1 | | | | | |
| 3.2 | | =RiskRayleigh(6) | | | |
| 3.3 | | | =RiskRayleigh(10) | =RiskRayleigh(10) | |
| 3.4 | | =RiskRayleigh(1) | | | |
| | | | | | |
| Total Work Package 3 | | =SUM(C31:F34) | | | |
| | | | | | |
| Work Package 4 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 4.1 | | =RiskRayleigh(2) | | | |
| 4.2 | | =RiskRayleigh(3) | | =RiskRayleigh(10) | |
| 4.3 | | =RiskRayleigh(2) | | =RiskRayleigh(7) | |
| 4.4 | | =RiskRayleigh(2) | | =RiskRayleigh(5) | |
| 4.5 | | =RiskRayleigh(4) | | =RiskRayleigh(7) | |
| | | | | | |
| Total Work Package 4 | | =SUM(C40:F44) | | | |
| | | | | | |
| Work Package 5 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 5.1 | | =RiskRayleigh(6) | | =RiskRayleigh(30) | |
| 5.2 | | =RiskRayleigh(30) | | =RiskRayleigh(30) | |
| 5.3 | | =RiskRayleigh(1) | | =RiskRayleigh(4) | |
| 5.4 | | =RiskRayleigh(2) | | =RiskRayleigh(2) | |
| 5.5 | | =RiskRayleigh(3) | | | |
| | | | | | |
| Total Work Package 5 | | =SUM(C50:F54) | | | |
| | | | | | |
| | | | | | |
| Total Work Package 6 | | =RiskRayleigh(37) | | | |
| | | | | | |
| | | | | | |
| Project Total | | =+C17+C27+C36+C4( | | | |

| | | | | | |
|---|---|---|---|---|---|
| Disaggregated Model Level 1 | | | | | |
| Project B Model 1 | | | | | |
| | | | | | |
| Work Package 1 | | | | | |
| Sub-package | Risk Category | Grade 1 | Grade 2 | Grade 3 | Grade 4 |
| 1.1 | | =RiskTriang(0, 14, 119) | | | |
| 1.2 | | | =RiskTriang(0, 14, 119) | | |
| 1.3 | | | =RiskTriang(0, 14, 119) | =RiskTriang(0, 7, 60) | |
| 1.4 | | | =RiskTriang(0, 14, 119) | | |
| | | | | | |
| Total Work package 1 | | =SUM(C6:F9) | | | |
| | | | | | |
| Work Package 2 | | | | | |
| Sub-Package | Risk Category | Grade 1 | Grade 2 | Grade 3 | Grade 4 |
| 2.1 | | =RiskTriang(0,21, 179) | =RiskTriang(0, 14, 119) | | |
| 2.2 | | | =RiskTriang(0,21, 179) | | |
| 2.3 | | =RiskTriang(0,21, 179) | =RiskTriang(0,36, 306) | | |
| | | | | | |
| Total Work Package 2 | | =SUM(C15:F17) | | | |
| | | | | | |
| Work Package 4 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 4.1 | | | =RiskTriang(0, 28,238) | =RiskTriang(0, 14, 119) | =RiskTriang(0,21, 179) |
| 4.2 | | | =RiskTriang(0, 28,238) | =RiskTriang(0, 14, 119) | |
| 4.3 | | | =RiskTriang(0, 28,238) | | =RiskTriang(0, 14, 119) |
| | | | | | |
| Total Work Package 4 | | =SUM(C23:F25) | | | |
| | | | | | |
| | | | | | |
| Work Package 5 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 5.1 | | | =RiskTriang(0,21, 179) | =RiskTriang(0, 14, 119) | |
| 5.2 | | | =RiskTriang(0, 28,238) | =RiskTriang(0, 14, 119) | |
| 5.3 | | | =RiskTriang(0,21, 179) | | =RiskTriang(0, 7, 59) |
| | | | | | |
| Total Work Package 5 | | =SUM(C32:F34) | | | |
| | | | | | |
| | | | | | |
| Work Package 6 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 6.1 | | | =RiskTriang(0,54, 459) | =RiskTriang(0,21, 179) | =RiskTriang(0, 28,238) |
| 6.2 | | | =RiskTriang(0, 54,459) | =RiskTriang(0, 28,238) | |
| 6.3 | | | =RiskTriang(0, 28,238) | | =RiskTriang(0, 28,238) |
| | | | | | |
| Total Work Package 6 | | =SUM(C41:F43) | | | |
| | | | | | |
| | | | | | |
| Work Package 7 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 7.1 | | | =RiskTriang(0, 28,238) | =RiskTriang(0,21, 179) | =RiskTriang(0, 7, 59) |
| 7.2 | | | =RiskTriang(0, 28,238) | | =RiskTriang(0,21, 179) |
| | | | | | |
| Total Work Package 7 | | =SUM(C50:F51) | | | |
| | | | | | |
| | | | | | |
| Work Package 8 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 8.1 | | | =RiskTriang(0, 28,238) | =RiskTriang(0, 14, 119) | =RiskTriang(0, 14, 119) |
| 8.2 | | | =RiskTriang(0, 28,238) | | =RiskTriang(0,21, 179) |
| | | | | | |
| Total Work Package 8 | | =SUM(C58:F59) | | | |
| | | | | | |
| | | | | | |
| Work Package 9 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 9.1 | | | =RiskTriang(0,21, 179) | | |
| 9.2 | | | =RiskTriang(0,21, 179) | | |
| | | | | | |
| Total Work Package 9 | | =SUM(C66:F67) | | | |
| | | | | | |
| | | | | | |
| Work Package 10 | | =RiskTriang(50, 126, 252 | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| PROJECT TOTAL | | =(C11+C19+C27+C36+C | | | |

| | | | | | |
|---|---|---|---|---|---|
| Disaggregated Model Level 1 | | | | | |
| Project B Model 3 | | | | | |
| | | | | | |
| Work Package 1 | | | | | |
| Sub-package | Risk Category | Grade 1 | Grade 2 | Grade 3 | Grade 4 |
| 1.1 | | =RiskLognorm(14, 8) | | | |
| 1.2 | | | =RiskLognorm(14, 8) | | |
| 1.3 | | | =RiskLognorm(14, 8) | =RiskLognorm(7, 4) | |
| 1.4 | | | =RiskLognorm(14, 8) | | |
| | | | | | |
| Total Work package 1 | | =SUM(C6:F9) | | | |
| | | | | | |
| Work Package 2 | | | | | |
| Sub-Package | Risk Category | Grade 1 | Grade 2 | Grade 3 | Grade 4 |
| 2.1 | | =RiskLognorm(21, 12) | =RiskLognorm(14, 8) | | |
| 2.2 | | | =RiskLognorm(21, 12) | | |
| 2.3 | | =RiskLognorm(21, 12) | =RiskLognorm(36, 20) | | |
| | | | | | |
| Total Work Package 2 | | =SUM(C15:F17) | | | |
| | | | | | |
| Work Package 4 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 4.1 | | | =RiskLognorm(28, 17) | =RiskLognorm(14, 8) | =RiskLognorm(21, 12) |
| 4.2 | | | =RiskLognorm(28, 17) | =RiskLognorm(14, 8) | |
| 4.3 | | | =RiskLognorm(28, 17) | | =RiskLognorm(14, 8) |
| | | | | | |
| Total Work Package 4 | | =SUM(C23:F25) | | | |
| | | | | | |
| | | | | | |
| Work Package 5 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 5.1 | | | =RiskLognorm(21, 12) | =RiskLognorm(14, 8) | |
| 5.2 | | | =RiskLognorm(28, 17) | =RiskLognorm(14, 8) | |
| 5.3 | | | =RiskLognorm(21, 12) | | =RiskLognorm(7, 4) |
| | | | | | |
| Total Work Package 5 | | =SUM(C32:F34) | | | |
| | | | | | |
| | | | | | |
| Work Package 6 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 6.1 | | | =RiskLognorm(54, 32) | =RiskLognorm(21, 12) | =RiskLognorm(28, 17) |
| 6.2 | | | =RiskLognorm(54, 32) | =RiskLognorm(28, 17) | |
| 6.3 | | | =RiskLognorm(28, 17) | | =RiskLognorm(28, 17) |
| | | | | | |
| Total Work Package 6 | | =SUM(C41:F43) | | | |
| | | | | | |
| | | | | | |
| Work Package 7 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 7.1 | | | =RiskLognorm(28, 17) | =RiskLognorm(21, 12) | =RiskLognorm(7, 4) |
| 7.2 | | | =RiskLognorm(28, 17) | | =RiskLognorm(21, 12) |
| | | | | | |
| Total Work Package 7 | | =SUM(C50:F51) | | | |
| | | | | | |
| | | | | | |
| Work Package 8 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 8.1 | | | =RiskLognorm(28, 17) | =RiskLognorm(14, 8) | =RiskLognorm(14, 8) |
| 8.2 | | | =RiskLognorm(28, 17) | | =RiskLognorm(21, 12) |
| | | | | | |
| Total Work Package 8 | | =SUM(C58:F59) | | | |
| | | | | | |
| | | | | | |
| Work Package 9 | | | | | |
| Sub-package | Risk Category | Cost | | | |
| 9.1 | | | =RiskLognorm(21, 12) | | |
| 9.2 | | | =RiskLognorm(21, 12) | | |
| | | | | | |
| Total Work Package 9 | | =SUM(C66:F67) | | | |
| | | | | | |
| | | | | | |
| Work Package 10 | | =RiskTriang(50, 126, 2 | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| PROJECT TOTAL | | =(C11+C19+C27+C36 | | | |

# Appendix H

## Publications arising from the work

**The published papers cited below have been removed from the e-thesis due to copyright restrictions:**

**Blackwood, D.J., Sarkar, S. and Price, A.D.F. (1992). Planning and estimating design work: a review of British practice. In: Nicholson, M.P. (ed.). Architectural management. London: Spon, pp.55-64. ISBN: 9780419177807.**

**Blackwood, D.J. and Price, A.D.F. (1993). Estimating design costs - the data dilemma. In: A*rchitectural management practice and research. Proceedings of the CIB W96 Architectural Management Workshop, 15-16 April 1993, Eindhoven University of Technology.***