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A Research Methodology For Modelling Construction Design Service Costs

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Abstract

The increased use of fee competition by construction industry clients has caused providers of professional design services to review their fee estimation and cost control approaches. This paper describes the development of a research methodology for a programme of work that was initiated at the request of industrial collaborators and was concerned with the development of a practical system for determining realistic fee estimates for design work using historic cost data. The paper explains why it became necessary for the focus of the work to shift from, what appeared at first to be, straightforward applied research to a more fundamental programme of research into design process management. The project is presented as a case study and highlights the difficulty in novel research work of identifying an appropriate hypothesis. The application of a grounded theory approach that facilitated the development of a suitable methodology from a standard research template is described and key decisions on the of selection the research techniques are explained and justified. The selection and integration of the research instruments are described and conclusions are drawn on the appropriateness of the methodological template to the research programme. Finally, the principal conclusion from the research work, that the potential for rationalisation of design cost estimation exists but was limited by the availability of relevant data, is outlined.

Keywords: Research methodology, questionnaire survey, design cost estimation.

Introduction

A research programme was established in 1989 in conjunction with, what was then, a Scottish Local Authority Water Services Department, who were aware of a number of developments relating to the water industry in Scotland that would affect the procurement of design services, such as:

- the privatisation of the water industry in England and Wales;
- the increased use of fee competition in the procurement of design services;
- the trend towards compulsory competitive tendering for professional services.

The Water Services Department was concerned that the cost estimating and cost control procedures used by in-house design teams might not be adequate in the changing environment and decided that a more rational approach to design cost estimating should be developed. The initial aim of the research programme was to develop a cost estimating model for the Water Services 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 a pattern of:

- a literature review to determine the state of the art in design cost estimating in the construction industry;
- the selection of an appropriate modelling approach;
- the collection of the necessary data to support the model;
- the development, testing and validation of the model.
It was further envisaged that the majority of the work would be concerned with the last two items given above. However, on completion of a preliminary literature review, it became apparent this approach to the research would not be possible for two reasons.

Firstly, design cost modelling approaches did not appear to be used by construction industry designers. Rowdon and Mansfield (1989) suggested that this was a result of a widely held view that, by its very nature, design work is not amenable to prescriptive planning and rigorous cost control. Secondly, 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 more recently by Latham (1994), who documented 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.

The preliminary literature review had supported the relevance of the programme, but it had also identified a paucity of literature on design cost estimation which continued throughout the duration of the study (Hudgins and Lavelle 1995). This indicated that the work would be more novel than might previously have been anticipated.

A grounded theory approach, developed by Glaser and Strauss (1967), was deemed to be appropriate for this research. 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 progresses. The general method used is one of comparative analysis whereby evidence collected from other comparative groups is used to test whether initial evidence was correct.

In keeping with the grounded theory approach, the research hypothesis and aims were developed during the initial stages of the research work as described later in the paper but, for convenience, 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 design cost estimating;
- to evaluate the practicality of enhanced data collection to support a more rational estimating approach;
- to select and develop a form of cost estimating model that is appropriate for the available data;
- to verify the performance of the cost model.

The purpose of this paper is to document a case study on the development of a research methodology for a novel research programme, consequently, emphasis has been given to an explanation of the evolution of the methodology. The conclusions from the work are summarised and are included only to the extent that this is necessary to illustrate why key decisions were made in the development of the methodology and to provide a measure of the success of the study.
The Development of the Research Methodology

Oppenheim (1992) provided a research design template that identified a fourteen stage approach to research work. This appeared to be appropriate for this study because it encompassed 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. undertaking the necessary pilot work;
8. designing the samples;
9. selection of the people to be approached;
10. undertaking the field work;
11. processing the data;
12. undertaking the statistical analysis;
13. testing the hypothesis;
14. writing the research report.

The first stage of Oppenheim's methodology required the selection of the aims of the study. This contrasts with the grounded theory approach and it was considered to be more appropriate to establish the area of research, which was concerned with design cost estimation for construction industry professional services.

