

DEVELOPMENT OF A MODEL OF TOTAL BUILDING PROCUREMENT COSTS FOR CONSTRUCTION CLIENTS

Roy Duff, Margaret Emsley, Michael Gregory, David Lowe and Jack Masterman

Department of Building Engineering, UMIST, PO Box 88, Manchester, M60 1QD, UK

There is a dearth of information on the comparative costs of projects carried out using the main procurement building systems. This paper reports the feasibility study of a research programme to produce a computer-based neural network cost model to show the effect on client costs of 'inter alia' using different procurement approaches.

A literature search identified 39 cost-significant project variables. Data were collected from collaborating QS practices, resulting in 46 project data-sets with which to test various modelling approaches.

Evaluation of the data and model objectives identified multiple regression and neural networks as potential model forms. Investigation and trials of both have shown that regression and neural networks can provide effective representation of the client costs model but neural networks, due to their greater ability in modelling interdependencies between input variables, modelling non-linear relationships, and handling incomplete data sets, will probably be the better choice with which to analyse the very much larger volume of data planned for the next phase of the research.

The results have demonstrated that such a model can be developed, that data to support it can be obtained and, additionally, that the utility of the model may be significantly greater than had been envisaged at the start of the study.

Keywords: Cost modelling, early stage estimating, neural networks, procurement.

INTRODUCTION

Background

Masterman (1994) found no evidence, in two studies of clients' selection procedures, of cost differences being considered when choosing a building procurement system. This discovery provided the motivation for an EPSRC sponsored, research project begun at UMIST in June 1996. The objectives of the whole programme of research, of which this paper is a report of the feasibility phase, are to:

- a) investigate and analyse the comparative costs of using different building procurement systems;
- b) develop a computer based cost model to allow clients to determine the most cost effective method of procuring each building project, at an early stage in the development process.

It was recognised at the outset that the full cost of procurement, to a client, embraces many elements, in addition to the construction costs. Considerable support would be required to obtain all the data relating to these costs, from clients as well as their professional advisors. Therefore, the first phase of the research was designed as a one year feasibility study.

The specific objectives of the feasibility study were to:

- evaluate the data currently available in the collaborating firms;
- identify the most appropriate analytical and predictive model(s);
- define any further data required to produce satisfactory analyses;
- establish the availability of these data; and
- carry out preliminary model testing.

PREVIOUS RESEARCH

The Building Economic Development Committee (1974) produced a guide in which cost performance on projects designed by different types of consultant was measured by comparing the percentage of projects completed within 5% of the estimated cost. The results were restricted to a comparison of conventional and design & build methods of procurement and the validity of the analysis is, of course, dependent upon the relative accuracy of the estimates.

The Department of Industry and the Department of the Environment (1982) produced a guide comparing the performance of traditional, design & build and management procurement routes against three cost criteria. Differences were not quantified but subjectively evaluated as “higher” or “lower” than the traditional procurement route.

Brandon et al (1988) suggested additions to the costs of a project to account for the procurement system. The additions range from 0% for the conventional and design & build systems to 15% for construction management, apparently based on experience.

Whilst design & build (Franks 1983, Rowlinson 1986), management contracting (CCMI 1985, Sidwell 1983) and construction management (Moore 1984, Olashore 1986, Reading University 1991) systems have been the subject of much individual examination, until recently no objective evaluation of comparative costs has emerged. In a recent report on design & build (Reading University 1996), the Centre for Strategic Studies in Construction has concluded that the design & build procurement system is “at least 13% cheaper than traditional procurement”. The analyses were carried out using multiple regression and identified 11 variables, including choice of procurement system, which together explained 51% of the variability in project cost.

Masterman (1994) investigated selection methods, examining all the aids to procurement system selection, and found that none provided a comparison of total project, design or construction costs. References to the financial aspects of selection are limited to clients’ strategic objectives, such as whether uncertainty on price is acceptable, price competition is important, or a firm price is required before work can commence.

The current need

Selection of the most appropriate procurement system is fundamental to a successful project. Yet there is little reliable information on comparative cost. Providing the client is receiving unbiased professional advice, or has appropriate in-house experience, the first stage in the procurement selection process will result in a small number of feasible approaches which will satisfy the client’s strategic criteria.