The literature review, which constituted the second stage of Oppenheim's methodological framework, was structured to address the first three of the project aims given above, by enabling:

- 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;
- 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 designers (Rutter and Martin 1991; Hudgins and Lavelle 1995). These were:

- using a broad comparison with previous projects of a similar nature with the estimates of the necessary man-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 recommended fee scales (with suitable adjustment), to required man-hours of the various grades;

by reference to a central data base of costs which would give data on the necessary resources for specific activities.

The literature review also provided enough 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. Hudgins and Lavelle (1995) and Nicolson and Popovic (1994) demonstrated that estimated design fees for a project could range from 60 per cent to 250 per cent of the mean value of all estimates and Latham (1994) reported evidence of levels of services being reduced to match available fees.

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 that 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 accountants’ auditing services were found (Boehm 1981; O’Keefe et al 1994). 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 of 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" in studying changes over a period of time;
- sample surveys - using appropriate sampling approaches 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 organisation;
- 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;
- 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 to this study for two reasons. Firstly, the magnitude of a survey of all organisations involved in design would be impractical, and, secondly, this would place an unnecessary burden on designers in the construction industry. Some form of sample survey would be more appropriate. Controlled experiments and predictive studies would also be inappropriate because the experimentation would involve 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. Hoineville et al (1978)
also suggested the use of in-depth interviews, which they described as "unstructured design work". They recommended that 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 the project's third aim (the assessment of the feasibility of collecting more detailed data), fourth aim (the development of a cost model), and fifth aim (the verification of the cost model) could be achieved. A more iterative, flexible approach to the research design was required, and the methodology, shown diagramatically in Figure 1, was devised based on Oppenheim's (1992) fourteen stage methodology.

![Diagram of research methodology]

Figure 1. Summary of the research methodology for the project

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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 consulting engineering practices (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);
- 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;
- **Phase 3** piloting the research instrument by structured interviews using the draft questionnaire.

**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) describes 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. Initially, 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;
- the extent to which historic design cost data are available and used in cost estimation.

During the interview detailed notes of the meeting were taken, with the consent of the interviewee, for subsequent analysis. The following general conclusions were drawn:

- three of the four estimating techniques that had been identified in the literature review were used by the organisation, the exception being that there was no available database of historic costs within the organisation;
- final fee bids were increasingly being determined on commercial grounds as it was becoming increasingly necessary to endeavour to establish the market value of the project.
Figure 2 shows that the findings from the interview and the literature review permitted stages three to five of the methodology to be undertaken. The project hypothesis and aims that were given previously were thus developed.

Figure 2. Stages 3 to 5 of the methodology

**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 exploratory work; and to begin to develop the research instrument for a more comprehensive survey of design organisations. A semi-structured approach was adopted for this round of interviews (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 question list contained four sections:

- Section 1, where information on the nature of the organisation could be noted;
- Section 2, which listed the planning and design cost estimating techniques that were identified in the literature review;
- Sections 3 and 4, which 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 offices, 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 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 in interpersonal communication to be identified and any inconsistencies in individual interviews to be highlighted.

The interviews allowed the first of the project aims to be partially achieved, namely the identification of the design cost estimation approaches that are currently applied by designers. The interviews confirmed that the first three estimating approaches identified in the literature review and exploratory interviews were consistently adopted by the organisations. The interviews also suggested that the fourth method, that of using historic cost data, was not adopted because this information would not be readily available in design organisations. The organisations monitored design resources on projects using information provided by cost monitoring systems, but the systems provided data on a whole project.
basis, or at best on the basis of major design stages. This information was not being used for cost estimation purposes and the absence of more detailed data was considered to be a barrier to the application of cost modelling approaches.

It was appreciated that the sample of organisations interviewed was too small to be taken as being representative of the construction industry at large. In order to fully achieve the first of the project aims, there was a need for a more comprehensive survey of design organisations to enable a fuller evaluation to be made of the extent of usage by designers of the various cost estimation approaches. The scope of the survey was also extended to determine 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.


The importance of testing the research instrument through pilot studies was highlighted in a number of publications (Hoinville et al 1978; Miller 1991; Oppenheim 1992). This was achieved during the later stages of the interviews, where the draft questionnaire was completed by the interviewee in the presence of the interviewer. In this way, an understanding of the thought processes of respondents during the completion of the questionnaires was developed. This enabled a final version of the questionnaire to be produced that would be readily understood by future respondents.