Use of a suitable cost model should be the final stage in determining the procurement system and, indeed, many other cost significant strategic construction decisions. This

research will provide such a model, containing all the identifiable cost significant variables, and permitting many “what if?” strategic questions to be answered for clients, at each stage of early project evolution.

RESEARCH STRATEGY

The research strategy for the feasibility study falls into two parts:

- a) identification of variables and data collection, covering identification of potentially cost significant project variables, investigation of availability and finding effective strategies for collection of samples of the data; and
- b) identification of appropriate modelling methods and preliminary testing of these methods.

The feasibility study has been supported by three leading quantity surveying/project management consultancies, E C Harris, Symonds and Tweeds, who have provided cost data, personnel assistance with their collection and interpretation and assistance in steering the research.

Identification of variables and data collection

Although the primary aim of the research is to analyse and model the effect of the choice of procurement system on total client project cost, it is clearly essential to investigate the effects of all project variables, in order that other cost significant variables can be discounted in the evaluation of the effect of procurement system. This immediately raises an important issue in the research strategy, whether to restrict the model to variables which would be known at the time of procurement selection, or to include other potentially cost significant variables, such as type of substructure or number of lifts, which would normally only be determined later in the design development process. It was decided to include all potentially cost significant variables, in order to avoid limiting the potential use of the model, and to attempt to explain as much of the variation in cost as possible. Subsequent use of the model at a time prior to the determination of the values of all these variables would still be possible, by using estimated or default values, and, in addition, permit more objective exploration of the possible range of cost outcomes, rather than the calculation of a single, apparently deterministic figure.

Cost significant variables

The identification of potentially cost significant variables was achieved through a thorough search of the research literature, books and other writings on construction project costs, and sources such as the RICS Building Cost Information Service. In all, reference was made to over 60 publications, too numerous to list here. This resulted in, in addition to choice of procurement system, 36 other variables which might influence the total cost, to the client, of a building project.

These variables can be divided into three types, project strategic, site related and design variables. The project strategic variables may be used, in the predictive model, to investigate other strategic choices, as well as procurement system. Site related variables may also be used to make cost related strategic choices between sites, in cases where the development site is undecided.

The variables identified are listed below.

Project strategic variables:

Tendering strategy;	Form of contract;
Type of contract;	Project duration;
Purpose (speculative/bespoke);	Quality.

Site related variables:

Access to site;	Topographical nature of site;
Special treatment of site;	Type of site;
Type of location.	

Design variables:

Gross internal floor area;	Type of construction;
Number of lifts;	Number of stories;
Type of substructure;	Type of frame;
Upper floor;	Roof construction;
Roof finishes;	Stairs;
External walls;	Windows/external doors;
Internal walls/partitions;	Internal wall finishes;
Floor finishes;	Ceiling finishes;
Fittings;	Sanitary appliances;
Disposal installation;	Mechanical installation;
Electrical installation;	Special installations;
Site works;	Drainage;
External services.	

Time and geographic location are also important variables and it was decided to standardise the raw cost data by use of BCIS 'Tender price' and 'Location' indices, rather than include these variables in the model analyses. Issues of clear non-linearity and progression of inflation indices, variability over time and lack of progression of location indices, together with the dangers of extrapolation in most predictive models, make these two variables worthy of separate treatment, rather than direct inclusion in the model.

Cost data

The model attempts to predict total building procurement costs and is not just concerned with construction costs, but total cost to the client, which is inevitably influenced by selection of procurement system. Cost data, therefore, have been collected under the headings of: client costs, including internal project management costs; building regulations approval and planning permission; other client on-costs; design costs; other professional fees; and total construction final account costs.

Selection of modelling method

In the first instance, there were several model forms considered for the development of the predictive model (Newton 1991). The most potentially attractive contenders were: a single regression equation, embracing all the cost significant variables; a model, probably also based on regression, with projects divided into work packages, with a predicted cost for each and each work package having its own set of cost significant variables; and, a neural network model which, by its nature, is capable of providing several output costs, for forecasting. For example, client administration, design, and construction costs can be output individually.

The two selected for detailed investigation were a regression model, based on a small number of individual costs related to major work packages (administration, design, professional services, construction, etc.), and a neural network model. A particular benefit of these two model forms is that they can both provide a breakdown of predicted costs, under any headings for which costs are collected.

Both normal and 'stepwise' approaches to multiple regression, using SPSS software, have been used to model clients' costs, construction costs and total project costs. The results are encouraging, with R^2 (a measure of the amount of variance in the data which is explained by the model) as high as 0.99, but these results must be treated with caution, given the small amount of data and the, therefore, very restricted ranges of many of the variables.

Applying the data to train a neural network, using NeuroShell 2 software, has resulted in a variety of results for R^2 , from 0.48 to 0.95, depending on the particular data patterns selected for network training. An R^2 of 0.95, was obtained from a network trained on 90% of the available data patterns, but, as with the multiple regression results, must be viewed with some caution. When a very small number of alternative patterns is included, R^2 can be considerably reduced; suggesting that there is a small number of 'outlier' data points in the data patterns.

This preliminary testing has demonstrated that both methods have the potential to be used to develop a more rigorous model based on a comprehensive data set; but, at this stage, because of the small number of data sets available, neither modelling technique can produce a viable model. However, neural networks have the following advantages, when compared to linear regression techniques:

- Neural networks, unlike linear regression, are able to model interdependencies between input data which will inevitably occur when considering construction cost significant variables. For example, the model variables such as number of stories, gross floor area and number of lifts will almost certainly be correlated.
- Neural networks can deal more readily with non-linear relationships.
- Neural networks can, more effectively than regression, handle incomplete data sets; it is difficult to guarantee that complete data sets will be always be available.

Therefore, neural networks have been identified as the most suitable modelling technique for the second phase.

The success of the analyses in explaining variance in cost helps to determine which of the variables are significant in cost prediction. Regression analyses can evaluate the relative significance of the independent variables; but neural network software can also determine the relative importance of the input variables by analysis of the connection weights of the trained network.

The analyses, to date, show that the effect of procurement system selection, as with other strategic variables, is significant. However, the degree of significance found is obtained from only about 10% of the volume of data necessary to be able to discount the effect of the other cost significant variables, and must not, therefore, be viewed as reliable.

Neural networks, as with other modelling techniques, are only reliable over the range of data included in the training sets. This will necessitate care in selection of data for the analyses in the second phase of the project, in order to ensure wide applicability of the model.

In the same way that the facility provided by non-linear regression to model a particular data set with great rigour can result in a non-representative model, neural networks can be over-trained. This will have to be guarded against.

FUTURE DEVELOPMENTS

Following the completion of the feasibility study, further funding has been obtained from EPSRC to enable the full programme of research to be completed. The aim is to develop a comparative cost model of the total cost to the client of all managerial, administrative, design and construction activities, using the main building procurement systems. Thus the cost of using any system, in combination with any other strategic choice such as location or tendering strategy, may be predicted and the most cost-effective approach identified. The procurement systems will include conventional (traditional), design & build, management contracting and construction management, and significant variants.

The proposed sequence of activities for the second phase of the research programme is as follows.

- a) development of complete data bases from sufficient projects (approximately 500), collected from project participants;
- b) analysis of data using the neural network models developed in the feasibility study and, if necessary, development of revised model architectures.
- c) validation of the models by use of further sets of test data and trials of their application and usefulness in the collaborating firms;
- d) production of a user guide and operating documentation for the modelling system;
- e) dissemination of the outcomes of the research through use of the cost analyses and computer model by the collaborating QS practices and clients and through the provision of cost estimates to supplement existing guides to procurement selection, in addition to demonstration of the computer cost model and through normal publication channels.