Questionnaire Survey Design and Administration

The role of the questionnaire survey in the overall research methodology is shown in Figure 3.

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Questionnaire Survey
7. Pilot Work
Interviews Phase 3

8. Sample Design
9. Sample Selection
10. Field Work
11. Processing Data
12. Statistical Analysis

Data Collection
Case Studies

13. Testing the Hypothesis
14. Research Conclusions
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Figure 3. Role of the questionnaire survey
Two approaches were considered for the extended survey, namely, interviews or 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 assist with 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;
- 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. 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. Including researcher's time, the direct cost of 300 interviews was estimated to be £75,000 with an associated duration equivalent to one-person year. In contrast, the estimated direct cost of a postal survey to a sample of 300 was £5,000, which included postage, printing and researcher's time with a duration of some three months. This confirmed that a postal survey 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, namely, the problem of non-respondents (Miller 1991).

**Questionnaire Content**

Stage 5 of Oppenheim's approach (Decisions on Hypotheses) involved the identification of the variables which must be measured in order to draw meaningful conclusions in support of the research objectives. This is an appropriate first stage in the determination of the content of the questionnaire. The project aims which were yet to be realised included:

- the 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 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 organisations and the stages of the design process. To facilitate this analysis, questions were devised that enabled the responses to be entered and processed using the Statistical Package for the Social Sciences software (SPSS) (Norusis 1988).
The questionnaire comprised four sections:

- Section A, provided information on the nature of the respondents' organisations to allow analytical comparisons 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, estimating and quality management;
- Section D, tested the applicability of a model of the cost estimating process which was developed following the 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. 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. Therefore, in order to enhance the response rate, priority was given in the questionnaire design to minimise the effort of the respondents in its completion. However, three open questions were included where more general information was required; for example, respondents were invited to list any estimating techniques not mentioned in the questionnaire. 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 easily devised for Section A, which enabled organisations to indicate the extent of their involvement in a predetermined list of design 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 design managers, 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, and a measure of the availability of data for cost modelling was included in this section.

To facilitate the enumeration and analysis of the questionnaire responses, some measurement scales were required. Nominal measures were considered inappropriate 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 were used in most cases, although ordinal scales were used to measure the organisation's degree of involvement in the various sectors of the construction industry.

Three linear 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" was devised with the intermediate values of
"Often", "Sometimes" and "Seldom" being chosen to guide the respondent to interpret the distance between scale 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 in Section D to test the validity of a model of the cost estimation process and a scale of agreement with the applicability of each stage of the model was devised.

Sampling Strategy

A comprehensive list of organisations involved in the provision of design services for construction industry-related projects was assembled, including:

- civil engineering consultants, drawn from a listing of organisations in the New Civil Engineer Consultants File (New Civil Engineer 1991);
- architectural practices, drawn from a list provided by the RIBA of the 100 largest architectural practices;
- national and local government departments and water authorities, drawn from the organisations listed in the Municipal Year Book (Clements 1991);
- 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 which included; simple random, multi-stage random, systematic, stratified proportionate, stratified disproportionate and judgmental.

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 stratified proportionate and two stage random sampling was appropriate. Consideration was given 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 removed from the sample frame. The interviews also revealed a difference in the sophistication of cost control systems between private organisations and those in the public sector, therefore a sub-division of the sample frame was introduced to reflect this. In total, three general groupings were established, namely:

- consulting engineers;
- architectural practices;
- miscellaneous, with sub-sets of public sector bodies, water authorities and building services engineers.

Having 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 organisations. 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-samples for the three categories of greater than 30 responses assuming a response rate of 40 per cent (Miller 1991).

**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, however, a variety of techniques that can be used to maximise response rates for postal surveys and these were outlined by a number of authors (Hoinville et al 1978; Oppenheim 1992; Mangione 1995). Additionally, Miller (1991) provided a detailed analysis of response rates to postal questionnaire studies and quantified the anticipated improvement in response rates 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:

- 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 an appropriately addressed letter and envelope with each letter being individually signed.
- A return envelope bearing a University address label and a postage 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 questionnaire being identified by a code number rather than by the name of the respondent.
- The rate of responses were monitored and reminders were issued to non-respondents when the response rate appeared to have levelled off.

**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. A strategy was devised for investigating the nature of the non-respondent organisations. Firstly, response rates were analysed to see if there was any significant variation 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; answer briefly during the telephone call some of the key questions on the questionnaire; or identify their reasons for not responding. Finally, the results from questionnaires obtained from this follow-up exercise were taken as a separate group to represent the population of non-respondents and a
statistical comparison was made between the results of this group and those of the initial respondents. No evidence of sample bias was detected.

**Outline Conclusions from Questionnaire Survey**

The questionnaire survey resulted in a response rate of 45 per cent. The main conclusion from the survey 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 that would enable detailed cost models to be constructed. This conclusion supports the observation by Rowdon and Mansfield (1989), that designers believe the nature of design work is such that it is not amenable to prescriptive planning and rigorous cost control. Whilst this finding suggested that the current 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.

**Data Collection Case Studies**

The role of the data collection case studies in the overall research methodology is shown in Figure 4.

- **Questionnaire Survey**
  - 7. Pilot Work
  - **Interviews Phase 3**
  - 8. Sample Design
  - 9. Sample Selection
  - 10. Field Work
  - 11. Processing Data
  - 12. Statistical Analysis

- **Data Collection Case Studies**

- **Cost Modelling**

- **13. Testing the Hypothesis**
- **14. Research Conclusions**

**Figure 4. Role of the data collection case studies**

It was apparent from the empirical surveys that, although some design cost data were available in design organisations, such data lacked detail. The data had been collected from staff time sheets that had been devised to support the organisations' cost control systems. These time sheets 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 described 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 detailed cost data for the design cost 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;
• 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:

• a case study provided an opportunity for intensive analysis of a single instance of the topic of study. 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;
• a more limited trial 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 performed in different organisations. However, 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 data collection system comprised a number of linked spread sheets as shown in Figure 5 and required the projects to be broken down to the second level of a work breakdown structure at the planning and estimating stage. Cost data were also collect against level two work packages.

The main conclusion was that it was possible to collect detailed cost data to the second level of the work breakdown structure, although the traditional approach of using time sheets to collect cost data would present a considerable barrier to the implementation of the system across an entire organisation. Hence the current potential for the establishment of a substantial and detailed data base of historic costs within organisations was limited. The case studies provided detailed cost data for a limited range of projects, although the data demonstrated that variation between estimated costs and actual costs for level two work packages was as much as 800 per cent of the initial estimate. It was now 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.
Model Development and Verification

Miller (1991: 51) described the purpose of a model in research design as being: "to assist in the identification of relationships within variables in such a way that tests of hypothesis can be defined more sharply."

Furthermore, in producing guidance on their usage (Miller 1991:52) noted that: "The modelling exercise and resultant simulations are regarded as tools to be used to further our understanding of how the system works".

These statements are particularly appropriate in the context of the aims of this study where the purpose of the modelling stage was 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 are currently available, or might reasonably be expected to be available in the near future.

The literature review identified the following possible cost modelling approaches for use in design cost estimating:

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

Each approach was critically appraised with consideration being given to the model's input and output, and to the context in which it would be applied. Figure 6 shows how the previous work in the project contributed to the model selection process.

![Diagram](image)

**Figure 6. Information supporting the model selection process**

Considering input data, the data collection case studies demonstrated that it should be possible for organisations to produce historic cost data for modelling at two levels of detail. Firstly, whole project costs could be readily provided and subdivided into costs for major stages such as feasibility studies, detailed design, and site supervision. Secondly, it would be feasible to provide more detailed data to the first level of a work breakdown structure (WBS) for individual projects or for major elements of larger projects. It would not be practicable however, using current time sheet based methods, 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.

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 comprised the development of project costs in a bottom up manner and the review of these costs 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 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 a WBS. There was evidence from the interviews to support the view that design managers consider that the nature of design work is such that it is not amenable to prescriptive planning and cost estimation, and therefore they would be sceptical about the practical use of any cost model. 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, and within the computer competency of designers.
The results of the appraisal are summarised in Table 1.