The use of the model as a predictive instrument will have value to the client at many stages of project development. Refinement of cost estimates will be achieved simply by repeated use of the model as the project becomes more precisely defined. The second phase of the research programme will, therefore, also investigate which input variables are known at the stage when each strategic decision is made, so that the input/output facilities of the model can be structured in the most useful form. Data collection will be refined so that, as far as is practicable, any data input is of a quantitative, rather than qualitative, nature. It should be emphasised that the output of the primary model is total cost to the client, of which construction cost is only one, albeit significant, component. However, individual models of the constituent costs, design, construction, administration, management etc, will be investigated. This will assist in detailed cost planning and control. Although the objective is to develop a model which will be used to give advice to clients about the most appropriate procurement system, this necessarily embodies the development of a rigorous cost model, covering all strategic client choices.

In applying neural network modelling techniques during the second phase the following are some of the factors that will be considered:

- Although neural networks are able to model interdependencies, it is still desirable to reduce the number of variables, as this reduces the number of data sets required to train the network effectively. Principal component analysis will be used to recognise interdependency among the variables, to see whether sets of highly correlated variables can be collapsed or redundant variables eliminated.
- Descriptive data are incorporated in the model by the use of ordinal scales. However, an ordered relationship must exist for a valid neural network variable. Where this is not the case, dummy variables will have to be incorporated. Many of the variables which have been identified as influencing total cost are ordinal and, in the analysis so far, assumptions based on experience have been made with respect to the ordered relationship which exists. An early part of the work in the second phase will be to verify, or otherwise, the order of these relationships, and introduce dummy variables where appropriate.
- Neural networks are not suited to extrapolation, and the validity of the model is closely related to the boundaries of the training set. Therefore, in the second phase, a technique will be applied which will not only warn of instances of extrapolation, but also give an indication of data “voids” within the domain of validity (Helliwell, Turega and Cottis,1995).

In order to obtain a wider spectrum of data for the large data analyses to be carried out in the second phase of the programme, the three QS practices will be joined by several major clients, representing a wide spread of construction experience: commercial development, petro-chemical, industrial and rural development.

CONCLUSIONS

Research outcomes

The feasibility study has:

- a) identified the range of potentially cost significant variables in building projects;
- b) established that data describing these variables and the full range of client costs of building procurement can be collected;
- c) collected data for 46 projects;
- d) identified and carried out tests on regression and neural network models for analysing these data;
- e) come to a conclusion as to the most effective modelling method - neural networks;
- f) established the resource needs and strategy for the full data collection programme required for the second phase of the research;
- g) identified the problems in data coding and model structure development, which will require solution in the second phase, and identified potential solutions to many of them.

Considerable experience has been gained in the process of data collection, which will be of great value in the second phase of the work. For example, although co-operation

was extensively and willingly given by the nominated members of the collaborating firms, most of the data had to be provided by other members of their firms. It was beneficial to spend a significant time introducing the research, in some detail, to the people in the offices providing the data, to ensure understanding of the objectives and encourage commitment to the project. It has been decided, for the second phase in which much greater volumes of data are required, to develop a formal presentation of the project for this purpose. `Buying-in' to the project, by the providers of data, is not only beneficial to the efficiency of data collection, but also to the long term potential value and application of the model developed.

A demonstration of the neural network model was given to members of the collaborating firms, which was very well received and prompted much discussion of its potential range of application during the whole period during which `early-stage' estimating advice is required of the client's professional advisers. Mr Christopher Powell, President of RICS QS Division, wrote, subsequent to the meeting, to express his appreciation of this wide potential in the following terms:

“I was pleased to see the progress that has been made with the demonstration of the building cost model. I was particularly impressed with the learning ability of the neural network software utilised and, given this attribute, can see three distinct phases of development.”

“First, ... the model should be able to predict client costs related to each method of procurement in particular circumstances.”

“The second stage would be in the medium term, when either greater volumes of data have been input At this stage the predictive qualities of the model would be much more reliable and attention could be concentrated on those critical factors that the (computer) program has weighted heavily, to further increase predictability of both client and construction costs.”

“The third stage is a long term view, but I can see that, with data input over a long period the learning capability must produce a method of cost prediction that could challenge the traditional quantity based method of assessment.”

Finally, both the research team and the professional collaborators now believe that the way is clear to enter the next stage of research, with a very high probability of success in the production of a reliable cost model for the advice of clients in many of the most important early strategic decisions in construction project procurement.

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