<table>
<thead>
<tr>
<th>MODELLING APPROACH</th>
<th>SELECTION CRITERIA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Availability of appropriate input data</td>
</tr>
<tr>
<td>Parametric cost modelling</td>
<td>Low</td>
</tr>
<tr>
<td>Simulation</td>
<td>Moderate</td>
</tr>
<tr>
<td>Risk analysis</td>
<td>Moderate</td>
</tr>
<tr>
<td>Fuzzy set theory</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

Table 1: Evaluation of the alternative modelling approaches.

On conclusion of the appraisal it was concluded that risk analysis was the most appropriate form of model. Risk analysis offered the following advantages over the other modelling approaches:

- Parametric cost modelling was less appropriate 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 were less suitable 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 was less appropriate principally because the technique lacks transparency and the methodology has not been sufficiently developed to be readily adopted by design managers (Kangari and Bakheet, 1994). This is particularly true in the context of its application to knowledge based decision support systems.

Risk analysis modelling was carried out using the "@Risk" extension to the Excel spreadsheet package. A general model which used Log-normal input distributions to represent the range of probable costs of each of the component work packages was developed and tested using the data from the case study projects. The performance of this model was further verified through its application to an additional project (Project E) where data were made available on the initial estimates to a level two WBS and final costs to level one WBS. For comparison purposes, the predictions of the general model were compared with those of a model developed to represent the estimator's perception of his estimating accuracy of work package costs. The results of the simulations are shown in Table 2.

<table>
<thead>
<tr>
<th>MODEL</th>
<th>Simulated Project Total Hours. (Actual Project Total Hours = 1928)</th>
<th>Simulation Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
<td>Mean</td>
</tr>
<tr>
<td>General Model</td>
<td>986</td>
<td>1916</td>
</tr>
<tr>
<td>Model of Perceived Accuracy</td>
<td>1272</td>
<td>1301</td>
</tr>
</tbody>
</table>

Table 2: Summary of Project E analysis
It was concluded that, on the basis of its performance on this project, the general model gave a realistic prediction of the required resource input for the project but the robustness of the model would have to be tested by its application to other projects. The model development and testing also provided useful insight into the estimator's perception of estimating accuracy and identified two components of estimating accuracy arising from:

- the estimator's attitude toward risk;
- the estimator's level of accuracy within each work package.

The overall conclusion from the model development and testing was that a risk analysis approach to cost modelling would be a valuable design management tool provided that a design organisation can develop and maintain a data base of historic costs through the application of more detailed cost control systems.

Conclusions

The primary aim of this paper was to provide a case study on the development of a research methodology for a research project which due to its originality, required grounded theory approach. Two main conclusions emerge.

Firstly, because the work was initiated at the request of industrial collaborators, the initial aim of the project was envisaged as being to develop a practical tool which could be used by practising design managers in the determination of fee estimates for professional design services. The research team anticipated that the methodology would primarily be concerned with the abstraction and evaluation of data and the development and testing of an appropriate form of model. However, it became apparent early in the research programme that the novel nature of the work had been underestimated and that the project aims and methodology had to be fundamentally reviewed. This demonstrated that, for novel research programmes, the identification of the project aims and the design of an appropriate methodology are not separate or distinct stages in the research but form an integrated part of the early stages. Novel research does not commence with a statement of a project's hypothesis and aims, but with the search for them.

Secondly, a methodological template which integrated the development of a research hypothesis and the design of the methodology (Oppenheim 1992) was identified and successfully applied to the project. This template suggested a sequential process but did not recognise the need for interaction between the stages, and between the research tools that were used. The development of the model of the research methodology presented in Figure 1 was crucial to the successful execution of the project. It was essential that the complex interaction between the literature review, the phased interviews, the questionnaire survey, the data collection case studies, and the model development and testing was fully understood so that the maximum contribution of each stage to the rigorous testing of the hypothesis could be ensured. The study of construction procurement is an emerging discipline and consequently research tends to be novel. Oppenheim's research design template provided a useful framework to guide the development of a research methodology for novel research programmes because it ensured that sufficient attention is given to the definition of the project.

The overall conclusion from the research programme was that the potential to apply cost modelling to evaluate costs for professional design services exists. This potential is currently limited by the availability of sufficiently detailed data within design organisations. The adoption and modification of the research design template enabled an early change of
emphasis from applied to more fundamental research to be accommodated and this resulted in a successful outcome to the project from the point of view of both the research team and the collaborating organisations.
REFERENCES:


