TENDER PRICE AND TIME PREDICTION FOR CONSTRUCTION WORK

Thesis submitted to the
University of Aston in Birmingham
for the degree of
Doctor of Philosophy

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April 1980

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Summary

The investment decision for a proposed building is usually based upon a prediction of the construction price. The thesis considers the reliability and accuracy of price predictions and develops a new approach to forecasting prices at the design stage based upon operational data.

The concept of construction prices is discussed together with the extent of the variability exhibited by prices for various trades and items of building work. Existing methods of price prediction for construction work are analysed, in particular, cost models are considered as a basis for prediction.

The accuracy of the quantity surveyor's price predictions and the contractor's estimates are investigated using case studies. A method of monitoring performance is put forward to show past trends and provide information on corrective action that should be taken.

The use of a construction duration model has been researched to predict, at the design stage, the time required to construct a building. The model gives the design team the opportunity of testing the effect of alternative design solutions on the construction time. The model has been linked to the preliminaries trade and by simulating the contractor's approach on pricing preliminaries, a price forecast is produced based upon the duration for each of the items in the trade. A case study of a medium rise office building is used to test the model.

An operational approach to price prediction is produced by using the duration model in conjunction with algorithms and factor tables for the activities in the construction process. The system takes account of the effect on prices of operational sequence of activities, the method of construction, and the factors that influence site productivity.

(Price and time prediction)

Preface

The research outlined in the following chapters was completed over the period 1973 to 1980. It is difficult to express my gratitude to all the people and organisations in the construction industry and allied professions who gave me their time, information and enthusiasm. Thanks must also go to the various government and local government departments associated with the industry, who were always very willing to provide advice and assistance.

Special thanks must go to Professor Biggs, Professor Bennett and Dr. Norman at the University of Reading for their constant guidance, advice, and encouragement, and to Professor Pratt and Professor Jepson at the University of Aston in Birmingham for their advice.

The work on the association between price and height (Appendix 3 at the back of the thesis) was undertaken in collaboration with Dr. Norman.

DEPARTMENT OF CONSTRUCTION AND ENVIRONMENTAL HEALTH

PhD Candidate : Roger Flanagan

Title : Tender Price and Time Prediction for Construction Work

AMENDMENTS

Page 3 (immediately preceding 1.2 Structure of the Thesis)

It is emphasised that the thesis addresses the problem of predicting tender prices and not the price clients eventually pay for completed buildings when account is taken of claims and other increases in costs.

Page 256 (insert as paragraph 2)

This leads to an overlying qualification of the whole work, namely that the various conjectures and proposals have been tested only to a limited extent. Whilst they are plausible, their relevance to building will need to be further tested. The thesis indicates how this may be attempted through further research which was not possible in the present investigation. In brief, the thesis points to possible rather than final solutions.

Chapter 1

Introduction and objectives of the research

1.0 Introduction.

Reliable price prediction[1] for a proposed building is probably one of the most important tasks performed by a consultant quantity surveyor because a client will often base his investment decision on this forecast.

If a project does not proceed because the contractor's tender price was not within acceptable limits of the quantity surveyor's price prediction, this will have serious implications for the client, the construction industry and the allied professions who will have been involved in abortive costs and work. Any research to improve the price prediction process could, therefore, make a useful contribution to the construction industry.

Price prediction at present is not a precise scientific exercise, but an art which involves intuition and expert judgment. When investigating any process which involves costs and prices, one must remember that the base data are often crude and subjective. This is not a criticism, but it does provide a reason why, academically, quantity surveying research today is probably at the equivalent stage of development that engineering was one hundred years ago. Unlike engineering and the sciences, quantity surveying suffers from the disadvantage that there are no theorems upon which to test hypotheses. Many of the current and impending problems of the quantity

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(1) Throughout the thesis we have used the terms prediction and forecast interchangeably to mean a prediction of a price for building work compiled by the quantity surveyor at the design stage.

surveying profession will remain insoluble until new decision aiding techniques are developed and adopted which are commensurate with the changes which have occurred in the construction process.

1.1 Objectives of the Research.

We recognised the importance of the price prediction process to the quantity surveying profession and felt that some fundamental research was necessary. The quantity surveyor relies extensively on the use of adjusted historical unit price rates as the basis for price prediction of proposed projects, whereas the contractor adopts a completely different approach to pricing estimates by using operational data to decide the resources required and the duration for which those resources are needed. Therefore, in the thesis our objectives are to consider:

1) the variability of prices for building work and the possible existence of any trend between groups of items or trade sections;

2) the adequacy of price prediction techniques currently used by quantity surveyors;

3) the accuracy of the quantity surveyor's price predictions measured against the contractor's low bids;

4) the accuracy of the contractor's estimate at the tender stage to the final cost shown in the contractor's cost book;

5) the effect of the project duration on the price, and whether, at the design stage, a knowledge by the quantity surveyor of the construction duration would improve the reliability of any part of the price prediction;

6) the effect on the quantity surveyor's price prediction if an operational approach to forecasting was used.

We have also set specific objectives at the beginning of each chapter, from which conclusions have been drawn.

1.2 Structure of the Thesis.

In Chapter 2 of the thesis, we examine the concept of prices for building work and consider the extent of variability of the contractor's price rates for a number of measured items and trades.

Chapter 3 discusses the causes of price variability and analyses the extent to which they are considered by existing forecasting techniques. In determining the price of a future project the quantity surveyor will normally use prices derived from the low bids on previous projects. This practice is examined for any characteristics associated with the contractors' approach to bidding which are relevant to price forecasting.

The concepts of accuracy and reliability are discussed in Chapter 4. The accuracy of the contractor's estimate compared with his true cost is considered. The accuracy of the quantity surveyors' price predictions measured against the contractor's low bid prices is also considered, with the use of data from two County Council cost planning departments. A graphical technique is propounded which provides a method of monitoring estimating performance for the quantity surveyor.

In Chapter 5 we investigate the significance of construction duration on construction prices. The duration model which is developed is used to calculate the construction duration at the design stage of a project. It also produces a price for the preliminaries trade and a cash flow analysis.

The duration model is used in Chapter 6 to research an operational approach to price prediction. The technique takes account of the operational sequence of work, the method of construction and the activity durations, while developing the price using resources rather than unit price rates.

Chapter 7 draws together the main conclusions and makes suggestions for changes in the present system.

1.3 Research Method.

Research into prices and costs involves investigation at all levels of construction and design activity. Considerable effort was directed to discussions with operatives, management and professional people. We found the co-operation provided by every sector of the construction industry and allied professions to be very encouraging. It was most valuable to talk to those performing construction operations about the problems associated with their tasks. We found this particularly important when we considered the operational approach to price prediction in Chapter 6.

The prediction of a price for a product is not unique to the construction industry. We therefore looked at other industries and disciplines to see if any of the prediction techniques could be used by quantity surveyors.

1.4 Abbreviations.

To save space the following acronyms have been used in the thesis:

AIA	-	American Institute of Architects.
BCIS	-	Building Cost Information Service.
BS	-	British Standards Institution.
CP	-	British Standards Institution Code of Practice.
DHSS	-	Department of Health and Social Security.
DOE	-	Department of the Environment.
DQSS	-	Directorate of Quantity Surveying Services.
IOB	-	Institute of Building.
IQS	-	Institute of Quantity Surveyors.
MPBW	-	Ministry of Public Buildings and Works.
NFBTE	-	National Federation of Building Trades Employers.
OECD	-	Organisation for Economic Co-operation and Development.
RIBA	-	Royal Institute of British Architects.
RICS	-	Royal Institution of Chartered Surveyors.
SMM	-	Standard Method of Measurement of Building Works.

Chapter 2

The concept of price and the variability of construction prices

2.0 Introduction.

The whole basis of the quantity surveying profession is a reliance on an extensive knowledge of construction prices. Despite the importance of a thorough understanding of the extent and causes of price variability for building work, very little is known or published about the subject.

The objectives of this chapter are:

1) to introduce the concept of building prices and consider the levels of price information used by quantity surveyors and to examine the relationship between price and cost;

2) to ascertain the extent of price variability exhibited by completed buildings, trades and measured items;

3) to determine whether a pattern of variability exists between the trades.

2.1 Costs and Prices for Building Work.

The terms cost and price tend to be used interchangeably in the construction industry. The price is the sum asked by an organisation for goods and services provided, whilst the cost is the direct cost to the organisation incurred in the provision of those services. In its simplest form, the price is the sum asked whilst the cost is the sum paid by the purchaser of the goods and services. Throughout this thesis we are primarily investigating the price of buildings but are occasionally forced by common usage to use the term "cost", e.g. cost planning.

Within the British construction industry the common language used to communicate price is the unit price rate related to a quantity of finished work. In simple terms the price of any measured item is given by:

$$P = NR$$

where N is a number and R is a unit price rate.

The unit price rate is derived from an analysis of the task labour, material, plant, supervision, making allowances for overheads and profit. The single figure therefore embodies all the allowances subsumed by the contractor. Figure 2.1 shows the factors the contractor will consider when building up unit price rates. The contractor needs a cost feedback system to measure his cost performance on projects. This feedback system should effectively monitor the time required and the cost associated with all the tasks on a project at the site activity level. In theory the feedback system provides cost and time information for the contractor from which unit price rates can be estimated for future projects.

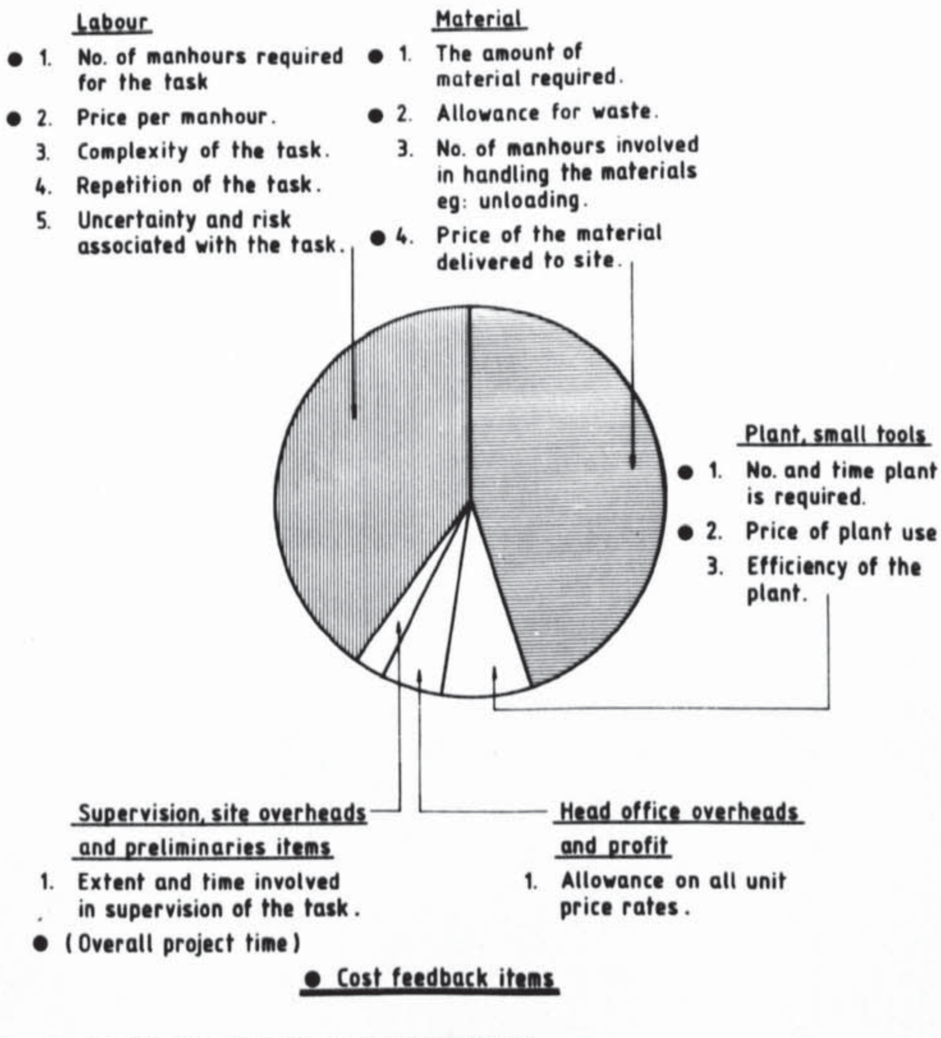

Fig 2·1 UNIT PRICE RATES & COST FEEDBACK

The consultant quantity surveyor's main task is to predict at the design stage the likely lowest bid price submitted by the contractor on a project. The quantity surveyor does not have access to the contractor's cost feedback information. He is, therefore, forced to place extensive reliability on unit price rates from completed projects as the basis of price information used for prediction.

If we examine the levels of price information used by the quantity surveyor in predicting prices during the design phase, we move from a single price rate approach for the total building through the elemental component or functional parts approach, to the detailed resource level of labour, material, plant and supervision. Figure 2.2 shows the level of price information at each of the design stages. The contractor's interest at the tender stage is at level 5, whilst the quantity surveyor will rarely consider prices below level 4, because he has information only about the current market unit price rate for an item.

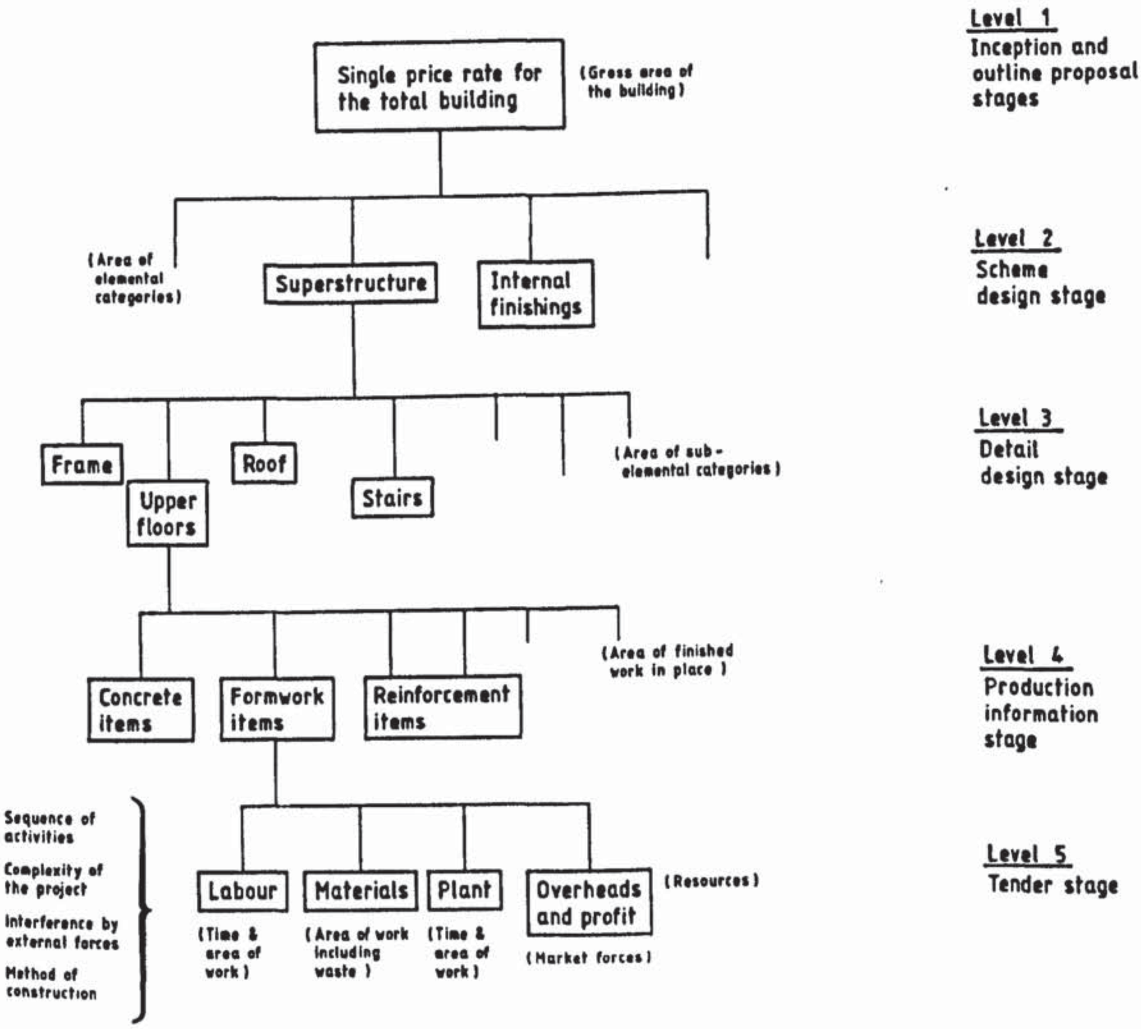

Fig 2.2 LEVELS OF PRICE INFORMATION

Whilst the contractor uses unit price rates to communicate with the design team, his system of monitoring cost is at the resource level. The process of compiling unit price rates involves an analysis of what resources are required and how the task will be undertaken.

To enable the contractor to understand and evaluate the sequence and interaction of all the variables likely to affect performance, a method statement and a pre-tender construction programme are prepared at the tender stage.

Figure 2.3 shows the relationship between the unit price rates and the contractor's approach to costs.

The contractor's method statement shows how a proposed building should be constructed, indicating the most suitable labour, plant and material resources required. The pre-tender construction programme gives the sequence of activities, the anticipated durations for the various activities and the overall construction duration. The estimator incorporates the information in the method statement and the pre-tender programme into the measured unit price rates. Furthermore, the contractor's estimator will display the unit price rates in the most advantageous format for the contractor. For example, the bill rates may be front loaded or rear loaded; the cost of plant for the project might all be included in the preliminaries trade instead of allocated to each item; the profit allowance could be included in the unit price rates or allocated only to certain trades. The contractor will also introduce a subjective evaluation of risk, i.e. the probability of completing a task within a defined time and price constraint.

The contractor must allow in his evaluation of risk for any interruption in the construction programme caused by rainfall, low air temperature, snow, fog, wind, etc. Consideration must be given not only to the extreme values

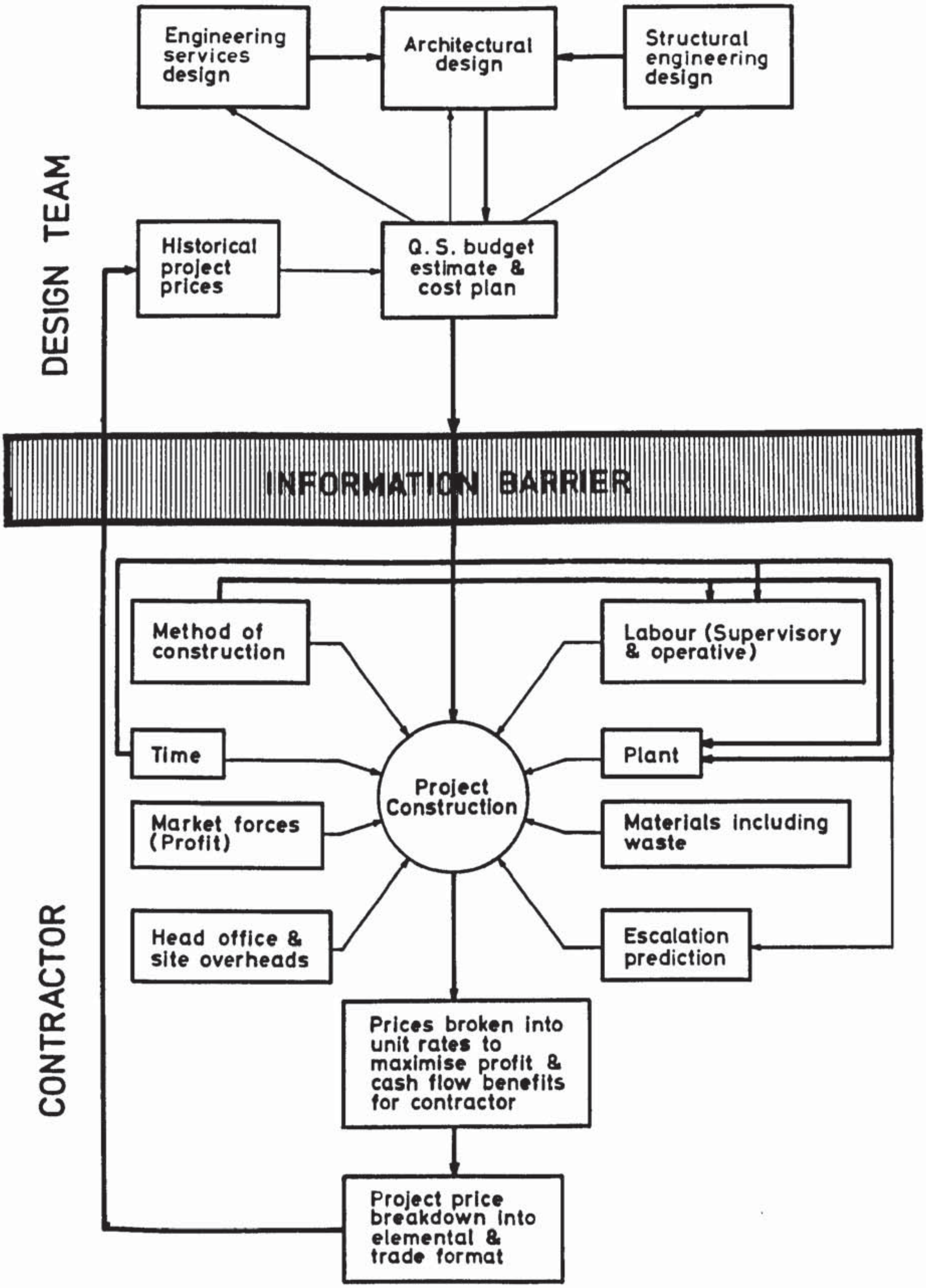

Fig 2.3 THE RELATIONSHIP BETWEEN UNIT PRICE RATES AND COSTS

of temperature, humidity and wind speed, but also to their frequency, duration, co-incidence and the order of diurnal variations.

Risk is difficult to quantify with building work because it involves a bewildering variety of conditions, with work being undertaken by operatives with varying degrees of competence and speed of working.

Another aspect which is taken into account is the way market forces influence the contractor's evaluation of an acceptable profit margin. Every project exists in a construction market place, that is, there is a definite supply of resources available to meet the demand placed by the project and by all others underway at the same time.

Professional consultants often have very little feel for the market in which they will place their product. The assumption is that the market place will quickly, easily and inexpensively provide all of the resources needed to build at the precise time and in the location they are needed.

Just as the consultant quantity surveyor does not have access to the contractor's feedback system, he also does not have access to the contractor's method statement, pre-tender programme or an indication of the contractor's profit margin. Therefore, he must rely on adjusted historical unit price rates as the basis for prediction. The sample of prices available to him may be large, and may provide insight into the range of prices likely to be encountered on any scheme. Nevertheless, there is an information barrier between the contractor and the consultant quantity surveyor as shown in Figure 2.3.

Attempts have been made to bridge the information barrier by the introduction of a bill of quantities in an operational format (Skoyles (1964)). The object was to give contractors the opportunity of providing prices at the resource and operational level based upon the sequence of work.

The experiments met with limited success, primarily because of the long standing attachment, by the industry, to the concept of the unit price rate. Further research work on the activity bill, which represented a shorter step forward, has also had very little impact on the industry.

The discussion above indicates that while the contractor has more information available to him at the tender stage, he also has a large number of imponderables - hence the need for a reliable cost feedback system to show levels of performance on completed projects. However, various authors (e.g. Miller (1969), Blain (1974), Roderick (1977)) have shown the inadequacy of the methods of cost feedback used by contractors.

Generally the problem seems to be that the collection of cost information is made difficult by the fact that the activities which form the contractor's costing system do not relate directly to the measured work terms in a bill of quantities.

A further difficulty arises from the trend towards greater specialisation. This has meant that contractors rely more heavily upon specialist subcontractors who submit prices to the contractor in one or other of various standard forms, so that the contractor cannot tender on the basis of an overall price breakdown but rather on the basis of a series of "lump sum" charges from the sub-contractors.

2.2 The Extent of the Variability of Building Prices.

Building is a custom industry where the products are tailored to suit the needs of a specific owner. Prices submitted by contractors, even for identical buildings, can be expected to vary for a variety of reasons. There is no one price for a given building, but rather several prices according to a range of circumstances.

Beeston (1975) described a price for the same item as existing in a large imaginary family of prices. The prices in the family have a wide range of values, any one of which could occur. He stated "If there is a 'right' price it is some sort of average of all the possible prices in the family, but if we have only one price we do not know where it stands in relation to the average". If more than one price in the family is known, the averave of the known prices is an estimate of the average of the whole family.

One of the shortcomings of the quantity surveyors' techniques in collecting and analysing price data is the lack of a suitable system of identifying the significant factors that influence families of prices. For example, the BCIS Standard Form of Cost Analysis uses the CI/SfB building classification system Table 0 for building types. The building function is a method of identification; what is subsumed within the identification and the price is the complexity and the time taken to construct the project.

The question to be considered is: what is the extent of price variability when many prices are obtained for the same item description?

The first test was an examination of the price per square metre of the gross floor area of 184 projects taken from the BCIS published and unpublished records. All the buildings were constructed between January 1974 and September 1977. The sample contained offices, flats, housing, factories and warehouses, all of varying construction type and size. The prices were re-based to the first quarter 1974 using the BCIS tender price index. No adjustment was made for the impact of geographical location on the prices.

No external works items were included in the prices because this would have distorted the results.

Firstly, prices were grouped by functional building types. We attempted to reduce the range of prices for each sample by improving the homogeneity of the sample.

The term homogeneity is used in the thesis to mean similarity. All buildings are both homogeneous and heterogeneous to varying degrees. For instance price data relating only to office buildings may be said to be homogeneous. The offices may be further divided into high, medium and low rise structures and the price data within each group can be expected to be even more homogeneous. Each category may be further sub-divided according to construction type. With this and each subsequent division a greater degree of homogeneity may be expected.

Skewness is the degree of asymmetry, or departure from symmetry, of a distribution. When a series of values is limited at one end the distribution is bound to be more or less asymmetrical. A logical analysis would confirm that prices are distributed with a skew to the right because price data are limited at the zero end. If an elemental category has an expected value of £10,000, it is more likely to over-run by £10,000 or be priced at £20,000, than it is to under-run by £10,000 and be priced at zero.

Figure 2.4 shows the histograms for the prices per square metre for housing, flats and offices. The spread of prices for the housing and flats samples are very similar, apart from one expensive project in the flats sample. One of the main reasons for the different spread between housing and flats, and offices is that 92% of the housing and flats projects were built for public sector clients who were constrained to build within the housing cost yardstick cost limits.

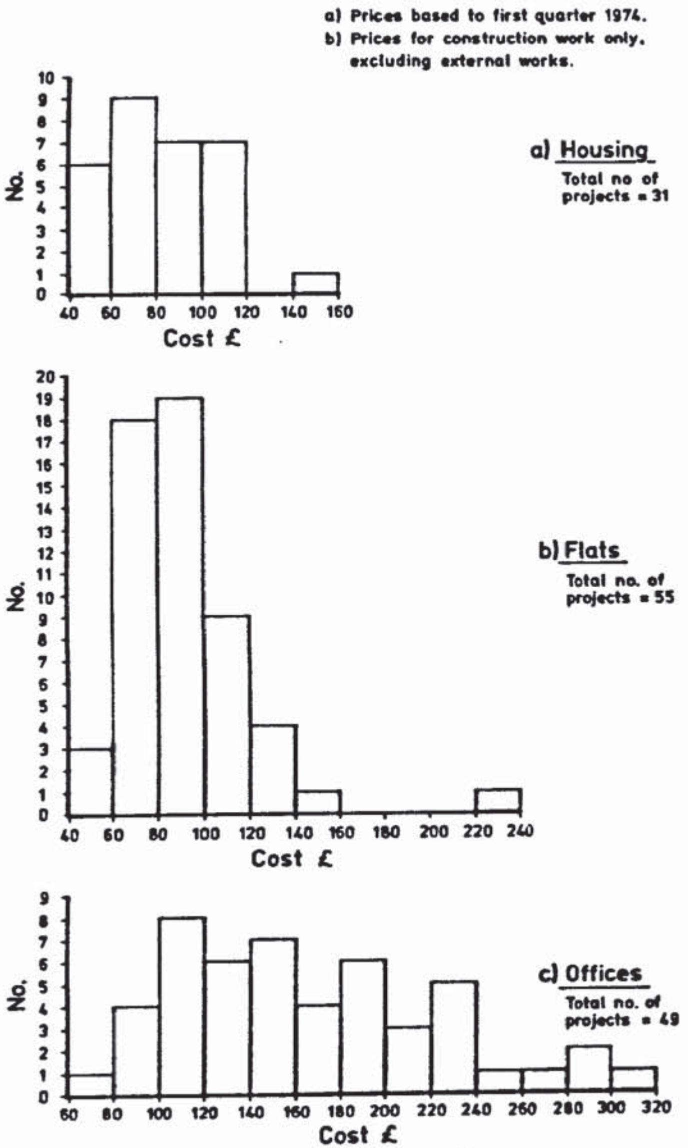

Fig 2.4 HISTOGRAMS OF £/m² BY TYPE OF BUILDING

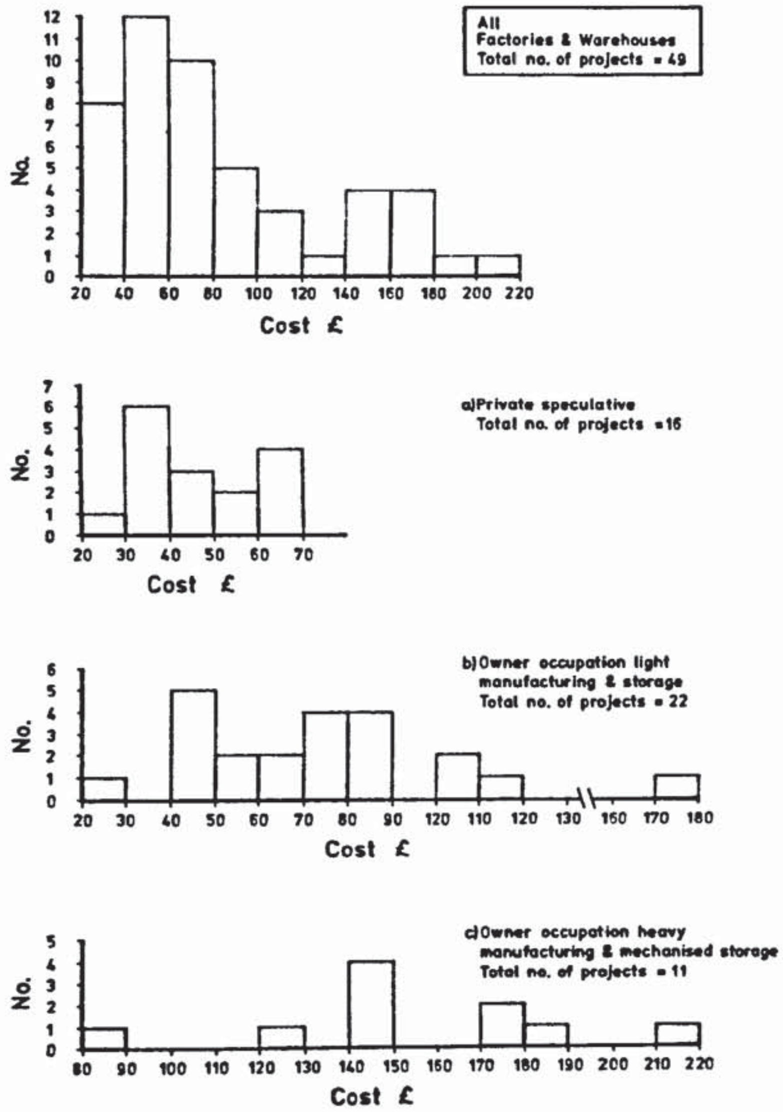

Fig 2.5 HISTOGRAMS OF £/m² FOR FACTORIES

The office buildings sample contains both public and private seçtor developments. The building types vary from speculative low quality offices to high quality owner occupied offices. The very nature of this heterogeneous sample for offices means that a very wide spread of prices must be expected.

Figure 2.5 shows the histograms for factory and warehouse units. We subdivided the sample into families. The objective was to test what impact the functional type had upon price variability. The groups selected were:

a) private speculative;

b) owner occupied light manufacturing and storage;

c) owner occupied heavy manufacturing and mechanised storage.

Our analysis shows that the price data for factories and warehouses are a number of families with specific characteristics. The sample for owner occupied factories exhibits significantly wider price variation than the private speculative factories sample. We would expect this situation to exist, because the private speculator will be constrained by the maximum potential rental income from the development. The owner occupier on the other hand, will generally demand a custom designed building to meet his production requirements. In most instances this can also be expected to be of a higher quality standard than the speculative factory building.

Tables 2A and 2B show an analysis of the price per square metre of all the sample projects. The prices have been analysed by functional type using the arithmetic mean, the median and the mode of the sample. A truncated arithmetic mean has been calculated by rejecting the highest and lowest observations in each sample and obtaining the mean of the remainder, because it was noted that in certain of the samples there were extreme observations which tended to distort the mean. The measure of variability which is of most value statistically, is the coefficient of variation. This is the standard deviation (root-mean-square of deviations from the arithmetic mean) expressed as a percentage of the mean.

TABLE 2A : ANALYSIS OF PRICE PER SQUARE METRE SAMPLE PROJECTS.

Project Type	No. in sample (Total=184)	Minimum price rate	Maximum price rate	Arithmetic mean rate	Truncated arithmetic mean	Median	Mode	Standard deviation	Co-efficient of variation %
Housing	31	45.96	152.50	85.05	84.66	80.87	76.35	24.99	29.28
Flats	55	49.76	237.99	91.73	89.76	85.37	81.82	27.76	30.26
Offices	49	66.56	300.98	166.38	165.62	154.84	113.33	58.70	35.28
Factories and ware-houses	49	25.01	210.49	83.34	81.87	65.31	53.33	48.20	57.83

All prices based to first quarter 1974.

All figures relate to £/m^2 of the gross superficial floor area.

TABLE 2B : ANALYSIS OF PRICE PER SQUARE METRE OF FACTORIES AND WAREHOUSES.

Project Type	No. in sample (Total= 49)	Minimum price rate	Maximum price rate	Arithmetic mean rate	Truncated arithmetic mean	Median	Mode	Standard deviation	Co-efficient of variation %
Private specula-tic	16	25.01	66.88	47.04	47.19	46.55	36.25	13.64	29.00
Owner occupation - Light Manufacturing	22	29.05	170.56	74.01	71.44	71.72	46.25	30.38	41.05
Owner occupation - Heavy Manufact-uring	11	85.69	210.49	154.67	156.16	147.26	145.00	32.21	20.32

All prices based to first quarter 1974.

All figures relate to £/m^2 of the gross superficial floor area.

TABLE 2C : ANALYSIS OF PRICE PER SQUARE METRE FOR OFFICE BUILDINGS BY PROJECT VALUE.

Project Cost		No. of projects (Total = 49)	Mean project size	Mean price per square metre	Correlation Co-efficient (1)
(i)	Up to £100,000	15	£49,647	£152.65	.02
(ii)	Over £100,000 but not exceeding £500,000	19	£206,024	£164.08	.14
(iii)	Over £500,000 but not exceeding £1,000,000	11	£633,201	£194.25	.36
(iv)	Over £1,000,000	4	£1,972,756	£177.24	.59

1) All correlation co-efficients produced in the thesis are Pearson product - moment correlation co-efficients.

By analysing the relationship of the mean, median and modal values in Table 2B, the degree of skewness of the frequency curves can be identified. The offices sample is positively skewed to a marked extent.

The coefficient of variation for the factories and warehouses of 57.83% is the highest of the four groups of buildings. Table 2B shows the breakdown of the factories and warehouses by function type. The coefficient of variation has been substantially reduced for the private speculative and owner occupied heavy manufacturing units; this is a result of the identification of types of family in the sample. A feature of Table 2B is the difference in the mean price rates for the three types of factory and warehouse units. The mean price per square metre for owner occupied heavy manufacturing buildings is over twice the price of the light manufacturing factories.

These data would appear to support the view that unit price rates of completed buildings are significantly affected by the homogeneity of the sample. To examine this further we selected 51 factory and warehouse projects completed by two major property development companies specialising in speculative industrial developments. The project prices were rebased to the first quarter 1974 using the BCIS tender price index. The mean construction price was £57.10 with a coefficient of variation of 15%. The buildings were constructed to a basic standard design using a standard specification with very few modifications for each project. These results suggest that by increasing the homogeneity of the sample, as in this case by using a standard design, the spread of the prices will be smaller and so lead to greater reliability when using the prices as the basis for future estimates.

Returning to our original data, the offices sample was tested to consider the effect on the price per square metre of the overall project value. The project prices were divided by value into four categories, which were established from observation of the data. Table 2C shows the results of the analysis. The correlation coefficient between the total project price and the price per square metre is not statistically significant.

This analysis supports the view that the contract value is not one of the selection criteria that should be used to improve the homogeneity of a sample. Bowley and Corlett (1970) and Beeston (1975) have stated that the contract value is one of the causes of price variability of complete buildings. We disagree with this viewpoint because the contract value embodies quantity, quality, technical complexity, and time required to undertake the project. Whilst we recognise that an increase in quantity of an item may lead to benefits of economies of scale, this ignores the complexity and time taken to undertake the work. This hypothesis is developed further in Chapter 5 of the thesis.

The conclusion to be drawn from the analysis of prices of completed buildings is that when only the functional type is considered, the price variability is very wide. When the homogeneity is improved, i.e. within the identification of families, it is possible to achieve a reduction in the spread of the prices.

Two questions arise from this: firstly, which major factors should be considered in improving the homogeneity of the sample, and secondly, what the size of the sample should be when using historical prices as the basis for future estimates? The thesis will consider these questions in more detail.

An interesting feature is that the selection criteria currently used by quantity surveyors always relate homogeneity to an aspect of the finished building. Homogeneity is not considered in terms of the number of weeks required for construction nor to a particular construction technique.

The question of the sample size has no perfect solution. Beeston (1975) suggests that great improvement in reliability can be obtained if historical price data are drawn from several buildings rather than one, even if this means sacrificing comparability. We support this viewpoint with the proviso that emphasis must be placed on the extent of the reduction in homogeneity. The analysis in Table 2B showed the price distortion that could take place if owner occupied light and heavy manufacturing buildings were combined as owner occupied manufacturing buildings.

One further point is on the use of the arithmetic mean value of a sample as a basis for future prices. The mean is a measure of centrality which is affected by extreme values and may not adequately characterise the frequency distribution of the prices. As Figures 2.4 and 2.5 illustrated, construction prices are skewed to the right, and therefore an alternative measure of central location, the median, might be more suitable, as it is less affected by extreme values. However, quantity surveyors should not just be interested only in a measure of central tendency. The coefficient of variation should be calculated to show the dispersion of the prices in the family.

2.3 <u>The Variability of Contractor's Prices contained in Bills of Quantities</u>

Barnes and Thompson (1971) found that with prices in civil engineering bills of quantities, the range of variation of individual unit price rates was between five and ten times that of tender totals. We could find no available evidence to support this argument in the prices for building work.

We analysed the extent of price variability of contractors' prices contained in bills of quantities at various levels, as follows.

1) The trade level prices for the lowest bids on a range of projects.

2) The trade level prices for bids submitted by contractors in competition for a single project.

3) The individual unit price rates for bids submitted by contractors in competition for a single project.

4) The individual unit price rates submitted by the specialist sub-contractors to the main contractor for inclusion in the measured work sections of a bill of quantities.

2.4 <u>Variability at the Trade Level</u>.

Our analysis of completed buildings has shown that the building function has an influence on the overall price. We therefore selected a sample of 20 factory projects from £60,000 to £300,000 value located in south-east England, built in the first half of 1977. In this instance the only selection criteria were the functional type and the type of structure. The plan layouts of all the buildings varied considerably. We took the quantities for one of the projects as the model and selected certain major items from each of the trades. The selected model items were re-priced using the rates from the lowest tenders of each of the 20 projects. The coefficients of variation for the trades were as follows:

Preliminaries	42%
Excavation and earthwork	38%
Concrete work	30%
Brickwork and blockwork	28%
Roofing	6%
Carpentry	29%
Joinery	11%
Plumbing and engineering installations ...	11%
Plasterwork and other floor wall and ceiling finishings	18%
Glazing	10%
Painting and decorating	13%

The analysis helps to classify the extent of variability exhibited by the various trades. As we would expect, the preliminaries and the excavation and earthwork have the highest coefficients, whereas roofing has the lowest. Excavation items generally carry the highest risk for a contractor, whilst the roofing work is usually sub-contracted and has less risk associated with it. The prices for the preliminaries trade will vary significantly because of the pricing method adopted by the contractors. Some contractors will include all their plant and overheads and profit allowances as lump sums in the preliminaries trade, whilst others will spread the items throughout the bill of quantities.

The roofing items comprised asphalt and built up felt roofing, both of which are undertaken by a relatively small group of specialist sub-contractors. It appears that the roofing specialists are submitting prices with very little variability.

We then examined the variability of prices at the trade level for a single project to see if the results were consistent with the 20 factory projects. We were thus moving from a low to a high level of homogeneity by considering a situation where all the contractors were pricing the same item for the same project.

A serial tender project for which 9 contractors had submitted bids to a county council in southern England was selected for analysis. There was an advantage in using the serial tender analysis because contractors were pricing a master bill of quantities for a series of proposed projects; the pricing was, therefore, likely to be highly competitive.

Table 2D shows the indexed values for each work section taken from the priced bills of quantities of each contractor. Table 2E gives the percentage value

TABLE 2D : INDEXED VALUE OF EACH WORK SECTION.

Work Section	CONTRACTOR									Mean	Standard deviation	Coefficient of variation %
	A	B	C	D	E	F	G	H	I			
Excavation and earthwork	113.20	100.00	283.00	144.10	146.30	143.60	136.00	177.00	136.60	153.31	53.19	34.69
Concrete work	137.80	100.00	176.70	130.70	121.70	120.50	136.10	125.50	175.70	137.19	24.98	18.21
Brickwork/blockwork	188.60	100.00	186.10	148.70	127.70	128.50	130.70	[illegible]	154.50	134.03	28.95	21.60
Asphalt work	105.10	100.40	110.80	100.00	101.10	103.40	100.60	104.60	108.30	103.81	3.79	3.66
Roofing	104.80	100.20	106.90	100.00	100.80	103.90	100.40	104.30	108.10	103.27	3.06	2.96
Carpentry	177.80	100.00	200.80	122.90	124.50	119.40	120.80	120.10	175.60	140.21	34.85	24.85
Joinery	119.10	110.00	121.60	115.00	110.50	104.10	112.00	114.90	120.80	113.11	7.38	6.53
Structural steelwork	104.80	100.00	110.00	101.30	102.00	103.70	101.40	105.00	109.40	104.18	3.54	3.41
Metalwork	103.80	100.00	118.50	100.40	102.40	107.80	101.80	103.60	114.50	105.87	6.52	6.16
Plumbing & Engineering Installation	105.00	100.00	108.60	103.20	100.90	107.30	100.40	104.80	108.70	104.32	3.43	3.29
Electrical installation	103.40	101.20	117.20	100.00	117.70	105.00	101.60	102.70	109.80	106.51	6.81	6.40
Plasterwork and other floor wall and ceiling finishes	108.70	100.00	125.20	114.10	114.70	107.40	113.30	111.00	152.50	116.32	15.15	13.03
Glazing	114.50	115.40	124.00	103.99	117.00	122.50	100.90	100.00	185.80	129.78	25.09	20.77
Painting and decorating	141.50	100.00	150.70	149.40	135.70	147.80	145.70	156.40	200.60	147.53	25.85	17.52
INDEX OF TOTAL PRICE:	113.50	100.00	125.50	110.00	109.40	108.90	108.30	111.70	124.50	112.42	8.04	7.15
TOTAL VALUE OF BUILDING WORK	£ 491,373	£ 432,7[illegible]9	£ 543,438	£ 476,043	£ 473,561	£ 471,344	£ 468,808	£ 483,614	£ 539,148			
Preliminaries	119.60	100.00	261.00	152.10	136.20	175.70	141.30	188.80	182.40			

(Note: Indexed to lowest price in each work section).

(Preliminaries priced separately because it relates also to work not included in building work prices shown).

TABLE 2E : PERCENTAGE VALUE OF EACH WORK SECTION.

Work Section	CONTRACTOR									Mean (%)	Standard deviation	Coefficient of variation (%)
	A	B	C	D	E	F	G	H	I			
Excavation and earthwork	1.80	1.80	4.10	2.40	2.50	2.40	2.30	2.90	2.00	2.47	0.71	28.62
Concrete work	5.30	4.40	6.20	5.20	4.90	4.80	5.50	5.30	6.20	5.31	0.60	11.31
Brickwork/blockwork	8.4[illegible]	[illegible].10	7.50	6.90	5.90	6.00	6.10	6.40	6.30	6.51	0.97	14.92
Asphalt work	4.00	4.30	3.80	3.90	3.90	4.10	4.00	4.00	3.70	4.00	0.14	3.53
Roofing	3.50	3.80	3.20	3.40	3.50	3.60	3.50	3.50	3.30	3.48	0.17	4.93
Carpentry	1.00	0.60	1.00	0.70	0.70	0.70	0.70	0.70	0.90	0.78	0.15	19.23
Joinery	11.90	11.40	11.00	11.90	11.50	10.90	11.80	11.70	11.00	11.45	0.40	3.52
Structural steelwork	11.00	11.90	10.50	11.00	11.10	11.40	11.20	11.20	10.50	11.08	0.43	3.89
Metalwork	9.00	9.80	9.30	9.00	9.20	9.70	9.20	9.20	9.00	9.26	0.30	3.19
Plumbing and engineering installation	20.10	21.70	18.80	20.40	20.00	21.40	20.20	20.40	19.00	20.21	0.95	4.69
Electrical installation	8.20	9.10	8.40	8.10	9.60	8.60	8.40	8.20	7.90	8.50	0.54	6.31
Plasterwork and other floor wall and ceiling finishes	13.80	14.40	14.40	15.00	15.20	14.20	15.10	14.40	17.70	14.90	1.14	7.65
Glazing	0.20	0.20	0.10	0.10	0.20	0.20	0.10	0.10	0.20	0.16	0.05	32.94
Painting and decorating	1.80	1.50	1.70	2.00	1.80	2.00	1.90	2.00	2.30	1.89	0.23	11.96
TOTAL:	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00		

of the total for each work section. To put the coefficient of variation figures into perspective they must be read in conjunction with the percentage value that each trade bears to the whole.

As with the 20 factory projects, the excavation and earthwork and preliminaries show a high variability. The pricing of excavation is heavily influenced by the contractor's choice of construction method and his assessment of the likely ground conditions and prevailing weather conditions. However, the mean value of the excavation represents only 2.47% of the project total. The preliminaries price relates also to building work not shown in the table. The preliminaries price represents 16.1% of the total overall project tender value, it is a highly significant item because it has the second highest trade value after the plumbing and engineering installation.

The carpentry section exhibits a high coefficient of variation, but it represents only 0.78% of the mean project value. The carpentry work is unlikely to be sub-contracted, but it will have a high labour/material ratio, perhaps as high as 70:30, and so the coefficient of variation is probably highlighting the variability of each contractor's estimate of labour performance.

To show a more realistic price impact of the measured items, the value of the prime cost sums and provisional sums was deducted from the work sections. Table 2F shows the results.

The number of measured items in each section was then calculated. The joinery section contained 981 joinery items, many of which were for specialist fitments. We can put forward two likely reasons for the low coefficient of variation for the joinery:

TABLE 2F : ADJUSTED PERCENTAGE VALUES.

Work Section	Mean % value of each section	Adjusted mean value % after deduction of P.C. and Provisional Sums from work sections	No. of unit items priced in bill of quantities *	Value of each priced item as a percentage of the total after deduction of P.C. and provisional sums
Excavation & Earthwork	2.47	2.47	25	0.099
Concrete Work	5.31	4.18	123	0.034
Brickwork/Blockwork	6.51	6.51	130	0.050
Asphalt Work	4.00	0.22	2	0.110
Roofing	3.48	0.17	5	0.034
Carpentry	0.78	0.78	87	0.009
Joinery	11.45	5.66	981	0.006
Structural Steelwork	11.08	0.58	11	0.053
Metalwork	9.26	1.74	178	0.010
Plumbing & Engineering Installation	20.21	2.26	268	0.008
Electrical Installation	8.50	0.79	22	0.036
Plasterwork & Other Floor Wall & Ceiling Finishes	14.90	6.19	221	0.028
Glazing	0.16	0.16	19	0.008
Painting & Decorating	1.89	1.89	97	0.019
P.C. and Provisional Sums	-	66.40	-	-
TOTALS:	100.00	100.00	2169	-

* Profit and attendance items on Prime Cost sums included with the work sections

Mean contract value £486,075

a) the value of each priced item was small;

b) because all the contractors were from the same region, it is likely that quotations were sought from a number of specialist joinery sub-contractors and, consequently, many of the quotations may have been submitted to more than one of the tendering contractors.

The high coefficient of variation for the glazing trade was the most surprising result, as we would have expected a low coefficient because glass is a monopoly supply material. The supply price is, therefore, very stable throughout the United Kingdom and the labour in fixing is not subject to high variability of performance. However, the percentage value of the total is 0.16% and therefore its impact was not significant.

The correlation coefficient between the standard deviation of the value of each work section and the percentage value of each priced item after deduction of the p.c. and provisional sums, was 0.2063. This shows that the percentage value of each item is not related to the variability in pricing.

The conclusion to be drawn from the analysis is that those trades which are influenced by the complexity of a project and which have a high labour : material ratio, that is, the excavation and earthwork, brickwork and blockwork and carpentry work, exhibit the highest variability. Much of the variability is caused by the contractor's evaluation of the labour performance for these trades, which is highly variable as has been shown (Forbes, (1966)).

To test this viewpoint a range of items was selected from the bill of quantities for the external works, a section chosen because of the varied nature of the work.

2.5 The Variability of Individual Unit Price Rates.

Table 2G lists the selected items from the external works. The data exhibit a wide spread, particularly on items where any ground work is involved. The works on site show a high coefficient of variation. We would expect consistency in pricing in the case of the entrance gates, but the range is from 100.00 to 229.60. The most noticeable aspect is the generally high coefficients exhibited by the majority of the items. To test this aspect further we took the 9 tenders and extracted certain measured items from each trade section, which represented approximately 25% by value of each trade. The results showed that the individual unit price rates varied up to eight times those of tender totals. This finding supports the Barnes and Thompson statement on the extent of price variability. The conclusions are that unit price rates for specific measured items in bills of quantities exhibit greater variability than at the trade level in the bill.

The next stage of the analysis was to investigate the extent of variability exhibited by the specialist sub-contractors who submit prices to the main contractors, for inclusion in tender prices.

The question we were attempting to answer was whether the specialist sub-contractor's prices exhibit the same price variability as the main contractor's prices.

We selected concrete work items for analysis because the increasing specialisation in the past five years in the erection of concrete frames, has created a move from mainly contractor generated unit price rates to sub-contractor produced unit price rates. The increasing emphasis by the sub-contractor on costing systems and method/time relationships has probably led to a greater pricing uniformity of unit price rates for formwork items at the sub-contractor level. We looked at three projects for which a national contractor was

TABLE 2E : PERCENTAGE VALUE OF EACH WORK SECTION.

Work Section	CONTRACTOR A	B	C	D	E	F	G	H	I	Mean (%)	Standard deviation	Coefficient of variation (%)
Excavation and earthwork	1.80	1.80	4.10	2.40	2.50	2.40	2.30	2.90	2.00	2.47	0.71	28.62
Concrete work	5.30	4.40	6.20	5.20	4.90	4.80	5.50	5.30	6.20	5.31	0.60	11.31
Brickwork/blockwork	8.40	5.10	7.50	6.90	5.90	6.00	6.10	6.40	6.30	6.51	0.97	14.92
Asphalt work	4.00	4.30	3.80	3.90	3.90	4.10	4.00	4.00	3.70	4.00	0.14	3.53
Roofing	3.50	3.80	3.20	3.40	3.50	3.60	3.50	3.50	3.30	3.48	0.17	4.93
Carpentry	1.00	0.60	1.00	0.70	0.70	0.70	0.70	0.70	0.90	0.78	0.15	19.23
Joinery	11.90	11.40	11.00	11.90	11.50	10.90	11.80	11.70	11.00	11.45	0.40	3.52
Structural steelwork	11.00	11.90	10.50	11.00	11.10	11.40	11.20	11.20	10.50	11.08	0.43	3.89
Metalwork	9.00	9.80	9.30	9.00	9.20	9.70	9.20	9.20	9.00	9.26	0.30	3.19
Plumbing and engineering installation	20.10	21.70	18.80	20.40	20.00	21.40	20.20	20.40	19.00	20.21	0.95	4.69
Electrical installation	8.20	9.10	8.40	8.10	9.60	8.60	8.40	8.20	7.90	8.50	0.54	6.31
Plasterwork and other floor wall and ceiling finishes	13.80	14.40	14.40	15.00	15.20	14.20	15.10	14.40	17.70	14.90	1.14	7.65
Glazing	0.20	0.20	0.10	0.10	0.20	0.20	0.10	0.10	0.20	0.16	0.05	32.94
Painting and decorating	1.80	1.50	1.70	2.00	1.80	2.00	1.90	2.00	2.30	1.89	0.23	11.96
TOTAL:	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00		

submitting tenders, and analysed the rates in quotations for the formwork submitted by a number of specialist sub-contractors. All the prices were current at January 1978 for projects in and around the Reading area.

Table 2H shows the results of the analysis. The major formwork items from the quotations were selected. There exists some small price variability, but generally the results show a consistency of pricing by the sub-contractors. The labour item of raking cutting shows the widest variation. Contractor A prepared quotations for all three projects, his prices for formwork to the soffit of suspended slabs ranged from £4.15 to £4.90. We examined the three projects and found that project 3 had greater construction complexity, which accounted for the higher prices for the work.

We then examined the same items of formwork in the bills of quantities of the lowest two bidders for each of the three projects on which the sub-contractors had tendered. The results are shown in Table 2J.

Item	Mean £/m^2	Coefficient of variation (%)
Formwork to soffit of suspended slab	5.60	32.8
Formwork to sides of walls	7.05	41.2
Formwork to sides of columns	5.30	46.6
Formwork to sloping soffit	6.80	37.0
Raking cutting	0.92	71.0

Table 2J : SUB-CONTRACTORS PRICES.

TABLE 2H : UNIT PRICE RATES FOR FORMWORK SUBMITTED BY SUB-CONTRACTORS TO A MAIN CONTRACTOR.

	Soffit of suspended slab (£/m^2)	Side of walls (£/m^2)	Side of Columns (£/m^2)	Sloping Soffit (£/m^2)	Raking Cutting (£/m)
(1) Overall Contract Value £520,000					
Sub-contractor A	4.15	5.00	4.90	5.00	0.60
B	4.60	5.10	5.00	6.00	0.80
C	5.20	5.70	5.50	5.00	1.00
Mean unit price rate	4.65	5.26	5.13	5.35	0.80
(2) Overall Contract Value £2,000,000					
Sub-contractor A	4.40	4.85	4.10	4.40	0.30
X	5.85	4.85	4.25	4.60	0.60
Y	4.73	4.99	4.36	4.33	0.83
Z	4.47	4.85	5.09	4.47	0.90
Mean unit price rate	4.86	4.89	4.45	4.45	0.66
(3) Overall Contract Value £4,520,000					
Sub-contractor A	4.90	5.25	4.85	6.00	0.30
Y	5.15	5.40	5.00	7.90	0.80
C	4.87	4.75	4.75	6.60	0.75
Mean unit price rate	4.97	5.13	4.86	7.16	0.62
ALL PROJECTS					
Mean unit price rate	4.83	5.07	4.78	5.43	0.69
Standard deviation	0.49	0.53	0.43	0.58	0.24
Coefficient of variation (%)	10	10	20	11	34

Note: The contract value relates to total value of building project.

The table shows there exists much greater price variability at the contractor's pricing level than with the sub-contractor's pricing. The contractor is making adjustments to the sub-contractor's prices to allow for such items as management, plant, unloading and non-productive work that might occur. It is important therefore, that the quantity surveyor fully understands the way that the sub-contractor's prices are adjusted and incorporated in bills of quantities.

2.6 Conclusions.

The analysis of the way construction prices are derived leads us to challenge the basis of using unit price rates to communicate price. Unit price rates say nothing about the resources allowed for in an item, nor the method of using the resources, or the time taken to complete the task. The basic premiss, that for the purposes of prediction all prices can be related to a quantity, is surely a sign that the approach to construction price prediction has not recognised the change in construction technology over the past hundred years. The most important questions that should be asked are those concerning the factors which are cost significant and the way in which these can be taken into account by the price prediction process.

1) One of the shortcomings of the quantity surveyor's techniques in collecting and analysing cost data is the lack of a suitable system of identifying families of prices. The homogeneity of the sample of buildings selected as the basis for future predictions has been shown to have an important influence on price. The current cost planning approach of analysing the elements of a building according to their functional use, is an aid to cost control, but it is of little help in the identification of cost significance, which is the whole basis of homogeneity.

2) The individual unit price rates for measured items in bills of quantities

exhibit greater variability than prices at the trade level or for completed buildings. The measured items showed a variability of up to eight times those of tender totals. Theoretically, we are dealing with a price pyramid as shown in Figure 2.4 where the extent of the variability reduces as we move from measured items through the trade level, to the complete building. A reduction in variability can also be achieved by improving the homogeneity at the three levels.

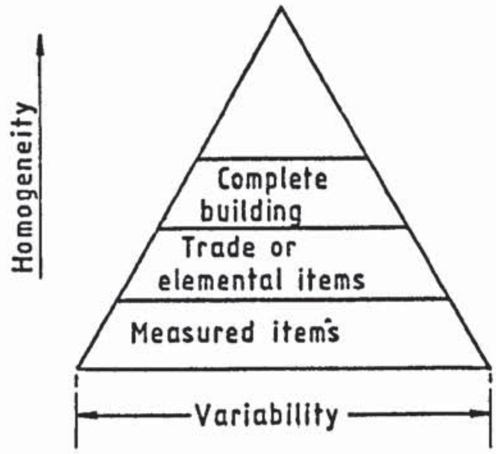

Figure 2.4

3) The view that the contract value has an influence on the homogeneity of a sample was not supported. We feel that other important influences which are subsumed in the contract value, such as project complexity, could have a greater cost significance. This viewpoint is researched further.

4) The trades which show the greatest price variability are preliminaries, excavation and earthwork, concrete work, and brickwork and blockwork. The specialist sub-contractor's prices exhibit much lower variability than the main contractor's prices for the same work items which are included in bills of quantities. There would be some merit in the quantity surveyor gaining a greater understanding of how the sub-contractor builds up his prices, as this would give greater awareness of cost significant factors.

Chapter 3

Analysis of existing price prediction techniques

3.0 Introduction.

When considering the quantity surveyor's price prediction we must determine what factors will ultimately affect the reliability of any price prediction system.

Chapter 2 discussed the extent of price variability exhibited by various trades. We now go on to look at the causes of price variability and to examine how these are taken into account by current price prediction techniques.

A major influence on any prediction technique used by the quantity surveyor is the extent of design information available at the time the prediction was prepared. In order to reach a price at the outline proposal stage, the surveyor must rely upon assumed or default values for many of the project details. In essence, ambiguity in the design and ambiguity in the prediction go hand in hand, whatever the method of prediction.

In this chapter our objectives are:

1) to consider the impact of the available design information on the prediction process;

2) to examine how current price prediction techniques take account of the causes of price variability;

3) to examine the concept of using the lowest bid prices as the basis for price prediction.

3.1 <u>The Impact of the Extent of Design Information on Price Prediction.</u>

At the early design stage the architect is confronted with a range of decisions concerning plan shape, layout, etc. A lack of available information often makes it impossible to establish specific design details at the budget and sketch design stage. As a result, the quantity surveyor must make qualitative and quantitative assumptions about the proposed building when giving the client an indication of the likely price.

In order to understand how the design variables of an element affect the unit price rates we shall consider one aspect of an elemental category, namely standard timber windows in the external doors and windows category. Early in the design when the budget is being formulated, the architect will rarely choose a specific window type. The window areas will be designated and the quantity surveyor will select an appropriate elemental unit price rate. As a result, he will not take account of factors such as shape, standard or non-standard design, material, type of window, type of glass and finish. Each of these factors will affect the appropriate unit price rate, and we now go on to consider this effect in more detail.

The price lists of three manufacturers of standard timber windows and a major glass manufacturer were used for the analysis. The first step was to calculate the mean purchase price of the various window types. Figure 3.1 shows the window prices plotted as a price per square metre of the window area by type. A best fit line was then drawn visually through the points. As would be expected, the price per square metre for the window falls with the increase in area. Further analysis was undertaken by calculating a price per lineal metre of frame to the window, which showed a minimum price of £1.81/m for top hung windows to a maximum price of £8.53/m for pivot hung windows.

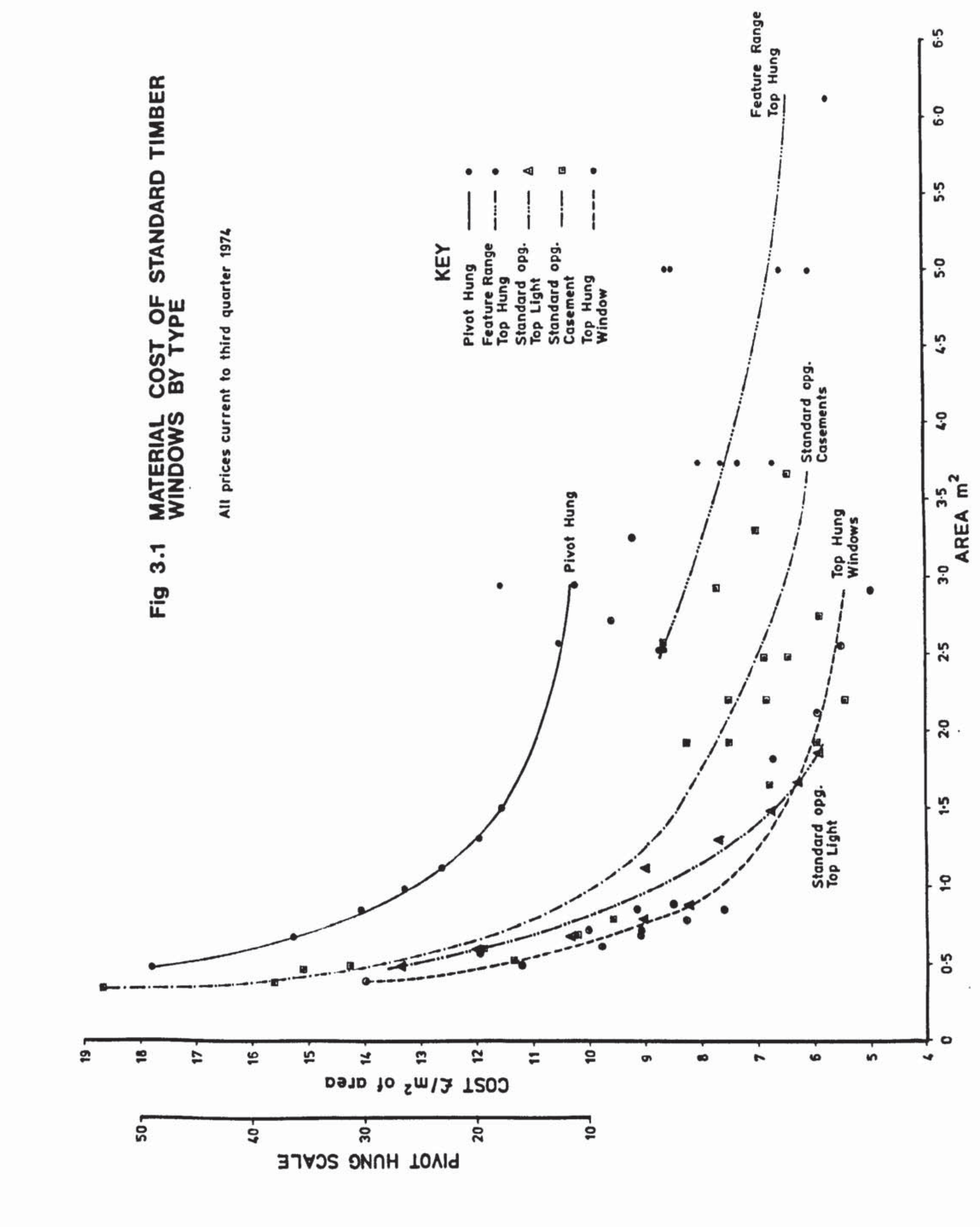

Fig 3.1 MATERIAL COST OF STANDARD TIMBER WINDOWS BY TYPE

All prices current to third quarter 1974

Two window manufacturers were interviewed to discover the reasons for the very high prices of pivot hung windows. We established that the pricing policy of the manufacturers for pivot hung windows is a result of marketing strategy rather than manufacturing cost. Pivot hung windows are not aimed at the home improvement nor the low cost housing market. They tend to be specified by architects on high quality schemes; hence the underlying marketing strategy is that these types of projects will withstand a higher market price.

Figure 3.2 shows the glass prices for various types obtained from a glass manufacturer, plotted against area. The cost per square metre increases with area, because the glass increases in thickness with area. The types of glass selected are representative of those used in the building industry. By plotting prices as shown on the graph, it is possible to identify the price relationships between glass types.

A model building of value £1,215,000 was used to show the effect on the elemental unit price rates and overall project price of alternative glass and window types. Table 3A shows the results for five window types, two glass types and two window areas. It is obviously understood that a building will have varying sizes of windows, but the analysis highlights the fact that the price for the same window area can range by as much as 42%, simply by changing the window and glass type.

Thus we can conclude that, even if there were complete certainty with respect to unit price rates, errors in price prediction are unavoidable because the quantity surveyor lacks essential information at the early design stage. Errors of this type will, of course, be reduced as the design progresses.

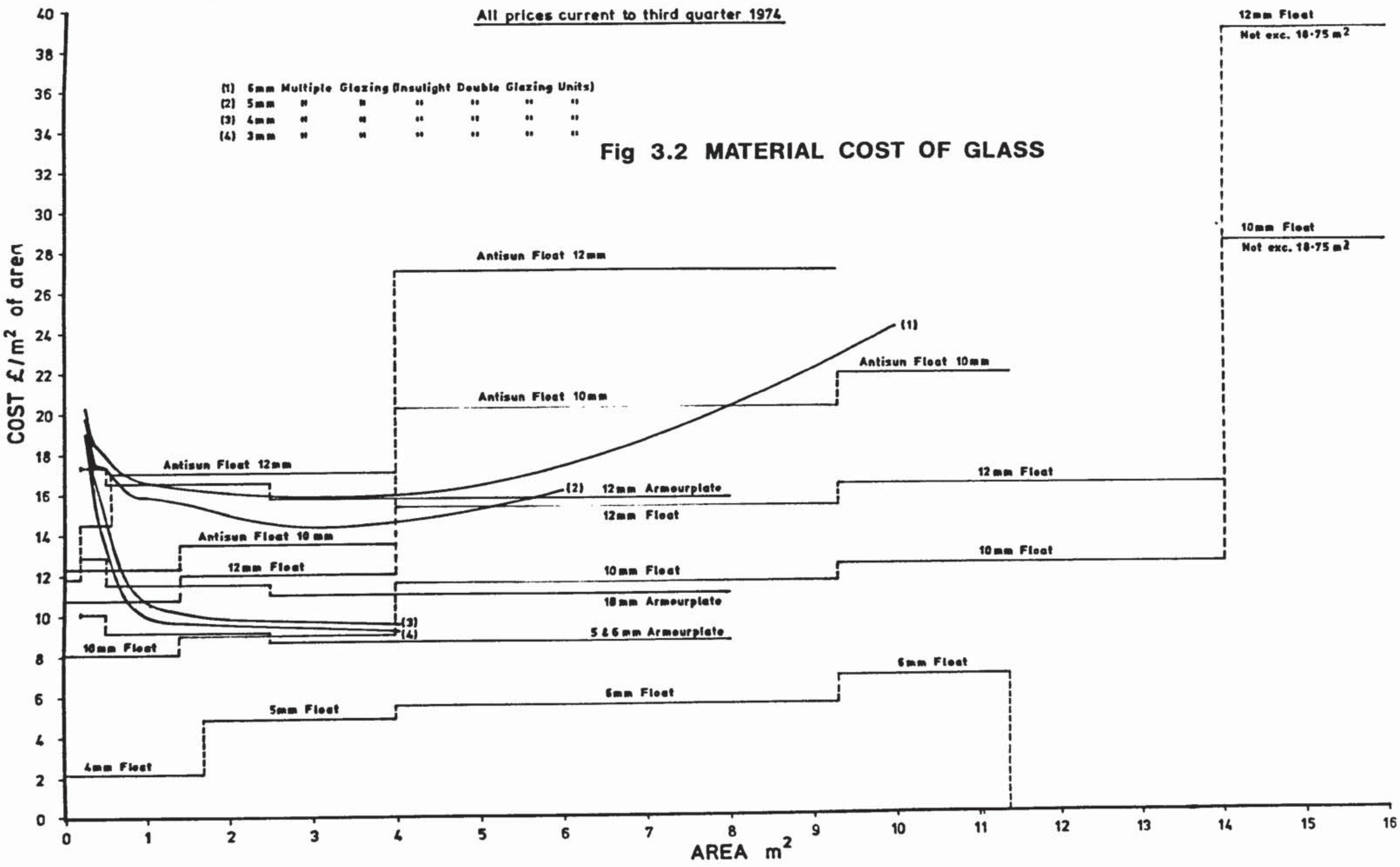

Fig 3.2 MATERIAL COST OF GLASS

TABLE 3A : THE EFFECT ON PRICE OF THE WINDOW AND GLASS TYPE.

Window Type	Window area glazed with 10mm float glass		Window area glazed with 10mm antisun float glass	
	$2.50m^2$	$1.50m^2$	$2.50m^2$	$1.50m^2$
Top hung	100.00 / 4.00	105.34 / 4.21	118.11 / 4.72	123.46 / 4.94
Standard Opening top Light	- / -	104.11 / 4.16	- / -	122.22 / 4.89
Standard Opening Casement	103.49 / 4.14	110.70 / 4.43	121.60 / 4.86	128.81 / 5.15
Feature Range top Hung	113.17 / 4.53	- / -	131.28 / 5.25	- / -
Pivot Hung	128.23 / 5.13	149.59 / 5.98	146.34 / 5.85	167.70 / 6.71

Notes: a) Contract value = £1,215,000.

b) Index 100 = £24.30/m^2 of window area.

c) Prices current third quarter 1974.

d) Prices include labour for fixing at a constant rate.

e) Window area = $2000m^2$.

Key:

Index of elemental unit price rate (upper part of cell)
Percentage value of contract of windows element (lower part of cell)

3.2 The Causes of Price Variability.

The causes of variability of prices can be looked upon as being at two levels:

a) those general factors which influence the prices of all buildings throughout the country, referred to as the macro factors;

b) those factors which are specific to a building design referred to as the micro factors.

Bowley and Corlett (1970) and numerous other studies have attempted to identify the causes of variability of building prices. There appears to be general agreement that at the macro level the market activity in the construction industry and the project location have the greatest influence on the prices for building work. We do not feel, however, that these influences are of central importance to the thesis. As a result we have relegated discussion of them to Appendix 1, at the back of the thesis, and concentrate on the micro factors in the remainder of this chapter.

3.3 Macro Level.

(1) Market activity in the building industry.
(2) The location of the projects.
(3) The contractor's evaluation of future inflation likely to be incurred on projects.

3.4 Micro Level.

(1) The building function and size.
(2) The technical complexity of the project and the contractor's evaluation of the risks associated with the construction.
(3) The time required for construction.
(4) Plan shape.
(5) Number of storeys.
(6) Quality levels.
(7) Site restrictions and peculiarities.
(8) Ground conditions and soil bearing capacity.
(9) Design loading and spans.
(10) The intensity of internal partitions.
(11) The extent of mechanical and electrical services.
(12) The extent of external works.

The analysis in Chapter 2 highlighted the importance of selecting buildings on the basis of homogeneity. The micro factors represent some of the items on which the quantity surveyor would select homogeneous families of completed buildings: variations in any of these factors would lead to heterogeneity.

The macro factors are taken into account by using intuitive judgment and using indexes to adjust the price forecast for the proposed building. These lump sum adjustments can have a significant effect upon the price, and the reliability of the computed price will be that of the original data combined with the reliability of the indexes. It is interesting that, despite their major importance, very little is published about the reliability of price indexes [(1)].

The question to be considered is the extent to which existing price prediction systems take account of the macro and micro factors.

3.5 Review and Analysis of Existing Price Prediction Techniques for Building.

The conventional model of the process of forecasting and controlling the price of construction projects during the design phase follows the work stages in the RIBA Plan of Work (1973). As the project design proceeds, more is known about the proposed building and more detailed information becomes available. Table 3B shows the stages with the cost information produced by the quantity surveyor together with the techniques employed in the price prediction process.

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(1) A discussion on cost and price indexes is included in Appendix 2 at the back of the thesis.

Stage	Design	Task	Prediction Systems
INCEPTION FEASIBILITY	Define client's objectives, investigate planning options, and consider cost/benefit.	Establish preliminary budget price.	1. Unit of use. 2. Superficial floor area using no drawn information.
OUTLINE PROPOSAL	Determine functional requirements. Consider alternative design solutions.	Estimate alternative design options. Establish budget price.	1. Superficial floor area. 2. Cubic volume. 3. Storey enclosure (Enclosure unit). 4. Group elements based upon percentage or superficial floor area.
SCHEME DESIGN	Develop design solution to meet technical requirements.	Validate budget price against design solution. Cost plan.	1. Cost plan based upon group elements and sub-elements using approximate quantities.
DETAIL DESIGN	Detail design of building elements.	Cost check to ensure compliance with cost plan. Detail cost plan.	1. Amplified cost plan using detail unit price rates with approximate quantities.
PRODUCTION INFORMATION	Design for construction.		

TABLE 3B : DESIGN STAGES AND THE PRICE PREDICTION SYSTEMS.

The techniques are either single-price rate or multi-price rate.

Single-price rates are:

(a) Unit of use.

(b) Superficial floor area.

(c) Cubic volume.

(d) Storey enclosure unit (partial single-price).

Multi-price rates are:

(e) Approximate quantities.

(f) Elemental cost planning.

(g) Cost models.

Reference can be made to any building economics text book for an exposition of the mechanics of using the various prediction techniques.

Single-price rate approaches are essentially a basis for comparison of completed and proposed projects. The systems are dependent upon the selection of an appropriate historical price rather than the technique used in preparing the forecast.

3.6 Single-price rate.

Unit of use.

The unit of use method is applied as a basis for establishing a budget at the early stages of project inception. The system uses a single price based upon the occupancy function of the building. For example, in the public sector a cost per bed space uses site development density and average number of persons to a house, whilst theatres use a cost allowance per seat in the auditorium. The unit of use price subsumes all the macro and micro factors.

3.7 Superficial Floor Area and Cubic Volume.

The use of a price per unit of superficial floor area derived from completed projects, is the commonest identifiable technique used by quantity surveyors in practice when undertaking price predictions for building work. The gross floor area is measured from the inside face of external walls over all internal walls and partitions, stairways, lift shafts and storage areas. The total internal superficial floor area is then divided into the overall project value to produce a price per unit of area.

The shortcoming of this approach has been evident for some considerable time. Thus Skaife (1774) referred to the making of pre-building estimates from drawings by stating, "Many surveyors have, or propose, methods for estimating, by knowing the exterior dimensions of a building, that is, guessing at the expense by the number of squares the house contains. This is a very uncertain rule and can never be followed with any degree of certainty, unless all buildings were finished in one manner, and consisted of no other variations than the size of the structure". Despite Skaife's perception, very little advance in refining the technique has been made in the past 200 years.

However, the acid test for any system in a practical situation is its application over time. This method of prediction has probably survived for many centuries because of its economy of use, speed of application and its ease of application.

The main criteria to be decided are the required degree of homogeneity of the selected completed buildings, and how this homogeneity is to be defined. These criteria also apply to the cubic volume method of price prediction which is one of the oldest prediction systems still used in practice. The purpose of using the cubic volume technique is that it takes account of both superficial floor area and the height of buildings.

TABLE 3C : OFFICE BUILDINGS

Project No.	Floor area m^3	Cubic volume of complete building m^3	No. of Storeys	£/m^2 of gross floor area	£/m^3 of gross volume	m^3/m^2 ratio
1	21,881	74,079	14	147.56	43.58	3.385
2	141	47,885	8	171.84	32.81	5.238
3	9,806	37,308	4	206.45	54.26	3.804
4	32,782	138,113	4	214.68	50.96	4.213
5	8,831	33,289	6	205.63	54.55	3.769
6	10,000	41,223	6	298.24	72.35	4.122
7	19,938	91,588	6	245.39	53.42	4.593
8	22,328	96,638	10	255.79	59.10	4.328
9	9,499	42,301	3	192.38	43.20	4.453
				Mean cost per m^2 = £215.33	Mean cost per m^3 = £51.58	Mean m^3/m^2 ratio = 4.212

All prices re-based to first quarter 1976.

We investigated the relationship between the cubic metre and square metre prices by selecting a sample of 9 public and private sector completed buildings shown in Table 3C. The prices were re-based for time using the BCIS tender price index, no adjustment was made for any differences in quality or location.

Table 3D shows the correlation coefficients, for certain selected parameters, chosen to determine whether any significant relationships could be discerned from the data.

TABLE 3D : CORRELATION COEFFICIENTS FOR SELECTED PARAMETERS FOR DATA IN TABLE 3C.

Item			Correlation Coefficient
Price per m^2/price per m^3	...	...	0.8813
No. of storeys/price per m^3	...	...	-0.1637
m^3 per floor/price per m^3	...	...	-0.0114
m^2 per floor/price per m^2	...	...	0.0016
Height per floor/price per m^3	...	...	0.0901
Total height/price per m^3	...	...	0.0403

The only correlation coefficient which is statistically significant is the price per square metre considered against the price per cubic metre. This demonstrates that although the cubic volume approach is recommended as a prediction technique that is sensitive to changes in height, in fact, this is not the case.

3.8 Storey Enclosure Method.

James (1954) produced a paper entitled "A new approach to single price-rate approximate estimating" which reported the results of some research by a group of chartered quantity surveyors who were dissatisfied with the accepted cubic volume method of prediction. They propounded a method of price prediction termed storey-enclosure, which took account of: plan shape, storey heights, vertical position of the floor areas in the building, and the extra cost of sinking usable floor area below ground level.

The group concluded that the price of a structure and its associated finishings could be calculated by a single-price rate, except for the following work items which had to be estimated separately:

1) site works including roads, paths, fences, etc.;
2) the extra cost of more expensive foundations than were normal for the type of building under consideration;
3) engineering and mechanical services;
4) features not general to the structure as a whole, e.g. dormers, balconies, canopies and the like;
5) the additional cost of circular work.

Storey enclosure consists of measuring the superficial areas of the horizontal and external vertical planes of the building to calculate the number of storey enclosure units. In calculating these, various weighting factors are applied to certain areas:

(a) to allow for the price of normal foundations a factor of two is applied to the ground floor area;
(b) to provide for the extra price of suspended upper floors a factor of 0.15 is added to the multiplier to the area of each floor above the lowest, i.e. 2.15 (first floor), 2.30 (second floor), 2.45 (third floor), etc.;
(c) to cover the extra cost of storeys wholly or partly below ground level, a factor of two is applied to the wall and floor areas and of any such

storey to the extent that its external walls and lowest floor adjoin the earth face.

To produce a price for a proposed building, the storey enclosure area is multiplied by a storey enclosure price rate derived from analysis of historical projects.

The following table shows the results of tests carried out by the study group who investigated reliability of the storey enclosure method compared with the cubic volume and superficial floor area approaches.

Type of Building	No. of cases examined (Total = 86)	Percentage Accuracy range of estimates to tender low bid	No. of estimates within given percentage range of tender.		
			Cubic Volume	Superficial floor area	Storey enclosure
Schools	14	±10%	9	8	12
Flats	16	±10%	9	10	12
Houses	17	±10%	8	9	10
Industrial Buildings	39	±20%	16	24	26

(Source: RICS Journal (May 1954)).

The points to be considered with these results are:

(a) the wider percentage accuracy range used for industrial buildings distorts the overall results;

(b) the cubic volume method and the superficial floor area method are single-price rate techniques. Storey enclosure uses more than one rate, it is not surprising, therefore, that the storey enclosure system performs rather better than the single-price rate techniques. As a result it is somewhat unfair to use this type of comparison;

(c) on the assumption that not all the predictions were compiled by the same individual, there will be estimating variability;

(d) the prices for the engineering and mechanical services and the site works will only have the same reliability as with any other single-price rate technique.

The shortcomings of the assumptions made in the storey enclosure system are:

(a) Foundation prices for buildings exhibit considerable price variation. Prices are affected by the total load to be carried on the foundation, the type of soil and the load bearing capacity, perimeter length of the foundation, presence of a high water table level, the superficial area of ground slab, and the foundation type. The belief that a factor of two would cover all these variables was poorly conceived.

(b) The assumption that there is a lineal relationship between price and height is incorrect [(2)].

(c) Basement prices will vary owing to a variety of factors. We tested the assumed price relationship of the basement area price to the ground floor area price by analysing 5 completed buildings with basements, and

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[(2)] A discussion on the relationship between price and height is given in Appendix 3 at the end of the thesis.

by making certain design assumptions. We calculated a total price for a ground slab and foundations having the same superficial ground floor area as the basement floor area with the same storey height. The results showed that the factor ranged from 1.4 to 5.2 times more expensive for a basement area as opposed to a ground floor area, with a mean factor of 3.1.

The underlying theory of storey enclosure was that it was attempting to take account of some of the micro factors which affect prices, but the research into the multiplying factors used to derive the storey enclosure price rate was not sufficiently rigorous to convince practitioners of the merit of the system. Thus, although the storey enclosure system was an enlightened approach to an art which at that time needed some fundamental research, apart from some field tests it appears not to have been adopted in practice.

3.9 Enclosure Unit Method.

Diehl (1966) developed in the USA the enclosure unit method, the concept being very similar to the storey enclosure approach. The enclosure ratio was calculated, being the total superficial surface area of a building measured both internally and externally, expressed as a ratio to the gross superficial floor area. The system, therefore, attempts to take account of the geometry of the building by considering the height, plan shape, and partition intensity. A building which is subdivided into small units has considerable cost significance; although the partitions themselves might be of relatively inexpensive construction, the subdivision requires additional doors, heating and ventilating controls and outlets, electrical outlets and switches, etc.

We felt Diehl's idea warranted further investigation, and therefore we looked at the development of a complexity factor for buildings. Quantity surveyors currently use ratios as a means of expressing density and complexity. Typical examples are wall/floor area ratios, window/wall area ratios, partition/floor area ratios. These provide a useful measure, but to be meaningful, one parameter is required which is capable of indicating the overall complexity of the project at the early design stage. If all the ratios are examined, they lack an instant overall performance measure.

The complexity factor would measure the number of "complexity units" to each square metre of gross floor area. The total number of complexity units is defined as being the sum measured in square metres of: the gross floor area, the roof area, the exterior closure area, the basement wall area, the partition area.

The sum total divided by the gross floor area represents the sum of all enclosing areas with floors/soffits being measured once only, and internal walls and partitions measured one side only. The process of measuring the floors/soffits and internal partitions on one side only is the difference between Diehl's enclosure unit method and our complexity factor approach.

The complexity factor takes account of plan shape and height. The main instance in which this measure is not totally satisfactory is when a building is heavily compartmentalised; a large area of partitions has the effect of distorting the ratio. We have therefore devised a partition intensity scale divided into three categories, (a) high, (b) medium, (c) low, which should be read in conjunction with the complexity factor.

TABLE 3E : COMPLEXITY FACTORS FOR DATA IN TABLE 3C.

Project No.	Price per square metre	Complexity factor	Enclosure unit factor
1	147.56	1.84 (low)	1.90
2	171.84	2.52 (low)	2.62
3	206.45	2.28 (low)	2.44
4	214.68	2.29 (high)	2.59
5	205.63	2.12 (medium)	2.42
6	298.24	3.04 (high)	3.44
7	245.39	2.33 (high)	2.83
8	255.79	2.55 (medium)	2.72
9	192.38	2.82 (medium)	2.90

Table 3E shows complexity factors for the buildings shown in Table 3C. Our objective was to test for a relationship between the price per square metre of a building and the complexity factor. We also tested the same relationship against Diehl's enclosure unit method. The correlation coefficient between the complexity factor and the price was 0.8187, and between the enclosure unit and the price was 0.6384. Both coefficients are significant at the 95% confidence level, but the complexity factor performs better than the enclosure unit factor, probably because Diehl's factor involves some double counting of partition area. Thus we consider that the complexity factor does provide a useful measure for the quantity surveyor when undertaking a price prediction for a proposed building at the very early design stage.

3.10 Multi-price Rate.

Multi-price rate techniques use prices at the elemental, trade, or individual measured items, i.e. levels 2, 3 and 4 of Figure 2.1 (Chapter 2). The breakdown of a prediction into a number of parts is an attempt to improve the reliability of the forecast. Barnes (1979) and Bragg (1974) have shown that the improvement in the reliability of an estimate by increaseing the number of items, roughly follows the formula

$$S = \frac{1}{\sqrt{n}}$$

where n is the number of observations. In other words, the law of diminishing returns applies, as for each tenfold increase in the number of observations the likely improvement in the error will diminish by only about one third.

Multi-price rate techniques also allow the micro factors to be given greater consideration. For example, by calculating a price for the substructure due account can be taken of the ground conditions and soil bearing capacity. This assumes that the quantity surveyor can relate prices to design information of this type.

3.11 Approximate Quantities.

Approximate measurements are used to prepare an estimate comprising composite items. There are no formal rules for measurement, as the detail depends upon the available design information. Measurements are usually to the nearest 150mm with all the labour items being ignored. One composite item describes a number of activities, e.g. excavate oversite, remove surplus soil, level and ram the surface of the ground, lay 150mm hardcore bed blinded with ashes, 150mm concrete bed including mesh reinforcement. The unit price rates are derived from analysis of priced bills of quantities.

The approximate quantities method is frequently used by quantity surveyors in practice. The system is flexible in its application, the detailed item break-down is easily modified for alternative specifications. The method is dependent upon the design being well developed, and therefore it is generally not used at the very early design stage.

Brook (1972) in South Africa attempted to simplify the approximate quantities method by using factored price rates. He produced factor tables similar in concept to the PSA early cost advice tables (1977). Tables with a number of alternative specifications were structured for particular items of a building, e.g. structural frame, windows, etc. A base specification was chosen and a base price calculated. All the other items in the table have a factor value which is a multiplier against the base price. With the use of the tables it was possible to consider the price implications of alternative designs. However, Brook's approach disregards the problems of price variability by assuming one price for a range of circumstances.

3.12 Elemental Cost Planning.

A pre-requisite of any cost control system is a logical framework within which the control process can function. Traditionally, in construction, this framework has followed the organisation of the industry, along trade or craft lines. Elemental cost planning involves dividing a project into elemental categories related to building function. All the elements are expressed both as a price per square metre of the gross superficial floor area and as an elemental unit price rate which relates to the unit of measure for each element. The elemental price rates can be derived from historical analyses or by developed rates. The BCIS has defined elemental categories, varying in number between six and seventy elements and sub-elements, dependent upon the level of design detail.

The primary function of an elemental cost plan is to show the distribution of the price of a building amongst the functional elements. The breaking down of the building into elemental categories allows cost exploration to take place. It also allows the quantity surveyor a method of cost control throughout the design phase.

Very little research has been undertaken in Britain in the field of cost planning since its introduction in the late 1950's. Wendland (1975), in West Germany, developed a cost planning system using different elemental categories to those used in Britain. He established, for certain building types, model cost plans with boundary percentage values for each elemental category, by stating a percentage range value band of the total price against each elemental category. If the percentage breakdown for the cost plan for the proposed building did not correlate with the model cost plan, there was not cost optimality. The cost plan was, thus, being used to evaluate the difference between the cost optimum and the design proposal, thus allowing the client to decide whether he was obtaining value for money in the proposed scheme. This technique suffers from the requirement that when the boundary values are small the designer is given no freedom of action in his design, he must fall within Wendland's design parameters. This is a difficult task because every designer brings his own experiences and prejudices to a problem, therefore making it difficult to structure a solution outside the boundaries set by this knowledge.

A more fundamental criticism of Wendland's hypothesis is his assumption that there is only one way of building a building. Current knowledge of building economics and cost optimisation techniques in Britain leads us to suggest that Wendland's hypothesis is open to question. The number of design variables that interact on building prices means that price ranges for elemental categories are very wide. This alternative view is supported by Davis, Belfield and Everest (1977) who produced a series of nomographs for use in elemental cost planning. These nomographs contained much wider value ranges for the elemental categories. The system has merit because the range is geared to a specification level, and also because of the very wide value ranges.

The lack of research into cost planning techniques has meant that many facets are still imperfectly understood. One question which is of vital importance to the quantity surveyor is whether the elemental categories can be considered as being mutually exclusive, in other words, whether the quantity surveyor can use the values of different elements from a variety of projects. We could find no published work on this topic to investigate this and therefore we selected a sample of 127 buildings containing factories and warehouses, offices and housing from the BCIS published records, no selection criterion other than the building function being used.

The elemental prices were re-based for time to the first quarter 1974 using the BCIS tender price index. The following elemental categories were used as the basis for comparison:

- Substructure
- Superstructure
- Internal finishings
- Fittings and furnishings
- Mechanical and electrical services
- Preliminaries
- Site development

The results of the analysis are summarised in Tables 3F, 3G and 3H. The prices used throughout are the elemental price rate per square metre of the gross floor area.

The factories and warehouses sample exhibits a different price relationship within the elements from the housing and administrative buildings sample. The substructure elements for factories and warehouses represents 14.09% of the total price, whilst for housing and administrative buildings the sub-structure is 8.53% and 7.04% respectively. The reason for this is that the

TABLE 3F : FACTORIES AND WAREHOUSES CORRELATION CO-EFFICIENT MATRIX AND STATISTICS.

	Sub-structure	Super-structure	Internal finishes	Fittings & Furnishings	Mechanical and Electrical Services	Pre-liminaries	Site development
Mean price per square metre of the gross floor area (£100.20/m²).	14.09	37.75	5.53	0.64	18.35	10.08	13.76
Percentage of total value	14.09	37.75	5.53	0.64	18.35	10.08	13.76
Standard deviation	8.22	11.59	3.44	0.91	10.98	6.10	6.72
Minimum price	1.86	9.93	0.74	-	1.82	3.50	2.22
Maximum price	41.25	68.53	13.11	3.66	41.61	30.63	30.78
Co-efficient of variation (%)	58.34	30.70	62.21	141.40	59.64	60.52	48.83
Element							
Substructure	1.00	-0.24	-0.25	-0.17	-0.35	-0.19	0.06
Superstructure		1.00	-0.37	-0.29	-0.51	-0.13	0.25
Internal finishes			1.00	0.44	0.38	0.06	-0.25
Fittings and furnishings				1.00	0.16	0.16	-0.05
Mechanical and electrical services					1.00	-0.23	-0.33
Preliminaries						1.00	-0.002
Site development							1.00

Factories and Warehouses = 38 buildings

TABLE 3G : HOUSING CORRELATION CO-EFFICIENT MATRIX AND STATISTICS

	Sub-structure	Super-structure	Internal finishes	Fittings & Furnishings	Mechanical and Electrical Services	Pre-liminaries	Site development
Mean price per square metre of the gross floor area	8.53	38.34	11.48	2.54	15.24	10.79	13.06
Percentage of total value	8.53	38.34	11.48	2.54	15.25	10.79	13.06
Standard deviation	2.60	7.14	2.35	1.29	3.04	5.61	7.50
Minimum price	4.38	20.29	[illegible].06	0.84	8.07	3.30	-
Maximum price	15.24	52.44	15.13	7.19	21.22	29.13	35.09
Co-efficient of variation (%)	30.48	18.62	20.47	50.78	19.95	51.99	57.43
Element							
Substructure	1.00	-0.04	-0.02	0.25	-0.51	-0.18	-0.01
Superstructure		1.00	0.38	0.05	-0.18	-0.47	-0.67
Internal finishes			1.00	0.06	0.09	-0.41	-0.33
Fittings and furnishings				1.00	-0.11	-0.12	-0.18
Mechanical and electrical services					1.00	0.13	-0.26
Preliminaries						1.00	-0.14
Site development							1.00

Housing 30 buildings

TABLE 3H : ADMINISTRATIVE BUILDINGS CORRELATION CO-EFFICIENT MATRIX AND STATISTICS.

	Sub-structure	Super-structure	Internal finishes	Fittings & Furnishings	Mechanical and Electrical Services	Pre-liminaries	Site development
Mean price per square metre of the gross floor area.	7.03	36.83	9.62	2.50	25.52	11.02	7.44
Percentage of total value	7.04	36.84	9.63	2.50	25.53	11.02	7.44
Standard deviation	3.31	7.31	3.00	2.94	7.85	5.23	4.99
Minimum price	0.92	21.43	4.76	-	5.12	2.09	0.85
Maximum price	20.54	58.95	18.97	13.36	42.49	28.11	24.62
Co-efficient of variation (%)	47.08	19.85	31.18	117.60	30.76	47.46	67.07
Element							
Substructure	1.00	-0.01	-0.10	0.08	-0.45	0.02	0.05
Superstructure		1.00	-0.25	-0.14	-0.55	-0.09	-0.25
Internal finishes			1.00	0.11	-0.01	-0.21	-0.01
Fittings and furnishings				1.00	-0.08	-0.29	-0.08
Mechanical and electrical services					1.00	-0.21	-0.19
Preliminaries						1.00	-0.29
Site development							1.00

Administrative = 51 buildings

factories and warehouses sample primarily has single storey buildings, which will cause a higher proportion of the total price to be spent on the substructure.

The correlation coefficients for each of the elements shows no statistically significant relationship between any of the elemental categories. This indicates that the elemental categories are mutually exclusive. When using the correlation matrix a certain caution must be exercised. Two things which appear to have absolutely nothing in common may statistically correlate at a high computed level of confidence. In other words, correlation does not necessarily imply causation.

We then tested this hypothesis on another sample of 27 factory buildings that were chosen on the basis of homogeneity of the floor area, the factory functional type, the type of superstructure, and the mechanical and electrical services. Our objective was to test if the homogeneous sample exhibited different results to our heterogeneous samples. The number of elemental categories used in the analysis was increased by separating the exterior closure prices from the superstructure prices, and by considering the electrical installation and the mechanical engineering services elements independently. The site development element was not considered. Table 3J shows the statistics for the 27 factory buildings and the correlation coefficients. By reference to the 't tables' with 25 degrees of freedom at the 95% confidence level, any correlation coefficient above 0.549 is statistically significant for the sample.

We would expect there to be a high correlation between, (a) the substructure and superstructure and, (b) between the mechanical engineering services and the electrical installation, because all the buildings were single storey. In both cases our assumption is confirmed. We would also have expected a

TABLE 3J : STATISTICS FOR 27 FACTORY BUILDINGS

Elemental category	Mean price per square metre of the gross floor area	Standard deviation	Coefficient of Variation (%)
Substructure	17.02	7.02	41.25
Superstructure	26.20	6.80	25.95
Exterior closure	8.27	2.48	29.99
Internal finishings	7.02	3.04	43.31
Fittings and furnishings	0.60	0.82	136.66
Mechanical engineering services	9.77	3.24	33.16
Electrical installation	4.88	2.10	43.03
Preliminaries	10.02	7.15	71.36

TABLE 3J : MATRIX OF CORRELATION COEFFICIENTS FOR 27 FACTORY BUILDINGS

	Sub-Structure	Super-Structure	Exterior closure	Internal finishes	Fittings & Equipment	Mechanical engineering services	Electrical services	Pre-liminaties
Substructure	1.000							
Superstructure	0.892	1.000						
Exterior closure	0.556	0.431	1.000					
Internal finishes	0.458	0.558	-0.032	1.000				
Fittings and equipment	0.492	0.301	-0.051	0.260	1.000			
Mechanical engineering services	0.592	0.590	-0.184	0.781	0.720	1.000		
Electrical installation	0.501	0.731	0.061	0.660	0.785	0.945	1.000	
Preliminaries	0.679	0.532	0.739	0.252	-0.010	0.086	0.290	1.000

high correlation between the exterior closure and the superstructure, but the analysis does not support this.

The correlation coefficients for both the samples show that most of the elemental categories are mutually exclusive, which means that for the purposes of cost planning it is possible to use price information for elements taken from different projects. However, caution should be adopted when using this approach, particularly for the substructure and superstructure categories of a homogeneous sample of completed projects.

Many organisations have attempted to produce alternative versions to the UK method of cost planning. The American Institute of Architects (1974) produced a report which involved analysis of all known cost planning systems used throughout the world. The objective was to introduce cost planning techniques into the USA by providing architects, through the AIA, with a central data bank of historical price information. A modified version of the BCIS elemental categories was produced based on hierarchical principles, permitting different levels of aggregation and summarisation. It is worth noting that the Americans adopted the British elemental categories because they were the most comprehensive list of categories which lent themselves to computer application.

Barrett (1970) developed a cost planning system for use in Sweden where room function was one of the elemental categories used. Barrett propounded that a building has natural basic divisions when considering a total price, which are (a) ground, (b) structure, and (c) rooms.

The price for work below ground will vary with the soil type and bearing capacity and should be measured and priced separately on every project. However, unit price rates for direct structural and room prices can be obtained from previous projects. The price of the structure is expressed as a price per cubic metre of the building. The factors influencing price, such as type of building, structural system, plan shape, and number of storeys, are stated to allow for 'intuitive' adjustments. The price of rooms is governed by occupancy function, standards and density.

Barrett's system adds little to our knowledge of cost planning. Whilst further research is needed to consider the price impact of room function, our current systems of cost analysis would require complete revision to allow us to capture price information broken down to room function.

Other researchers have postulated the significance of room use as a major influence on price. Jarle (1973) developed a cost planning system in Finland which considered only housing. The conclusions showed that a room specific method of estimating produced the most reliable results. Souder (1963) in the USA produced a method of establishing cost planning targets at the design stage for buildings using room function as the price basis. The prices were derived from the analysis of completed buildings which were considered to four elemental categories:

(1) that which is part of basic shelter and occurs uniformly through the building, e.g. structural frame, lift installation, heating installation;

(2) that which is used in varying concentration in different areas, e.g. partitions, interior finishes, fixed equipment;

(3) that in which fixed equipment is connected to central distribution systems, e.g. plumbing fixtures. Thus, with one hundred plumbing fixtures of varying types and prices, each fixture has its price augmented

by 1% of the total cost of plumbing;

(4) that in which local area demands are supplied by central distribution systems, e.g. electricity, air conditioning and ventilation.

A list of room functions was compiled for a proposed building and a price for each of the categories apportioned to each room. Souder's hypothesis that room use was highly cost significant had merit, but the breakdown into the four elemental categories does not provide a cost control tool for the design. Souder appears to have sacrificed many of the fundamental principles of design cost planning in pursuit of capturing price information by room function. His system is insensitive to such things as changes in plan shape, storey heights, and specification levels.

It must be recognised that space use does have important cost significance. Unfortunately, current systems of cost planning do not generate price information in the format necessary to allow analysis of space use. We feel that there is scope for amalgamation of the work on space use with current estimating wisdom.

Everett (1963) propounded a system called P.A.K.S. (Pris-Analys och Kostnads-Syntes) for use in Sweden. The system involved cost analysing tenders in accordance with an account plan which was structured in a format that allowed items such as all the vertical surfaces and all horizontal surfaces of a building to be cost analysed separately. A further aspect of the work was the inclusion of pessimistic and optimistic unit price rates for the elements.

P.A.K.S. provided a highly complex theoretical elemental structure for cost planning. We tested the system by attempting a cost analysis of a tender for an office building. It became apparent that more detailed breakdown of measured items and unit price rates than is currently used in the UK would be required to implement P.A.K.S.

3.13 Cost Models.

There is a generally held view that the stages of design are analysis, synthesis and appraisal. Watts (1966) and Markus (1973) have suggested that each stage is progressively less general and more detailed than the one before it. Models need to fit a system and this provides a framework for their construction. The objective of the designer is to consider all the factors relevant to the problem, to deliberately increase uncertainty in certain areas to rid himself of preconceived notions, and to isolate information pertinent to the problem. The cost model must be able to contribute to this investigation by supplying cost information for alternative options. Jones (1973) states "to search diligently is also to provide, as cheaply and quickly as possible, sufficient new experience to counteract any false assumptions that the design team members and the sponsors held at the start".

A model is a representation of reality by something which has similar characteristics to the object represented. The main purpose of a model is to provide a simplified and intelligible picture of reality in order to understand it better. Chorfas (1965) states "a model should be simple enough for manipulation and understanding by those who use it, representative enough in the total range of the implications it may have, and complex enough to accurately represent the system".

Models may be used to describe, to explain, to explore, to predict, to communicate, or to form a framework of study. Models do have limitations in that they do not create plans, they only show the implications. Models can be distinguished as:

(A) Descriptive model - the establishment of a particular phenomenon to describe the relationships between the relevant factors.

(B) Predictive model - helps to conclude what is likely to happen given certain observations.

(C) Explorative model - helps to discover by speculation other realities that may be logically possible.

(D) Planning model - optimises stated planning objectives.

The predictive model expressed in mathematical terms is used for price prediction. With a mathematical model the description of reality is expressed by the use of symbols. There are four types of mathematical model: equation systems; statistical techniques; simulation; and computer algorithms.

Whilst the concepts of mathematical modelling have provided a logical basis for responding rationally to the prediction of construction price, the computational capability and large data storage and retrieval capacity of digital computers has provided a means for implementation.

Research in the price prediction field has been mainly in the development of cost models using equation systems.

Models as abstract representations of reality will generally consist of two parts:

1) given information or data;
2) an algorithm for manipulating the information.

The derivation of the algorithm can be accomplished in many ways, and will be affected by whether the model is static or dynamic. The static model uses an algorithm with predefined values, whereas the dynamic model uses values that change with pre-determined criteria.

Trimble (1973) and his colleagues at Loughborough University of Technology have developed cost models using regression techniques for various facets of building work. Buchanan (1969) developed a cost model for predicting the cost of a reinforced concrete structural frame using the design parameters. Gould (1970) produced a cost model which deals with the capital cost of heating, ventilating and air conditioning installations for various building types. Badby (1971), Wood (1976), Baker (1974) and McCaffer (1975) have also produced cost models related to building elemental categories.

Regression techniques not only allow potential relationships to be formulated, but the strength of the relationship and significance of variables can be measured with the careful application of statistics such as the correlation coefficient, standard error, t-statistic, and f-statistic. Draper and Smith (1966) suggest alternatives for selecting the best regression.

Various studies overseas have attempted to represent a complete building in a mathematical form. The design variables are stated in algebraic form and prices are superimposed on the mathematical model. The main advantage of this technique is that the designer is able to evaluate alternative conceptual design options prior to the commencement of detailed design. One such approach was used in France by the Centre Scientifique et Technique du Batiment (CSTB). Between 1959 and 1964 a series of studies "variations in construction costs according to the different parameters involved in the conception of projects" was published. The object was to show the influence on the total cost of the following parameters: structural design envelope, depth of the building, storey height, number of rooms, surface area of the dwelling unit, type of circulation spaces and prices per unit.

The technique A.R.C. (Appreciation rapide du cout) was developed specifically to deal with housing projects. Noel (1966), Meyrat (1969) and Bietry (1970) have tested the system. Patricio (1971) attempted to transpose the A.R.C. method for use on housing contracts in Spain, unfortunately without success.

Regdon (1972) in Hungary researched a mathematical modelling technique, FOBER, for use on housing projects. Essentially A.R.C. and FOBER attempted to model the impact upon price of the geometry and compartmentation of the building. This was possible for housing in the public sector, but would prove very difficult to develop for structures other than housing.

An alternative to the regression model is the simulation model. A simulation model has the advantage over a regression model of being easily updated as more knowledge becomes available.

The Property Services Agency (1973) derived their COCO (Cost of Contractors' Operations) model by modelling the sequence of decisions made by the contractor when compiling a tender. The work represents one of the few attempts to analyse the effect on prices of the contractor's method of construction. A computer programme was written to simulate the decision making sequence of the contractor's planner when preparing the pre-tender construction programme and method statement.

Cost modelling using simulation is the only price prediction technique which is representative of something that happens in reality. The algorithms are developed by simulating the contractor's approach to pricing, whether it be a single measured item or a total building price, or by simulating the interaction of the design variables. The regression model approach is to say, "these are the prices we have achieved on previous projects, and using statistical techniques these are the relationships we can discern from the data". However, as we demonstrated in Chapter 2, the contractor's unit price rates do not necessarily reflect the true cost of an item.

The simulation model has the advantage of giving the quantity surveyor greater understanding of the factors that affect the price of an item. To develop this approach further we produced a dynamic cost model for the lift installation elemental category based upon a simulation of the design process. The lift installation is a specialised trade in which it is often difficult to forecast a price using current prediction systems.

The algorithmic part of constructing the model was a search and investigatory process of the design parameters and their effect on price. Two alternative techniques were available for the development of the algorithm:

1) to analyse by statistical techniques a breakdown of historical prices for lift installations;

2) to develop an empirical model on the basis of price information supplied by lift manufacturers.

As it was not possible to obtain a breakdown of historical prices in a format suitable for analysis, option 2 was therefore adopted.

Knight and Duck (1962) identified the major cost components of a lift installation as being:

(i) the number of lift cars;

(ii) the number of floors served by the lift cars;

(iii) the speed of the lift car;

(iv) the type of control system;

(v) size and specification of the lift car;

(vi) height of the building.

Items (i) to (vi) all influence the total price, but additional factors were identified by the two lift manufacturers who participated by providing prices for our study. These were:

(a) the grouping of lift cars;

(b) special considerations, e.g. exposure to weather;

(c) location of the lift motor room.

The building type influences the type of lifts used and the quality of finishings in the lift car. For the purposes of the exercise the model developed was for office buildings.

The first step was to consider the effect of height, the population per floor, and the other design parameters on the cost components. Table 3K shows the design criteria considered. The data were derived from CP 407, BS 2655, Phillips (1966), Williams (1972), Clarke (1972) and Otis (1977). Items for the quality of finishings have been grouped on a high, medium and basic scale, the selection being undertaken by judgment. Item 6 in the table refers to the possible quality of finishings within the lift car, whilst Item 7 takes account of the entrance configuration, e.g. two speed centre opening doors, advance door opening systems, the presence of door detectors, and safety devices.

TABLE 3K : DESIGN CRITERIA FOR THE DESIGN OF A LIFT INSTALLATION.

	Item		Design Criteria	
1.	No. of lift cars		Derived from population per floor and overall height of building (source data - F.H. Williams, (1972)).	
2.	Type of lift	2(1)	Passenger lifts Loading = no. of persons x 75 kg. Standard lifts = A - up to 4 persons, B - 5 to 12 persons, C - over 12 persons.	
		2(2)	General purpose goods lifts Loading = 500 kg., 1000 kg., 1500 kg., 2000 kg., 3000 kg.	
		2(3)	Heavy duty goods lifts Loading = 1800 kg., 2000 kg.	
3.	Type of drive	3(1)	Up to 0.75 m/second - single speed.	
		3(2)	0.75 - 1.00 m/second - two speed.	
		3(3)	1.00 - 2.50 m/second - geared variable volume.	
		3(4)	Over 2.50 m/second - gearless variable volume.	
4.	Lift speed Recommended heights and speeds of lift cars for office buildings.		Building height (metres)	Speed m/second
		4(1)	10	0.50
		4(2)	15	0.75
		4(3)	20	1.00
		4(4)	30	1.50
		4(5)	45	2.50
		4(6)	60	3.50
		4(7)	125	5.00
5.	Type of control	5(1)	Single automatic control (up to 4 storeys).	
		5(2)	Collective (5-9 storeys).	
		5(3)	Group supervisory (10 storeys and above).	
6.	Quality of finishings in lift car.	6(1)	High.	
		6(2)	Medium.	
		6(3)	Basic.	
7.	Quality of finish on landing doors and frame	7(1)	High.	
		7(2)	Medium.	
		7(3)	Basic.	
8.	Special considerations.	8(1)	Exposure to weather (car parks)	
		8(2)	Exposure to low temperatures (cold store).	
		8(3)	Exposure to corrosive or dusty atmosphere.	
		8(4)	Reduction in noise of operation.	

The requirement for the model was a series of reasonable assumptions as to when changes became necessary in the type of control system and lift speed.

Wiles (1974) produced a series of cost equations that went to the detail of modelling the cost of car guides, ropes, counterweights and buffers. We consider this to be too detailed to be meaningful at the early design stage.

The cost model produced as a result of discussion with the manufacturers is shown in Table 3L. The values given by the lift manufacturers are based upon the manufacturing cost, an allowance for the site installation of the lifts, and a provision for overheads and profits. The designer must know the number of floors, the number of lift cars and a grouping arrangement for the lift cars. The multiplier M is a factor which relates to a particular condition, for example, the quality of finishings in the lift car is considered as high, medium or basic. The equation for the allowance for quality is considered at the medium quality level, a factor of 0.90 is used to bring the equation down to a basic quality level, and a factor of 1.10 to raise to a high quality level.

We should ask not only how well does the model perform with respect to the actual prices for lift installations, but also how well it performs with respect to the alternative prediction methods available.

The model was tested against the historical price data for 11 projects. The prices have been rebased for time to the first quarter 1978 using the BCIS tender price index. No adjustment was made for the effect of the regional variations in building prices or the differences in quality.

Table 3M and Figure 3.3 give the results of the analysis.

TABLE 3L : COST MODEL FOR LIFT INSTALLATIONS

Component	Equation	Multiplier (M_A M_B M_C M_D M_E) Figures in parenthesis refer to Table 3K.	
A. Size and capacity of lift	$P = 9000\ M_A C$	(2.1A)	1.00
		(2.1B)	1.20
		(2.1C)	1.30
B. Lift speed (Motor, guides, ropes, counter-weights, etc.)	$P = M_B C + 500\ N$	(4.1)	1.00
		(4.2)	1.02
		(4.3)	1.04
		(4.4)	1.10
		(4.5)	1.20
		(4.6)	1.40
		(4.7)	2.00
C. Control system	$P = 2000\ M_C C + 100N$	(5.1)	1.00
		(5.2)	1.15
		(5.3)	1.75
D. Quality of finishings in lift car	$P = 1000\ M_D C$	(6.1)	1.10
		(6.2)	1.00
		(6.3)	0.90
E. Quality of finish on landing doors and frame	$P = 600\ NC \times M_E$	(7.1)	1.20
		(7.2)	1.10
		(7.3)	1.00
F. Grouping of lift cars	$P = 3000\ Z$	When appropriate	

TOTAL PRICE = A + B + C + D + E + F

Key
P = Price in pounds.
N = No. of floors.
C = No. of lift cars.
Z = No. of lift shaft groups.

The prices are inclusive of installation on site, overheads and profit.
Prices are current to first quarter 1978.

TABLE 3M : TEST OF THE COST MODEL AGAINST ACTUAL PRICES

No. of storeys	No. of lift cars	ACTUAL		COST MODEL	
		Price of lift installation (£)	Price per lift car per floor (£)	Total price	Price per lift car per floor (£)
9	4	128,000	3,555	110,760	3,078
5	1	15,400	3,080	22,640	4,528
6	5	132,500	4,083	116,400	3,880
15	4	255,000	4,250	147,900	2,465
7	4	118,550	4,232	108,480	3,874
3	1	22,800	7,600	25,520	8,506
8	2	48,300	2,518	61,160	3,822
5	4	86,500	4,325	96,320	4,816
6	3	66,000	3,666	72,240	4,013
9	3	76,000	2,814	89,100	3,300
5	2	48,300	4,830	50,200	5,020
11	4	169,500	3,852	143,080	3,250
	Mean	90,668	4,086	81,883	4,300
	Standard deviation	67,548	1,362	39,451	1,582

While we recognise the shortcomings of our model we consider that it provides a reasonable basis for price prediction. The model appears to overestimate on smaller contracts and underestimate on the larger projects, the over-estimation is being greater the fewer the number of lift cars. But this must be viewed in the light of systems currently used by quantity surveyors to predict the price of a lift installation for a proposed project [(3)].

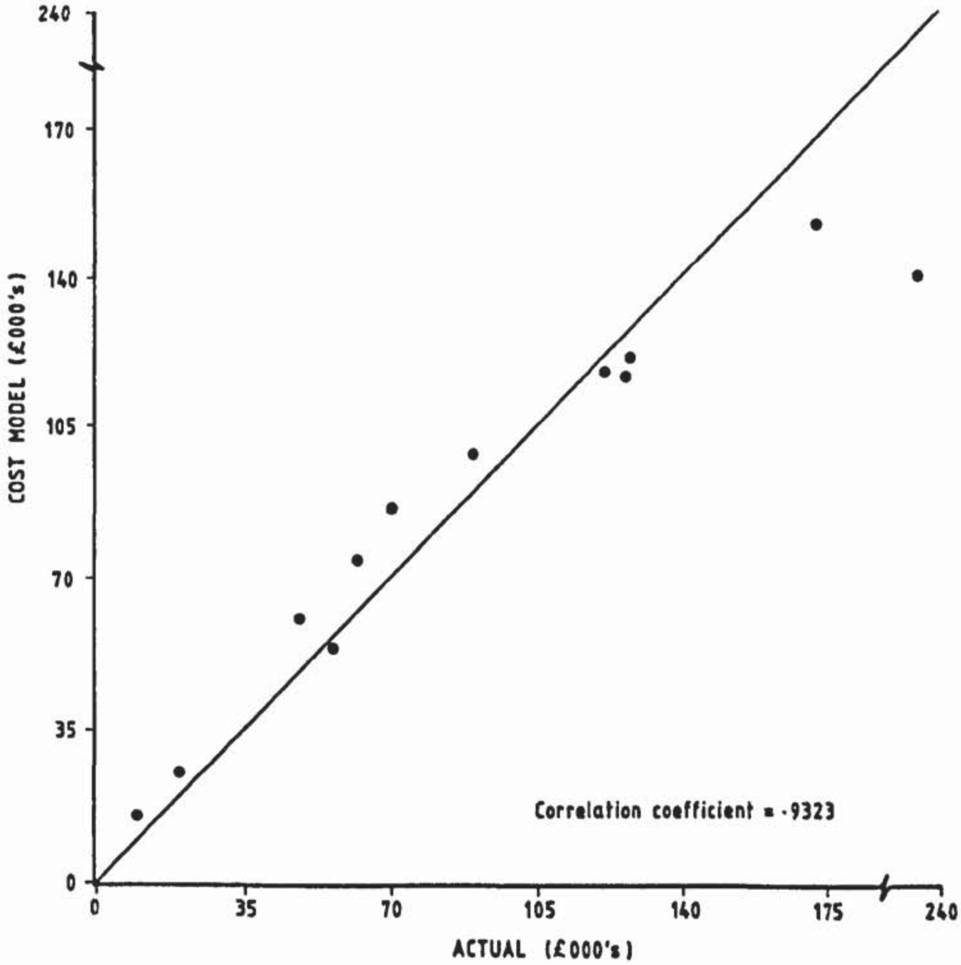

Fig 3·3 RESULTS OF LIFT COST MODEL PLOTTED AGAINST ACTUAL PRICES

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(3) A computer programme has been written to use the cost model we have developed. A discussion on the use of the computerised model is in Appendix 4 at the back of the thesis.

Our discussion with the industry indicates that our model does, in fact, outperform current predictive methods. The model takes account of the design variables for the lift installation in a proposed building, whereas it is extremely difficult to isolate the price implications of all the variables with the use of historical prices taken from buildings having a similar type of lift installation to the proposed project.

3.14 Conclusions on Existing Price Prediction Techniques.

The assumption of all the current price prediction techniques is that the price, whether it be for the total building or the individual measured items, must be related to a measurement parameter. Apart from simulation cost models, all the price prediction systems rely extensively on historical price data. The general conclusion is that reliance on historical prices has meant that quantity surveyors have placed too much emphasis on considering the effect, rather than analysing the factors that cause price differences for building work.

The conclusions can be summarised as:

1) Single-price rate techniques should only be used if they are applied to a sample of buildings which have been selected to achieve homogeneity of the micro level factors. Quantity surveyors, therefore, need techniques which assist them in the selection of suitable completed buildings. One such measure which can be used at the early design stage is the complexity factor which takes account of the plan shape and the intensity of internal partitions in a building.

2) The multi-price rate techniques assume that the unit price rates are sensitive to the design criteria. For example, the substructure price is determined by the foundation type, which results from, the total live

and dead loads of the building, the soil bearing capacity, the characteristics of the soil, and the location of surrounding buildings. However, the BCIS Standard Form of Cost Analysis requires only the details of general ground conditions and does not require the load of the building to be stated nor details of the soil bearing capacity. This situation has arisen as a result of the lack of research into cost analysis and cost planning. New approaches at the early design stages are required that are more sensitive to cost significant design items; it appears that simulation cost models could satisfactorily provide this basis.

3) The UK price prediction techniques ignore the room function of a building as a cost parameter, whereas overseas research has highlighted the significance of room function. We should like, at a later stage, to undertake research to enable us to take account of the room function in buildings as a cost parameter.

4) None of the price prediction techniques consider the construction time, the operational sequence of construction, or the construction complexity of historical projects. Apart from the overall project duration, no details of time are recorded in cost analyses.

5) Extensive reliability is placed upon the use of indexes and adjustment factors to adjust prices at the macro level, yet very little is known about the reliability of the indexes.

Of fundamental importance to all the existing price prediction systems is a reliance upon the use of prices derived from the low bids of historical projects. As Fine (1975) stated: "Over the whole of industry and commerce it is common to make decisions on the basis of estimates for future activities.

Because businesses survive we tend to ascribe unwarranted precision to these cost estimates". Therefore, in the remainder of this chapter we shall examine the use by the quantity surveyor of the low bid prices as the basis for predictions.

3.15 The Use of Low Bids as the Basis for Future Predictions.

In determining the price of a future project the quantity surveyor will normally use prices derived from previous projects. These prices will be based upon the successful tender which, in most cases, is the lowest tender received. This tender will not necessarily reflect the "true" cost of the project and, indeed, this may never be known except to the contractor who may well be prepared to take a loss or who may, alternatively, deliberately submit an artificially low price with a view to improving his profit margin by the expedient of making contractual claims during the progress of the work.

In the present section we consider whether the lowest bid on an earlier project is necessarily an appropriate yardstick for assessing the cost of a future project. To investigate this we need to look at the pattern of bidding and the relationship that exists between the bidding of different contractors[4]. Some particular aspects are as follows:

1) Is the bidding pattern affected by market forces, i.e. by the volume of work available?

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(4) We should perhaps state that our intention is not to enter the area of bidding strategy, which involves the development of a probabilistic model to derive the relationship between number of bids and the chances of winning a contract. The concept was first introduced by Friedman (1956) and has been extensively researched since that time.

2) Is the bidding pattern affected by the type of client?

3) Does an individual contractor display a consistent pattern of bidding?

4) Does a contractor display a particular bidding pattern when in competition with other, known, competitors?

Questions 1) and 2) are rather general and it is not easy to establish a criterion for judging them. Thus, we might expect that a consideration of the range of bids might provide an indication of the effect of market conditions upon the bidding pattern of contractors.

(1) Influence of market forces.

In a depressed market when work is scarce we assume that all contractors are in a competitive situation. Thus we would expect all bids to lie within a fairly narrow range about the mean. By contrast, when work is freely available we would expect a wider spread dominated, in some cases, by 'holding' bids in order to remain upon the tender list while not seriously competing for any one particular project.

We examined the range of bids over the period 1971 to 1978 by selecting a sample of 129 projects from the records of a contractors' trade association. The bidding range was calculated, as a percentage, by considering:

$$\frac{\text{high bid} - \text{low bid}}{\text{low bid}} \times 100$$

with the following results:

Mean bidding range		No. of projects	Coefficient of variation
1971	26%	18	21%
1972	19%	20	20%
1973	20%	13	16%
1974	22%	16	23%
1975	22%	15	24%
1976	24%	17	22%
1977	19%	18	19%
1978	23%	12	26%

The first point is the very wide bidding range. Secondly, the data shows that there is no correlation between periods of high market activity in the construction industry with the bidding rañge. During the period 1974 to 1976 there was a scarcity of work, yet 1976 exhibited the second highest mean bidding range. These results indicate that the range of bidding is not affected by the market activity in the industry. The likely reason for this is that during periods of low market activity all the contractors reduce their prices, thus whilst the bidding range remains the same, all the prices throughout the range are lower.

(2) Size and type of client.

In the absence of more detailed information the selection of a suitable criterion is even more difficult than in the previous case. Thus we could, in principle, classify jobs as small or large, simple or complex. A large simple job may, however, attract the same price as a small but complex one. But even so the range of bids should still provide a guide since it will, to a first approximation, be a measure of the risk, taken by the contractor in making his estimate.

From visual inspection of the data we divided the 129 projects into three groups by total value. The histograms exclude the lowest and highest bids because we are aware of their position at the lowest and highest points.

Figure 3.2 shows the re-based histograms and bidding range for the three groups. The distribution for the two groups of prices up to £1,000,000 value are skewed to the right, whereas the group over £1,000,000 is more uniformly distributed. This suggests that the bids on smaller projects are biased towards the low bid, whereas on projects over £1,000,000 the bids are more evenly spread throughout the range between the lowest and highest bids. The reduction in the bidding range for the larger projects is also evident. There is a secondary peak in the histograms between 0.6 and 0.7 which might be caused by the extent of cover bids taken by contractors who are not genuinely interested in obtaining the project, but who want the bid to appear to be in genuine competition. Obviously, it would be difficult to obtain the evidence to support this hypothesis.

A viewpoint frequently expressed by quantity surveyors is the use of the second or third lowest bid as the basis for price predictions, might be more valid than using the low bids. The argument is that this would reduce the possibility of using historical prices where the contractor had incurred a financial loss. We, therefore, investigated the position of the second and third lowest mean bids, which were as follows:

	Second lowest bid above lowest bid (Mean %)		Third lowest bid above lowest bid (Mean %)
Up to £500,000	3.4%	...	4.4%
Over £500,000 and up to £1,000,000	3.6%	...	4.9%
Over £1,000,000	4.3%	...	6.8%

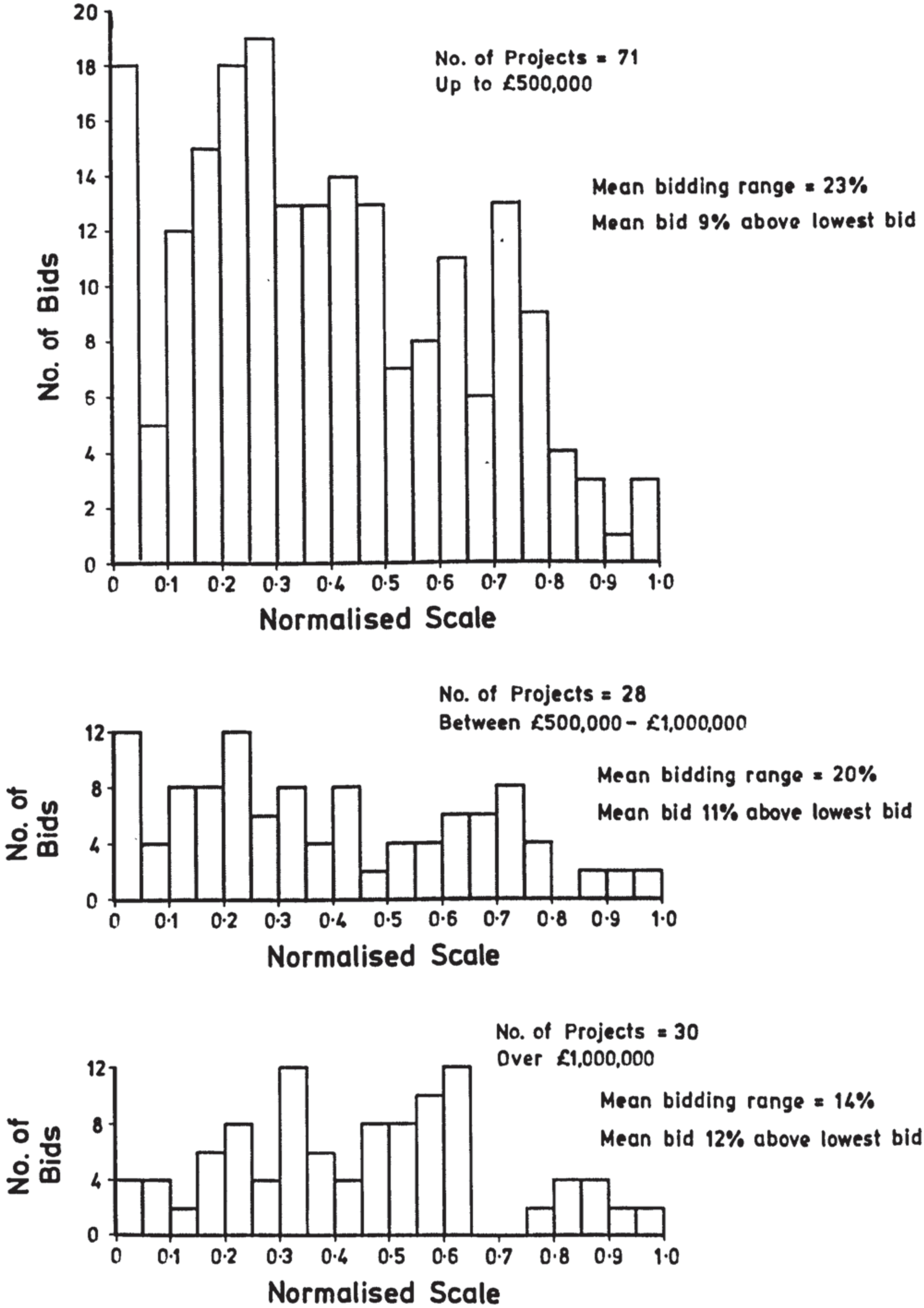


Fig 3·2 Re-based bidding range

These results show that as the project value increases, the margin between the lowest and second lowest bidder gets larger. This implies that the bidding on projects over £1,000,000 exhibits different characteristics to bidding on smaller projects. The use of the second lowest bid price as the basis for price prediction would only have the effect of inflating the quantity surveyor's price forecast. We suggest there is some means of using the relationship between the lowest and the second lowest bids to ascertain the acceptability of using the low bidders prices for price predictions. We discussed this relationship with a number of general contractors, whose consensus of opinion was that when the margin between the lowest and second lowest bidder was greater than 5% of the low bid price, then the low bid prices should be treated with caution when being used for predictions.

When we apply this approach to the projects over £1,000,000 shown in Figure 3.2, there appears to be a greater likelihood that the 5% margin will be exceeded, than exists for the smaller projects.

We now turn our attention to investigating the impact of the type of client upon the range of bidding. We selected the client type because many types of project are only required by particular clients, e.g. schools, health care buildings, and prisons. The data set of 129 projects was not suitable for this analysis because of the wide range of client types contained in the sample. Therefore, we obtained from a County Council located in southern England the bidding details of 63 projects which contained mainly schools, fire and police stations, and hostels; the group can be broadly defined as specialist public sector buildings. The project values ranged from £20,000 to £950,000, and they were all bid during the period 1971 to 1978.

Figure 3.3 shows the scatter diagram of the range of bids. The mean bidding range from 1971 to 1978 is 16% with a coefficient of variation of 21%; the

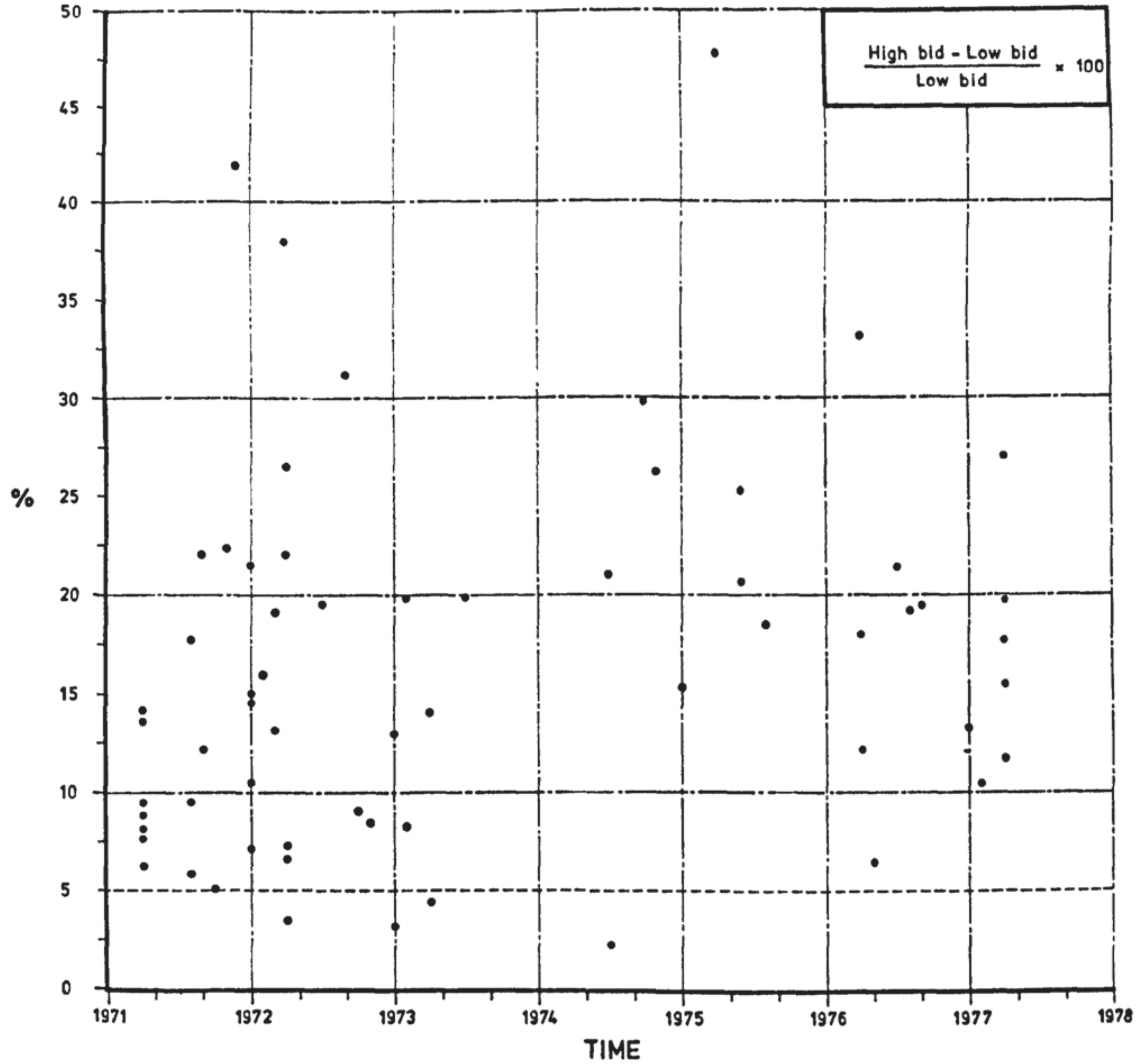


Fig 3.3 SPREAD OF BIDS AGAINST TIME

range is lower than the 129 project sample. The reason might be the influence of the County Council policy of selective tendering using contractors who are familiar with the County Council's work. One noticeable feature of Figure 3.3 is the absence, apart from a few bids, of 'wild' bids which was evident in the 129 project sample. Again, this could be the result of the Council's policy on tendering. Our conclusion is that the type of client does have an influence on the range of bidding. On the question of the influence on the level of bidding this would require considerable in depth research which is outside the scope of this thesis.

3.16 The Bidding Pattern of Individual Contractors.

The previous analysis suggests that there exists a bidding trend exhibited by contractors when tendering for projects of a particular value and for a particular type of client. We shall, therefore, test individual contractor's performances for specific clients, then take a sample from the industry using public and private sector clients.

We examined the bidding performance of three contractors who had submitted bids for projects contained in our sample of 63 County Council schemes. The contractors had tendered consistently throughout 1971 to 1978. Contractor A was a small contractor working within approximately a 20 mile radius of the county town; Contractor B, a medium sized contractor operating throughout the county; and Contractor C, a large national contractor. We were, therefore, considering contractors who were likely to be tendering for projects in the categories we had previously investigated, i.e. up to £500,000, over £500,000 and up to £1,000,000, and over £1,000,000.

Figures 3.4, 3.5 and 3.6 show the bidding performance of the contractors. Each dot on the charts represents a bid by a contractor. We were considering three questions about Contractors A, B and C:

Fig 3.4 CONTRACTOR A BIDDING PERFORMANCE

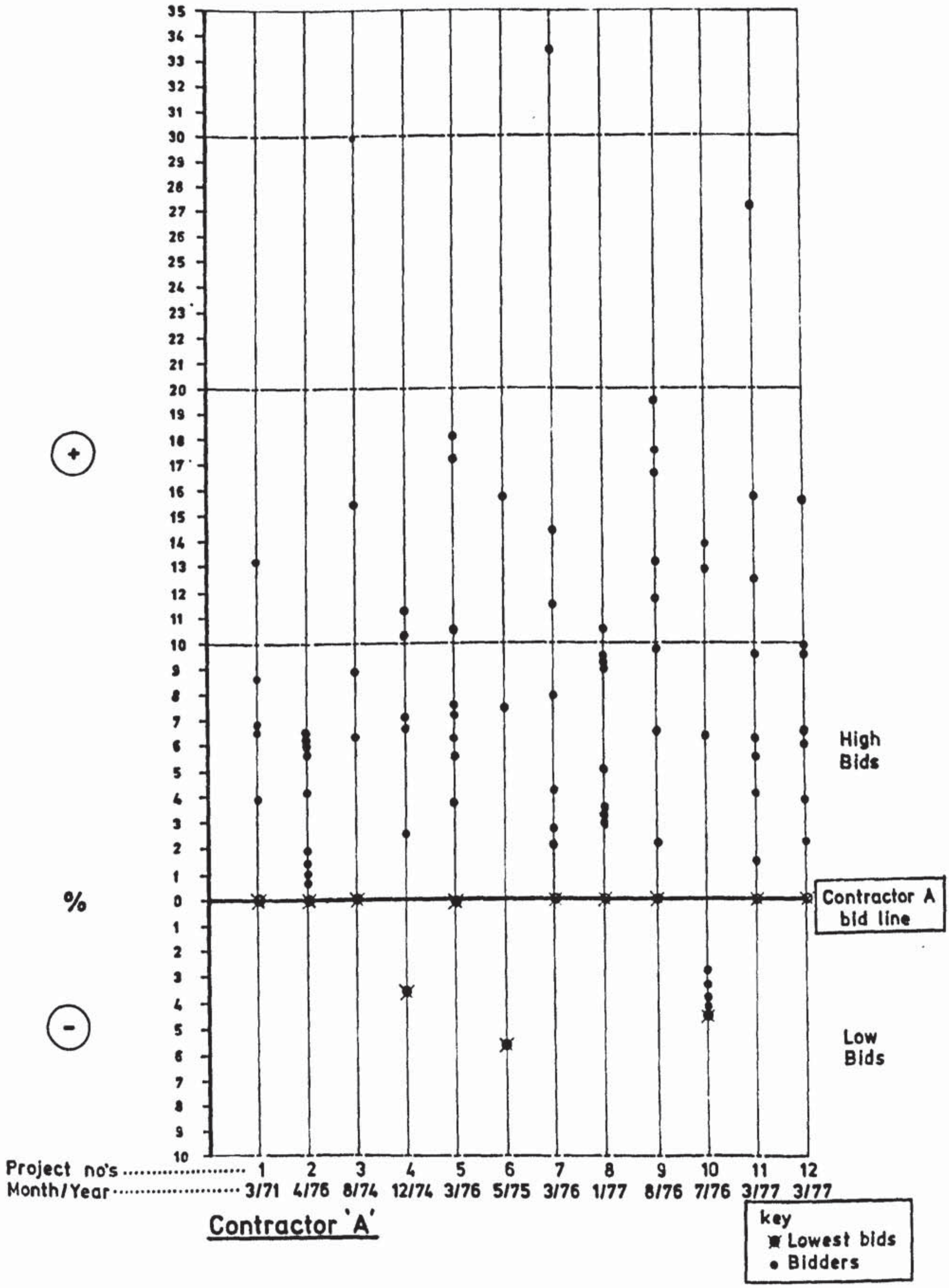
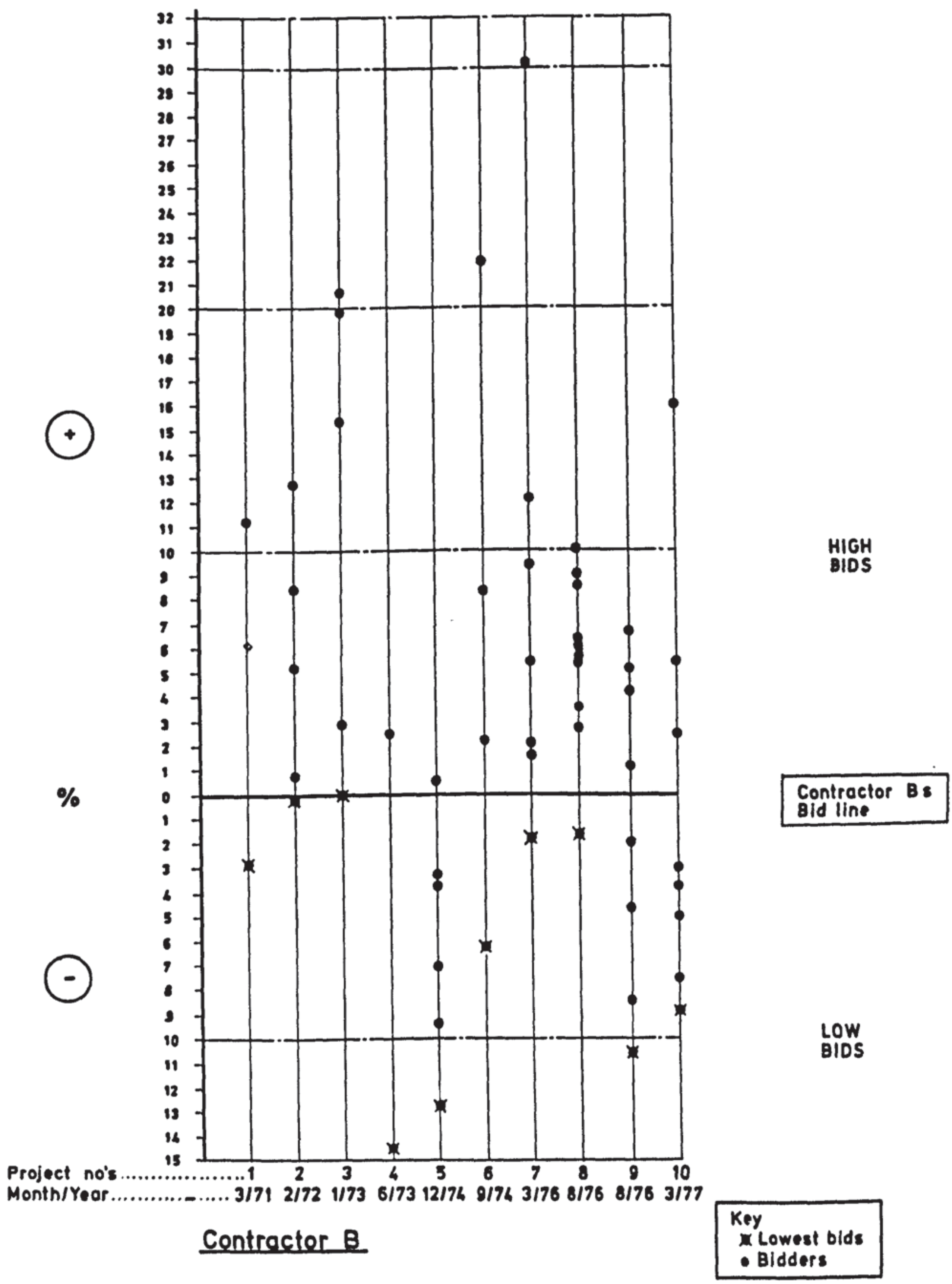
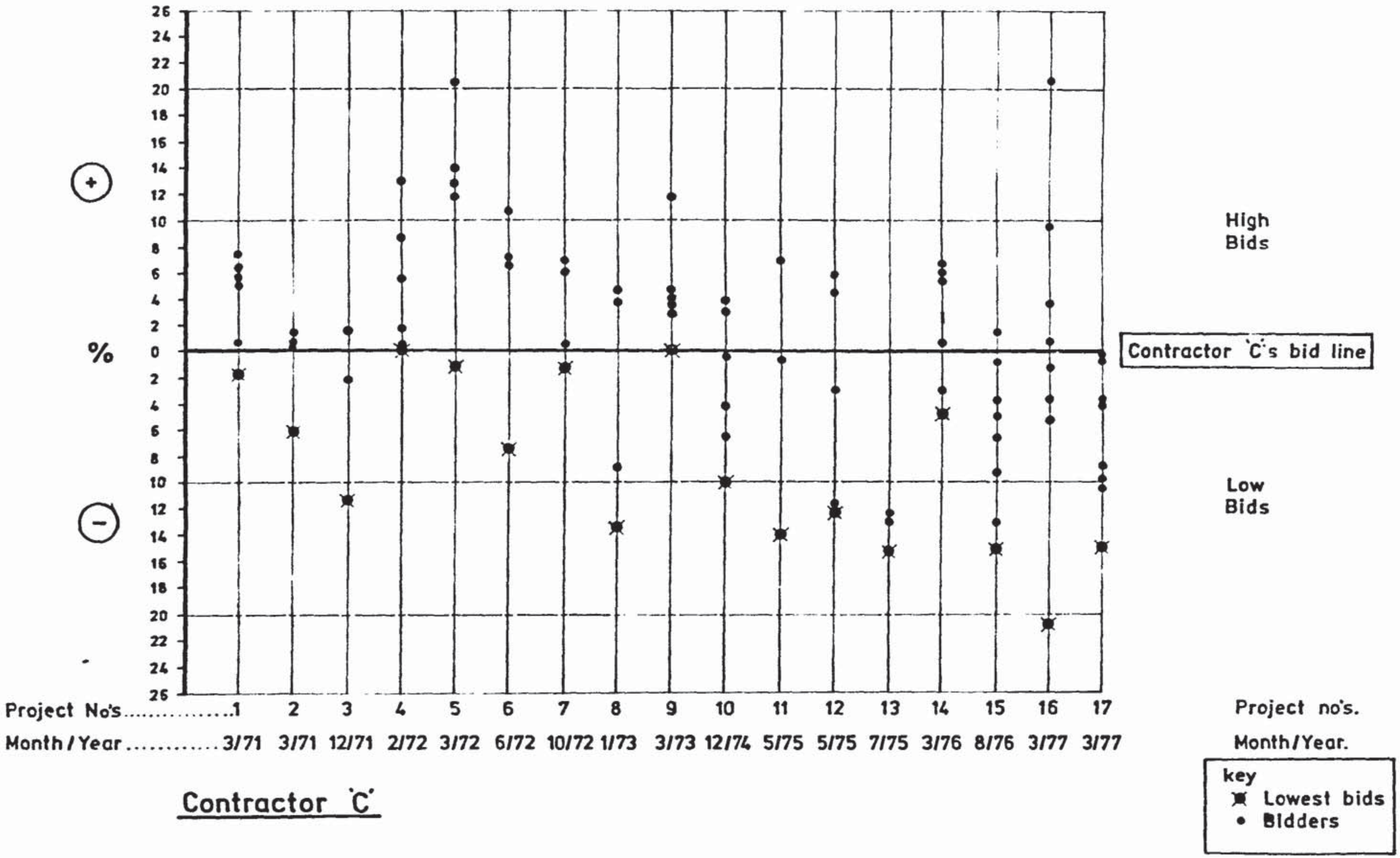


Fig 3.5 CONTRACTOR B BIDDING PERFORMANCE



Contractor B

Fig 3.6 CONTRACTOR C BIDDING PERFORMANCE



Contractor 'C'

1) Do they exhibit an erratic bidding pattern?

2) Do they show a similar pattern to the general bidding pattern?

3) When they were the lowest bidders on a project, what was the margin from the second lowest bidder?

The success rates of obtaining contracts were:

A	...	8	in	12	(66.67%)
B	...	1	in	10	(10.00%)
C	...	2	in	17	(11.76%)

Contractor A was by far the most successful of the three contractors in obtaining contracts. All the tenders submitted by Contractor A were for the erection of schools, no project was over £350,000 value. We interviewed Contractor A to ascertain why his results were so good. His reasons were:

a) he knew the client and the demands made by the client's staff and professional advisers;

b) he was conversant with the client's required quality standards;

c) he was aware of the problems inherent in building County Council schools;

d) he only tendered for work with the Council when he felt he could be highly competitive.

Of the four contracts A did not obtain, he was the second lowest bidder on three.

Contractor B shows no particular bidding trend, whilst Contractor C was successful in obtaining contracts on the two occasions when the project value exceeded £600,000.

In no case was the margin between the lowest bid, when submitted by A, B or C, and the second lowest bid, greater than 4% of the contract value, which is within the 5% margin noted above. It is worth noting that on projects where A, B and C were not the lowest bidder there are many low bids that were substantially below the second lowest bid. For example, the low bidder on project 4 in Figure 3.5 was 14% below the second lowest bidder. In these situations when considering the use of the low bid prices for prediction the quantity surveyor should exercise due care.

The analysis supports our view that bidding strategy is, in general, affected by the type of client and by the value range. Contractor A works only within a well defined range and sticks to a well defined product, while Contractor C appears to bid more competitively on the large projects.

One by-product of the analysis which is, perhaps, worth noting is the extent to which low bids deviate 'substantially' from other bids. Of the 39 projects, 9 were such that the lowest bid was more than 5% below the second lowest bid. The implications of this will be considered in more detail in Chapter 4.

We were interested to test what happens when the same contractors are consistently in competition, but Contractors A, B and C were in competition on only two projects. Therefore, we selected three contractors, W, X and Y from the same County Council's tender lists for 1976-77. All the contractors had an annual turnover in the region of £10,000,000 and they were in competition with each other on a large number of projects. The objective was to consider if there was any significant trend exhibited by any of the contractors when they were in direct competition.

Figures 3.7, 3.8 and 3.9 show the scatter diagram of the results plotted on a logarithmic scale. The 45^{o} line has been drawn on the graph; points above the line indicate that the contractor on the vertical axis is the higher

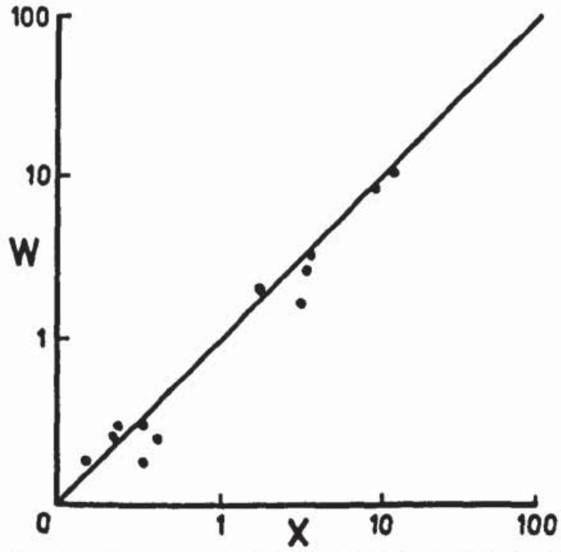
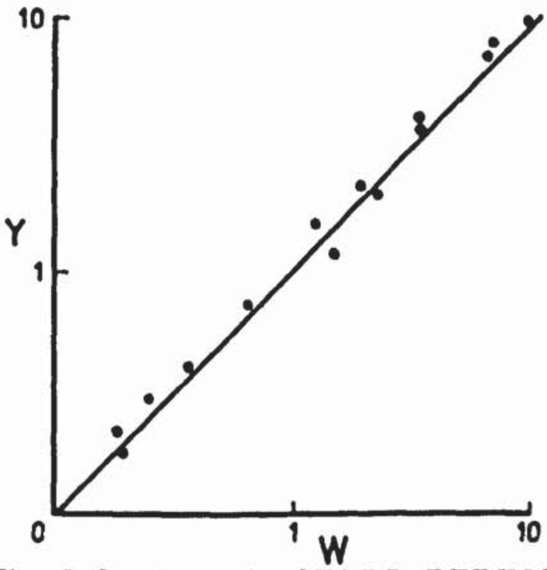


Fig 3·7 CONTRACTORS PERFORMANCE
Log 3 cycles × 3 cycles



All scales × £100,000

Fig 3·8 CONTRACTORS PERFORMANCE
Log 2 cycles × 2 cycles

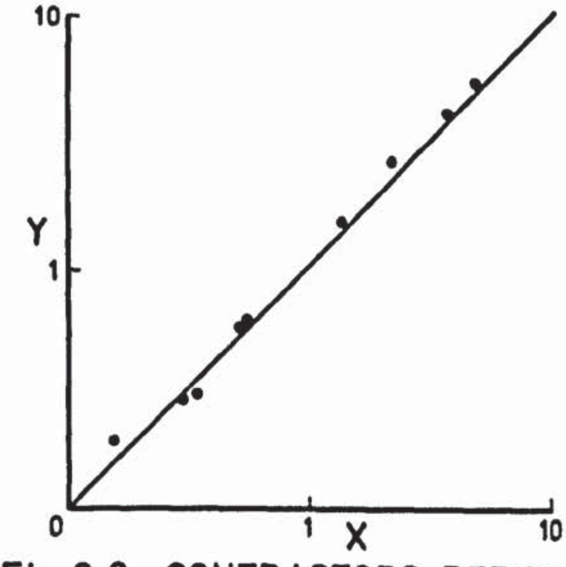


Fig 3·9 CONTRACTORS PERFORMANCE
Log 2 cycles × 2 cycles

bidder, points below the line mean that the contractor on the horizontal axis is the higher bidder.

Contractor Y only managed to beat W on three out of fourteen tenders, and Y beat X on only two out of nine tenders. Contractor W beat X on eight out of twelve tenders. The analysis shows that W is by far the most successful tenderer when in competition with X and Y. It is also worth noting that when W bids against X, he is the lower bidder on all projects above £200,000 value, but on only three out of seven when the project value was below £200,000.

We can conclude that when contractors are consistently in competition, the pattern of bidding cannot be regarded as random. There is a trend which can be discerned between specific contractors when bidding in competition. Consultant quantity surveyors should be aware of the significance of this aspect of bidding.

3.17 <u>Conclusions on Bidding</u>.

We can summarise our conclusions on bidding as being:

1) The market activity affects the level of bids, shown for example by changes in the tender price index, but it does not affect the overall range of bidding.

2) The characteristics of bidding on projects over £1,000,000 value exhibits a different pattern to bidding on projects under £1,000,000. The break point of £1,000,000 was identified by visual inspection of the data. It cannot, therefore, be considered as definitive, but it does imply that quantity surveyors should have an awareness of the relationship between the project size and the pricing level when using unit price rates

derived from schemes of significantly different project size.

3) In our opinion the low bidder's price should be used as the data for price predictions with one important proviso, that the consultant quantity surveyor should consider the relationship between the lowest and second lowest tender. If the low bid is more than 5% below the second lowest bid, then the low bid prices should not be used for price prediction. If this approach had been adopted for the 129 project sample, 24 of the project prices would have been rejected as being unsuitable.

Chapter 4

Accuracy and error in price prediction

4.0 Introduction.

The analysis in Chapter 3 was based on the assumption that the contractor's tender is an accurate reflection of the final charge he will make for the project, in other words the contractor's estimates are accurate.

The first part of this chapter considers what is meant by the terms accuracy and error. We then examine the accuracy of the contractor's tender prices measured against his true cost. We also consider the accuracy of the quantity surveyor's price prediction measured against the contractor's lowest bid for building projects.

4.1 Accuracy, Error, Reliability and Predictability.

The starting point for our discussion must be a consideration of what is meant by the term accuracy. The naive definition is simply the absence of error, that is the smaller the error the higher the accuracy and vice-versa. This is, largely, true but merely restates the problem by requiring a definition of error.

To define error mathematically we suppose that there exists a number X which we know to be "exact". In describing X we use another number x which is an approximation of the "exact" value. Thus the "exact" number might be π the approximation x is 22/7; or X might be the actual volume of concrete in a ready mix concrete truck, whereas x is the volume of concrete shown as being delivered on the delivery ticket. The absolute error in x is defined as:

$$e_x = x - X$$

An absolute error may not be as useful as a relative error, i.e. a percentage error, for example, an error of $2m^2$ in $200m^2$ is better than $1m^3$ in $5m^3$.

The assessment of accuracy then is determined by the magnitude of the error which we are prepared to accept. Since errors can be positive or negative the "exact" number is bounded on either side to produce an error interval:

$$X - e_x \qquad X \qquad X + e_x$$

where e_x is some positive number defining the absolute error bound of X. Note that the error bounds need not be symmetrical about X.

Whence do these errors arise? There are several sources but we must recognise inherent errors which are:

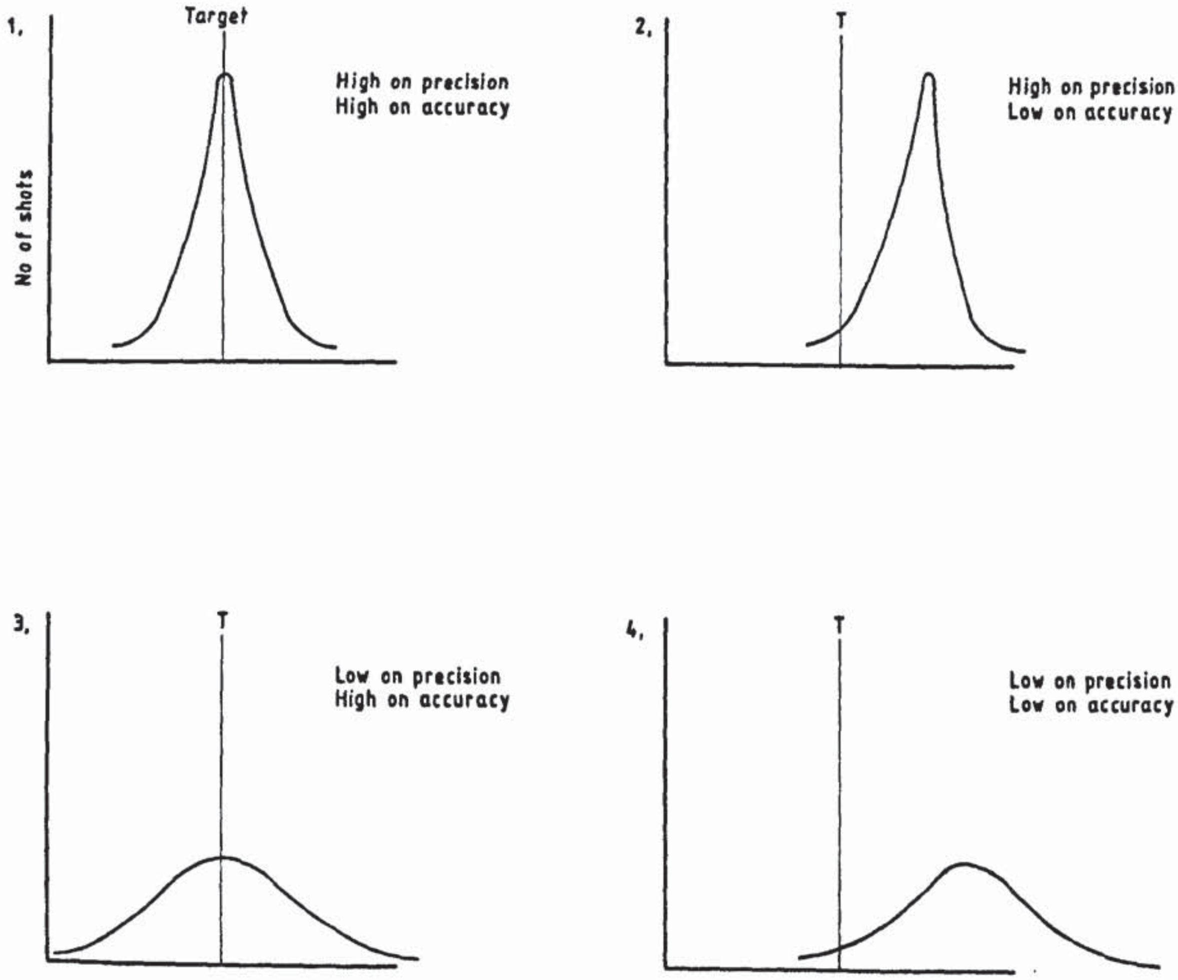
a) measurement errors - the measurement of a physical quantity is never perfectly exact, and indeed cannot ever be so (Heisenberg 1967);

b) rounding off errors - for instance using 4.52m for 4.516m.

In addition there are propagation errors resulting from arithmetical operation, for example squaring an approximate number (e.g. one including a measurement error) roughly doubles both absolute and relative error.

Precision, or reproducability, is a measure of the closeness of grouping of data. Thus a good marksman may get all his shots within a 50mm circle, his precision is high, but his accuracy is high only if the shots fall on the target (e.g. the bull).

If the target is not known then we can only measure precision, not accuracy. Thus, in the situation described above where an exact number X ("the bull") cannot be established, we cannot measure accuracy but only precision. Statistics enables us to do this and no more. To develop the analogy further, what can then be argued is that the better the marksman the more closely grouped will be his shots, and the more likely it is that a large proportion of them will contain the target. If, however, an excellent marksman is using a rifle with a consistent, but unknown bias, then his shots will be very closely grouped on the wrong target. He is being precise, but not accurate unless he receives feedback on his initial shots. With such feedback, of course, we would expect adjustment of the bias and convergence on the 'true' target. This is illustrated in the diagrams below.



We run into trouble when we try to apply these concepts to price prediction. The difficulty arises from the fact that neither of the two quantities with which we are immediately concerned (i.e. the quantity surveyor's price prediction and the contractor's bid) are "true" values. Both are, in fact, estimates and both, therefore, have associated relative error bounds.

The problem resolves into three elements:

a) the accuracy of the tender price submitted by the contractor;
b) the accuracy of the price prediction made by the quantity surveyor;
c) the true cost; this may be the actual cost to the client or it may be the difference between what the contractor charges and the ultimate cost to him.

Ideally all three should match, that is to say the price prediction should predict the tender price and the tender price should represent the cost to the client. In practice this is not generally so, even in stable market conditions.

Thus, in trying to make a formal analysis of the problems of price prediction we should have, at very least, three quantities - the estimate, the bid price and the true cost.

In the next section we analyse the relationship between the contractor's bid price and the true cost and in the subsequent section we analyse the relationship between the quantity surveyor's estimate and the contractor's bid price.

4.2 The Accuracy of the Contractor's Tender.

The first aspect was to consider the accuracy of contractors' tenders. We gained access to a national contractor's cost books to investigate the relationship of the true cost at the end of a project measured against the estimated cost at the tender stage.

The contractor in 1979 had an annual turnover in excess of £100 million. For reasons of confidentiality we were permitted to look only at 65 projects that were completed from 1970 to 1974, this represented the total workload of the contractor during that period. The tenders had been prepared from 1965 onwards.

The information we collected was as follows:

a) the tender price;
b) the contractor's allowance for head office overheads and profit included in the tender price;
c) the final account price;
d) the contractor's cost book figure which showed the cost to the contractor of undertaking the completed work.

The contractor included his overheads and profit as a lump sum allowance in the tender price, therefore we were unable to consider the profit as a separate entity.

The project prices ranged from £11,700 to £7,250,000 and included housing, schools, hospitals, offices, shops, factories and military schemes located throughout Great Britain. On most of the projects the final account value was above the tender figure, therefore, the cost book included additional work items. This does not invalidate the exercise so long as we assume the contractor will be seeking the same level of overheads and profit for the additional work as upon the original work.

We calculated two sets of values:

i) the percentage allowance included in the tender sum for overheads and profit;

ii) the actual percentage for overheads and profit earned by the project.

The data were analysed by project value into four groups:

1) up to £100,000;

2) over £100,000 and up to £500,000;

3) over £500,000 and up to £1,000,000;

4) over £1,000,000.

Because of the large number of projects up to £100,000 it was decided to keep this as a separate category.

Figure 4.1 shows the performance of the contractor. When an observation falls below the zero line the contractor incurred an overall loss on the project (11 cases). When the point is between zero and 1.0 (26 cases) the contractor did not achieve the expected margin for overheads and profit, and above 1.0 (28 cases) the contractor achieved a greater margin for overheads and profit. Table 4A shows the statistics associated with the observations. These indicate that, over the period as a whole, the contractor achieved his expected margin for overheads and profit. In that sense the contractor would probably regard his estimating as accurate and reliable. However, when individual contracts are examined the contractor achieved at least the expected mark up for overheads and profit on only 43% of the cases. With the exception of projects with value less than £100,000, there is no evident trend of the project value having an influence on the contractor's estimating accuracy, he is equally unreliable on both small and large projects. The projects up to £100,000 value had the highest mark up for overheads and profit and they also exhibited the highest mean absolute error. This could be symptomatic of the competitiveness of the market as was exhibited by our analysis on bidding in Chapter 3, but, more likely, it is the nature of this contractor who by his

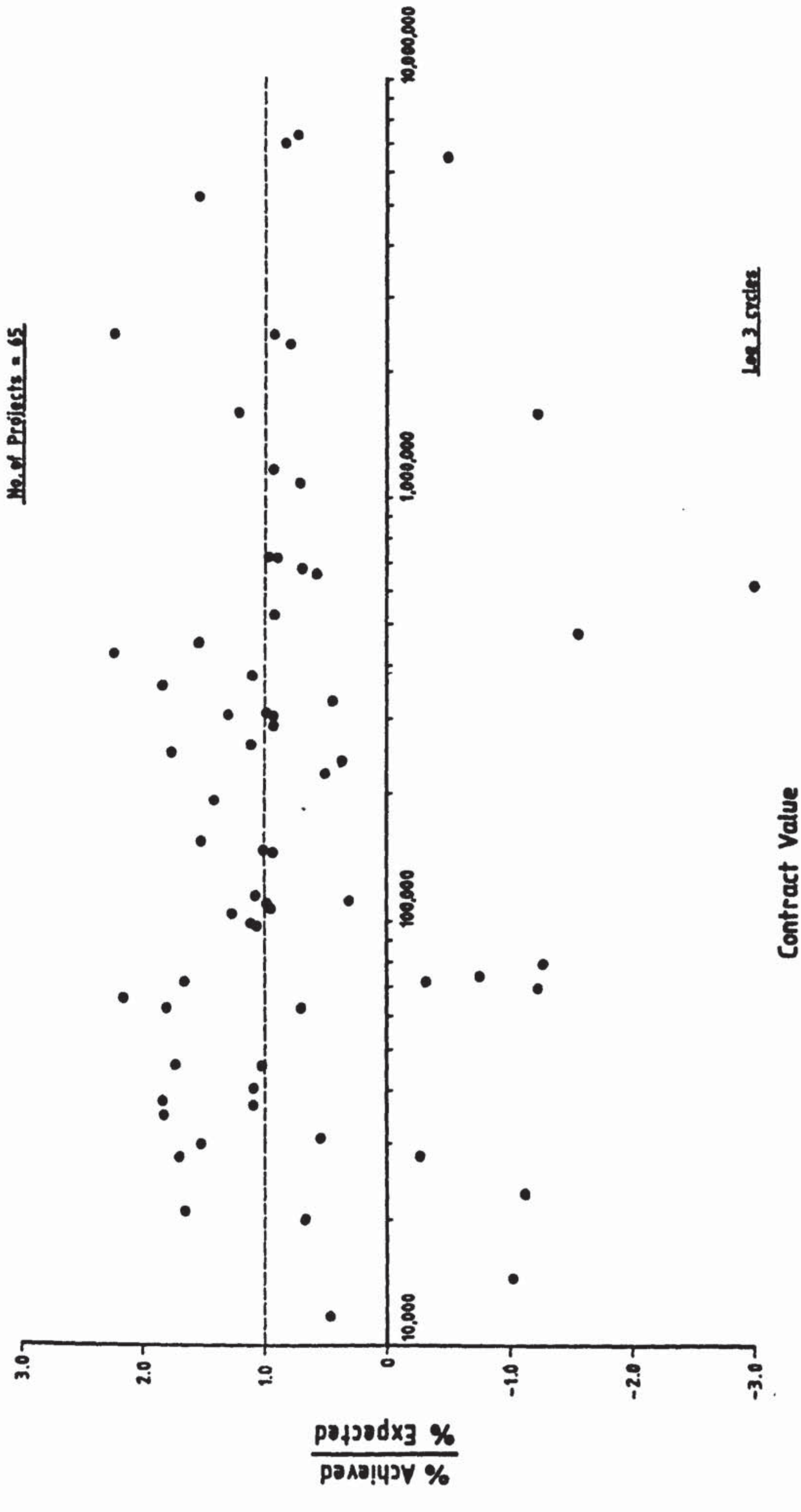


Fig 4·1 PROFITABILITY OF CONTRACTS

size, is better equipped to undertake larger projects. We also looked at the contractor's estimating accuracy over the period 1966 to 1973 to see if the period when the estimate was prepared had any significance, but again, no trend was evident.

TABLE 4A.

Project Categories	Expected overheads and profit		
	Mean %	Standard Deviation	Mean absolute % error between expected and achieved
Up to £100,000	10.65	2.69	8.60
Over £100,000 and up to £500,000	8.25	3.13	3.75
Over £500,000 and up to £1,000,000	5.00	1.64	-6.75
Over £1,000,000	5.64	1.92	4.18

The quantity surveyor's concern must be that he is using historical prices as the basis for future predictions where the contractor has made significant errors in the tender. In only 36% of the cases was the contractor's tender within 10% of the actual cost, whilst in 11 cases a direct loss was incurred. Published cost analyses do not reveal anything about the accuracy of the contractor's bid, or indeed, whether the contractor incurred a financial loss on the project. Even the project quantity surveyor may not be aware that the contractor is suffering a loss.

We noted, however, that 'on average' the contractor achieved his target margin. This leads us to the view that the quantity surveyor should not use one historical project as the basis for a future price prediction, but should assemble a set of projects. Furthermore, it would be advantageous if, when it is known, the BCIS published the final account price for the analysis, together with an indication of the extent of variation orders.

From the contractor's point of view it would appear that tender prices are not particularly accurate. In terms of the analogy discussed above, we can argue that the contractor is often aiming at the wrong target. The question then arises as to whether we can design a feedback mechanism which would tell the contractor when and how he is missing the target, i.e. not achieving the desired rate of return on specific projects.

The design of such a mechanism is outside the scope of this thesis. It is, however, worth noting that a major problem which would need to be overcome is that there are very long time lags between the preparation of the tender and receipt of any useful information on the true cost of the project. The contractor's costing system is supposed to provide useful feedback for the estimator on past performance. The contractor's results would suggest that his feedback system was not sufficiently sensitive.

4.3 The Accuracy of the Quantity Surveyor's Price Prediction.

One of our objectives for this chapter was to measure the accuracy and reliability of the consultant quantity surveyor's tender price prediction. We feel this facet of our research is very important because very little appears to be known about the reliability of the quantity surveyors' price predictions.

As we previously stated the true cost is rarely known to the quantity surveyor. We shall, therefore, look at the relationship between the quantity surveyor's price prediction and the bids he is receiving from contractors. In doing so we are assuming that the direction of causation is from the bid to the prediction, i.e. that the estimate is in some sense the dependent variable. This is reasonable because we can generally conclude that tenders submitted by contractors are based upon cost considerations plus desired overheads and profit, whereas price predictions are based upon previous tenders.

We undertook an extensive literature search to trace any work that had been carried out in analysing the quantity surveyor's performance in relation to price prediction, but we found no significant available documentation. Since we had no factual evidence upon which to base our measure of performance, we undertook a case study to analyse the consultant quantity surveyor's estimating performance over a period of time. Unfortunately, it proved impossible to obtain sufficient data on projects from any one private practice. For this reason, two County Councils were approached. County Council A located in the north west, and County Council B in the south east of England. The Councils were selected because they both had fully documented records, the price predictions for projects were being undertaken by in-house cost planning departments using cost planning techniques, there was a similarity in the types of projects being constructed, and selective tendering was being used to obtain tenders.

In order to test performance of the two Councils, the Council's last price prediction, prior to tenders being sought, were related for each project to the lowest tender price received from a contractor. Both councils were using the superficial floor area method of prediction at the inception and outline proposal stages of a project, and cost planning with approximate quantities at the sketch and detail design stages. Council A was considered on a sample of 103 projects and Council B on a sample of 63 projects. The sample for

Council A consists of all documented projects over the period 1975 to early 1978, and for Council B all documented projects during the period 1971 to early 1977.

Our first consideration was to consider the functional types of building in our samples, these are shown in Table 4B.

TABLE 4B : ANALYSIS OF PROJECT TYPE

Types of Project	Council A (103 Projects)	Council B (63 Projects)
Schools (all types)	66	31
Police stations	3	3
Fire stations	2	5
Hostels	-	5
Childrens nurseries	-	7
Old peoples homes	6	-
Day care centres	13	-
Other	13	12

The majority of projects were schools for both councils.

Table 4C shows the relationship of the quantity surveyor's prediction to the low bid measured in percentage bands of 5%. The percentages relate to the total number of projects undertaken by the Councils. In view of the large proportion of schools both Councils were building, we also looked independantly at the quantity surveyor's performance on schools projects. However, the performance by both councils is not significantly better for schools than for other types of projects.

TABLE 4C : ACCURACY OF ESTIMATE TO LOW BID.

	Relationship of price prediction to low bid (%)					
	± 5%	± 10%	± 15%	± 20%	± 25%	Over ± 25%
Council A (103 Projects)	25.27	48.57	63.13	78.66	86.42	100.00
Council B (63 Projects)	28.57	57.14	76.19	85.71	93.65	100.00
Council A Schools only (66 Projects)	27.14	52.60	68.46	92.10	100.00	
Council B Schools only (31 Projects)	32.33	59.16	74.48	92.11	100.00	

We used regression analysis to test the performance of both Councils. If the Councils were estimating perfectly we would expect to find:

$$\text{ESTIMATE} = \text{LOW BID} \qquad (1)$$

The regression analysis used a least squares technique to estimate an equation of the form:

$$\text{ESTIMATE} = A + B \times \text{LOW BID} \qquad (2)$$

From equation (1) it can be seen that perfect accuracy would lead to the estimated parameters of equation (2) being such that:

$A = 0.0$

$B = 1.0$

The results are summarised in Tables 4D and 4E.

Footnote: In Tables 4D to 4M inclusive the following legend applies:

*	Significantly different from zero at 95% confidence level.
**	Significantly different from unity at 95% confidence level.
Ø	Not significantly different from zero at 95% confidence level.
ØØ	Not significantly different from unity at 95% confidence level.

TABLE 4D : COUNCIL A - ALL PROJECTS.

No. of Projects	Mean of all estimates	Mean of all low bids	Multiple R (correlation)	R^2
103	193,045	176,518	0.9938	0.9877
Variable	Coefficient	t statistic (+)	95% confidence interval	
Low bid Constant	1.1146 ** -3.7076 Ø	90.0145 -0.9987	1.0900 -11.0721	1.1392 3.6567

TABLE 4E : COUNCIL B - ALL PROJECTS.

No. of Projects	Mean of all estimates	Mean of all low bids	Multiple R (correlation)	R^2
63	167,294	183,102	0.9839	0.9681
Variable	Coefficient	t statistic	95% confidence interval	
Low bid Constant	0.8328 ** 14.7982 *	42.6647 2.9091	0.7938 4.6227	0.8719 24.9729

(+) The t statistic is the statistic that is conventionally used to test the significance of coefficients generated from a least squares estimating procedure.

The estimated equations are [3]:

Council A ESTIMATE = -3.7076 + 1.1146 x LOW BID (3)

Council B ESTIMATE = 14.7982 + 0.8328 x LOW BID (4)

R^2 in both cases is significant at the 95% confidence level.

Tables 4D and 4E indicate firstly, that the constant term for Council A is not significantly different from zero. Secondly, the slope coefficient (1.1146) is significantly different from unity at the 95% confidence level.

(3) All figures in this and subsequent equations are in multiples of thousands of pounds.

For Council B the slope coefficient (0.8328) is also significantly different from unity and the constant term is significantly different from zero.

The interpretation of equation (3) is that Council A is over-estimating by approximately 11.5% on all projects. For Council B interpretation is somewhat more awkward, since the constant term in equation (4) cannot be ignored. A graphical analysis may be of some help. In Figure 4.2 line E represents equation (2) and line B equation (4).

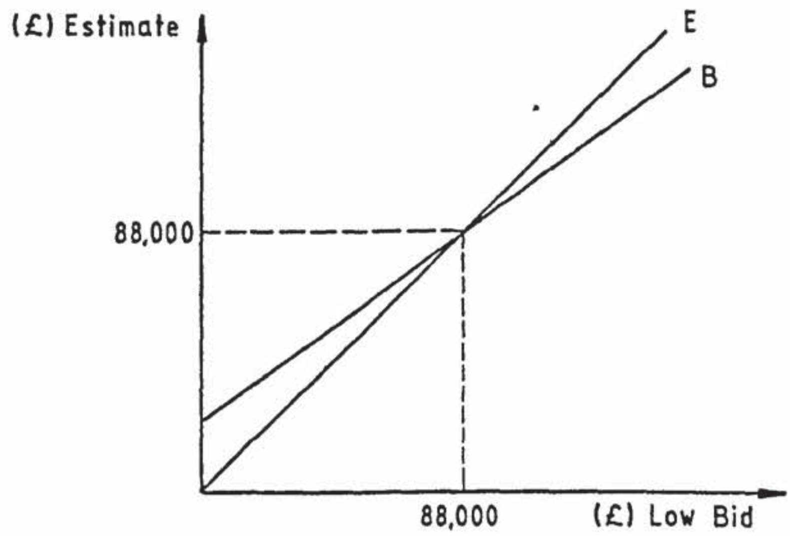


Figure 4.2

Equation (4) then indicates that Council B is over-estimating on small jobs - up to £88,000 value (14.798 ÷ (1.0 - 0.8328)) and under-estimating on jobs above this value. In addition, the percentage under-estimate increases as projects increase in value. Put another way, for every £100,000 increase in project size, Council B's estimate increases by only £83,280.

Examination of scatter diagrams of the observations for both Councils - reproduced in Figures 4.3 and 4.4 - suggests that a simple linear regression, as in equations (3) and (4) might not be the correct specification of estimating performance. It would appear that both Councils exhibit a reasonable measure of accuracy when forecasting prices for projects up to approximately £300,000 value, but above this the estimates are less successful. Council B, for example, has a tendency consistently to under-estimate on projects over £300,000 value.

A curvilinear regression was undertaken on Council B's data, but this did not capture sufficiently the under-estimation on very large projects.

We felt that a more appropriate hypothesis was that estimating performance on small jobs differs in some distinct way from that on large jobs.

The projects for both Councils were, therefore, analysed by project size on the assumption that estimating performance on projects up to £300,000 differed from performance on projects over £300,000. The results are summarised in Tables 4F, 4G, 4H and 4I.

The break point was chosen from visual inspection of the data rather than from a statistical analysis. Subsequent testing indicated that it was an appropriate choice. We also tested to see if the break point at £300,000 was changed if all the estimates were rebased to the first quarter in 1974. However, this made no difference to the break point which remained at £300,000.

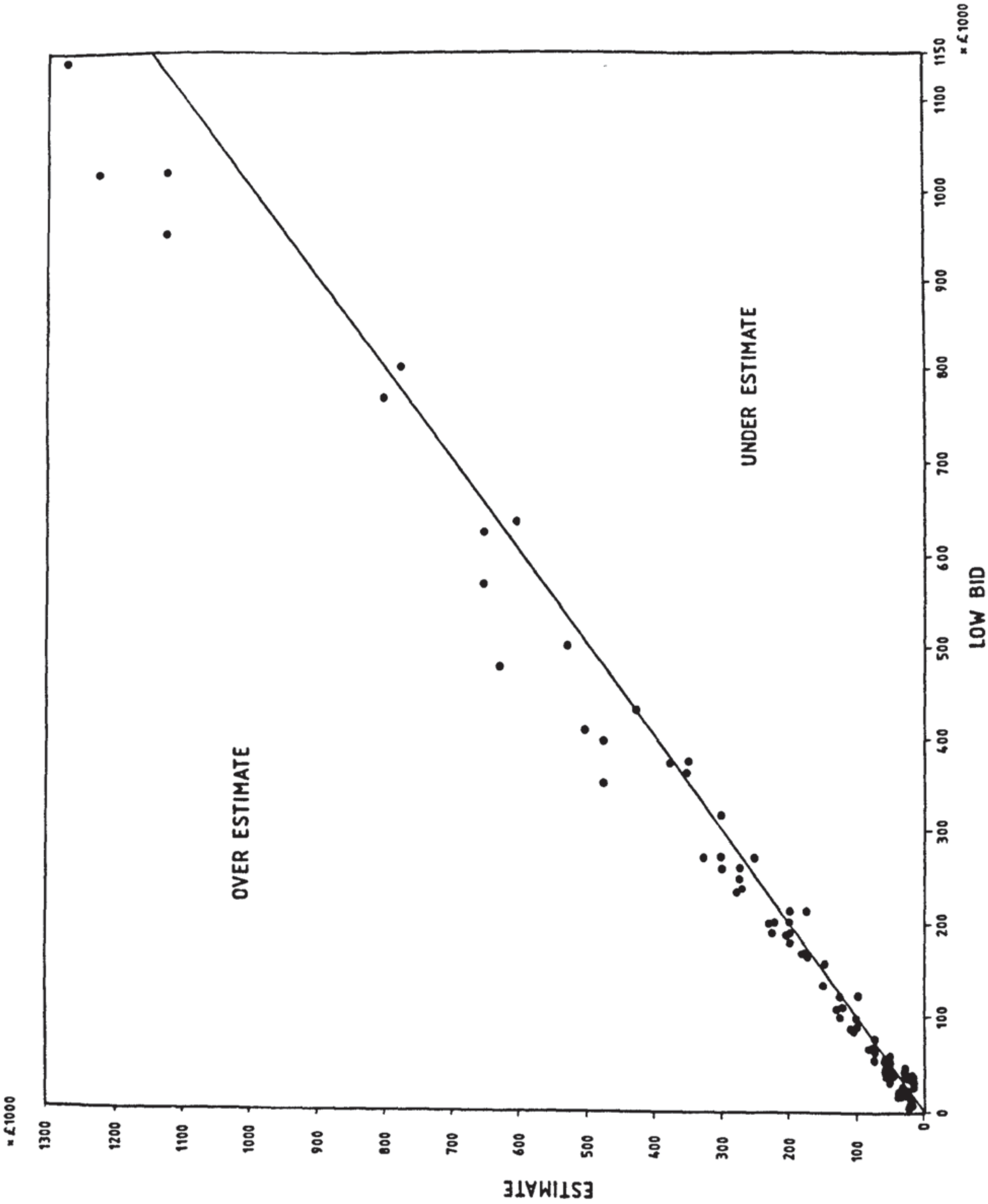


Fig 4·3 COUNCIL A SCATTER DIAGRAM OF ESTIMATE AGAINST LOW BID

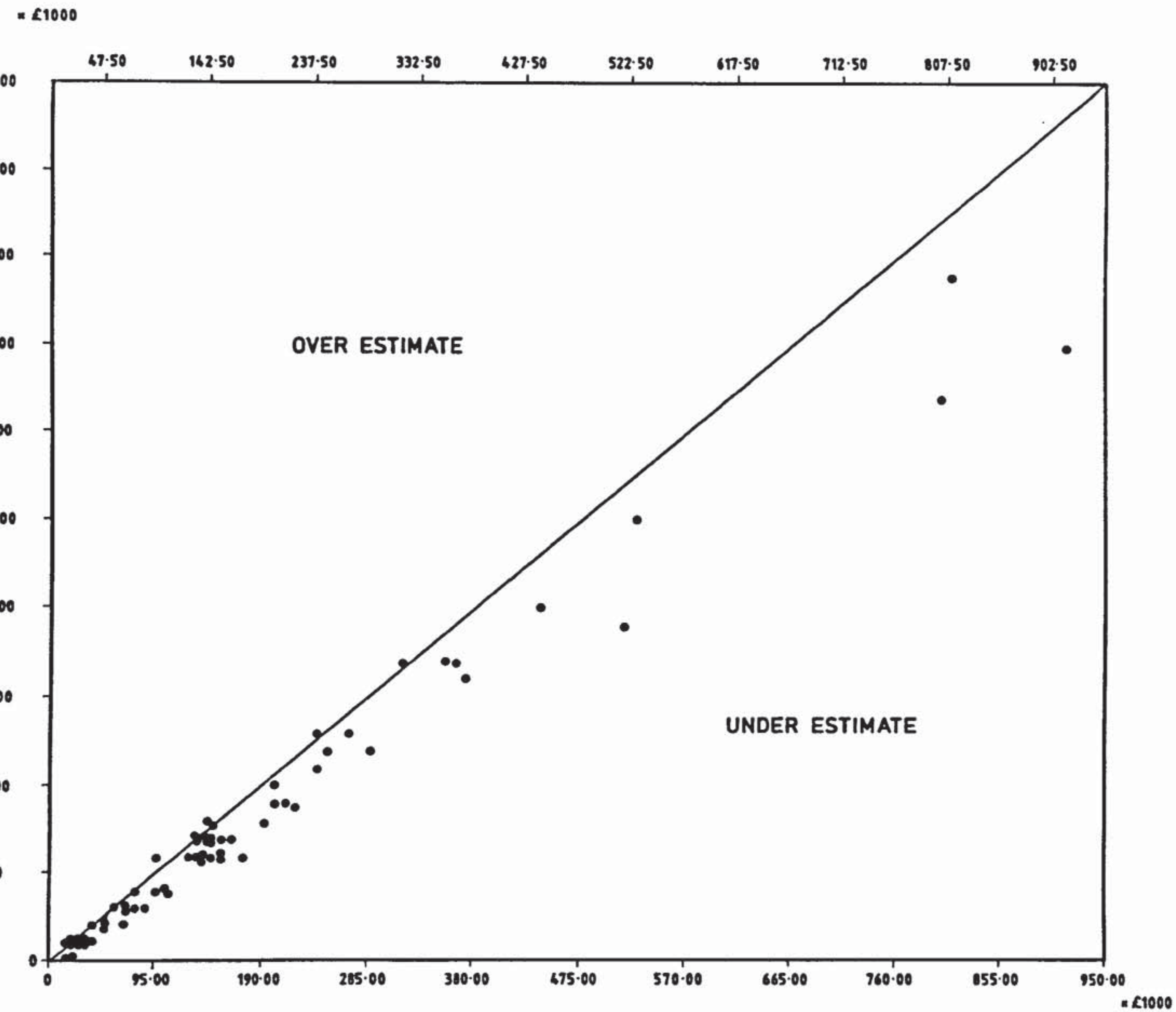


Fig 4·4 COUNCIL B SCATTER DIAGRAM OF ESTIMATE AGAINST LOW BID

TABLE 4F : COUNCIL A - PROJECTS LESS THAN £300,000 VALUE.

No. of Projects	Mean of all estimates	Mean of all low bids	Multiple R (correlation)	R^2
84	86,155	80,316	0.9915	0.9830
Variable	Coefficient	t statistic	95% confidence interval	
Low bid Constant	1.0668 ** 0.4753 Ø	68.8714 0.2702	1.0360 -3.0246	1.0976 3.9752

TABLE 4G : COUNCIL A - PROJECTS GREATER THAN £300,000 VALUE

No. of Projects	Mean of all estimates	Mean of all low bids	Multiple R (correlation)	R^2
19	665,612	601,832	0.9771	0.9548
Variable	Coefficient	t statistic	95% confidence interval	
Low bid Constant	1.1462 ** -24.2168 Ø	18.9433 -0.6102	1.0186 -107.9489	1.2739 59.5172

TABLE 4H : COUNCIL B - PROJECTS LESS THAN £300,000 VALUE

No. of Projects	Mean of all estimates	Mean of all low bids	Multiple R (correlation)	R^2
52	106,179	111,484	0.9836	0.9675
Variable	Coefficient	t statistic	95% confidence interval	
Low bid Constant	0.9825 ØØ -3.3577 Ø	38.1981 -0.9772	0.9308 -10.2629	1.0342 3.5476

TABLE 4I : COUNCIL B - PROJECTS GREATER THAN £300,000 VALUE

No. of Projects	Mean of all estimates	Mean of all low bids	Multiple R (correlation)	R^2
11	450,545	515,148	0.9436	0.8903
Variable	Coefficient	t statistic	95% confidence interval	
Low bid Constant	0.6449 ** 118.4474 *	8.5465 2.8661	0.4741 24.9592	0.8156 211.9355

For projects costing less than £300,000, the estimated equations for the two Councils are:

Council A ESTIMATE = 0.4753 + 1.0668 x LOW BID (5)

Council B ESTIMATE = -3.3577 + 0.9825 x LOW BID (6)

Equation (5) indicates that Council A is over-estimating on small projects by about 7%. For Council B, however, equation (6) is not statistically different from the 'perfect estimating' equation (2). To all intents and purposes, Council B is estimating perfectly on small projects: equation (6) if taken literally implies under-estimation of something less than 2%.

For projects greater than £300,000, a somewhat different pattern emerges. The estimated equations are now:

Council A ESTIMATE = -24.1216 + 1.1462 x LOW BID (7)

Council B ESTIMATE = 118.4474 + 0.6449 x LOW BID (8)

For Council A, over-estimating is now rather more severe. Every £100,000 increase in project size leads to an increase of £114,620 in the estimate. In percentage terms, over-estimation exceeds 10% for projects above £600,000 and exceeds 12% for projects above £1,000,000.

Council B, on the other hand, exhibits consistent and serious under-estimation. Every £100,000 increase in project size leads to an increase of only £64,490 in the estimate. Under-estimation exceeds 10% for projects above approximately £480,000, exceeds 20% for projects in excess of £750,000 and exceeds 24% for projects in excess of £1,000,000.

Graphically, Council A is performing as in line A in Figure 4.5 and Council B as in line B.

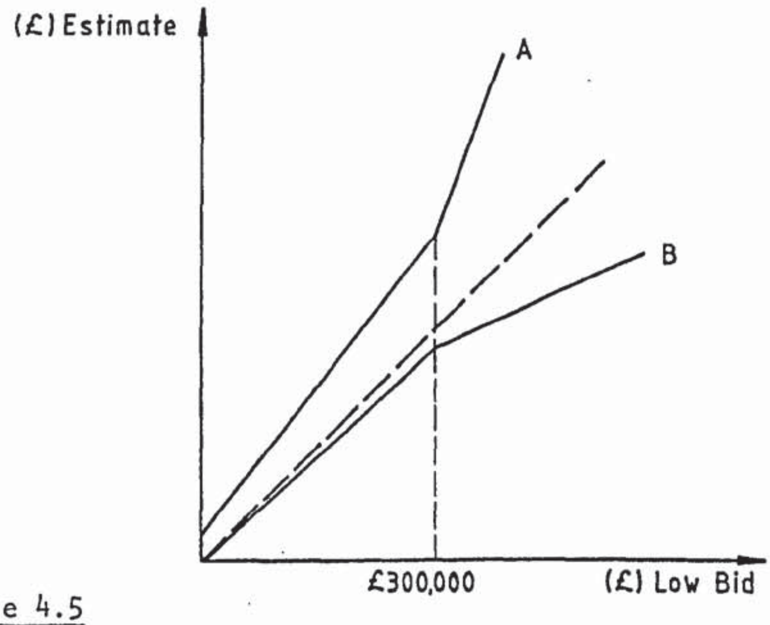


Figure 4.5

The results would appear to confirm our hypothesis regarding the effect of project size on estimating performance. It also highlights the very different performance of the two Councils. Neither Council would appear to be good at predicting the price of the larger projects, Council B having a particularly poor performance record.

Specific reasons for these differences in performance would require a detailed analysis of estimating procedures which we were not able to undertake. They are likely to include the estimating methods used, staff expertise, etc.

One important point should be made at this stage. For Council B severe under-estimation was apparent on only 11 of the 63 projects. But as the Lorenz curve in Figure 4.6 indicates, these 11 projects accounted for 46.72% of total proposed expenditure. Similarly for Council A, significant over-estimation occurred on only 19 out of 103 projects, but as Figure 4.7 shows, these accounted for 63.17% of total planned expenditure. In other words, significant estimating errors occurred on relatively few projects, but these

Total expenditure. £11,420,412
Total projects analysed. 63
Time span. March '71 - March '77

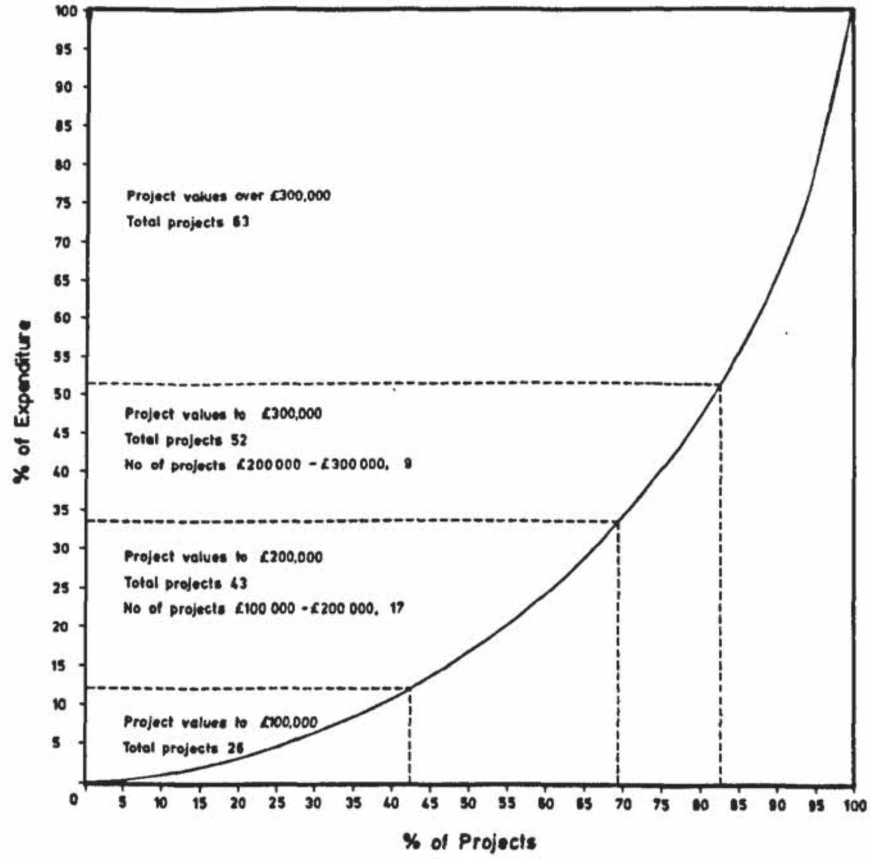


Fig 4.7 COUNCIL B LORENZ CURVE OF TOTAL EXPENDITURE

Total expenditure £18,181,354
Total projects analysed 103
Time span March '75 - March '78

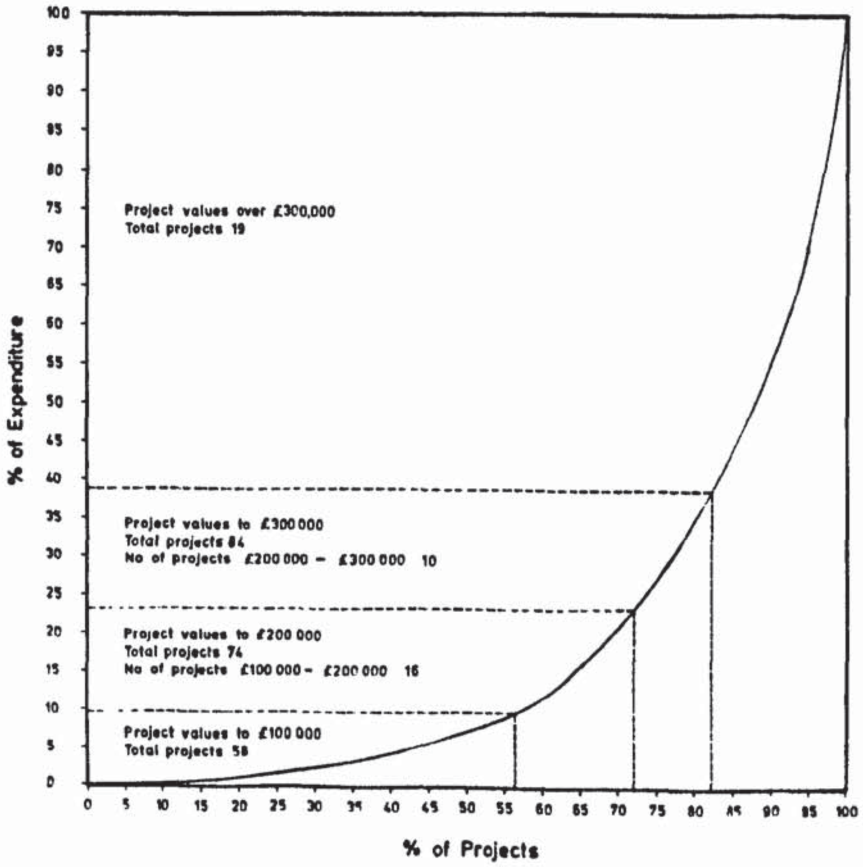


Fig4.6 COUNCIL A LORENZ CURVE OF TOTAL EXPENDITURE

projects accounted for a large proportion of the total construction budget.

Figure 4.8 relates the Lorenz curves of the two Councils. The closer the Lorenz curve approaches the 45° line the smaller are the differences in individual project sizes; a Lorenz curve lying on the 45° line would indicate that projects are exactly the same size. As can be seen Council A has a greater proportion of large projects.

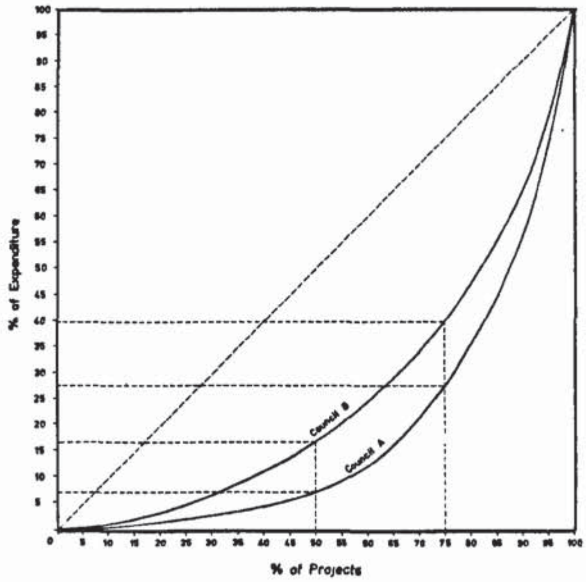


Fig 4.8 COMPARISION OF LORENZ CURVE FOR COUNCILS A & B

Because of Council A's tendency towards over-estimation, we investigated whether there might be a relationship between the second lowest bid and Council A's estimate, this was also of interest in view of our work in Chapter 3. Table 4J summarises the results for all the projects, Table 4K for projects under £300,000 value and Table 4L for projects over £300,000.

The estimated equations are:

All projects:	ESTIMATE = -6.4342 + 1.0930 x SECOND BID	(9)
Projects up to £300,000:	ESTIMATE = -0.5529 + 1.0235 x SECOND BID	(10)
Projects over £300,000:	ESTIMATE = -24.8413 + 1.1229 x SECOND BID	(11)

TABLE 4J : COUNCIL A - ALL PROJECTS (SECOND LOWEST BID)

Total No. of Projects	Mean of all estimates	Mean of all second lowest bids	Multiple R (correlation)	R^2
103	193,045	182,505	0.9945	0.9891
Variable	Coefficient	t statistic	95% confidence interval	
Second lowest bid	1.0930 **	95.8625	1.0707	1.1156
Constant	-6.4342 Ø	-1.8361	-13.3860	0.5175

TABLE 4K : COUNCIL A - PROJECTS LESS THAN £300,000 VALUE (SECOND LOWEST BID)

Total No. of Projects	Mean of all estimates	Mean of all second lowest bids	Multiple R (correlation)	R^2
84	86,155	84,133	0.9905	0.9812
Variable	Coefficient	t statistic	95% confidence interval	
Second lowest bid	1.0235 ØØ	65,3242	0.9924	1.0547
Constant	-0.5529 Ø	-0.2964	-4.2633	3.1576

TABLE 4L : COUNCIL A - PROJECTS GREATER THAN £300,000 VALUE (SECOND LOWEST BID)

Total No. of Projects	Mean of all estimates	Mean of all second lowest bids	Multiple R (correlation)	R^2
19	665,612	614,846	0.9813	0.9624
Variable	Coefficient	t statistic	95% confidence interval	
Second lowest bid	1.1299 **	20.8643	1.0094	1.2365
Constant	-24.8413 Ø	-0.6884	-100.9711	51.2885

On all projects, the Council was over-estimating on average by 5.78% with respect to the mean second lowest bid. On projects up to £300,000 the average over-estimation is reduced to 2.40%, while on projects over £300,000 the average over-estimation is 8.26%. In fact, equation (10) is not statistically different from the perfect estimating equation. Thus, Council A would appear to be estimating perfectly on small projects with respect to the second lowest bid, bût to be over-estimating on larger schemes even when the second bid is taken as the "true" price. At this stage in our analysis, therefore, we can conclude that there is a significant gain to be made by attempts to improve estimating performance on large projects, even if this is at the expense of time spent estimating project cost for small projects.

The analysis has, however, ignored a ñumber of factors which may well be of importance. In particular, no account has been taken of the impact of market condition on estimating performance. The projects being analysed are spread over the period 1971 to 1977, a period during which activity in the construction industry fluctuated sharply. We now turn, therefore, to a consideration of the role of market conditions.

One manifestation of market condition may be the number of tenders received for particular projects. As a result, further analysis was undertaken to identify the effect on estimating performance of the number of tenders received. The hypothesis is that the greater the number of bids received for a project, the lower the bid price would be. Lack of data meant that analysis had to be confined to Council B. The results are shown in Table 4M.

The regression equation derived from Table 4M is:

ESTIMATE = -25.5299 + 7.9190 x NO. OF BIDS + 0.8124 x LOW BID (12)

This can be written in an alternative fashion:

LOW BID - ESTIMATE = 25.5299 - 7.9190 x NO. OF BIDS + 0.1876 x LOW BID (13)

TABLE 4M : COUNCIL B - ALL PROJECTS AND NUMBER OF BIDDERS.

Total No. of Projects	Mean of all estimates	Mean of all low bids	Mean No. of bids for each project	Multiple R (correlation)	R^2
63	167,294	183,102	5.5645	0.9901	0.9802
Variable	Coefficient	t statistic	96% confidence interval		
Low bid	0.8124 **	51.1881	0.7807		0.8442
No. of bids	7.9190 *	6.0099	5.2823		10.5557
Constant	-25.5299 *	-3.2595	-41.2029		-9.8570

to show that an increase by one in the number of bidders reduces the estimating error by nearly £8,000. In other words, the estimating error becomes smaller as the number of bidders for a scheme increases (4).

Equation (13) supports our hypothesis, given that the number of tenders received on a particular project is a reflection, admittedly imperfect, of prevailing market conditions; the more depressed the market the greater the number of firms who would wish to compete for a particular project. In other words Council B's estimating performance has been better the more depressed the market.

To develop this idea further the accuracy of the estimate to the low bid was related to the time scale 1971 to 1978. Figure 4.9 shows the error in the Council's estimate to the low bid expressed as a percentage over time and Table 4N shows the overall results.

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(4) It should be noted that this conflicts with the policy of the Council, which intuitively felt that the greater the number of bidders the higher the bid price they received.

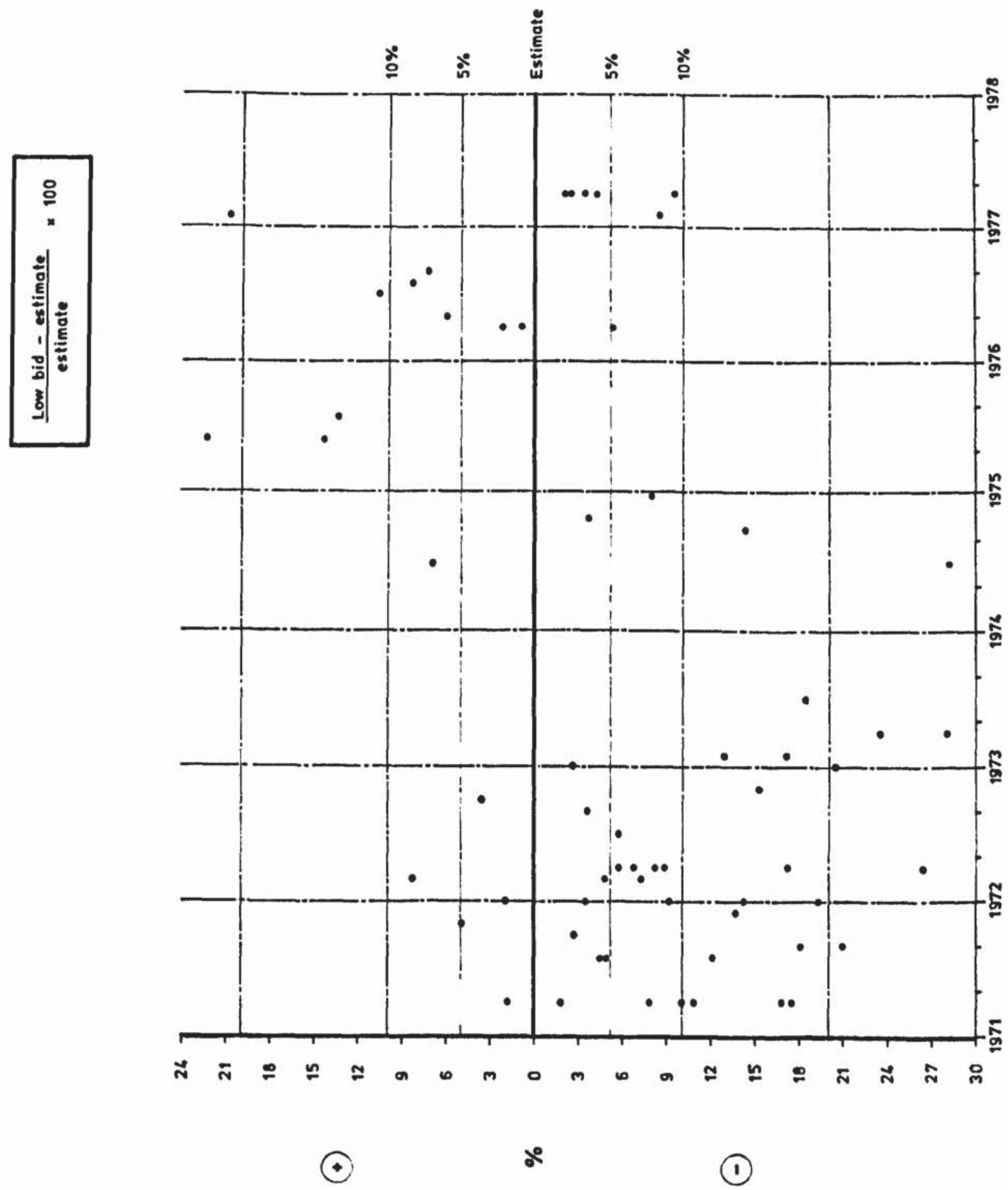


Fig 4.9 COUNCIL B ESTIMATE ACCURACY AGAINST TIME

TABLE 4N : COUNCIL B - ESTIMATING PERFORMANCE.

	Year 1971 to 1977						
	71	72	73	74	75	76	77
Percentage of total projects where low bid exceeded quantity surveyor's estimate	85	87	100	80	-	14	86

During the period 1971 to 1974 there was a tendency to consistently underestimate by a significant amount. The consistency leads to the conclusion that the Council were not responding quickly to the prevailing market conditions. During 1975 and 1976 two factors led to a different pattern emerging. The downturn in market activity accounted for a slower rate of price inflation and the Council changed their system of cost planning. These moves gave rise to a dramatic improvement in the Council's estimating performance. The results for 1977 are not so encouraging, but the Council have now recognised that their pricing strategy has not responded quickly enough to the changed market condition.

The analysis above indicates, firstly, that the quantity surveyor's price prediction does exhibit quite high degrees of inaccuracy. Secondly, while there is no consistency in the inaccuracy across organisations, there does appear to be consistency in the inaccuracy within a particular organisation. Going back to the marksman analogy at the beginning of this chapter, therefore, we now go on to consider a feedback mechanism which will allow a particular organisation to monitor its performance, and, in terms of the analogy, adjust its sights to take account of identifiable bias.

The feedback mechanism we shall consider is trend and deviation control analysis.

4.4 Trend Control Analysis.

The objective of trend control analysis is to identify whether estimating errors exhibit a consistent trend over time. A trend control chart is built up as follows:

(i) List existing projects in chronological order.

(ii) Enter the projects along the horizontal axis of the trend control chart, spacing the projects equally along this axis as in Figure 4.10.

(iii) For each project calculate the percentage deviation between estimate and low bid (positive if estimate exceeds low bid, negative if estimate is less than low bid).

(iv) Cumulate the percentage deviations and plot the cumulated deviation against the last project used.

An example may be useful to illustrate these various stages. Table 4P lists three (hypothetical) projects with estimates and low bids. Percentage deviation for each project is given in column (4) and cumulative deviation in column (5).

The points plotted on the trend control chart (Figure 4.10) are given in column (6).

TABLE 4P : TREND CONTROL CHART : HYPOTHETICAL EXAMPLE 1.

Project (1)	Estimate (£'000) (2)	Low bid (£'000) (3)	Percentage deviation (4)	Cumulative deviation (5)	Plotted point (6)
1	20	25	-20	-20	A
2	105	100	+5	-15	B
3	80	100	-20	-35	C

Since the projects are evenly spaced on the horizontal axis, the slope of a line between a point on the curve, and the initial point, is the average deviation for all projects up to that point. The slope is the total deviation divided by the number of projects. For example the slope of the line from the origin to the point C is -11.66%, which is the average percentage estimating error for the three projects in Table 4P. Similarly, the slope of the line from point A to point C is -7½% which is the average percentage deviation for all projects completed after project 1.

The line joining the various points identifies the trend of estimating performance. The nearer the trend line to horizontal the closer the estimate is to the low bid. An upward trend line shows a tendency towards over-estimates, whilst a downward trend line indicates a tendency towards under-estimates. This form of plot enables the surveyor to identify a consistent trend within a time frame.

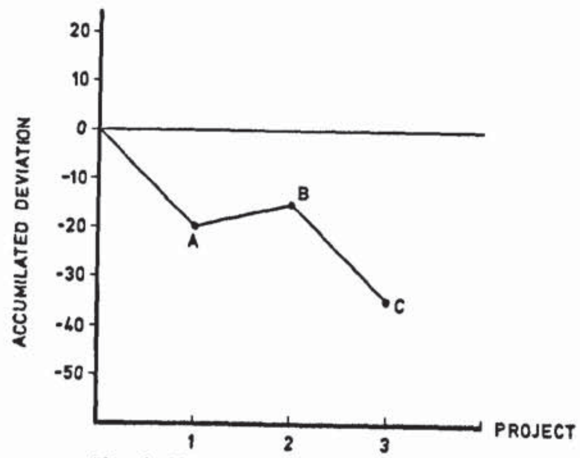


Fig 4.10

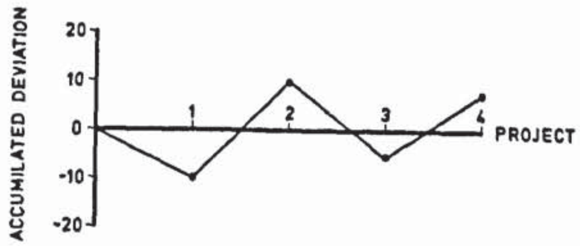


Fig 4.11

But consider the example in Table 4Q, for which the trend control chart is Figure 4.11. In this case no consistent trend can be identified, and the average percentage deviation over the four projects is 2%.

TABLE 4Q : TREND CONTROL CHART : HYPOTHETICAL EXAMPLE 2.

Project (1)	Estimate (£'000) (2)	Low bid (£'000) (3)	Percentage deviation (4)	Cumulative deviation (5)	Plotted point (6)
1	90	100	-10%	-10	A
2	120	100	+20%	+10	B
3	170	200	-15%	-5	C
4	113	100	+13%	+8	D

Clearly, however, estimating performance as illustrated for Table 4Q cannot be described as "good", for no low bid was within 10% of the estimate. This indicates that the trend control chart needs to be supplemented by another chart which indicates the deviation of estimates from low bid, and we now describe that chart.

4.5 Deviation Control Analysis.

A deviation control chart is constructed as follows:

(i) perform elements (i) and (ii) for the construction of the trend control chart,

(ii) take the percentage deviations obtained from step (iii) and plot the cumulated deviation against the last project used.

This exercise is performed in Tables 4R and 4S.

TABLE 4R : DEVIATION CONTROL CHART : HYPOTHETICAL EXAMPLE 1.

Project	Percentage deviation	Squared deviation	Cumulative squared deviations
1	-20	400	400
2	+ 5	25	425
3	-20	400	825

TABLE 4S : DEVIATION CONTROL CHART : HYPOTHETICAL EXAMPLE 2.

Project	Percentage deviation	Squared deviation	Cumulative squared deviations
1	-10	100	100
2	+20	400	500
3	-15	225	725
4	+13	169	894

It is now possible to derive the standard deviation of the estimate measured against the low bid between any two points in time. The construction of the deviation control chart is such that the slope of a line from the origin to any point on the curve, gives the variance of estimate about low bid for all projects up to that point. The variance is the square of the standard deviation, thus a slope scale can be constructed to allow the standard deviation to be read off.

It should be noted that the slope in the slope chart will carry ' $\pm$ ' signs, since we cannot derive from the deviation control chart the sign of the standard deviation; squaring the deviation removes the sign. This must, therefore, be obtained from the trend control chart.

Bringing the trend control and deviation control charts together, we can indicate from the former whether any consistent trend is emerging in estimating performance, and from the latter the deviation of the estimate from low bid. Clearly, the two control charts must be used together if estimating performance is to be properly assessed. The deviation control chart assesses the accuracy of estimating and the trend control chart indicates whether any inaccuracy is consistent in its direction.

Trend control and deviation control charts have been constructed for Council B's projects and are presented in Figures 4.12 and 4.13.

The trend control chart shows up the consistent under-estimating up to December 1974, followed by a period of over-estimating and finally a period of further under-estimating. The deviation control chart shows the sharp jump in deviations in 1973 and 1974, and then a deviation of approximately $\pm$ 11% over the period June 1974 to May 1975.

4.6 Conclusions for the Case Study on Accuracy.

A number of major conclusions can be drawn from our analysis of Council A and Council B's estimating performance. Firstly, there need be no consistency in estimating errors between different organisations. Our analysis has shown significant differences in performance between two organisations in the same sector, commissioning similar work. The only common factor is that both perform badly on large projects.

Secondly, there is a need for estimating performance to be monitored consistently. The custom in the industry appears often to have been to take the estimate, as being 'correct' and the tenders, when they differ from the estimate, as being 'wrong'. We would argue that this is very far from being the case, particularly in situations where estimates differ from low bids in some consistent fashion. The quantity surveyor must constantly monitor his performance, in order to quickly identify any patterns which may emerge.

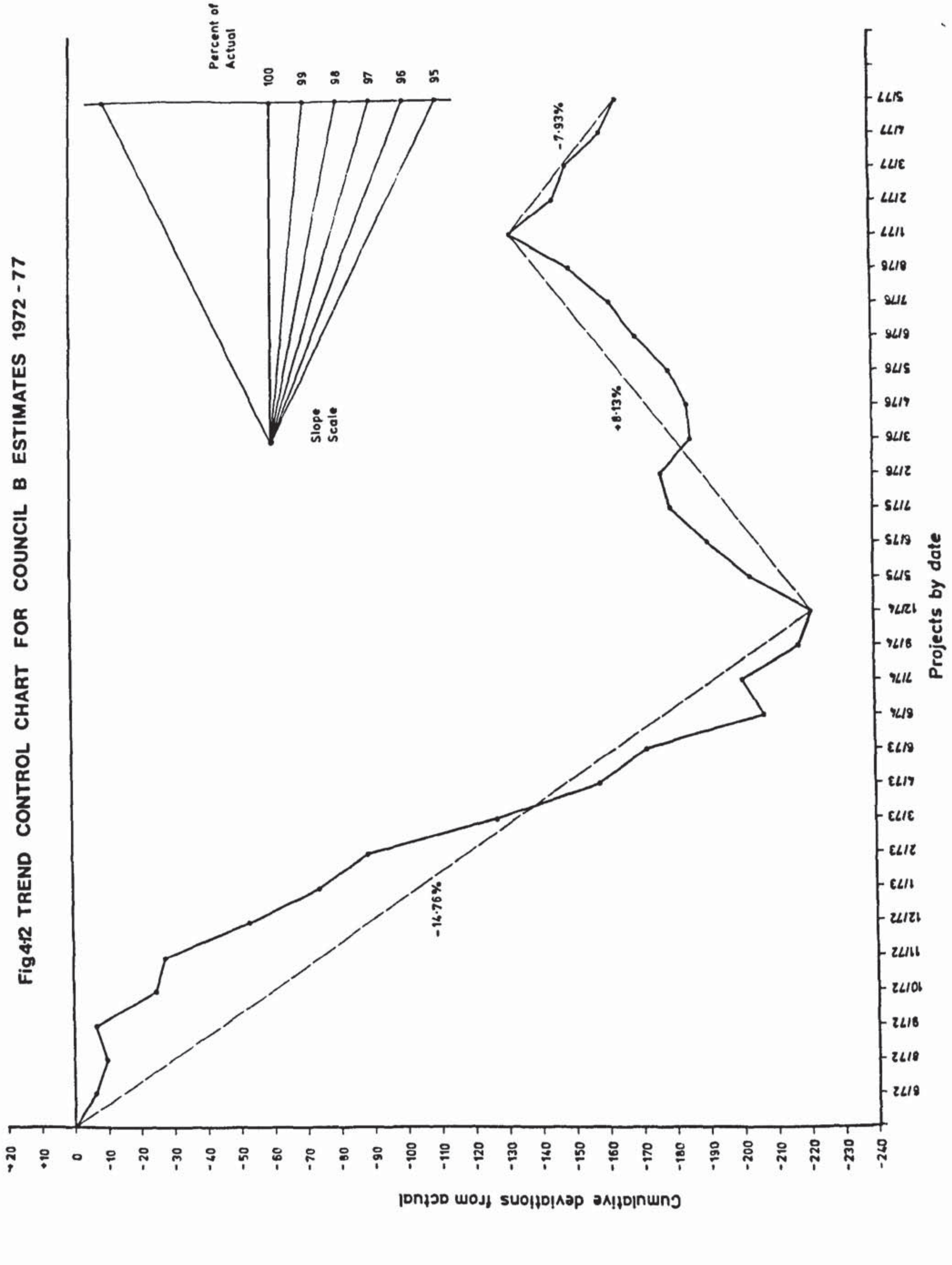
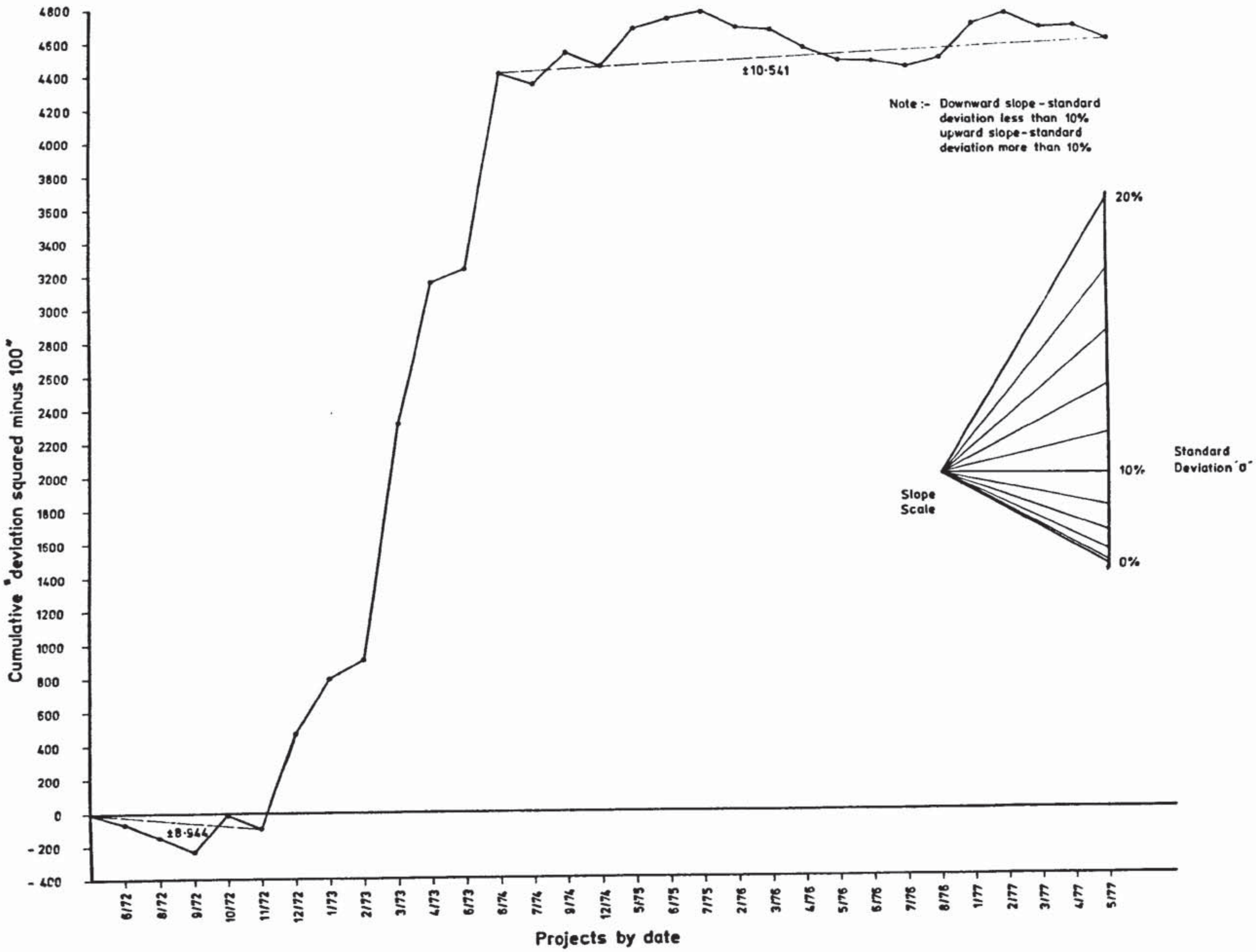


Fig 4.12 TREND CONTROL CHART FOR COUNCIL B ESTIMATES 1972 - 77

Fig 4.13 DEVIATION CONTROL CHART FOR COUNCIL B ESTIMATES 1972 - 77



Complete accuracy is unattainable, but consistent errors can and should be avoided.

Thirdly, market condition has a significant influence on estimating performance. Once again this implies that the quantity surveyor should be aware of current and future market trends and must be able to adapt to them.

Finally, project size is closely related to estimating accuracy. Unfortunately, projects which tend to have the most inaccurate estimates tend also to be the largest. This would imply that resources should be devoted to the few large projects which arise in any given period, even if this is at the expense of accuracy on the small projects. The gains to be made would certainly justify such a transfer of effort.

4.7 Error Bounds for Price Prediction.

The analysis above has concentrated overall on accuracy in price prediction. We noted in Chapter 3, however, that the quantity surveyor's estimate is often constructed from some form of elemental breakdown. Errors in overall price prediction, therefore, point to errors in estimation within some, or all, of the individual elemental categories.

This proposition forms the basis of the work by Lichtenberg (1971), Trimble and Jupp (1973), who have suggested expressing each elemental category of a cost plan as a percentage of the total price. The error range in each elemental category could then be predicted using a regression model. Each elemental category will exhibit residual variability about the predicted price. The quantity surveyor's task at the design stage should be to associate error bounds with each of the categories and to produce an error analysis for the building. Error analysis has been used for some years in the costing of chemical engineering plants (Bauman (1961), Hackney (1965))

We have taken this technique and applied it to an illustrative example for the cost planning of building work. Table 4T shows an error analysis for a cost plan for a proposed office block with a £500,000 predicted construction price.

In essence, the quantity surveyor predicts the price for each elemental category of work, and also assesses the uncertainty associated with each category. By expressing the elemental uncertainties as standard deviations, multiplying them by the value of the element, then squaring them to get the variances, and finally, taking the square root of the variances, the surveyor can quantify the error bound for the price prediction as a whole.

It is interesting to see what happens to overall accuracy in the table when the estimating accuracy of a single class is improved. If the preliminaries prediction has an improved standard deviation of error of ± 5%, the total range improved only from ± 8.21% to ± 8.08%. However, if the superstructure prediction is similarly improved to ± 5% the prediction range is significantly better from ± 8.21% to ± 6.75%.

We can also use the variability within elemental categories to develop a measure of the variability of the overall price prediction. From this we can derive the likelihood that any particular prediction will be achieved. In doing so, we are developing a form of risk analysis to be applied to price prediction.

4.8 Risk Analysis and Price Prediction.

Most clients understand that the single value price prediction represents, under normal conditions, the most likely construction price. However, they lack some means of gauging the chances that the tender price will either exceed or be less than the price forecast.

TABLE 4T : ERROR ANALYSIS APPLIED TO COST PLANNING OF BUILDING

Element	Price Prediction (e)	Error bound (d)	Weighted error (ed)	Square weighted error $(ed)^2$
	£			£
Substructure	40,000	± 30%	12,000	144,000
Superstructure	165,000	± 15%	24,750	612,562
Internal finishings	45,000	± 10%	4,500	20,250
Fittings and furnishings	10,000	± 10%	1,000	1,000
Mechanical and electrical services	135,000	± 20%	27,000	729,000
Preliminaries	50,000	± 15%	7,500	56,250
Site works	55,000	± 20%	11,000	121,000
Total:	500,000			$\sqrt{1,684,062,000}$ = £41,037

$$= \pm \frac{£41,037}{£500,000} = \pm \ 8.21\%$$

Price prediction range = £500,000 ± 8.21%

Risk analysis by the means of Monte Carlo simulation [(1)] has been suggested as an alternative to the utilisation of single cost estimates by Campbell (1970), Picardi (1973), Curran (1975), Doyle (1977), and others. Risk analysis can be defined as the study of the relationship between an estimated price and the chance or probability of the tender price deviating from that amount.

The objective of risk analysis is to identify and evaluate the potential variation in price for the project. The technique will not necessarily improve the accuracy of estimates, but it does permit the systematic consideration of potential errors. It is not a substitute for human judgment.

Given the fact that an estimate of construction price is the sum of many parts, an objective evaluation of its accuracy is possible only by the use of probability and statistics. Probability theory allows future uncertainty to be expressed by a number, so that the uncertainty of different events may be directly compared. Information describing the probability of a future event recurring, or condition existing is generally presented in the form of a probability density function. A price prediction is generated from historical data which are selected according to the desired degree of homogeneity between the proposed building and completed buildings. No matter the level of homogeneity desired, as long as elemental prices are generated from observations of more than one building, each elemental price will exhibit some residual variation about the mean price. The objective of risk analysis applied to price prediction and cost planning is to use the residual variation in assessing the price of the proposed building by:

[(1)] Monte Carlo methods comprise that part of experimental mathematics concerned with experiments using random numbers.

a) performing a series of simulations;

b) using the results of the simulations to identify the most likely price.

Since each unit price rate is drawn from a probability distribution, it follows that the overall estimate is also a member of a probability distribution, the characteristics of this distribution being determined by the characteristics of the individual distributions for each elemental category. Using risk analysis, it is possible to approximate the probability distribution of the overall estimate to identify the characteristics of the family from which it is drawn. This in turn will allow us to identify (a) the probability that the contractor's tender price will not exceed the prediction, and (b) the most likely range within which the contractor's tender price will lie.

Risk analysis proceeds by generating a series of simulations of the proposed project, each simulation giving a price prediction for the project. The predictions are then plotted, firstly as a cumulative frequency curve to give (a) above, and secondly as a histogram to give (b). There are several steps to the analysis:

Step I. For any particular elemental category, e.g. substructure, identify the probability distribution from which the unit rate used in the prediction is taken. We shall call this the mean unit price rate because the rate will be derived from several projects. This is the crucial, and most difficult, part of the analysis, particularly since we must make some a priori choice of probability distributions. It will be useful to illustrate this with a hypothetical example. Let us assume that the mean rate for substructure has been generated from the analysis of 10 completed buildings with unit rates as follows:

Building	1	2	3	4	5	6	7	8	9	10
Unit price rate for substructures (£)	12	10	12.50	13.50	14.50	11	13	14.50	15	16
Mean unit price rate = £13.20	Variance = 3.16									

These data can also be used to identify a range within which the mean unit rate falls. We could approximate this range as running from the lowest to the highest unit rate for substructure in our data, i.e. to be £10/m^2 - £16/m^2. In addition, we can calculate the variance of the unit rates, which is 3.16.

Now consider the various probability distributions we could use:

(i) Uniform distribution: Such a distribution has the advantage of having a finite range. Its major disadvantage, at least for our purposes, is that it assigns an equal probability to all numbers within that range, i.e. there is assumed to be no skewness.

(ii) Normal distribution: This is a distribution which is widely used in many fields. It is inappropriate for our purposes, however, because it has an infinite range (from $-\infty$ to $+\infty$) whereas unit rates are bounded below and above. Secondly, skewness is again eliminated by assumption.

(iii) Beta distribution: This distribution has a finite range, and can take many forms within that range, i.e. skewness can be accommodated. It has the further advantage that its parameters can be generated given knowledge of the mean, variance and range of the actual data.

We shall assume that our data are drawn from a Beta distribution. This distribution has the equation:

$$P(x) = \frac{1}{B\ (p,q)} \cdot \frac{(x - a)^{p-1}\ (b - x)^{q-1}}{(b - a)^{p+q-1}} \quad (a \leq x \leq b)$$

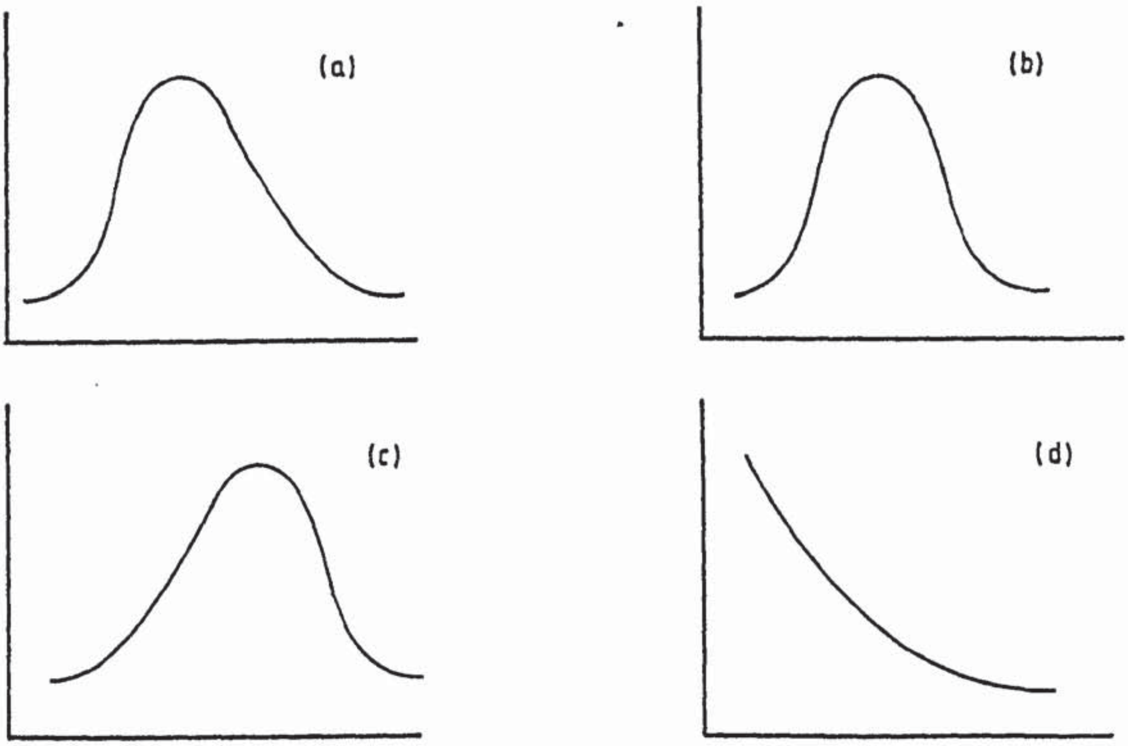
where: a = minimum

b = maximum

p, q = parameters of the distribution; p, q $>$ 0

B (p, q) = beta function

Figure 4.14 illustrates Beta distributions for various sets of values of p and q.



Using the data above, we can estimate the required Beta distribution. This has the following characteristics:

a = £10

b = £16

p = 2

q = 3

i.e. it is of the type illustrated in Figure 4.14 (b).

Step II. Having identified the Beta distribution for each elemental category, generate a random number from each of these distributions. This is best done using a random number generator on a computer. Each such random number is an estimate of the unit rate for the appropriate elemental category, in our hypothetical example the number generated might be £12.75. Note that this number need not equal any of the actual observations, it must, however, lie within the range (a, b), i.e. £10/m^2 - £16/m^2.

Step III. Multiply the random numbers by the quantities in the appropriate elemental categories, e.g. if the quantity of substructure is 1000m^2, we obtain £12.75 x 1000 = £12,750.

Step IV. Add the results of Step III to give an estimate of the project price. Store this estimate and return to Step II. Repeat N times, where typically N = 50, 100, 200 ....., to generate N simulations of the project.

Step V. Plot the N estimates as a cumulative frequency curve and a histogram.

This process was undertaken for a particular project and the results are presented in Figures 4.15, 4.16 and 4.17. Figure 4.15 is the listing of the simulated estimates, Figure 4.16 is the cumulative frequency curve indicating that 500 simulations were conducted. This curve indicates the probability of the price of the proposed building falling within a specified range. For example, reading along from the 250 point on the vertical axis we note there is a 50% probability ($^{250}/_{500}$) that the building price will be less than approximately £360,000, while reading along from the 400 point on the vertical axis indicates that there is an 80% probability ($^{400}/_{500}$) that the building price will be less than £410,000.

The histogram in Figure 4.17 is used to supplement the cumulative frequency

Fig 4.15

ESTIMATES GENERATED FROM COST PLAN BY PERT ANALYSIS

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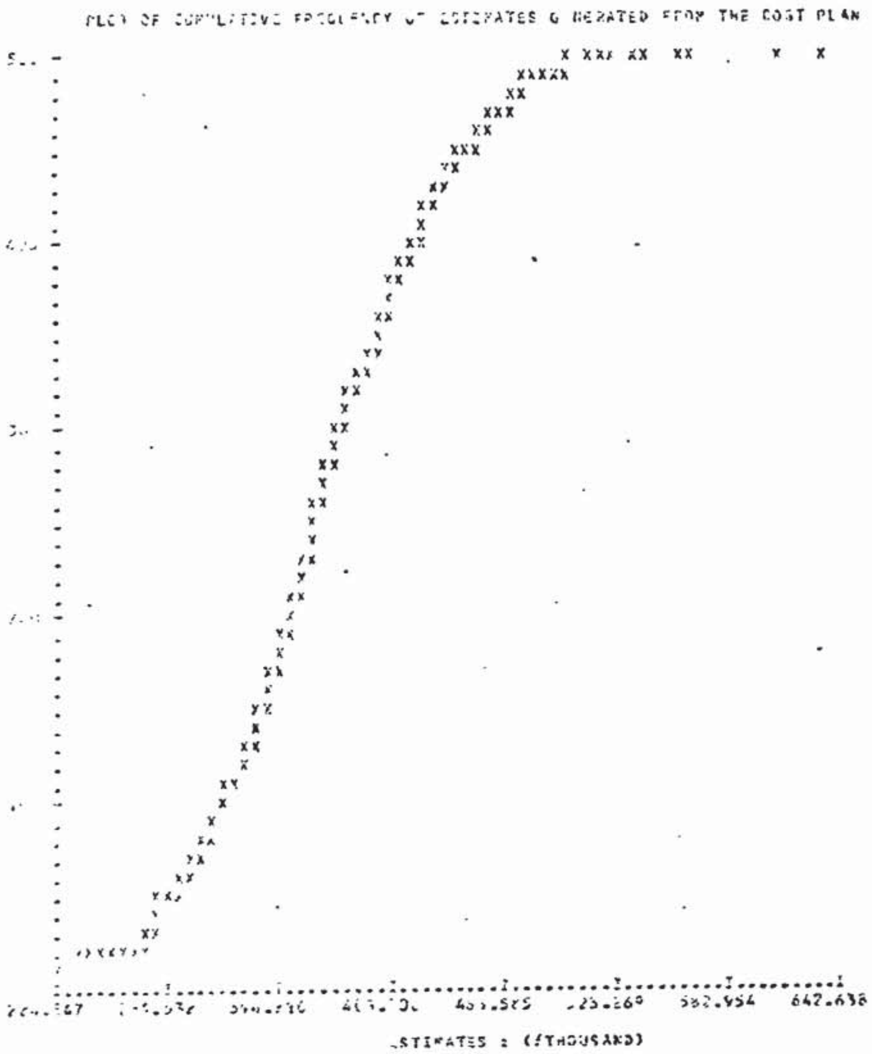


Fig 4.16

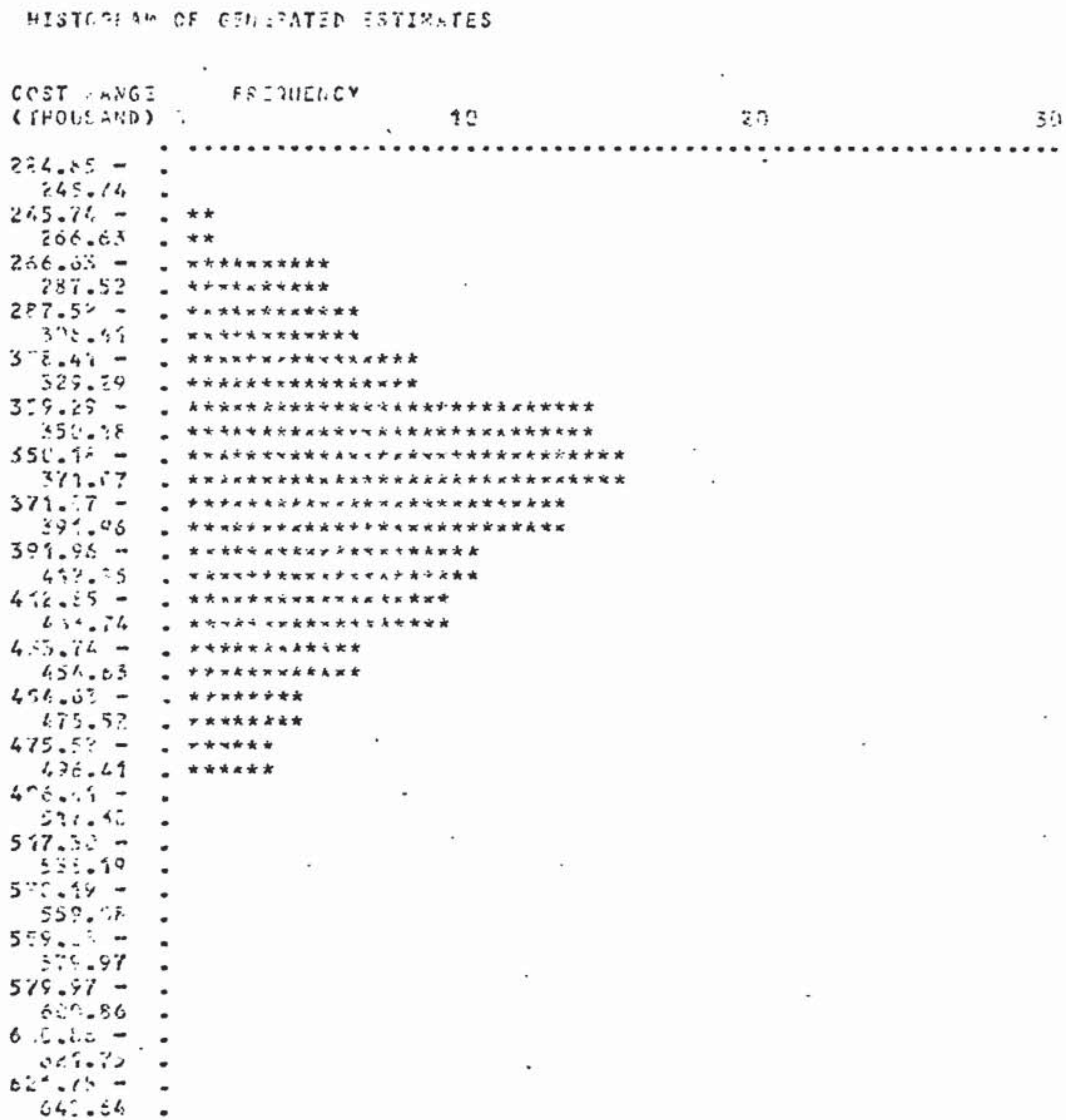


Fig 4.17

curve, since it indicates the 'most likely' price range for the proposed building. In this case, the most likely building price is between £350,000 and £371,000.

This analysis indicates that the implementation of risk analysis in price prediction is feasible. It does, of course, require the use of the computer, but provides a useful extension of price prediction techniques available to the quantity surveyor.

4.9 Conclusions.

The chapter has dealt step by step with accuracy error, reliability and predictability of price forecasts. The scope has been intentionally wide, in an attempt to gain greater understanding of estimating variability on the part of the contractor and the quantity surveyor. We have drawn conclusions at the end of various sections within the chapter, which can be summarised as:

1) The contractor's tender price cannot be taken as an accurate reflection of the true cost of a particular project, but on average contractors appear to achieve their target margin over a range of projects. The quantity surveyor should, therefore, attempt whenever possible to identify the final account price, making due allowance for any changes in the scope of work. This also reinforces the view that price prediction should be based upon a range of historical projects.

2) We feel there is a need for the quantity surveying profession to pay greater attention to the analysis of its performance when undertaking price predictions for proposed buildings. Our research highlighted a different estimating trend exhibited by two County Council cost planning departments; in both cases the detrimental trend could have been detected and remedied by closely monitoring performance. The trend

control and deviation control charts we have developed provide a method of monitoring the estimating performance of the quantity surveyor.

3) The analysis of error bounds indicates that the quantity surveyor can reduce errors in price prediction by concentrating on reducing the variability within selected elemental categories.

4) The application of risk analysis applied to cost planning provides a method of determining the level of probability of obtaining a tender for a proposed building within the price prediction.

Chapter 5

The use of duration models in the prediction process

5.0 Introduction.

In the previous chapters we have concentrated on examining price prediction techniques using unit price rates. We discussed some of the limitations of unit price rates and we now go on to consider the development of a new approach to price prediction. The project and activity durations have been identified as having an influence on price. The central concern of the next two chapters is, therefore, incorporation of the duration and the operational sequence of construction activities into a price prediction technique.

At first sight the need for an accurate assessment of construction time is primarily vested in the client, whose outgoings and income may well be dependent upon reasonably accurate forward planning. Equally the contractor wishes to optimise resources and, ideally, will prescribe a construction time which ensures a satisfactory balance between time and cost. On the whole the design team takes little regard of construction time and, even though a construction duration may be stipulated in the tender documents, this is generally derived from a knowledge of the performance which has previously been achieved in constructing buildings of similar type and size.

Such predictions are, however, notoriously inaccurate largely because of the limitations set by the input data. We may treat these broadly as follows:

a) Information on duration and performance, as collected by the quantity surveyor from published data and personal experience of completed buildings, is inadequate and often unreliable.

b) The information available at the early design stage when the client requires the price and time prediction is not in a form which currently lends itself easily to the task of making a reliable prediction of construction time.

c) Even when the bill is prepared the unit price concept does not permit a separate evaluation of time, even though many of the items in the bill are demonstrably time sensitive.

In Chapter 2 we stated that the price of any measured item is

$$P = NR$$

where N is a number and R is a unit price rate. R may, however, be further subdivided into:

$$R = f(M,L,K)$$

where M = material, L = labour, K = plant. Further terms may be added to represent the cost of supervision, risk, overheads and profit. Now at the very least L and K are time dependent so that:

$$P = NM + t(L,K)$$

and the significance of time as an element depends entirely upon the magnitude of the term $t(L,K)$ relative to other terms in the total equation. This term is in turn affected by the ways in which labour and plant are combined. Thus, the time required for an activity might be reduced by the substitution of additional plant for labour. In terms of the derivation of the unit price, it is evident that the time aspect of the work has a strong influence upon the total price, but the quantity surveyor takes little direct account when calculating prices of the length of time taken for an activity, or even the total project duration. His prime concern being the relationship of the price to the quantity of finished work.

The BCIS Standard Form of Cost Analysis (1978) requires only the overall construction time to be stated in the cost analysis. The bill of quantities relates to the overall construction period, but does not specifically consider the sequence of activities for a project, nor the time required for any particular event in the building process.

The questions therefore to be considered are:

1) the extent to which the quantity surveyor should try to produce an accurate estimate of construction time and, in particular, to whom this would be helpful;

2) the type of information which might be needed, its acquisition and usage, in order to provide a reliable estimate of the construction duration, assuming such to be desirable.

5.1 The Significance of the Construction Duration.

We have stated that most unit price rates are time sensitive. At this juncture we shall concentrate our research on one trade which could be predicted with greater accuracy if an estimate of the total, or parts of the construction duration were known. We shall, therefore, first develop a general system which allows us to evaluate the price implications of construction duration and shall then apply this system to one particular trade. In doing so we have chosen the preliminaries trade for three main reasons. Firstly, the value of the preliminaries as a proportion of the total project value represents a significant part of the construction price. To gauge the extent of the value of preliminaries we analysed a sample of 216 low bids for projects of varying job types and size constructed from 1975 to 1979.

Figures 5.1, 5.2, 5.3, 5.4, 5.5 and 5.6 show the scatter diagrams for the projects, with the preliminaries percentage value plotted against the total project value for the period 1975 to 1979 inclusive. The mean overall percentage value of the preliminaries is 25.22% with a coefficient of variation of 41.47%. Interestingly, 10 years ago a value of 10% for the preliminaries trade would have been considered as the normal value, as was shown by the analysis in Chapter 3, yet for none of the years we analysed over the period 1975-1979 was there a mean value below 22%.

Secondly, as can be seen from Figures 5.1 to 5.6 and from the analysis in Chapter 2, the preliminaries items exhibit wide price variability. This is partly caused by the contractor's strategy when pricing preliminaries items in the bill of quantities. For example, the cost of the crane might be included in the concrete price rates, alternatively or it may be given as a lump sum in the preliminaries trade. This lack of uniformity from the quantity surveyor's viewpoint will lead to error when using historical prices for prediction.

Thirdly, from the quantity surveyor's viewpoint, the contractor's method of pricing preliminaries items is probably the most imperfectly understood of all the trades, partly because of a lack of knowledge about the construction duration. Many of the preliminaries items are significantly affected by the total construction duration, for example, site supervision, site huts, etc.

In addition, there are other items of preliminaries, the prices for which are time dependent, in what might be termed a partial sense; in other words the prices are affected by a duration which is less than the total project duration, e.g. external scaffolding and craneage.

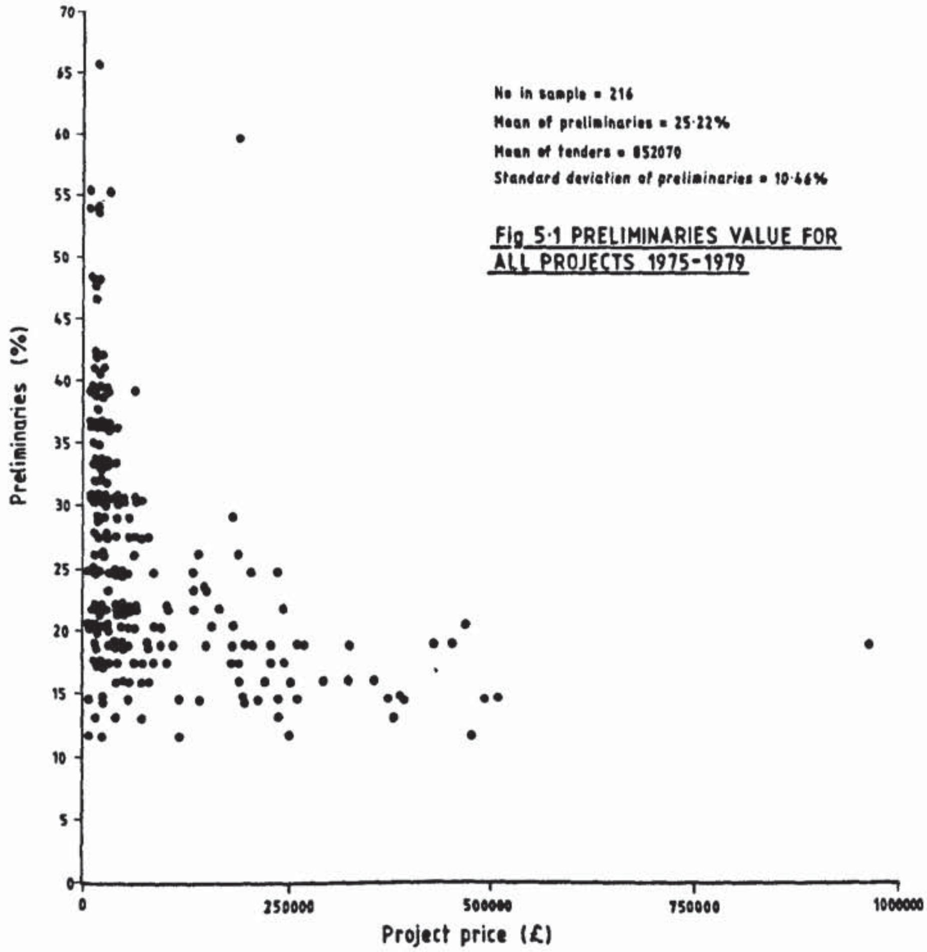


Fig 5·1 PRELIMINARIES VALUE FOR ALL PROJECTS 1975-1979

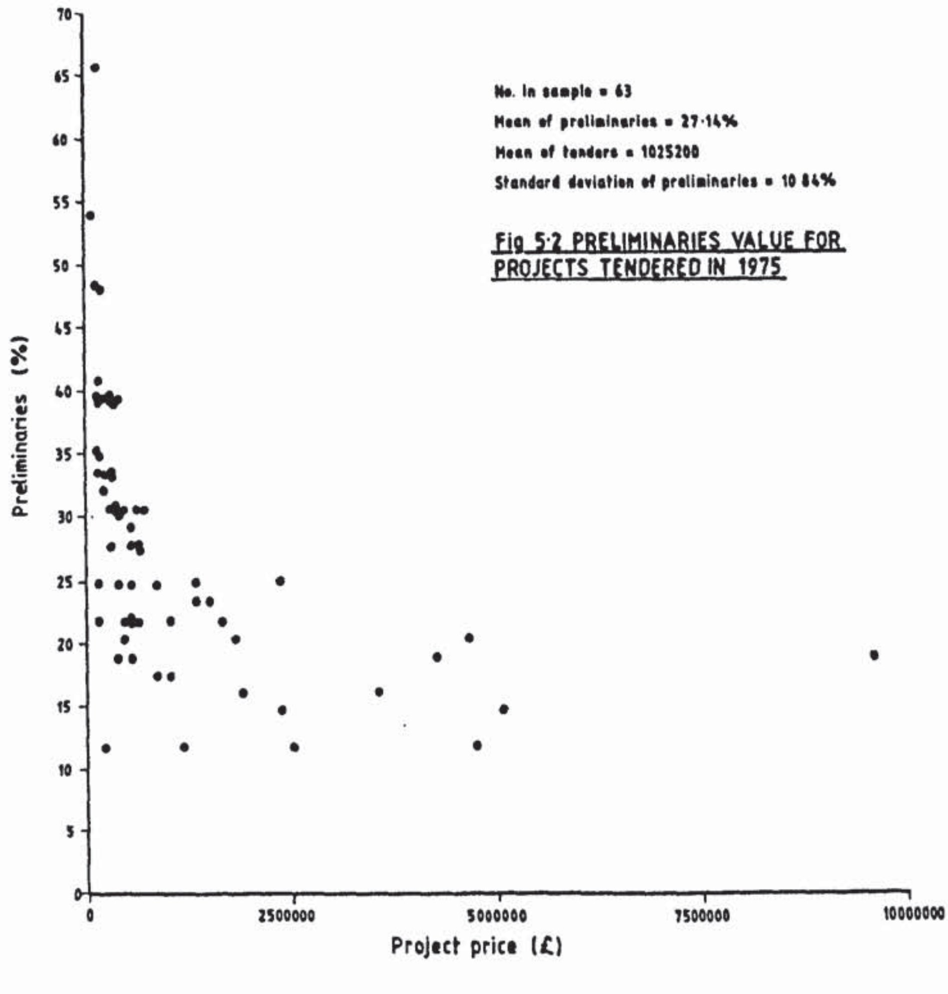


Fig 5·2 PRELIMINARIES VALUE FOR PROJECTS TENDERED IN 1975

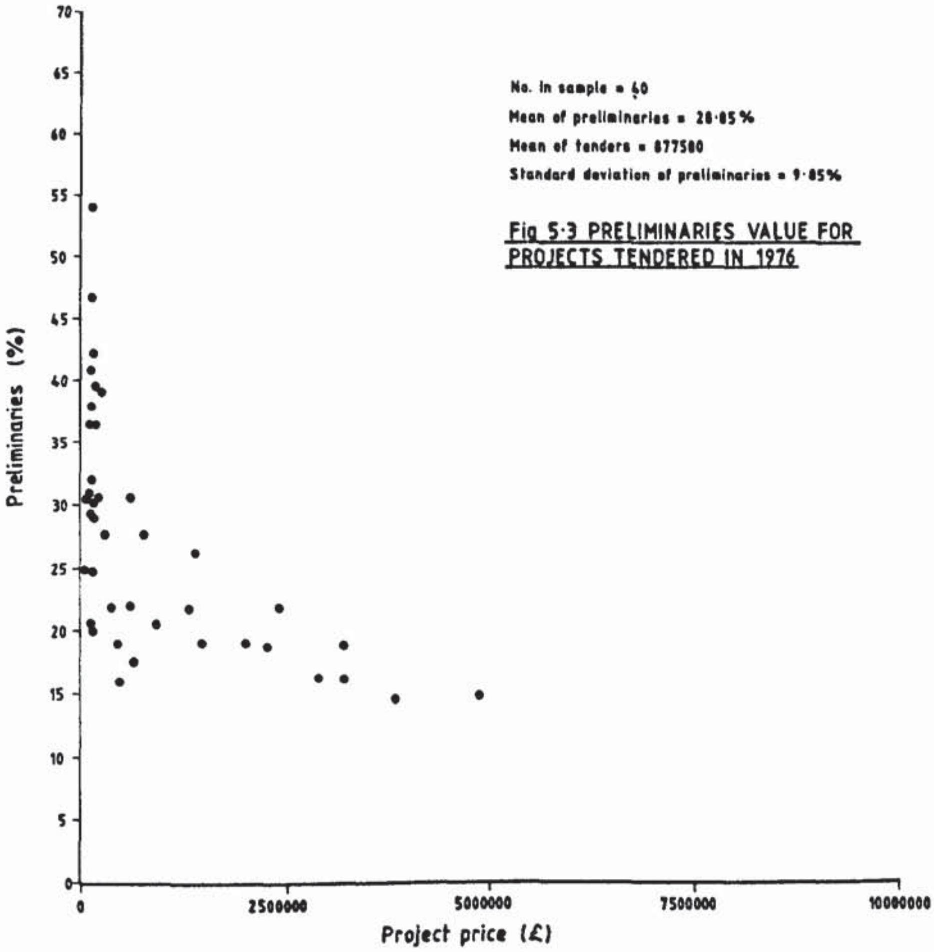


Fig 5·3 PRELIMINARIES VALUE FOR PROJECTS TENDERED IN 1976

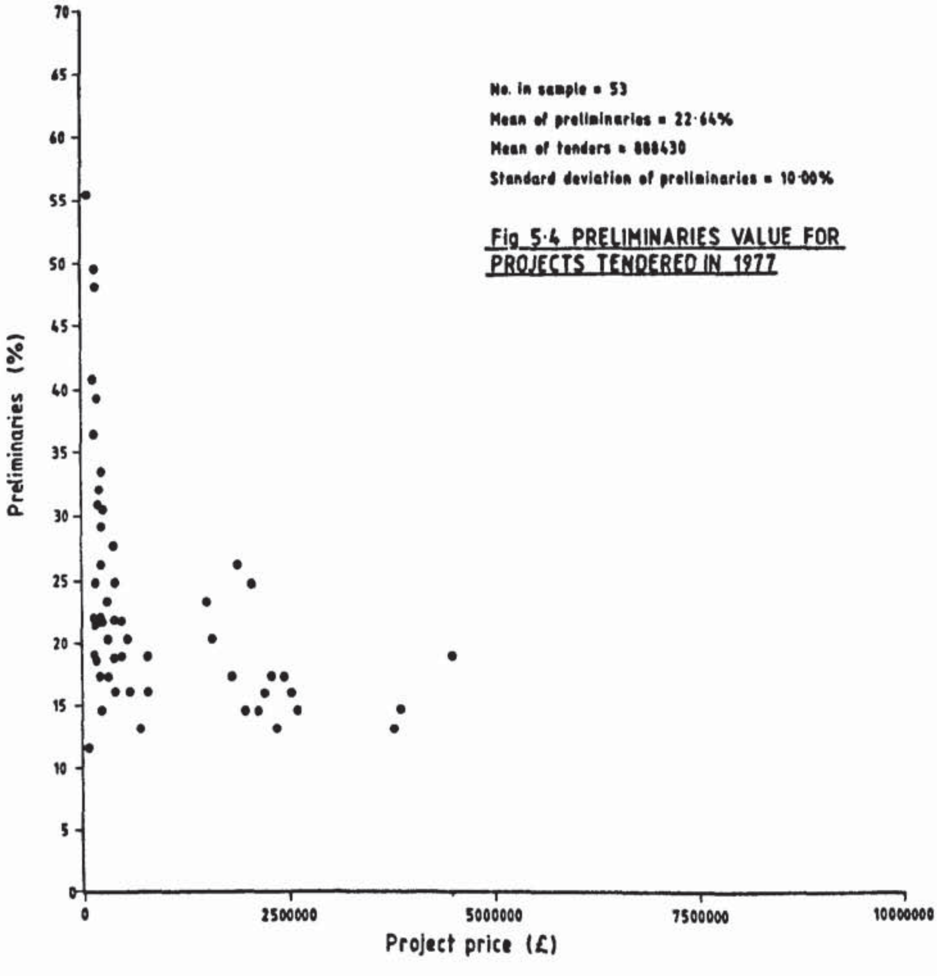


Fig 5·4 PRELIMINARIES VALUE FOR PROJECTS TENDERED IN 1977

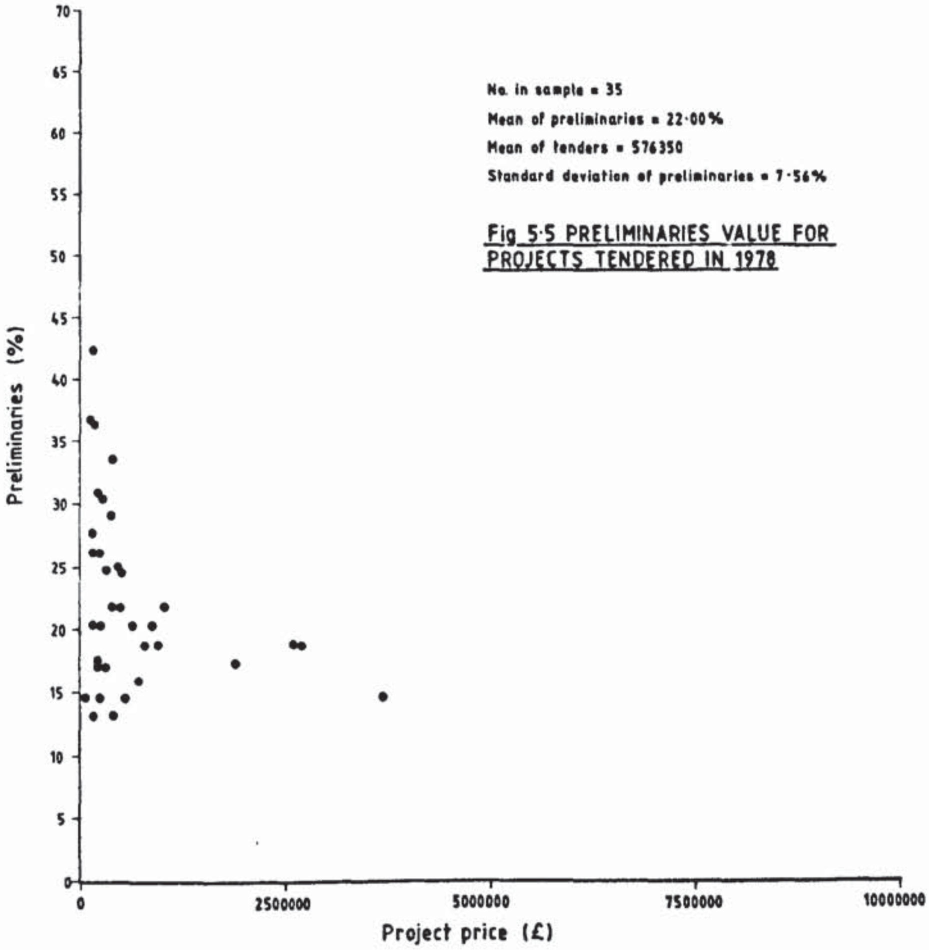


Fig 5·5 PRELIMINARIES VALUE FOR PROJECTS TENDERED IN 1978

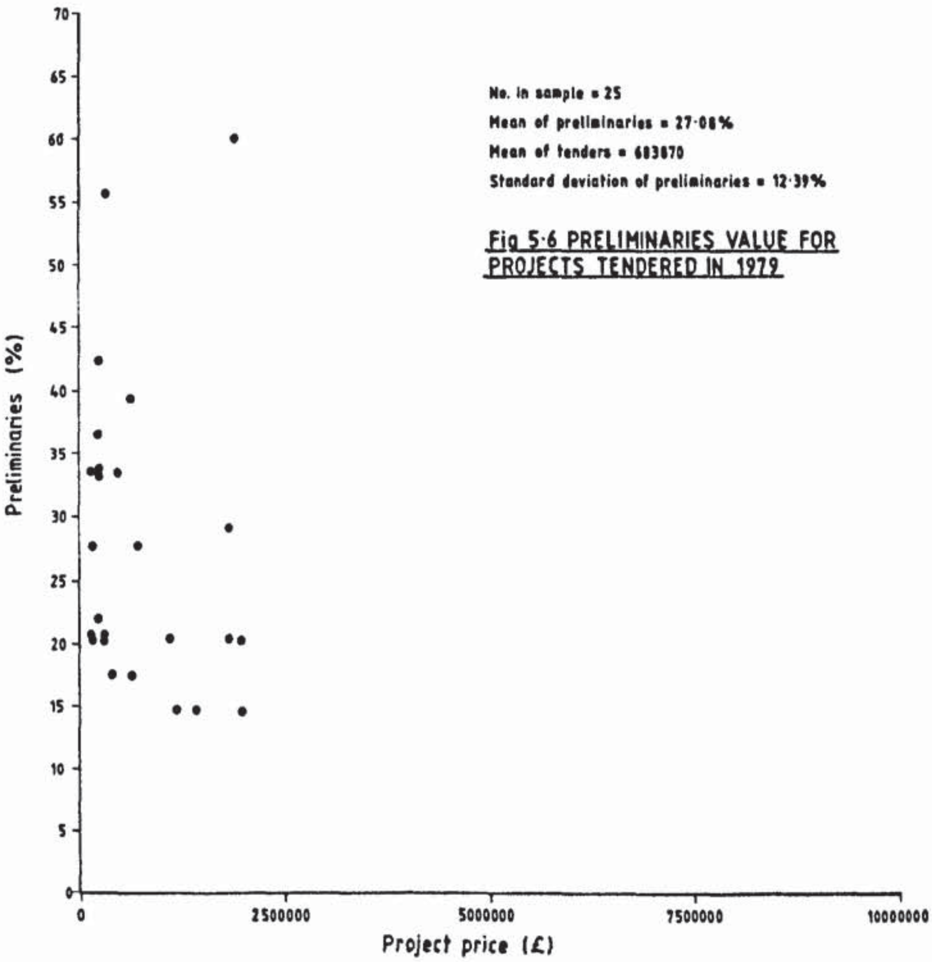


Fig 5·6 PRELIMINARIES VALUE FOR PROJECTS TENDERED IN 1979

We can conclude that a knowledge at the design stage of the project duration would help the quantity surveyor in predicting the preliminaries. However, a new price prediction technique would be required that would enable the quantity surveyor to use that information. We now go on to develop such a technique, and will return to the topic of preliminaries later in the chapter.

The high interest charges levied upon clients and contractors for borrowed money to finance projects, has meant that a greater awareness of cash flow forecasting has emerged within the construction industry over the past few years.

There are two viewpoints to cash flow forecasting, (a) the client's and (b) the contractor's. The client is concerned with the flow of money during construction and the retention conditions. The contractor is interested in the sequence of cash flow throughout the project, the retention conditions, the delay in receiving payment from the client, the credit arrangements with sub-contractors and suppliers, and the profit margin.

Various analytical techniques exist to predict cash flow profiles, but none of these is capable of application by the quantity surveyor at the cost plan stage, because of a lack of knowledge of the sequence of activities and their durations. In our opinion it is desirable to have a reliable prediction of the construction duration.

We first consider what techniques are currently used by quantity surveyors to predict the construction duration.

The quantity surveyor's approach to forecasting construction duration is based on the use of historical data. The obvious limitation is that because building is a custom industry, productivity is affected by project type, size, repetition and complexity. As a result, even within a homogeneous sample of completed buildings there is likely to be considerable hetereogeneity in the construction duration of the buildings.

Various authors have undertaken research into the implications for the contractor of the speed of construction (Bromilow (1976), Fine (1978), Bennett (1978) and others). We do not intend to extend into this area of research other than at a general level.

Relf (1974) looked at the effect of the project size on the contractor's performance by analysing 250 schools and housing projects. He concluded that larger contractors are able to deploy resources on site at a faster rate than small contractors and that smaller contracts proceed on average at a lower intensity than larger contracts. Relf's view was that the size of the contractor has an influence on the speed of construction whereas quantity surveyors tend to use project price as the main determinant for selecting homogeneous samples. We investigated the significance of the project duration on price by analysing a sample of 80 completed projects containing factories and warehouses, schools, and office buildings (certain of the office buildings contained shops and banks at ground level). Private sector clients accounted for 57 of these buildings.

We were interested in investigating the relationship between project price and project duration by considering:

a) project type;
b) construction type; and
c) construction complexity.

The data were categorised as follows:

Project value:	Tender price. All the prices were rebased to April 1976 using the BCIS tender price index.
Project duration:	Number of weeks required for construction stated in the tender.
Project type:	1. Factories and warehouses. 2. Schools. 3. Offices.
Construction type:	1. Steel framed structure. 2. Concrete framed structure. 3. Brickwork structure.
Project complexity:	1. High complexity. 2. Medium complexity. 3. Basic complexity.

The complexity of any project is difficult to assess without a detailed knowledge of the building under construction. The level of complexity was based upon subjective judgment using the presence or absence of a basement or abnormal foundations; the volume of mechanical and electrical services; the intensity of internal partitions; and the plan shape and exterior closure.

Figure 5.7 shows the scatter diagram of the construction duration considered against the project value for the full sample. There was a correlation coefficient of 0.588 between construction time and the construction price for all projects which confirms that there is a relationship between the

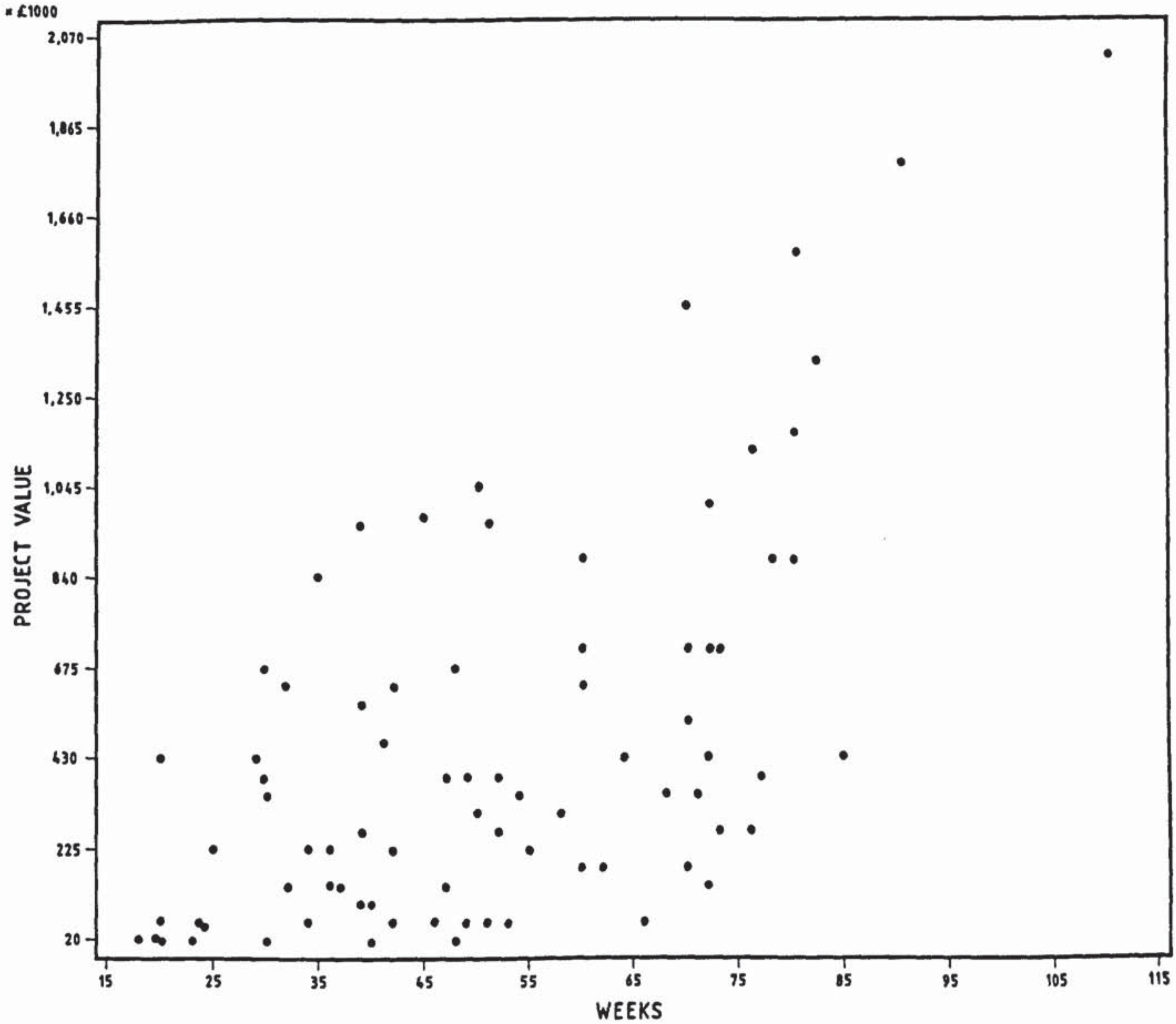


Fig 5·7 SCATTER DIAGRAM DURATION AGAINST VALUE project price and project duration. Table 5A further shows, however, that this relationship is stronger when the total sample is partitioned into various groups, particularly in the case of complexity. When the offices sample is considered as one group there is a low correlation, but when the complexity is taken into account there is a significant improvement in the correlation coefficient.

TABLE 5A

	Category	No. of Projects	Correlation coefficient for relationship between construction price and construction duration.
1.	Factories and warehouses ...	35	.792
2.	Schools	9	.671
3.	Offices	36	.543
4.	Steel framed structure ...	37	.489
5.	Concrete framed structure ...	27	.472
6.	Brickwork structure	16	.702
7.	High complexity	20	.896
8.	Medium complexity	25	.742
9.	Basic complexity	35	.776
10.	High complexity factories and warehouses	4	.682
11.	High complexity offices ...	16	.941
12.	Medium complexity factories and warehouses	11	.703
13.	Medium complexity offices ...	10	.821
14.	Medium complexity schools ...	4	.615
15.	Basic complexity factories and warehouses	20	.933
16.	Basic complexity offices ...	10	.660
17.	Basic complexity schools ...	5	.599

The results of the analysis suggest that the quantity surveyor needs a more reliable system of predicting a construction duration, a system which preferably, is derived from the measurement information produced during the sketch and scheme design stages, and which is capable of taking account of the specific design characteristics and the complexity of a proposed scheme. As in Chapter 3, we feel that the appropriate system should be based upon some kind of simulation model, in this case simulating the activities of the construction planner at the tender stage to produce a construction duration.

5.2 Construction Planning at the Pre-Tender and Tender Stages.

The objective of the quantity surveyor is that of predicting the final cost while the objective of the construction planner is that of predicting the total construction duration. As we have shown, construction time enters into the bill of quantities only as an item compounded into a unit price rate. The precise details of how the time is to be used are left to the construction planner whose essential tool is the network, in one form or another. This specifies time but does not, in the first analysis, specify the finished price.

Neither the bill of quantities nor the network provides the information that both need if the building is to be completed on an optimal (though not necessarily a minimal) cost/time basis. In fact the quantity surveyor, working from the finished dimensions, possesses a considerable volume of information, but the contractor must generate this same information in a different format for himself in the production of the pre-tender programme. The construction planner is primarily interested in the sequence of activities and, in particular, in those activities which fall upon the critical path through the network. Thus the planner produces a construction duration model, the quantity surveyor a cost model; both are valid in their different ways.

What is needed is a prediction technique that can link both the price and time and which the quantity surveyor can use at the design stage. This is the purpose of the proposed duration model based upon a precedence diagram.

For the purposes of construction planning, the building process may be regarded as consisting of a series of independent work packages which must relate to each other, and in general the performance of any given package will be dependent upon the performance of the preceding work packages.

The construction planner. therefore, is essentially dealing with two classes of problem. In the nomenclature of operations research these would be described as sequencing problems and co-ordination problems (Ackoff and Sasieni (1968). In their simplest terms, sequencing problems are, essentially, a branch of queueing theory, the theory which determines the selection of an appropriate order in which a series of operations can most effectively be carried out. In building, many of these sequences are largely predetermined, thus, bricks cannot be laid until the concrete foundations are complete, etc. Sequencing problems may, however, be complicated by a number of conditions of which the following are pertinent in the present case:

(a) Overlap: it may be possible to start a second work package before the first is complete.

(b) Rework: if any one of the packages involves an inspection, defective work may need to be corrected, thus causing delay to succeeding work.

(c) Expediting: in order to achieve a deadline, which may be set by the client or by external factors, such as delivery of goods, a task may be moved out of sequence and speeded up. This is equivalent to promoting the place of that task within the queue.

(d) Delay: this may be caused by shortage of material, labour or plant.

(e) *Variable processing time: in a multi-shift operation the time required* for a given work package may vary from shift to shift or from operative to operative.

Once a sequence has been determined, the problem of construction planning now becomes one of the general class known as co-ordination problems. These involve the relationship between the completion date of a project and the times of starting each of the individual tasks of which it is composed. The following conditions must be met if analytical techniques are to be applied.

1) The collection of tasks must be clearly defined.
2) Each task can be started and completed independently within a previously specified sequence.
3) The tasks are ordered so that we may specify what precedes and what follows a particular activity.

In general, analysts have concentrated upon two questions:

(1) how to identify the tasks that must be completed on schedule if the entire project is to be completed on schedule, and how to review progress of the project over a period of time;

(2) how, if it is possible to reduce the time taken on some or all of the tasks at increased cost, the tasks should be arranged so as to minimise time and cost of the whole project.

Two techniques have been developed to handle these problems, PERT (project evaluation and review technique) and CPM (critical path method). The construction literature abounds in these, and in nearly every case misses the whole point. Whilst it is perfectly correct to define PERT as an event orientated system and CPM as an activity orientated system, these definitions are at best superficial, and at worst uncritical.

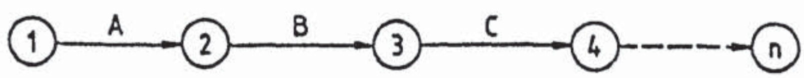
There is, in fact, one fundamental difference between the two. CPM assumes that each task is subject to control, that is to say that the cost of performing a task depends upon the scheduled time. Usually the more rapidly a task is performed the higher is the cost.

PERT on the other hand assumes that the task times are not subject to control and that there exists a unimodal distribution of completion times from which we can estimate a most likely completion time. In its complete form (so-called "full PERT") it is used to calculate the expected project duration and to estimate the probability of various delays. But, although PERT can take account of uncertainties in task times, it is not concerned with the direct control of task times by the allocation of resources to tasks. As its name implies, it is a review technique rather than a control technique.

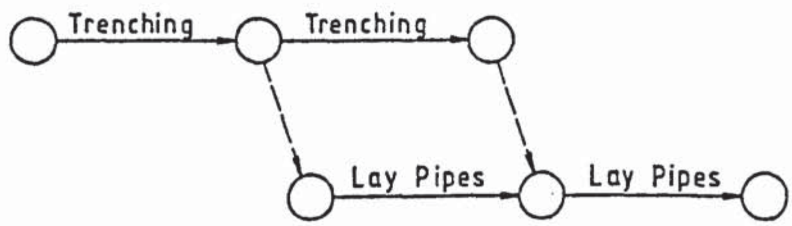
Despite their limitations, both methods are quite widely used in construction planning, generally in the form of a network based upon a precedence diagram format. The objective of the network is solely that of defining a series of processes. The cost of performing these and the additional cost of expediting some or all of them represents a separate problem.

5.3 Delay Ratio and Activity Links.

Consider first a simple network in which the critical path may be identified as a series of operations as shown below.



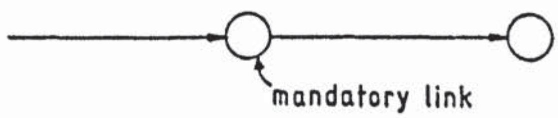
There are many practical situations in which this idealised picture may be modified once it is recognised that it is not necessary to complete activity A before commencing activity B. Thus, in pipelaying if A represents trenching and B represents pipelaying, B can commence as soon as trenching has produced an adequate length of run. The sequence now takes on the form of a ladder diagram:



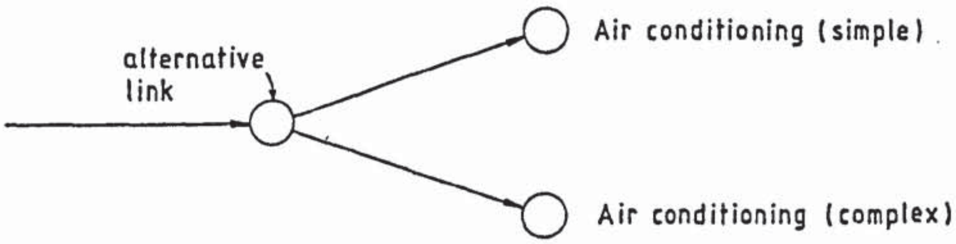
Clearly, there must be defined a certain level of progress of activity A before B can commence. We call this the "delay ratio" whose purpose is to express the level of performance of one activity which should be achieved before another activity can start. The delay ratio is expressed as a percentage of completion of the preceding activity.

The links between activities represent decision points and we may define these according to the manner in which each is activated.

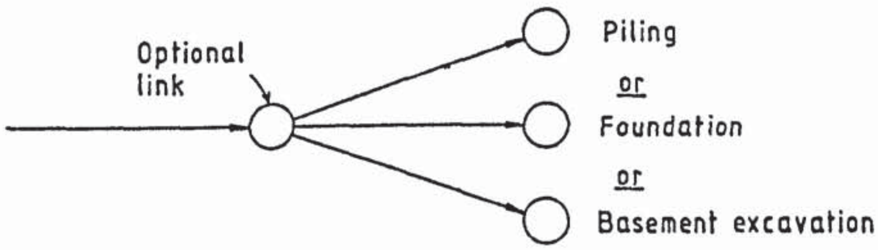
(a) A "mandatory" link. Once the activity is complete the path must continue to the next link.



(b) An "alternative" link where, once the link is activated the path continues as mandatory, otherwise the path is stopped.



(c) An "optional" link where a set of activities exist of which only one may be activated and which thereafter becomes mandatory.



5.4 Criteria for the Development of Duration Models.

The duration model should be useable from the sketch design stage. It is pointless developing a highly sophisticated duration model if the output constants used to calculate activity durations are derived from insensitive data. The objective is to predict the contractor's evaluation of the construction duration at the tender stage. However, the research undertaken in producing the duration model showed that contractors, at the pre-tender planning stage, do not go to a high level of detail.

It must be clear that it would be impractical for the quantity surveyor to produce a precedence diagram for every project at the cost planning stage. With this point in mind, the following criteria were considered desirable for the development of a duration model for use by the quantity surveyor:

1) Simple, economical and quick to use.
2) Capable of either manual or computer assisted application.
3) Flexible enough to meet continuously changing criteria and conditions.
4) Capable of giving the designer the impact upon construction duration of alternative designs.
5) Capable of being easily updated.
6) Uses only the input measurement information which is readily available to the quantity surveyor.
7) Having the activities in the duration model readily identifiable to the elemental categories used in cost planning.

But it must be noted that the emphasis is that of desirability rather than that of necessity. Thus the term "simple" in 1) above is not a necessary requirement as long as "computer assisted" remains in item 2), since there is no virtue or advantage in simplicity, as long as there exist techniques which can adequately handle complexity. Similarly item 6) assumes that a duration model must be based upon the assumption that the only input information is that which is available to the quantity surveyor. We may well suggest that this information is not only inadequate but that it represents an input which is totally out of keeping with modern developments. Indeed the quantity surveyor may, in this part of the twentieth century, be totally wrong and wholly reactionary in requiring data to be presented in the same form as was customary a century or so ago. Nonetheless, for the present purpose we shall try to consider the use that may be made of the situation as it currently exists before considering the possible changes which would help to improve the estimate of construction time.

5.5 Constructing the Duration Model.

Initially, the constructional characteristics of a building, i.e. frame type, exterior closure type, etc. were considered as the basis for the model.

thisidea was discarded because the system would have required a prohibitive number of models to cope with all the eventualities that occur in construction. Therefore, we decided that the duration models should be developed based upon a precedence network of the critical path for each functional type of building, using the building types included in the CI/Sfb Table 0 matrix.

To avoid unnecessary duplication in the thesis, the research at this stage has been restricted to producing a model for office buildings (32)* up to ten storeys high. The principle involved in the development of the models for other building types will remain exactly the same.

A model building was required as the archetype for producing the precedence diagram and deriving the output constants. Completed projects were not considered to be appropriate for the model because a design was needed which was sufficiently flexible to be adapted for various alternative forms of construction. A hypothetical ten storey office building of square plan shape as illustrated in Figure 5.8 was therefore chosen as the most suitable plan form.

The first task was to list the major construction activities from which a precedence network was produced showing the logical inter-relationship between the activities. The next step was to plot the critical path through the network, and to eliminate those items which, once given the critical path, did not affect the overall construction period. The term critical means that succession or chain of activities through the network which minimises the time from the beginning of the first to the end of the

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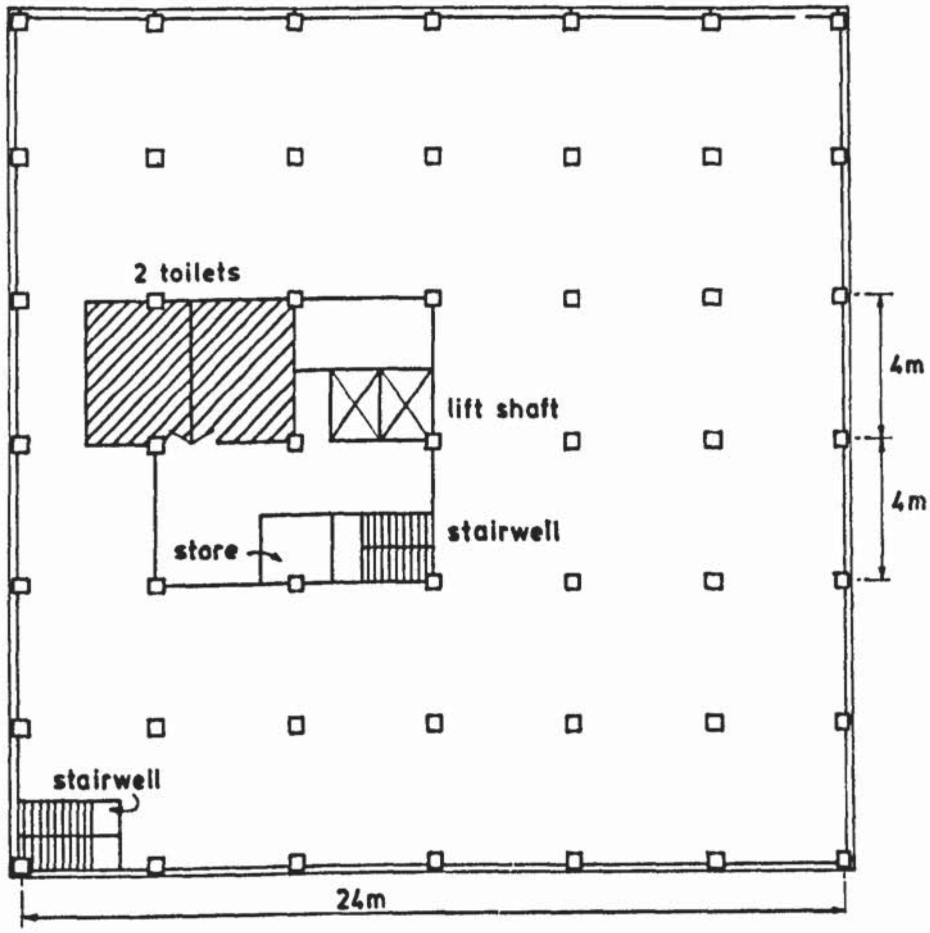
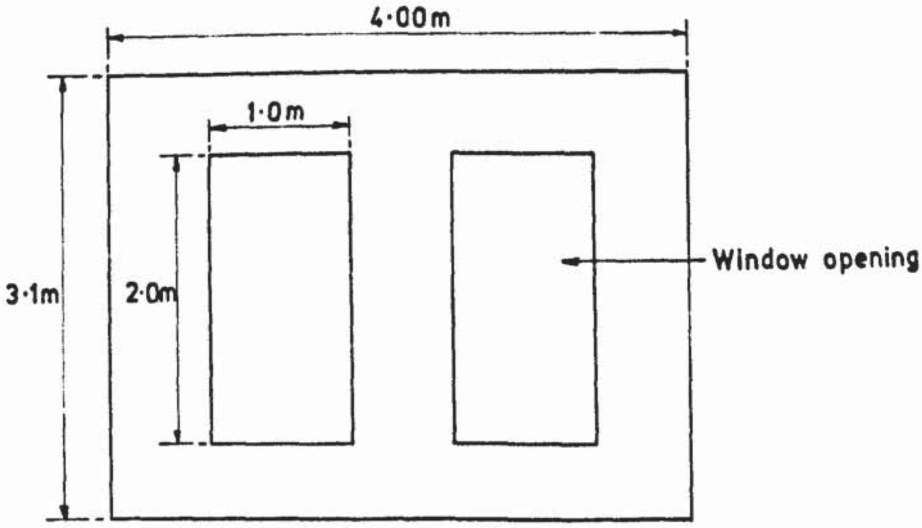
* CI/Sfb Categories

Fig 5.8 MODEL FOR HIGH RISE OFFICE BUILDING.



Typical Floor Plan

A ten storey office building including a basement area extending the area of a typical floor.



Typical Brickwork Panel To Elevation

Plant & lift motor room located on roof.

last event. Some of the activity items were grouped together to reduce the network to a manageable size, which was considered to be a maximum of 100 activities. For example, the joinery activity includes doors, skirtings, fittings, etc.

Figure 5.9 shows the precedence network duration model for a proposed office building together with the estimated delay ratios. Where possible, the activities have been numbered in sequence. In order to use the model for a proposed building, choices are made at each of the alternative and optional links, these choices being based upon the construction type.

Where possible, all the likely constructional options have been included in the network. Invariably, some constructional option will occur which is not in the network. The model has been constructed with this difficulty in mind, and a substitution of items is easily undertaken.

A drawback of a network is that it requires the inter-dependencies among activities to be laid down with complete certainty. Eismer (1962) and Elmaghraby (1964) developed new network algebras to overcome this shortcoming, allowing probabilistic transitions from one network node to another. However, the detailed network that would be required for the duration model to conform to the probabilistic networks were not felt to be warranted in view of the insensitive construction industry data.

The output values for each of the activities were then considered. Each activity was given an estimated time for completion of the task. The quantities for the model building were measured in accordance with the activities in the model. Advice was obtained from construction planners as to the most likely output constants. These were estimated on the basis of a normal approach to performing any particular operation, with a normal

Fig 5·9 PRECEDENCE NETWORK OFFICE DURATION MODEL

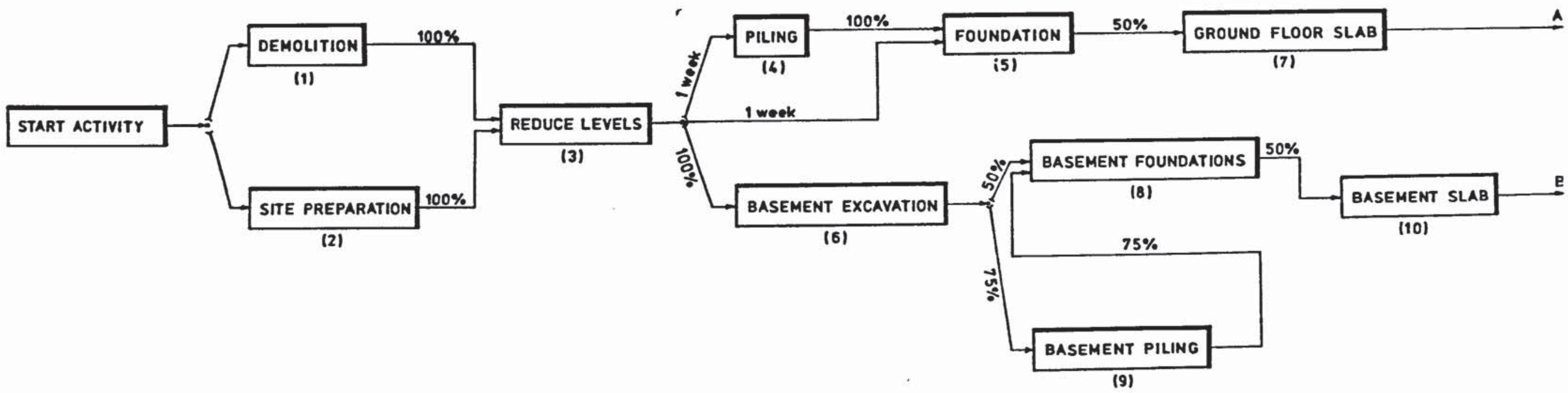
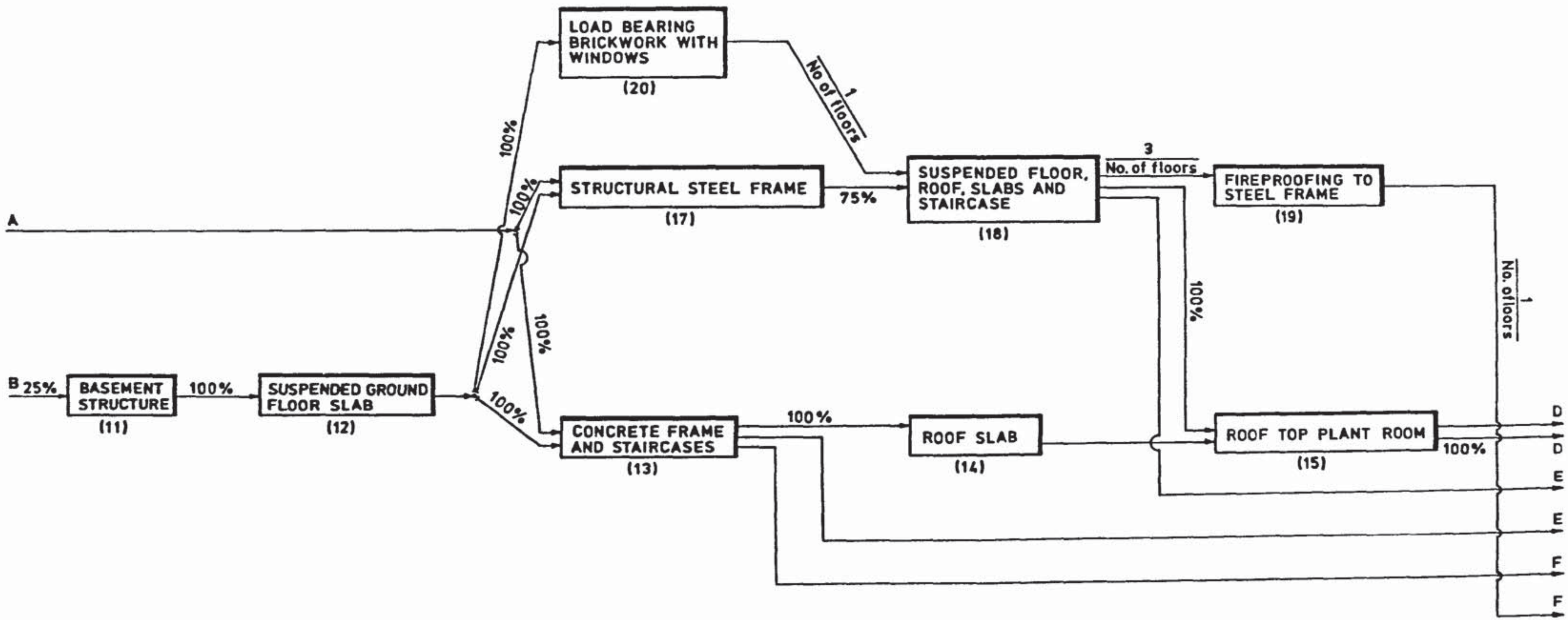


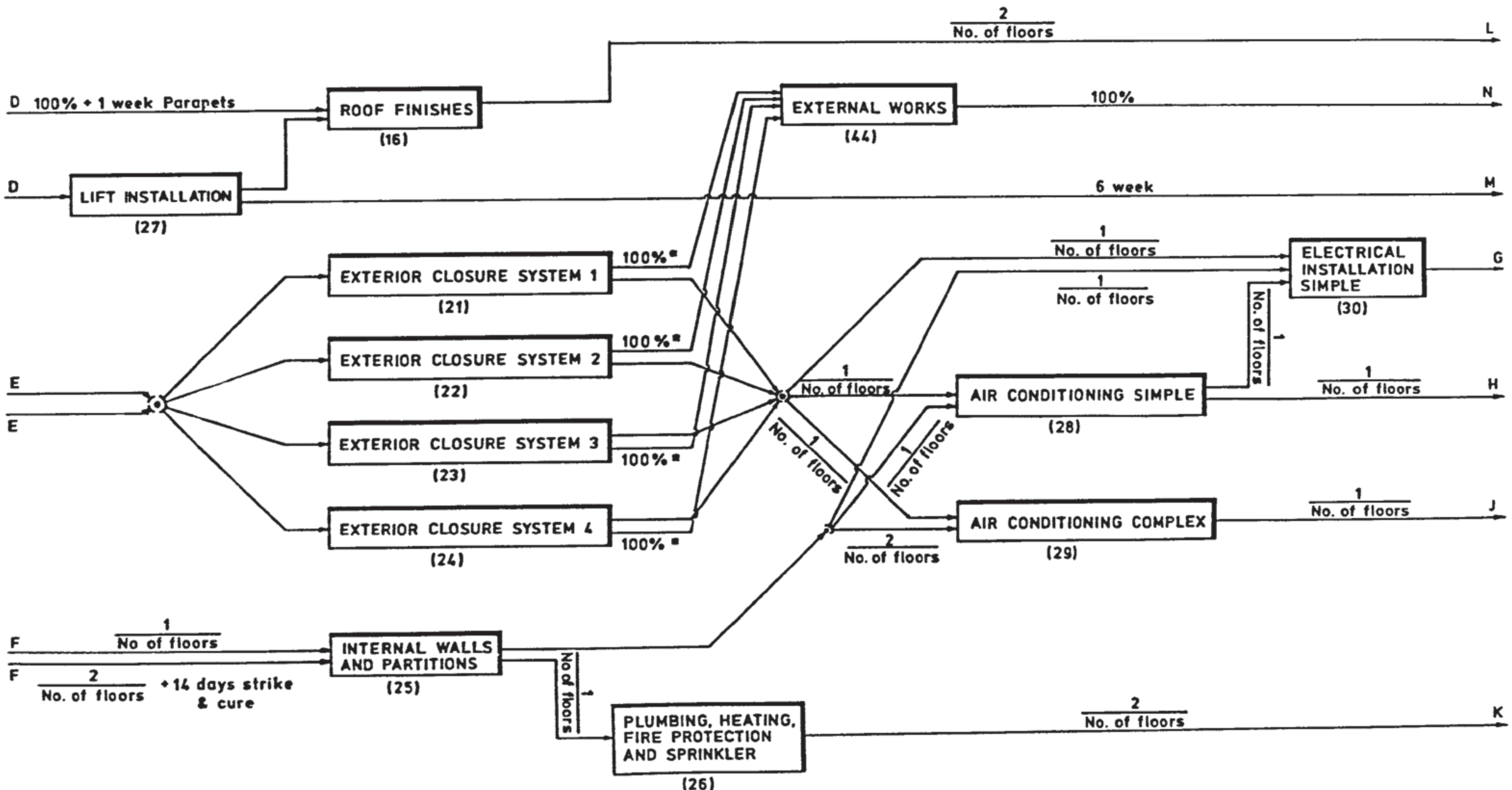
Fig 5·9 (Cont'd)


A
B
25%
BASEMENT STRUCTURE
(11)
100%
SUSPENDED GROUND FLOOR SLAB
(12)
100%
100%
100%
100%
100%
100%
LOAD BEARING BRICKWORK WITH WINDOWS
(20)
1 / No of floors
STRUCTURAL STEEL FRAME
(17)
75%
CONCRETE FRAME AND STAIRCASES
(13)
100%
ROOF SLAB
(14)
SUSPENDED FLOOR, ROOF, SLABS AND STAIRCASE
(18)
3 / No. of floors
FIREPROOFING TO STEEL FRAME
(19)
100%
ROOF TOP PLANT ROOM
(15)
100%
1 / No. of floors
D
D
E
E
F
F

Details of Exterior Closure Systems

System 1	Brickwork & window	$\frac{4}{\text{No. of floors}}$
System 2	Cill height pre-cast concrete & window	$\frac{2}{\text{No. of floors}}$ + 14 days strike & cure
System 3	Storey height pre-cast concrete & window	$\frac{2}{\text{No. of floors}}$ + 14 days strike & cure
System 4	Curtain wall	100%

Fig 5·9 (Cont'd)



* + 1 week strike scaffold

Fig 5·9 (Cont'd)

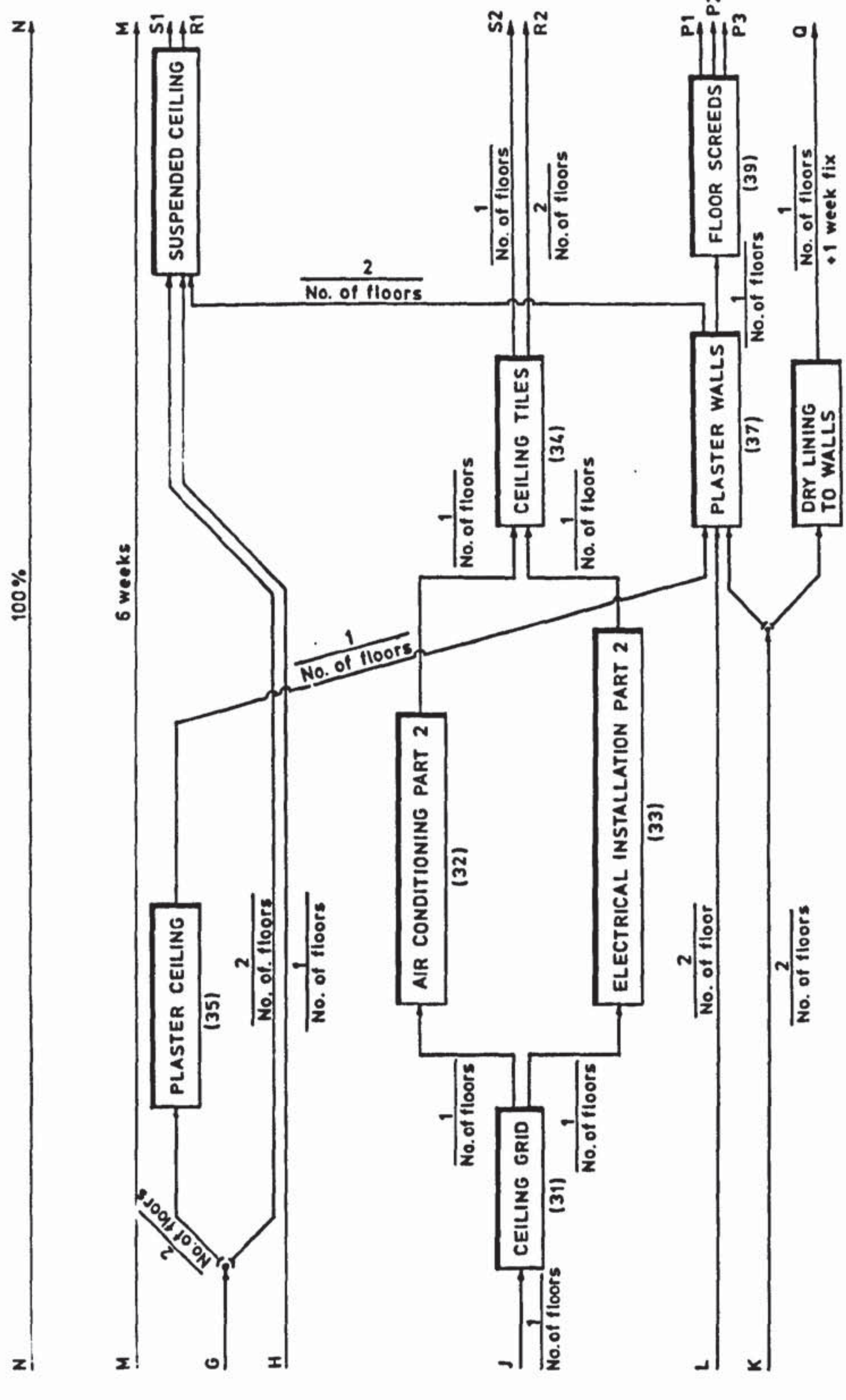
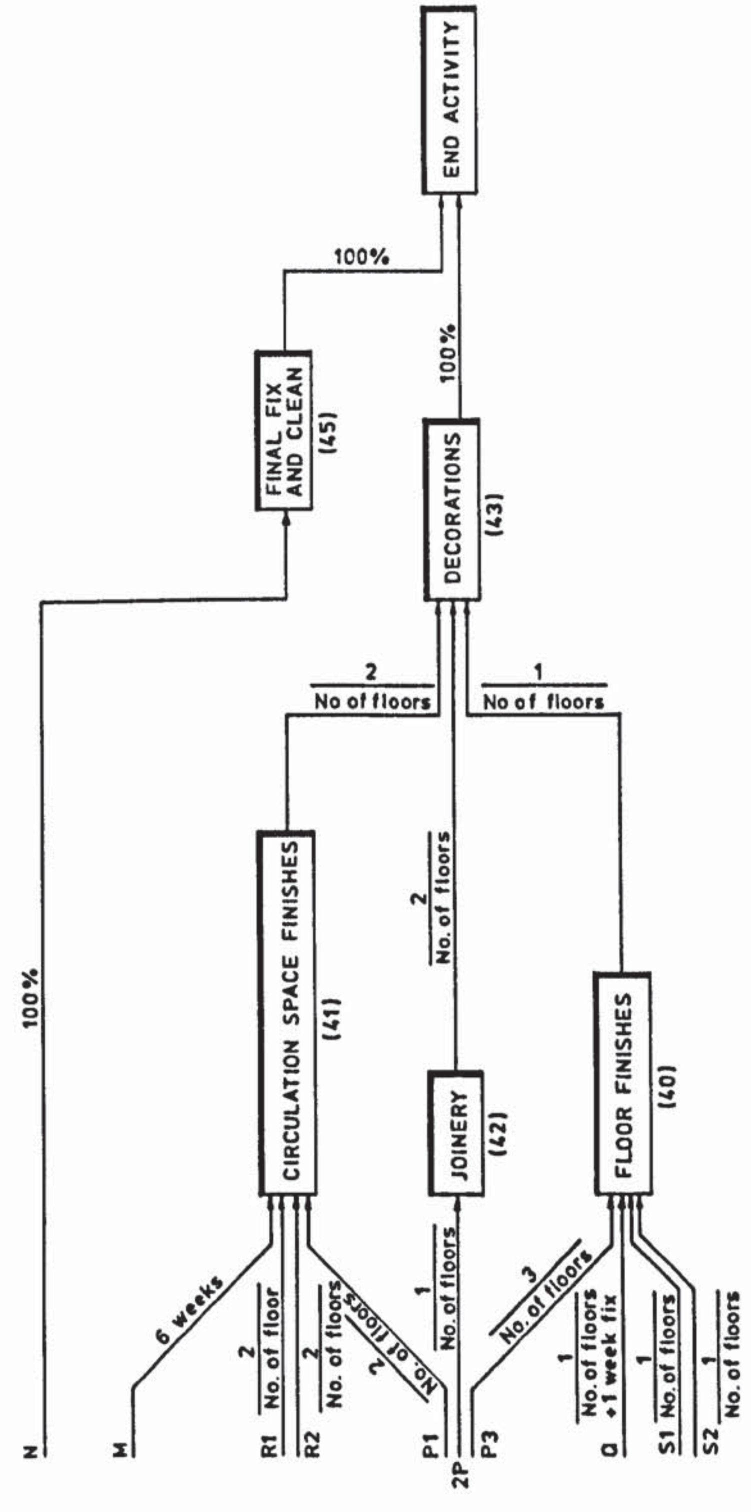

SUSPENDED CEILING
CEILING TILES (34)
PLASTER WALLS (37)
FLOOR SCREEDS (39)
DRY LINING TO WALLS (38)
PLASTER CEILING (35)
AIR CONDITIONING PART 2 (32)
ELECTRICAL INSTALLATION PART 2 (33)
CEILING GRID (31)
100%
6 weeks
1 / No. of floors
2 / No. of floors
2 / No. of floor
1 / No. of floors +1 week fix
N
M
G
H
J
L
K
S1
R1
S2
R2
P1
P2
P3
Q

Fig 5·9 (Cont'd)


END ACTIVITY
100%
FINAL FIX AND CLEAN (45)
100%
DECORATIONS (43)
2 / No of floors
1 / No of floors
100%
CIRCULATION SPACE FINISHES (41)
2 / No. of floors
JOINERY (42)
FLOOR FINISHES (40)
6 weeks
2 / No. of floor
2 / No. of floors
2 / No. of floors
1 / No. of floors
3 / No. of floors
1 / No. of floors +1 week fix
1 / No. of floors
1 / No. of floors
N
M
R1
R2
P1
2P
P3
Q
S1
S2

team of men, and with this being the only operation on which the men are working. It is assumed for time estimates that the crew will start the operation and continue it until completed. Sub-contractors were consulted on the more specialised aspects of the construction. Often the outputs supplied by planners for the same activity item varied quite considerably, in which cases a duration was derived using a PERT analysis.

The construction planner does not use productivity factors taken from text books, because the constants represent average outputs for average projects, irrespective of the functional building type. The utilisation of the constants from text books was, therefore, inappropriate for the duration model. A further difficulty would have arisen because the text book items do not show constants related to the measurement information envisaged for the models. One of the main criteria was to relate the output constants for the activities to the quantity surveyor's measurement parameters used in the preparation of the cost plan. Table 5B lists the required measurement parameters which the quantity surveyor must produce in order to use the duration model.

Table 5C shows the output constants for use with the duration model for the office building. The 'normal' outputs for each activity are listed together with appropriate adjustment factors which take account of alternative design implications. In some instances the construction considerations are shown. For example, the piling output is based upon the number of rigs. If the quantity surveyor has a project where he feels that it is feasible to increase the number of rigs, then the output factor should be increased.

The output constants were derived by analysing the sequence and extent of the tasks involved in each of the activities. Each activity comprises a number of sub-activities. A sub-network routine was, therefore, used to

TABLE 5B : MEASUREMENT PARAMETERS FOR DURATION MODEL

MEASUREMENT / ACTIVITY	No. of storeys of existing building	Gross floor area	Basement floor area	Ground floor area	Suspended floor area (1)	Roof area (2)	Roof top plant room area	Total perimeter length of exterior closure per storey	Area of site preparation	No. of lift shafts	Area of suspended ceilings	Area of plastered ceilings	Area of floor finishes	Floor area of plasterwork	Area of circulation space finishes	Area of external works
(1) Demolition	O															
(2) Site preparation									O							
(3) Reduce levels				O												
(4) Piling				O												
(5) Foundations				O												
(6) Basement excavation			O													
(7) Ground floor slab				O												
(8) Basement foundations				O												
(9) Basement piling			O													
(10) Basement slab			O													
(11) Basement structure			O													
(12) Suspended ground floor slab				O												
(13) Concrete frame and staircases					O											
(14) Roof slab						O										
(15) Roof top plant room							O									
(16) Roof finishes						O										
(17) Structural steel frame					O											
(18) Suspended floor, roof slab and staircases					O											

TABLE 5B : MEASUREMENT PARAMETERS FOR DURATION MODEL(continued)

ACTIVITY \ MEASUREMENT	No. of storeys of existing building	Gross floor area	Basement floor area	Ground floor area	Suspended floor area (1)	Roof area (2)	Roof top plant room area	Total perimeter length of exterior closure per storey	Area of site preparation	No. of lift shafts	Area of suspended ceilings	Area of plastered ceilings	Area of floor finishes	Floor area of plasterwork	Area of circulation space finishes	Area of external works
(19) Fire proofing to steel frame		●														
(20) Load bearing brickwork with windows								●								
(21) Exterior closure (Brickwork and windows)								●								
(22) Exterior closure (precast concrete and windows)								●								
(23) Exterior closure (storey height precast concrete and windows)								●								
(24) Exterior closure (curtain wall)								●								
(25) Internal walls and partitions		●														
(26) Plumbing, heating, fire protection and sprinkler installation		●														
(27) Lift installation										●						
(28) Air conditioning simple		●														
(29) Air conditioning complex		●														
(30) Electrical installation simple		●														
(31) Ceiling grid											●					
(32) Air conditioning part 2		●														
(33) Electrical installation part 2		●														
(34) Ceiling tiles											●					
(35) Plaster ceiling												●				

TABLE 5B : MEASUREMENT PARAMETERS FOR DURATION MODEL (continued)

ACTIVITY \ MEASUREMENT	No. of storeys of existing building	Gross floor area	Basement floor area	Ground floor area	Suspended floor area (1)	Roof area (2)	Roof top plant room area	Total perimeter length of exterior closure per storey	Area of site preparation	No. of lift shafts	Area of suspended ceilings	Area of plastered ceilings	Area of floor finishes	Floor area of plasterwork	Area of circulation space finishes	Area of external works
(36) Suspended ceiling											●					
(37) Plaster walls		●														
(38) Dry lining		●														
(39) Floor screeds													●			
(40) Floor finishes													●			
(41) Circulation space finishes															●	
(42) Joinery		●														
(43) Decorations		●														
(44) External works																●

MEASUREMENT RULES

(1) Suspended floor area measured overall staircases, internal columns and lift shafts.

(2) Roof area measured on plan.

TABLE 5c : OUTPUT FACTORS

Activity and No.	Normal output factor used for activity duration	Construction and basis of output considerations
(1) Demolition	Housing - 1 day per dwelling Commercial - minimum 2 weeks and $200m^2$ per day.	Based upon a detached building on an isolated site. Reinforced concrete construction with brick cladding. 1 mechanical pusher 5 man gang
(2) Site preparation	Site preparation area $700m^2$ per day.	Assume no site restrictions and all machine work
(3) Reduce levels	Site area $500m^2$ per day.	Ditto
(4) Foundations	Ground floor area $30m^2$ per day.	Assumed water depth over 5m with excavation in clay.
(5) Piling	Ground floor area $20m^2$ per day. Adjustment factors Bored piles 1.00 Driven piles 1.05 Precast shell piles 1.10	Allow 1 rig driving 80m of piling per day. Piling assumed 375mm diameter piles.
(6) Basement excavation	Volume of basement excavation 400m3 per day. Adjustment factors Open cut excavation 1.00 Sheet piling 0.90 Diaphragm wall system 0.50	Based upon 2 machines
(7) Ground floor slab	Ground floor area $35m^2$ per day.	Standard bay sizes.
(8) Basement foundations	Basement floor area $25m^2$ per day. Adjustment factors Pile cap and beam 1.20	Assumed water depth 1.5m with excavation in clay.
(9) Basement piling	Basement floor area $20m^2$ per day.	

TABLE 5c : OUTPUT FACTORS (continued)

Activity and No.	Normal output factor used for activity duration	Construction and basis of output considerations
(10) Basement slab	Basement floor area 30m^2 per day	Standard bay sizes
(11) Basement structure	Basement floor area 25m^2 per day	Reinforced concrete walls with asphalt tanking.
(12) Suspended ground floor slabs	Suspended ground floor slab area 35m^2 per day.	
(13) Concrete frame and staircases	Suspended floor area 35m^2 per day or minimum 12 days per floor. Adjustment factors Flat slab 1.00 Slab and beam 0.85 Coffered 0.70 Hollow pot 0.70	A 90% learning curve assumed up to height on model. Based upon a high level of repetition for the shuttering with one deck. Output is on a minimum 12 day floor cycle, using one gang.
(14) Roof slab	Roof area 40m^2 per day. Adjustment factors Flat slab 1.00 Slab and beam 0.85 Coffered 0.70 Hollow pot 0.70	Based upon one gang.
(15) Roof top plant room	Roof top plant room area 8m^2 per day	Based upon brick or concrete walls with timber or concrete roof.
(16) Roof finishes	Roof area 20m^2 per day. Adjustment factors Built-up felt 1.00 Asphalt 0.80	Based upon one gang (2 roofers and 1 labourer)
(17) Structural steel frame	Suspended floor area 115m^2 per day	Repetitive frame with few size changes. Use of one erection team with one mobile crane.
(18) Suspended floor and roof slabs and staircases	Suspended floor area 90m^2 per day. Adjustment factors Precast concrete 1.00 Insitu concrete 0.60 Composite steel and concrete 0.80	

TABLE 5C : OUTPUT FACTORS (continued)

Activity and No.	Normal output factor used for activity duration	Construction and basis of output considerations
(19) Fireproofing to steel frame	Gross floor area 120m^2 per day. Adjustment factors Spray 1.00 Pre-formed cladding panels 1.10	
(20) Loadbearing Brickwork with windows	Perimeter length 3.5m per day per storey. Adjustment factors 40% Openings 4.0m per day per storey	Assume 30% openings with two skins of brickwork or blockwork faced one side. Non-complex plan shape using two brick-laying gangs.
(21) Exterior closure system 1 - Brick-work and windows	Perimeter length 3.7m per day per storey. Adjustment factors 40% Openings 4.0m per day per storey	Assume 30% openings with two skins of brickwork or blockwork faced one side. Non-complex plan shape, using two brick-laying gangs.
(22) Exterior closure system 2. - Cill height precast concrete and windows	Perimeter length 4.5m per day per storey.	Non-complex plan shape. Use of 1 crane.
(23) Exterior closure system 3. - Storey height precast concrete with integrated windows	Perimeter length 25.0m per day per storey	Non-complex plan shape. Use of 1 crane.
(24) Exterior closure system 4. - Curtain wall	Perimeter length 20.0m per day per storey	Non-complex plan shape. Includes backing wall.

TABLE 5c : OUTPUT FACTORS (continued)

Activity and No.	Normal output factor used for activity duration	Construction and basis of output considerations
(25) Internal walls and partitions	Gross floor area 95m^2 per day Adjustment factors High intensity 0.75 Medium intensity 1.00 Low intensity 1.25	Based upon an intensity for the whole development.
(26) Plumbing, heating and fire protection	Gross floor area 30m^2 per day. Additional outputs and Adjustment factors Mechanical ventilation 0.90 Dry fire protection systems 1.15 Kitchen equipment services installation) 5m^2 per day for kitchen floor area.	Factor based upon Plumbing (external) Plumbing (internal) Plumbing (sanitary fittings) Heating installation (from central boiler plant) Fire protection (Sprinkler installation)
(27) Lift installation	No. of lift cars x 5 days per floor	
(28) Simple air conditioning	Floor area of air conditioned area 30m^2 per day.	
(29) Complex air conditioning	Floor area of air conditioned area 25m^2 per day	Includes integrated ceiling air conditioning and electrical installation carcassing.
(30) Electrical Installation	Gross floor area 25m^2 per day. Adjustment factors Intensity of partitions High 1.15 Medium 1.00 Low 0.85	Includes general power, lighting and fittings, lightning protection, clocks, lift power, power to mechanical services, fire alarms, telephone installation.
(31) Ceiling grid	Area of suspended ceiling 50m^2 per day. Adjustment factors High intensity of partitioning 0.75 Medium intensity 0.90 Low intensity 1.00	

TABLE 5 C : OUTPUT FACTORS (continued)

Activity and No.	Normal output factor used for activity duration	Construction and basis of output considerations
(32) Air conditioning part 2	Floor area of air conditioned area 70m^2 per day.	
(33) Electrical installation part 2	Gross floor area 30m^2 per day	Includes fittings and items shown in (30)
(34) Ceiling tiles	Area of suspended ceiling 100m^2 per day. Adjustment factors High intensity of partitioning 0.80 Medium intensity 0.95 Low intensity 1.00	Based upon 2 pairs working in large uninterrupted areas with very little cutting (low intensity of partitions)
(35) Plaster Ceilings	Area of plastered ceilings 60m^2 per day Adjustment factors High intensity of partitioning 0.80 Medium intensity 0.90 Low intensity 1.00	Based upon 2 pairs working in large uninterrupted areas.
(36) Suspended Ceilings	Area of suspended ceiling 40m^2 per day. Adjustment factors High intensity of partitioning 0.75 Medium intensity 0.90 Low intensity 1.00	Based upon 2 pairs of fixers working in large uninterrupted areas (low intensity of partitions).
(37) Plaster walls	Gross floor area of building where plastered areas 60m^2 per day	Based upon 2 gangs with approximately 30% openings.
(38) Dry lining to walls and demountable partitions.	Gross floor area of partitioned area 40m^2 per day. Adjustment factors High intensity of dry lining 0.75 Medium intensity 0.90 Low intensity 1.00	
(39) Floor screeds	Area of floor finishes 40m^2 per day	Assuming cement and sand screeds (2 men and 1 labourer).

TABLE 5C : OUTPUT FACTORS (continued)

Activity and No.	Normal output factor used for activity duration	Construction and basis of output considerations
(40) Floor finishes	Area of floor finishes $80m^2$ per day.	Output based upon 70% use of vinyl tile thermoplastic tile, sheet linoleum, and carpet tiles; with 30% use of granolithic and terrazzo (4 Fixers)
(41) Circulation space finishes	Area of circulation space finishes $30m^2$ per day	Output based upon 50% use of vinyl tile, and thermoplastic tile; with 50% use of granolithic and terrazzo (4 Fixers)
(42) Joinery	Gross floor area $45m^2$ per day.	Includes doors, ironmongery, toilet partitions and fittings.
(43) Decorations	Gross floor area $70m^2$ per day. Adjustment factors If suspended ceiling 1.40 If high quality finishings 0.75	Includes interior and exterior decorations. Mainly emulsion paint finish.
(44) External works	Gross area of work for external works $100m^2$ per day	Assume area includes 50% car parking, 30% turfing with allowance for boundary fencing and gates.
(45) Final fix and clean	Gross floor area $70m^2$ per day.	

analyse the critical path within each individual activity. A typical breakdown is shown below for the ground floor slab activity (activity number 7 in Figure 5.9).

	Quantities from the model	Sub-activities	'Normal' output constant (per day)	Duration (days)
(a)	$100m^3$	Back fill around foundations	$25m^3$	4
(b)	$200m^3$	Hardcore bed	$40m^3$	5
(c)	$33m^3$	Blinding	$11m^3$	3
(d)	15 tonne	Mesh and rod reinforcement	1.5 tonne	10
(e)	$200m^2$	Formwork to edge of bed	$25m^2$	8
(f)	$156m^3$	Concrete in bed	$20m^3$	8

The formula incorporating the delay ratios is (Figure 5.10 shows a graphical representation):

(a x .5) + (b x .5) + (c x .33) + (d x .25) + (e x .25) + f = 18 days

Output data = $35m^2$/day of the ground floor area.

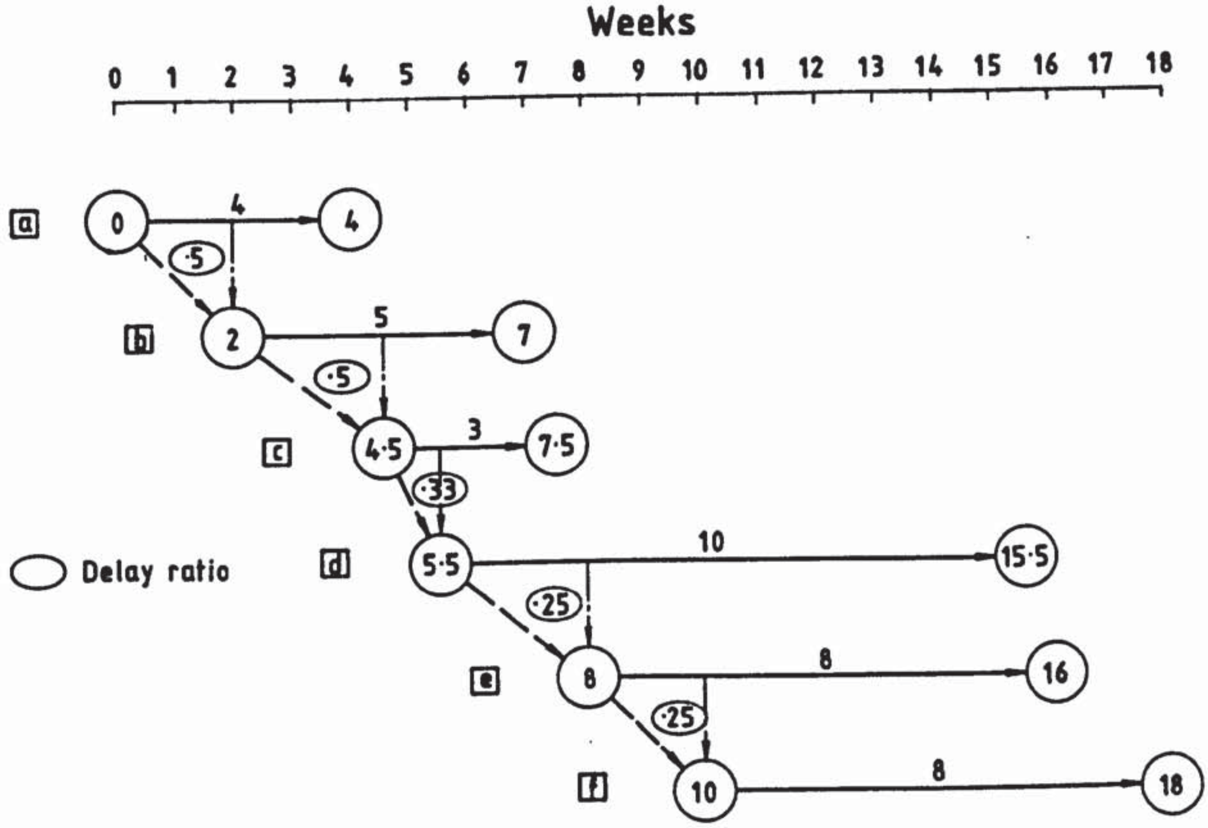


Fig 5·10 GRAPHICAL REPRESENTATION OF THE GROUND FLOOR SLAB ACTIVITY

These delay ratios are based upon subjective judgment and were obtained by analysing the construction programme for numberous building projects and deriving, by empirical judgment, suitable elapse times for each of the activities.

To take account of the differences in output that might occur on projects of varying size, consideration was given to including an overall adjustment factor for outputs on small, medium and large projects. Investigation showed that this was impractical because the productivity for each activity is not determined solely by the number of gangs on an operation. For example, the concrete frame floor cycle is dependent upon the availability of shuttering. The reduction from a twelve day to a ten day floor cycle is not determined by the job size but the availability of an additional set of shutters. The most satisfactory method of coping with varying project sizes is for the quantity surveyor to adjust the outputs where he considers the project type or size will have an influence on likely performance.

The deviation of the duration model from the construction planner's approach can be seen if activity (5), piling, is considered as an example. The planner will, at the construction phase, take account of the number of piles and the lengths of piles to be driven or bored, but it is unlikely that the quantity surveyor will have this information available at the early design stage. The activity duration derived in Table 5C is based upon an assumed number of piles related to the ground floor area of the building. As more becomes known about the piling details during the design phase, the quantity surveyor can use a more accurate output constant based upon a precise number of piles and pile diameter.

A word of caution must be expressed about the output constants. No matter how sophisticated any method of prediction, its usefulness will be limited by the accuracy with which actual performance can be measured. The main difficulty in measuring performance is caused by the fragmented nature of site operations, and by differences in productivity, the effect of repetition, the intensity with which resources are deployed and the choice of the construction method. The details of outputs provided by the specialists in the field and presented in Table 5C are the result of experience and achieved performance on completed projects.

The rationale of the precedence network is that by disaggregating the process into discrete activities, it is easier to predict the performance in each. When using the duration models the quantity surveyor should, therefore, check the output constants on completed construction projects; this will force surveyors to take greater account of the construction programme than is currently the case.

Ultimately, the quantity surveyor will build up a data bank of output information and will gain greater awareness of the reliability of particular output constants. The activities in the model are closely related to the cost planning elemental categories and, therefore, the analysis of completed projects becomes one of considering both price and time.

5.6 Using the Duration Model.

The quantity surveyor calculates the construction duration of a proposed project in the following sequence:

1) Select the required duration model (this assumes the development of a number of duration models). One difficulty likely to be encountered is that some projects contain a mix of building types, for example shops with flats or offices over. In those instances the duration model for the predominant building type should be used.

2) Choose the activities to be included in the model where alternatives exist, for example, type of structural frame, type of ceiling, etc.

3) Select the construction type, where options exist within an activity, for example, type of exterior closure.

4) If considered necessary, change the output constants for any of the activities. Revised constants must be in the same format as those they replace.

5) Calculate the required measurement parameters for the proposed building.

6) Use the output constants with the adjustment factors shown in Table 5C to derive a duration for each selected activity in the network and develop the network.

7) If required, draw up a bar chart from the computed network showing activities and durations.

5.7 Sensitivity of the Model.

At this juncture the sensitivity of the duration model must be considered. The model takes account of the size and changes in the plan shape by the use of the measurement parameters. The design and construction complexity is taken into account by the incorporation of alternative output constants. For example, a high density of internal partitions will tend to slow the pace of construction because of the finishings, decorations and services. An optional link is, therefore, introduced for partitioning and plastering, and the quantity surveyor can choose between high, medium and basic intensity with their appropriate outputs.

The complexity of the external envelope is adjusted by the adjustment factors shown in Table 5C. In this context complexity means the number of openings in the walls, the regularity of the plan shape and elevations, and the design repetition. The level and complexity of environmental services in a project is taken into account by selecting from the alternative items in Table 5C and making the relevant adjustments.

A test was undertaken to analyse the sensitivity of the output factors when dealing with a varying number of storeys. Five hypothetical projects were considered, each with varying floor areas and numbers of storeys. The results are shown in Table 5D.

TABLE 5D : SENSITIVITY OF THE OUTPUT FACTORS.

Floor Area	$4,000m^2$	$5,000m^2$		$10,000m^2$	
Number of storeys	5	5	10	5	10
Construction duration in weeks	65	69	77	90	102
Output per m^2 per week of the gross floor area (excluding external works)	61.5	72.5	64.9	111.1	98.0

These indicate significant differences between the outputs per m^2 of the gross floor area per week, and the differences in construction durations for the 5 storey $4,000m^2$ and $10,000m^2$ buildings, where despite the floor area being substantially increasedthe construction duration has increased by only 39%.

The duration model permits the designer to experiment with alternative plan forms and heights to test the impact on construction duration.

5.8 Testing the Duration Model.

A proposed six storey speculative office building with a basement area located in Maidenhead was selected as a project on which to test the office duration model. The project value was approximately £1,000,000 and the project was being tendered in selective competition. The test was undertaken in conjunction with a national contractor, and therefore there was an opportunity to discuss the project in detail with the construction planners.

The quantities for the proposed building were measured and the relevant activities were selected from the office duration model, from which the precedence network and the bar chart shown on Figure 5.11 were derived.

The model gave an overall construction duration of 62 weeks and 3 days. Four contractors tendered for the project; their duration times were

A = 66 weeks,

B = 68 weeks,

C = 69 weeks,

D = 80 weeks.

The advice of contractor C, with whom we were working, was sought as to why the duration model gave a time below his anticipated programme.

The major criticism was that the model had allowed insufficient time for the work below ground level. The soil report for the project showed there was considerable risk involved in the excavation because of the presence of water. The activity duration allowances should have been adjusted to take account of this factor. Subsequent research in Chapter 6 considers this aspect further in more detail.

The test, whilst not providing a perfect result, does support the further application of the model on live projects.

5.9 The Use of the Duration Model to Derive Preliminaries Prices.

One of the objectives in deriving the duration model was to produce a method of predicting the preliminaries price for a proposed building, which can be used by the quantity surveyor at the cost plan stage.

We were advised extensively during this part of the research by estimators and planners working for contractors and sub-contractors.

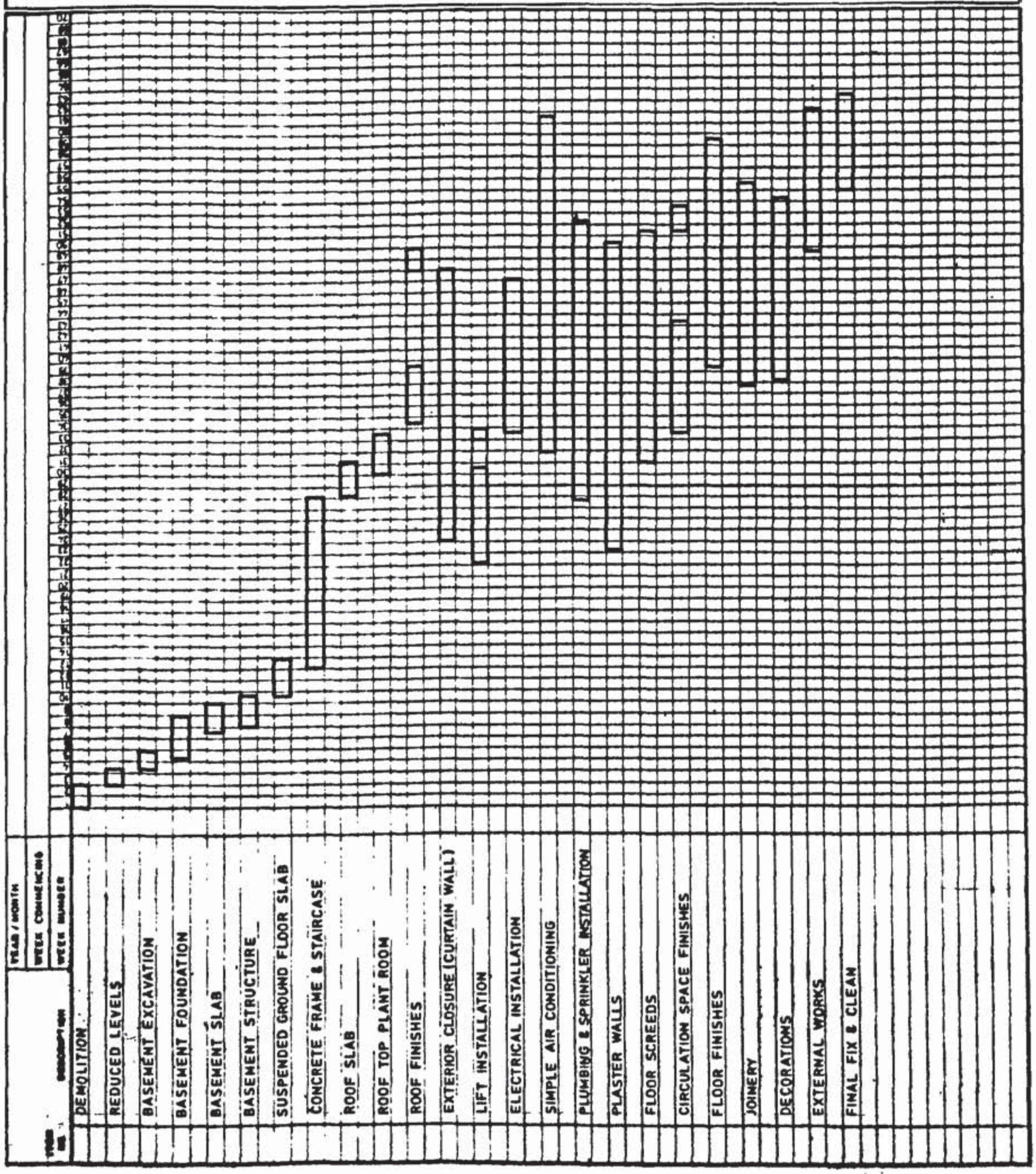


Fig 5.11 BAR CHART FOR CONCRETE FRAMED PROJECT

To gain a greater understanding of the relationship between the preliminaries price and the project price we analysed the sample of 35 factories and warehouses which were discussed above (see Table 5A). For this sample we used regression analysis to test the relationship between the value of the preliminaries calculated per week for the construction duration of a project and the total project value.

Figure 5.12 shows the results. The regression equation showed an R^2 of 0.7188 which is statistically significant, but the estimated equation is dominated by the few large projects. To overcome this, we re-estimated the regression equation in logorithms. The data from this regression are illustrated in Figure 5.13. The estimated equation was statistically significant and the coefficients supports the hypothesis that there exists a linear relationship between the project value and the preliminaries price per week. Thus if we can obtain an estimate of the duration of the preliminaries items, we shall be able to derive a price for the preliminaries.

Preliminaries items can be considered as falling within four categories:

(a) Time related - the cost will be dictated by the time requirement on site.

(b) Method related - items which are used in connection with a specific activity.

(c) Quantity related - an item which has the price generated by a measurement parameter.

(d) Price related - certain items are priced as a percentage value of the contract sum or constituent parts of the project value.

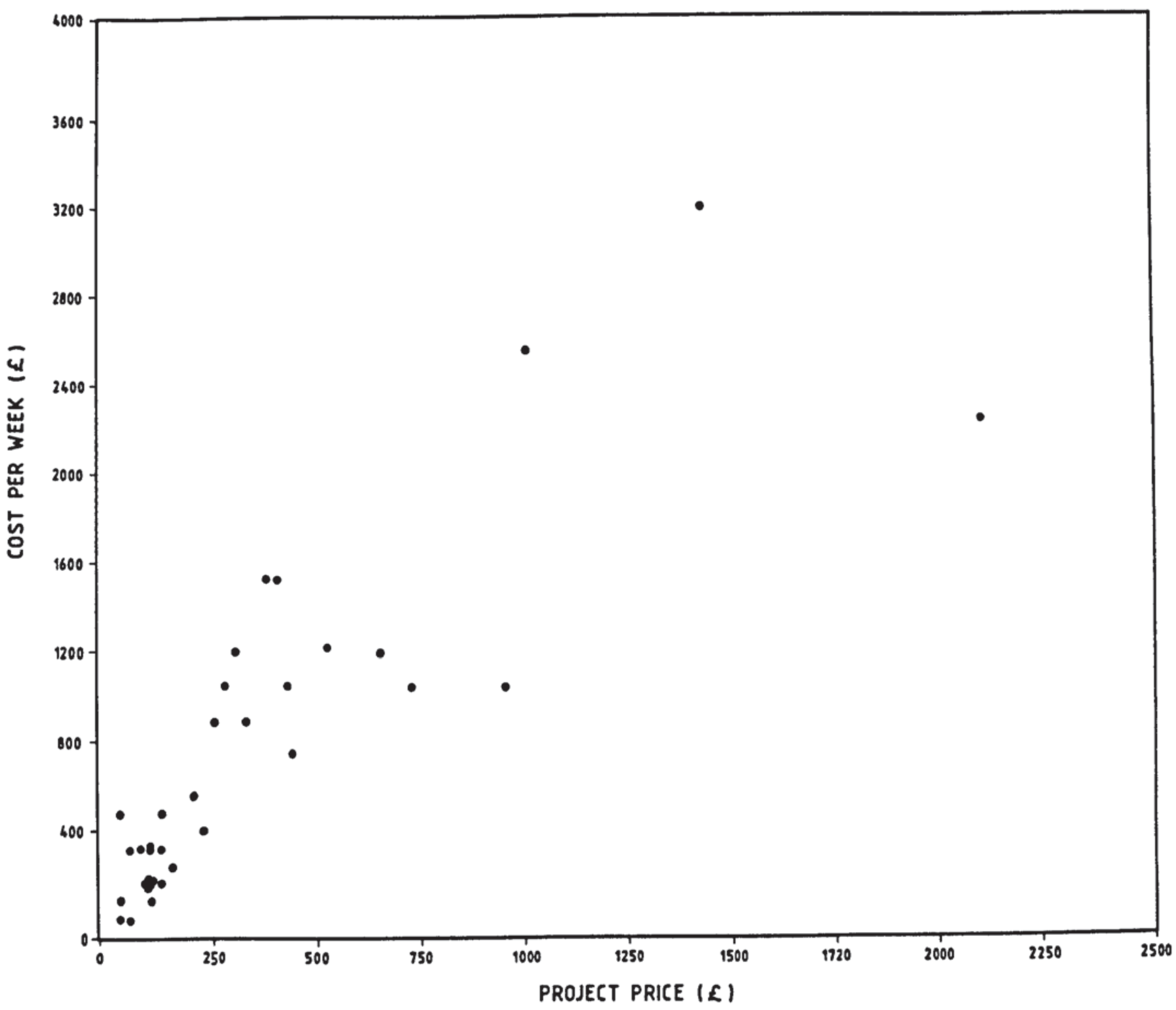


Fig 5·12 PRELIMINARIES PRICES

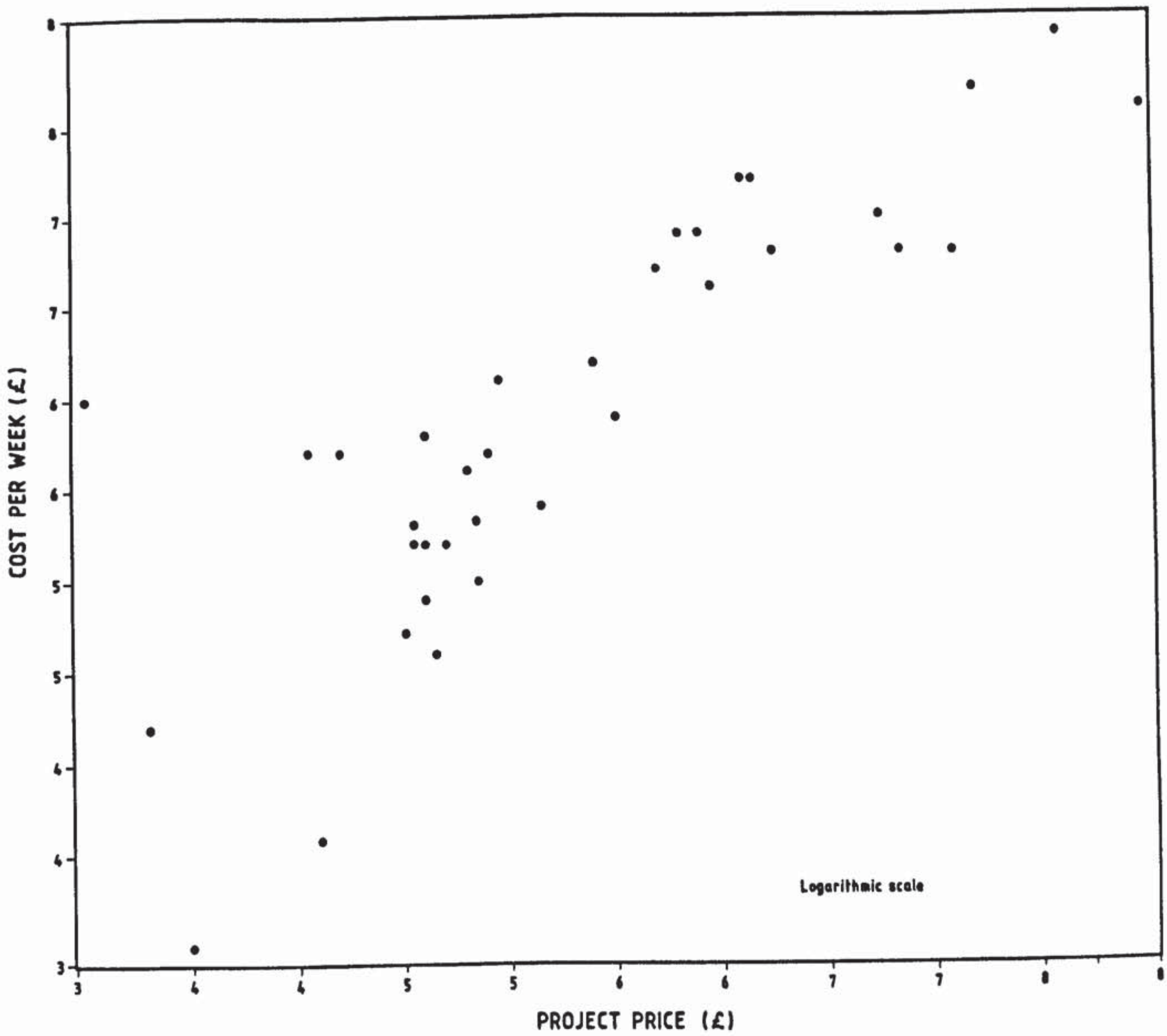


Fig 5·13 PRELIMINARIES PRICES

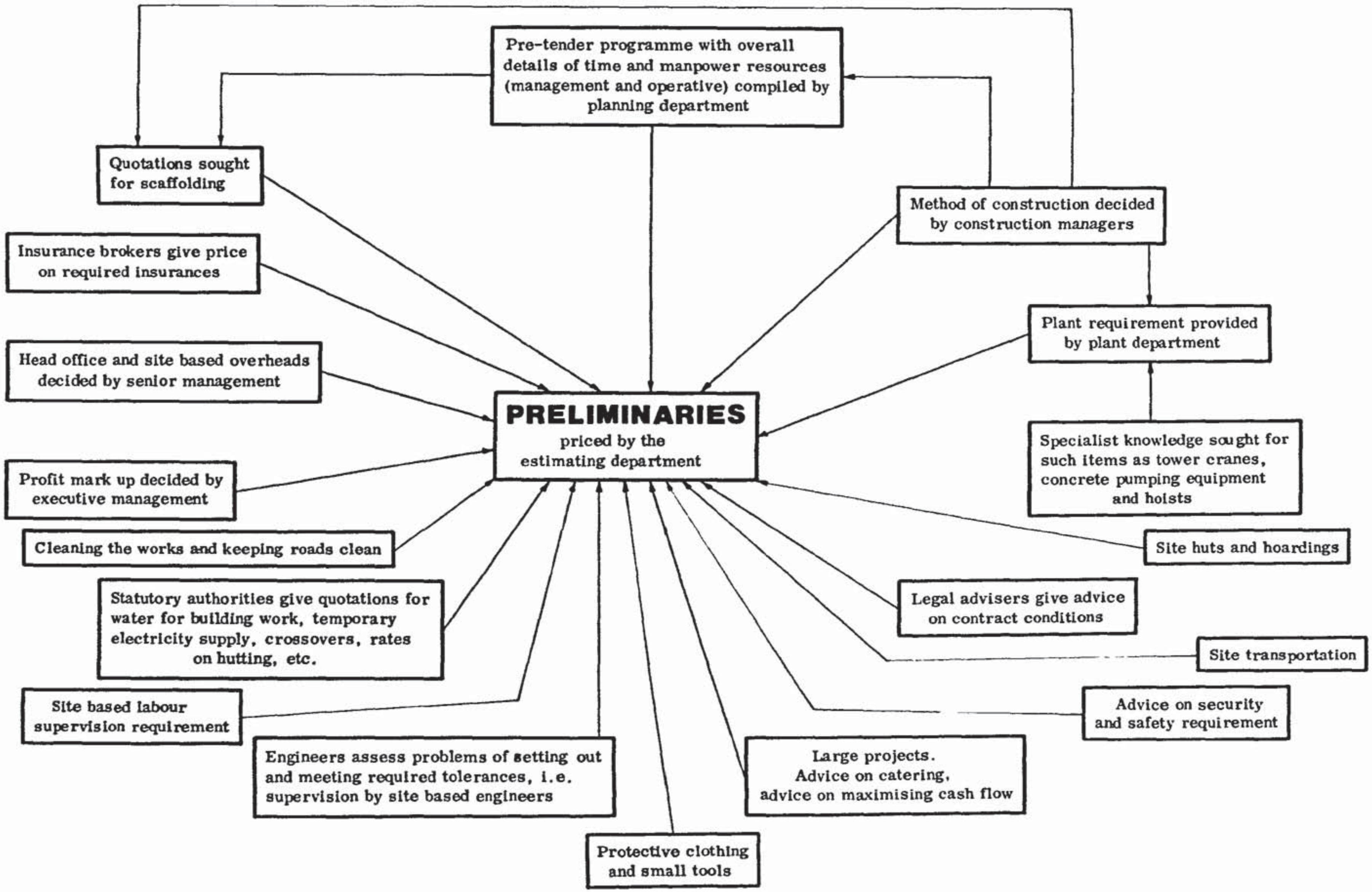
The pricing strategy requires an awareness of the sequence of activities and the proposed construction time.

We have researched and developed a means of predicting construction time at the design stage for a proposed building, and are, therefore, in a position to take account of time related items.

First we shall consider what the contractor includes in the preliminaries price that causes such wide price variability in our historical data. The majority of contractors use a standard format for compiling a preliminaries price build-up. We analysed standard preliminaries pricing forms supplied to us by fourteen national contractors, and it was noticeable that the structure had generally been adapted from the Code of Estimating Practice (1973). Figure 5.14 shows in diagrammatic form the information flow of items which the contractors usually include within the preliminaries section of a bill of quantities. The estimator has the benefit of receiving advice given by outside specialist organisations and from various departments within a contracting organisation. There is a constant interchange of information between all the parties throughout the tender period. The cost of site management is included in the preliminaries price. Small and large contractors alike are faced with the same requirement for management; consequently there is a degree of uniformity of the cost of management; the main determinates being the type of project and the total value.

Some contractors will incorporate the plant costs in the measured unit price rates. For example, it could be more advantageous financially to spread the total cost of hiring and operating a tower crane on a project throughout all the unit price rates for the concrete frame, thereby inflating the concrete work measured unit price rates. The benefit arises if any variation orders are issued for extra concrete work. The contractor,

FIGURE 5.14 : PRELIMINARIES ITEMS.



because of the higher prices, will benefit to a greater extent than if the crane price had been included in the preliminaries section. The converse argument applies if an extension of time to the contract period is granted to the contractor by the architect. Whilst we must be aware of this approach to pricing, we are unable to adopt the technique when simulating our preliminaries price for a proposed building.

Table 5E shows the preliminaries items which must be simulated as the basis for calculating their value on a proposed project. The concept is that the quantity surveyor will use the technique at the cost plan stage. The table has been produced as a result of examination of numerous contractors' tender build-ups for the preliminaries element.

The table shows the items, the basis for calculation, the cost considerations and the cost parameters. We were made aware by estimators that the project type and size have a significant influence upon the items included in the tender and this confirmed the results of our analysis above. The most cost significant aspect was the overall project value; a project with a value over £2,000,000 requires a large number of supervisory and specialist technical staff. We, therefore, adopted three categories of project value to determine the cost parameters:

(a) Up to £500,000,

(b) Over £500,000 to £2,000,000,

(c) Over £2,000,000.

Smaller contracting organisations will usually be involved in the projects in category (a), whilst the larger contractors will primarily operate in categories (b) and (c). There are two factors which must be considered: firstly, the larger contractors will have the benefit of economies of scale for supervision, plant security, etc., and secondly, larger contractors are

TABLE 5E : BASIS OF CALCULATION FOR PRICING PRELIMINARIES ITEMS AT THE COST PLAN STAGE.

Price base : 1st Quarter 1977.

Preliminaries item	Related to	Basis for calculation	Cost considerations	Cost parameters
1.A Construction time	Time related	Time calculated for pre-tender construction programme. Breakdown into 1. Foundations 2. Structure 3. Finishings 4. Services 5. Site development		
1.B Method of construction	Method related	1. Defines plant required and sequence of operational activities		
2. Site personnel	Time related	1. Operational Management 1.1 Project manager 1.2 Site manager 1.3 General foreman 1.4 Section foreman (specify whether supervisory only or working) 1.5 Planner 1.6 Engineer 1.7 Chainman 1.8 General labour 2. Administration 2.1 Site clerk 2.2 Accountant/time keeper 2.3 Storekeeper 2.4 Typist/telephonist 3. Cost management 3.1 Quantity Surveyor 3.2 Bonus surveyor	A. Allow cost of each person based upon time required. B. Study pre-tender construction programme to decide sequence of personnel requirement. C. On large schemes allow medical assistance and safety officer. D. Consider security separately.	Prices per week — per week (including overheads) Project manager £180 Site manager £150 General foreman £140 Section foreman £130 Planner £130 Engineer £130 Chainman £80 General labour £100 Site clerk £80 Accountant/timekeeper £90 Storekeeper £80 Typist/telephonist £70 Quantity surveyor £140 Bonus surveyor £100 (See Table 5F for basis of calculation)

	Preliminaries item	Related to	Basis for calculation	Cost considerations	Cost parameters
3.	Site accommodation	Time related	1. Staff accommodation. Calculate no. of staff on project x 4.0m² per person. Where staff are on site only part of the time, make an assumption. 2. Canteen facilities. Calculate maximum labour force x 1m² per person. 3. Welfare facilities. Calculate maximum labour force x 0.5m² per person. 4. Consultants accommodation. 5. Stores. 6. Mobile toilets. 7. First aid hut	A. Hire or buy hutting, if purchased depreciation over what period. B. Allowance for establishment of the accommodation, decorating and cleaning. C. Allowance for subsidised food, if required. D. Allowance for first aid equipment. E. Allow for car park areas. F. Allow for drainage and plumbing to huts.	Up to 52 weeks / Over 52 week Staff accommodation 85p/m²/wk 70p/m²/wk Canteen facilities 70p/m²/wk 60p/m²/wk Welfare facilities 60p/m²/wk 50p/m²/wk Consultants Accommodation 85p/m²/wk 70p/m²/wk Stores 60p/m²/wk 50p/m²/wk Mobile toilets (per set) £10/wk £8/wk First aid hut £15/wk £13/wk (See Table 5G for basis of calculation)
4.	Telephones and communication	Time related	Calculate staff on site and divide by 3 for the number of handsets.	A. Allow for installation charge. B. Allow for rental charge. C. Allow for cost of calls.	1 line no extensions £30/wk 2 line 3 extensions £100/wk 3 line 10 extensions £200/wk
5.	Temporary power supply	Time related Method related Quantity related	Calculate maximum demand broken down into: 1. Major plant 2. Portable tools 3. Site huts 4. Flood lighting 5. General lighting applying an appropriate diversity factor	A. Consider use of transformer equipment. B. Allow an installation charge. C. Allow for temporary supply tariff. D. No. of outlet units calculated by dividing floor area by 650m².	Installation and removal 5p/m² of total floor area of project Temporary power charge - calculate as a percentage value of the construction work - See Appendix 1 at back of thesis
6.	Plant	Time related Method related Quantity related	1. Crane 1.1 Erect 1.2 Dismantle 1.3 Track 1.4 Additional lifts 1.5 Anchor to building 1.6 Moves on site 1.7 Driver and banksman	A. Calculate a hire charge per week x time required on site. B. Allow for transportation to and from site. C. Allow for fuel. D. Allow for maintenance and repairs. E. Allow for theft. F. Allow for inspection, insurance and testing. G. Allow for breaking out and removal of crane base.	Project duration: Up to 50 wks / Over 50 wks A. Mobile crane £400/wk £250/wk B. Tower crane £800/wk £500/wk Establishment, maintenance, etc. A - £400 A - £300 B - £3 000 B - £4 000

Preliminaries item	Related to	Basis for calculation	Cost considerations	Cost parameters
Plant (continued)		2. Batching plant 3. Mortar mixer 4. Vibrators 5. Compressors 5.1 2 tool 5.2 4 tool 6. Pumps and pump hoses. 7. Goods and passenger hoist 7.1 Erect 7.2 Dismantle 7.3 Run-in to building 7.4 Base 7.5 Driver and banksman 8. Dumper 9. Bar bender 10. Bar cutter 11. Welding set 12 Saw bench 13. Pneumatic drills 14. Saw 15. Grinder 16. Traffic lights 17. Chaser 18. Fuel for plant 19. Skips 20. Signalling equipment 21. Road works equipment 22. Rollers 23. Protection plant, alarms, tarpaulins, etc.	F. Check for restrictions on routes to site, i.e. low bridges, etc. G. Analyse programme to check optimum use of plant.	Allow for plant and small tools as a percentage of the construction total. Up to £500 000 - 5% £500 000 - £2 000 000 - 4% Over £2 000 000 - 4%
7. Protective clothing	Time related	1. Calculate maximum no. of personnel	A. General cost parameter is an allowance of .05% of the labour value.	Calculate labour value by assuming a 45% labour content of the construction value.
8. Setting out the works	Time related	1. Consider number of pegs and profiles likely to be required. 2. Survey equipment.	A. Allow a cost per week for survey equipment. B. Site engineers and chainman included elsewhere.	Allow a lump sum Up to £500 000 - £100 £500 000 - £2 000 000 - £500 Over £2 000 000 - £1 000

Preliminaries item	Related to	Basis for calculation	Cost considerations	Cost parameters
9. Scaffolding	Time related Method related	1. Scaffold - general items 1.1 Erect 1.2 Adapt 1.3 Dismantle 2. External scaffold 2.1 Hoist towers 2.2 Fans 3. Internal scaffold 3.1 Internal walls 3.2 Lift shafts 3.3 Services and suspended ceilings Types X. Independent scaffold for buildings with cladding panels. Y. Independent scaffold used with buildings having external brick cladding.	A. Consider programme requirement and calculate anticipated maximum number of weeks on site. B. Measure external superficial area of the building. Labour output is 70 lineal metres lift per 3 man gang. C. Buildings over 15 storeys treat as a special case. D. Check for storage facilities on restricted sites. E. Where a concrete frame has been erected with a standard 2 metre lift, if clad with brickwork scaffold must all be adapted for a 1.45 metre lift. F. Complex designed structures will require engineer designed scaffolding. Allow design cost. G. Allow a transportation cost.	1. Gross superficial external area of building measured over openings Type X - $15p/wk/m^2$ Type Y - $20p/wk/m^2$ 2. Internal superficial gross floor area - $5p/wk/m^2$
10. Water supply for building work	Method related Price related	1. Calculated based upon estimated consumption.	A. Use tariff supplied by water company. B. Allow for connection charges and distribution throughout site.	Installation and removal. Temporary water charge - calculate as a percentage of the construction work See Appendix 1 at back of thesis.
11. Temporary hoardings and nameboards.	Quantity related	1. Assess quality required and measure square metres of hoarding and gates.	A. Allow for purchase, erection, painting and maintaining. B. Allow for nameboard. C. Allow for erecting consultants nameboards.	Measure total perimeter length x £2.70/m (total price).
12. Security	Quantity related Time related	1. Consider use of visiting security personnel or site based security officer.	A. Allow for additional security precautions during period of finishings and service installations	Allow a sum per week based upon contract value Up to £500 000 - £10/week £500 000 - £2 000 000 - £50/week Over £2 000 000 - £100/week

Preliminaries item	Related to	Basis for calculation	Cost considerations	Cost parameters
13. Temporary roads	Method related Time related	1. Consider number of crossovers required. 2. If piling work or structural steel frame erection, allow 20% extra for temporary roads.	A. Allow for keeping all roads clean, in city centres add 10%. If required allow for lorry cleaning pad. B. Allow a sum to reinstate existing roads and paths. C. Allow cost of crossovers.	Allow a sum based upon percentage of construction value. Up to £500 000 - 0.2% £500 000 - £2 000 000 - 0.1% Over £2 000 000 - 0.1%
14. Temporary works	Method related	1. Consider use of temporary yards for storage or production	A. Allow for establishment of temporary yard.	At surveyor's discretion.
15. Drying out	Quantity related Price related	1. Consider programme requirement. If suspended ceilings allow additional drying out.	A. Allow 0.003% of the construction value, includes fuel.	.003% of the construction value.
16. Local authority notices and fees	Price related Method related	1. If contract over 12 months duration, rates on site huts will be payable.	A. Allow for rates. B. Allow for licence fees and building inspection charges	Up to 52 weeks - no charge. Over 52 weeks - 5p/wk/m^2 of staff accommodation, canteen facilities, welfare facilities and consultants accommodation.
17. Insurances	Price related	1. Price relates to level of risk, high rise buildings rated high risk.	A. Allow as a percentage of the contractors work for employers liability. B. Allow as a percentage of the contract sum for other insurances	All risks policy - 0.042% of construction value.
18. Contract conditions	Method related Time related Quantity related Price related	1. Price unusual risk items separately.		At surveyor's discretion.
19. Allowance for inclement weather.	Time related Method related	1. Consider the effect of weather on the overall programme.	A. Allow for frost precautions. B. Allow for temporary rainwater collection.	At surveyor's discretion.
20. Cleaning the works	Time related	1. Cleaning during progress of the work. 2. Final clean upon completion.	A. Allow cleaning materials B. Allow for labour and time for cleaning.	Allow for cleaning gross floor area six times. Output $40m^2$/hr x hr rate of £2, i.e $\frac{6 \times area \times £2}{40}$

Preliminaries item	Related to	Basis for calculation	Cost considerations	Cost parameters
21. Defects in the building	Method related	1. Consider volume of wet trades and joinery	A. Allow a figure for making good during the defects liability period.	Allow a sum based upon percentage of construction value Up to £500 000 - 0.05% £500 000 - £2 000 000 - 0.04% Over £2 000 000 - 0.03%
22. Adjustment for escalation in prices on items not recoverable.	Time related.	1. Consider cash flow profile, calculate anticipated shortfall on contract.	A. Allow overall figure.	At surveyor's discretion.
23. Overheads	Price related	1. Site based overhead to cover postage, stationery, etc. 2. Head office overhead.		At surveyor's discretion. Range 2%-8% of project value for overheads and profit.
24. Profit	Price related	1. Market assessment of profit range.		At surveyor's discretion.

TABLE 5F - BASIS OF CALCULATION FOR SITE PERSONNEL, RELATING TO ITEM 2.

Item	Project value		
	Up to £500 000	£500 000 - £2 000 000	Over £2 000 000
1. Site personnel operational management			
1.1 Project manager			*
1.2 Site manager		*	*
1.3 General foreman	*	*	*
1.4 Section foreman		*	*
1.5 Planner		* (10%)	* (40%)
1.6 Engineer	4 weeks	* (60%)	*
1.7 Chainman		* (20%)	*
1.8 General labour (ganger)	*	*	*
2. Administration			
2.1 Site clerk	* (40%)		
2.2 Accountant/time keeper		*	*
2.3 Storekeeper		*	*
2.4 Typist/telephonist			*
3. Cost management			
3.1 Quantity surveyor	* (20%)	* (110%)	* (120%)
3.2 Bonus surveyor		* (40%)	* (60%)

Note: Figures in parenthesis refer to the amount of time a person is required on site as a percentage of the total project duration. Percentages greater than 100 mean time is spent working on project after completion).

TABLE 5G

	Canteen facilities	Welfare facilities	Consultants accommodation	Stores
When labour force not known based upon contract value Up to £500 000	-	$30m^2$	$10m^2$	$30m^2$
£500 000 - £2 000 000.	$25m^2$	$150m^2$	$20m^2$	$60m^2$
Over £2 000 000	$80m^2$	$250m^2$	$30m^2$	$100m^2$

able to deploy resources on site at a faster rate than small contractors. When developing our cost parameters we have taken these facts into account.

The quantity surveyor uses Table 5E in conjunction with the duration model. Table 5H shows those items selected from Table 5E which are time sensitive. The duration model gives the construction duration, to which the quantity surveyor must apply the price rate shown in the Table 5E.

In some instances, because of the selected route through the duration model, there are alternative activity options. It is significant that the time dependent items include the most expensive preliminaries items. The site personnel represent a large proportion of preliminaries expenditure together with scaffolding and craneage. To illustrate this point, two completed contracts were analysed: a housing project value £2,000,000 and a seven storey office building value £3,000,000. The site personnel percentage value of the tender price was 5.8% for the housing and 6.2% for the office building, while the scaffolding was 0.6% for the housing and 2.6% for the office building. On these two preliminaries items along total expenditure was 6.4% and 8.8% for the two projects.

In the table, construction price means the cost plan price of a proposed building exclusive of any allowance for preliminaries. The problems the surveyor is likely to have when using the table concern such items as plant. Firstly, he must decide whether construction of the proposed project requires the use of a crane. For crane selection he must ask the questions and follow the decision tree shown in Table 5J.

The major decision to be made is the likely number of cranes required on the project. Some projects are designed where the building comprises several blocks interconnected by link blocks. Consideration should be given as to

TABLE 5H.

Item	Start Activity No.	Finish Activity No.
Site personnel	(1)	(45)
Site accommodation		
Staff accommodation	(1)	(45)
Canteen facilities	(1)	(39)
Welfare facilities	(1)	(45)
Consultants accommodation	(1)	(45)
Stores	(6)	(45)
Mobile toilets	(1)	(39)
First aid hut	(1)	(45)
Telephones and communication	(1)	(45)
Temporary power supply	(1)	(45)
Plant and tools		
Mobile crane	(13), (17) or (20)	(21), (22), (23) or (24)
Tower crane	(7) or (10)	(21), (22), (23) or (24)
Passenger and materials hoist	(13), (17) or (20)	(42)
Scaffolding		
External	(13), (17) or (20)	(21), (22), (23) or (24) + external decoration time.
Internal	(28), (29) or (30)	(35) or (36)
Security	(1)	(45)

whether the blocks are located such that they could be serviced by one crane.

We ascertained from hire companies the weekly hire rates for various crane types. Using a price base of February 1977, crawler crane hire rates ranged from £180 per week to £460 per week. Tower cranes were dependent upon the total length of hire. On a twelve week hire, the hire rate ranged from £300 per week for the smaller capacity cranes to £950 per week for the large lifting capacity cranes. Over a longer period of a one hundred week hire, the same cranes ranged from £200 per week to £600 per week.

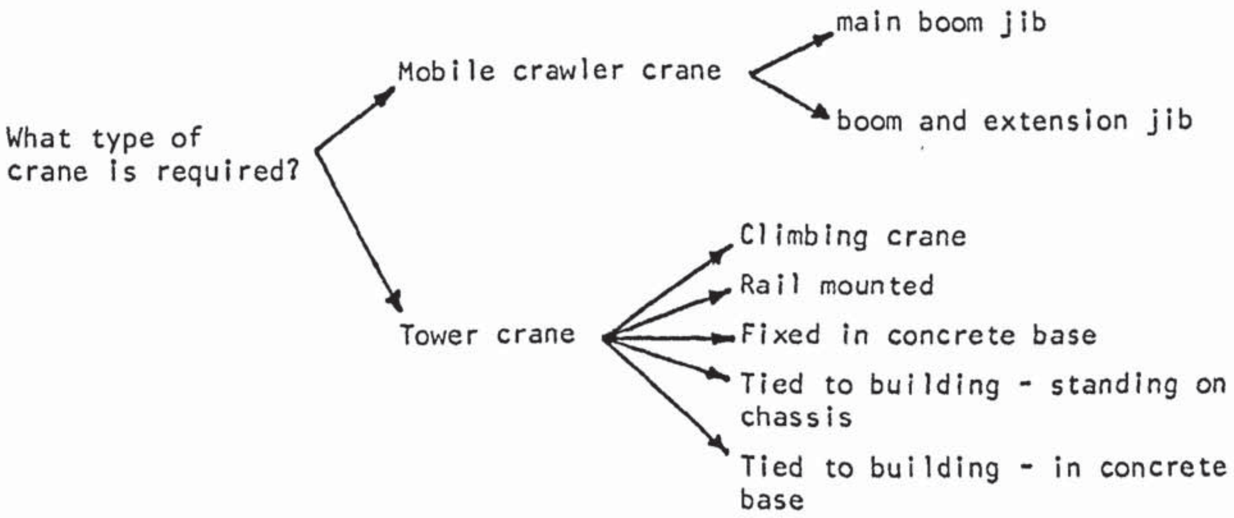
Pricing the plant requirement for a scheme is a very specialised task. We decided, therefore, to take a price for plant based upon a percentage of the total construction value. The percentages were derived from values given by estimators. Initially, we felt this method would prove unsatisfactory, but subsequent testing on projects showed that this was not so.

The temporary works, contract conditions, the adjustment for escalation in prices on items not recoverable under the conditions of the J.C.T. contract and the overheads and profit items must be priced by the quantity surveyor, based upon his knowledge of the proposed project.

The wage rates, site accommodation rates, security, hoarding prices, etc., have all been produced as a result of our discussions with estimators and specialist organisations. Although the same basic principles of decision making and resource allocation can be applied to all contractors, there will be variability of pricing between contractors. We tested our system by applying the method on six projects, two schemes under £500,000, two over £500,000 and up to £2,000,000 and two over £2,000,000 value.

TABLE 5J : SELECTION OF A CRANE

What is heaviest object to be lifted?	=	Weight
What is maximum distance of heaviest object from crane?	=	Distance
How many cranes are required?	=	Number



The time base for the items containing prices in Table 5E.

The BCIS tender based price index should be used to adjust to current prices.

It is recommended that all the items in the table are re-priced every five years.

5.10 Testing the Preliminaries Price

Since we were simulating the contractor's decision process, we felt the only rigorous test was to compare preliminaries prices compiled by the contractor, prior to the tender adjudication meeting. Pre-tender adjudication was chosen because at that stage, market forces and the individual contractor's company requirements are considered. Invariably, if any reductions or additions are made it is the preliminaries items that are adjusted, and this would have distorted our results. We used the anticipated construction programme proposed by the contractors.

Two contractors, A and B, participated in our testing, contractor A with a turnover of circa £8,000,000 per annum and B with a £20,000,000 turnover per annum. Initially, both contractors were very reluctant to participate in the research for fear of disclosure of commercial secrets; confidentiality was therefore guaranteed. Prices are current at February 1977. The results are shown in Table 5K.

TABLE 5K : RESULTS OF PRELIMINARIES TESTS.

Contractor	Total projects value (£)	Contractors Preliminaries value (£)	%	Preliminaries value derived by using system (£)	%
B	102,000	16,000	15.7	19,500	19.1
A	210,000	37,800	18.0	44,200	21.0
A	640,000	134,400	21.0	122,000	19.0
B	1,200,000	178,000	14.8	196,000	16.3
B	2,400,000	408,000	17.0	406,000	16.9
A	3,100,000	672,000	21.7	470,000	15.2

Contractors A and B appear to adopt a different pricing strategy; all of contractor B's preliminaries percentage values are higher than contractor A's. The system as a means of prediction is not perfect, but we obtained a preliminaries price within 0.1% of the contract value for a project of £2,400,000. On the smaller contracts the system tends to overestimate, probably because contractors price very competitively on the smaller contracts, realising there is no room for 'fat'. Our method is not sufficiently flexible to make due allowance for this, but we feel the results do validate the use of the system as a basis for compiling a preliminaries price at the cost planning stage.

5.11 The Theory of a Cash Flow Analysis.

Attention is now turned to the use of the construction duration model, in conjunction with the cost plan, to produce a cash flow analysis for a proposed project. The client could use the cash flow analysis to plan the sequence of payments made during the progress of the work.

A number of techniques are used by quantity surveyors to produce a cash flow analysis for a project at the design stage. However, they are all based upon an analysis of expenditure on past projects of a similar value and type and not on the characteristics of the proposed project. No system currently exists by which the cost plan can be linked to the project duration to provide a cash flow analysis. The contractor prepares a cash flow analysis for himself, not the client, but he uses the pre-tender programme as the basis on which to derive duration.

Pilcher (1972) suggests that work on a construction project usually starts slowly, builds to a peak and then slows again towards completion. Graphically, this output can be expressed as an 'S' curve and will also give rise to an 'S' curve for the cash flow. This is a generally held viewpoint but very little is published about the reliability of cash flow forecasts produced by quantity surveyors and contractors.

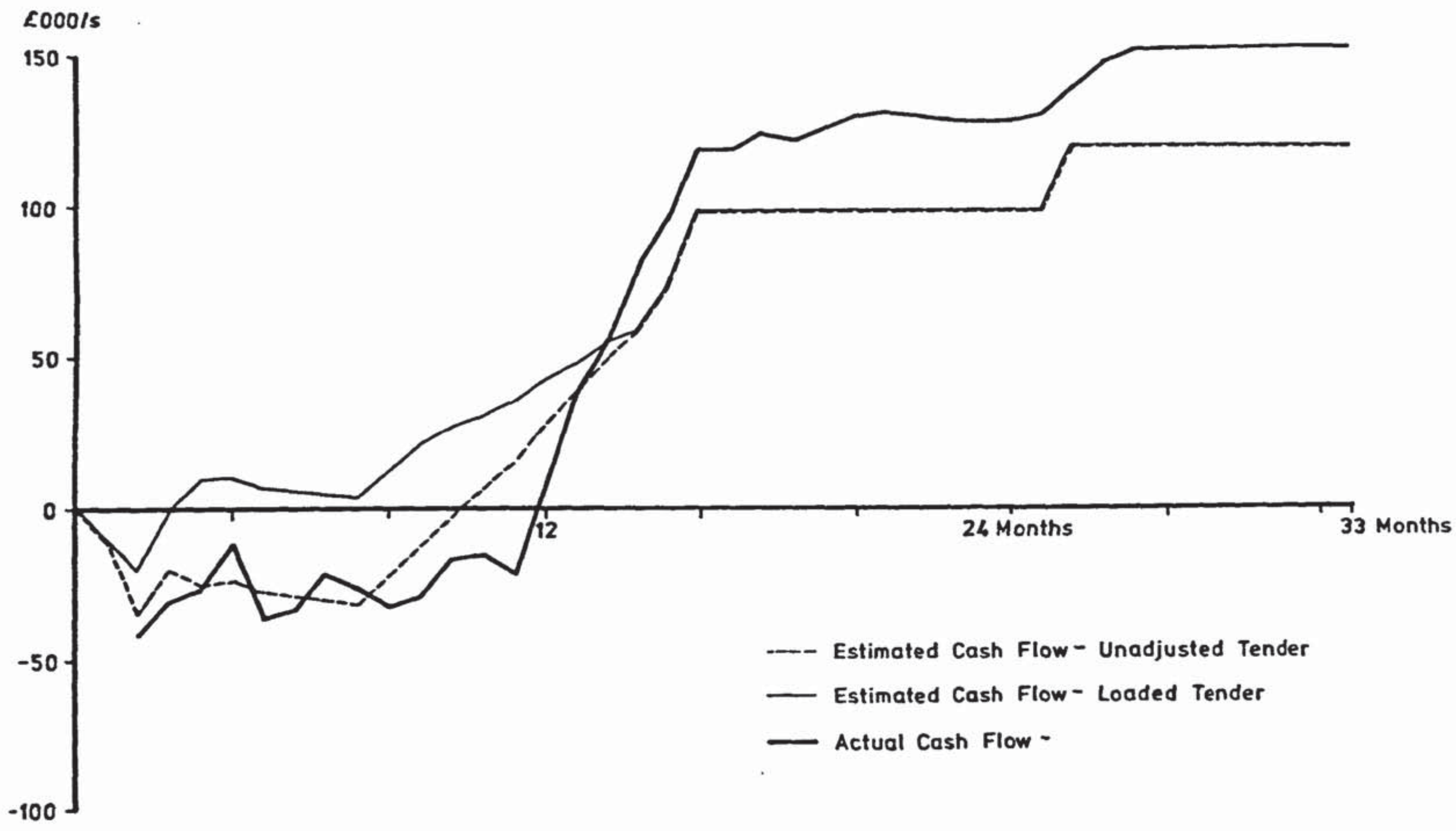
Various contracting organisations were investigated to ascertain the accuracy of the contractor's cash flow forecasts produced from the pre-tender construction programme and the bill of quantities. The results obtained were very mixed, ranging from extremely poor to moderately good. One contractor permitted an in depth analysis of one of his projects, with the aim of considering the reliability of the cash flow forecast produced at the tender stage.

The scheme was a £1,500,000 office block in London constructed under a J.C.T. contract during the period 1973 to mid 1976. The main interest was to consider the reliability of the forecast, not the contractor's profitability on the project. The contractor prepared his cash flow forecast by analysing the priced bill of quantities and the pre-tender construction programme. The tender had been front loaded by inflating the substructure unit price rates, and deflating the unit price rates that occurred towards the end of the job; this is not an uncommon phenomenon.

A graph was plotted from data supplied by the contractor showing the estimated cash flow at the tender stage, the estimated cash flow with the loaded tender, and the actual cash flow. The results are shown in Figure 5.15. The graph shows the difference between the value of payments received from the client and cost of construction to the contractor. The actual cash flow includes payments during progress for variation orders and contractual claims. Therefore, the relationship between the estimated and actual cash flows towards the end of the contract should be treated with some caution. However, the results for the first 12 months of the project show an interesting pattern. Despite the contractor's loading of the tender prices, it appears to have been of little help, because the project was showing a negative cash flow for the first twelve months of construction on site. The contractor had not seen his results plotted in this manner before. He expressed some alarm at his poor prediction as he had spent considerable time in its preparation.

From this study it can be concluded that the art of predicting a reliable cash flow analysis is by no means precise. However, it is important to have some basis upon which to make a prediction of cash flow.

Fig 5.15 TENDER & ACTUAL CASH FLOWS FOR A CONTRACTOR



5.12 The Production of a Cash Flow Analysis using the Duration Model.

The first requirement in the production of a cash flow analysis was to structure the link between the duration model and the cost plan for a proposed building.

Table 5L shows the activities in the duration model listed in chronological order and defined to the corresponding BCIS elemental categories.

The cost plan categories are apportioned against each activity as a percentage of the total value of the category expended against the activity. A percentage value approach was adopted because it is capable of being easily revised and updated. Where the percentage values in the table are shown in brackets, this means alternative expenditure options exist. For example, if activities 13, 17 and 18 are considered, activity 13, the concrete frame and staircases, will have 100% of the elemental frame and upper floors categories apportioned to it. Activities 17 and 18, structural steel frame and fire proofing to the frame, have been apportioned 90% and 10% respectively of the elemental frame category. The percentage values for both frame types add up to 100% of the frame value, the choice being between a steel or concrete structural frame.

Inevitably, there will be projects where there are both steel and concrete frames. The quantity surveyor must, therefore, check each elemental category percentage value before using the table, to ensure an acceptable spread of values on the proposed project.

The foundations and substructure elements have multiple choices for the activities, dependent upon the foundation type and the presence of a basement. Figure 5.16 shows the optional breakdown by sequential activity, together with the percentage value of the elemental category against each option.

TABLE 5L

Activity No.	Activity	Foundations	Ground slab	Basement construction	Frame	Upper floors	Roof and covering	Exterior walls	Exterior doors and windows	Partitions and walls	Plumbing	Lift installation
1	Demolition	Separately defined										
2	Site preparation	5										
3	Reduce levels	10 (A) (B) (C) (D)										
4	Piling	20(A)										
5	Foundations	65(A) 85(B)										
6	Basement excavation			60(C) 60(D)								
7	Ground floor slab		100(A) 100(B)									
8	Basement foundations	85(C) 65(D)										
9	Basement piling	20(D)										
10	Basement slab			20(C) 20(D)								
11	Basement structure			20(C) 20(D)								
12	Suspended ground floor slab		100(C) 100(D)									
13	Concrete frame and staircases				100	(100)						
14	Roof slab						60					
15	Roof top plant room						20					
16	Roof finishes						20					
17	Structural steel frame	(90)			(90)							
18	Suspended floor slab, roof slab and staircase					(100)						
19	Fireproofing to steel frame	(10)			(10)							
20	Load bearing brickwork with windows							(100)	(100)			
21 - 24	Exterior closure (Systems 1 - 4)							(100)	(100)			
25	Internal walls and partitions									100		
26	Plumbing, heating, fire protection and sprinkler										100	
27	Lift installation											100

(Activities 3 – 12: See Figure 5.15)

Activity No.	Activity	Wall finishes	Floor finishes	Ceiling finishes	Plumbing	Heating, ventilation and air conditioning	Fire protection	Electrical installation	Internal doors	External works
28	Air conditioning simple					100				
29	Air conditioning complex					(60)		(10)		
30	Electrical installation simple							100		
31	Ceiling grid			(30)						
32	Air conditioning part 2					(40)				
33	Electrical installation part 2							(90)		
34	Ceiling tiles			(60)						
35	Plaster ceiling			(70)						
36	Suspended ceiling			(70)						
37	Plaster walls	40								
38	Dry lining to walls	20								
39	Floor screeds		30							
40	Floor finishes		50							
41	Circulation space finishes	20	20	10						
42	Joinery								100	
43	Demolition	20		20						
44	External works									100
45	Final fix and clean	-	-							

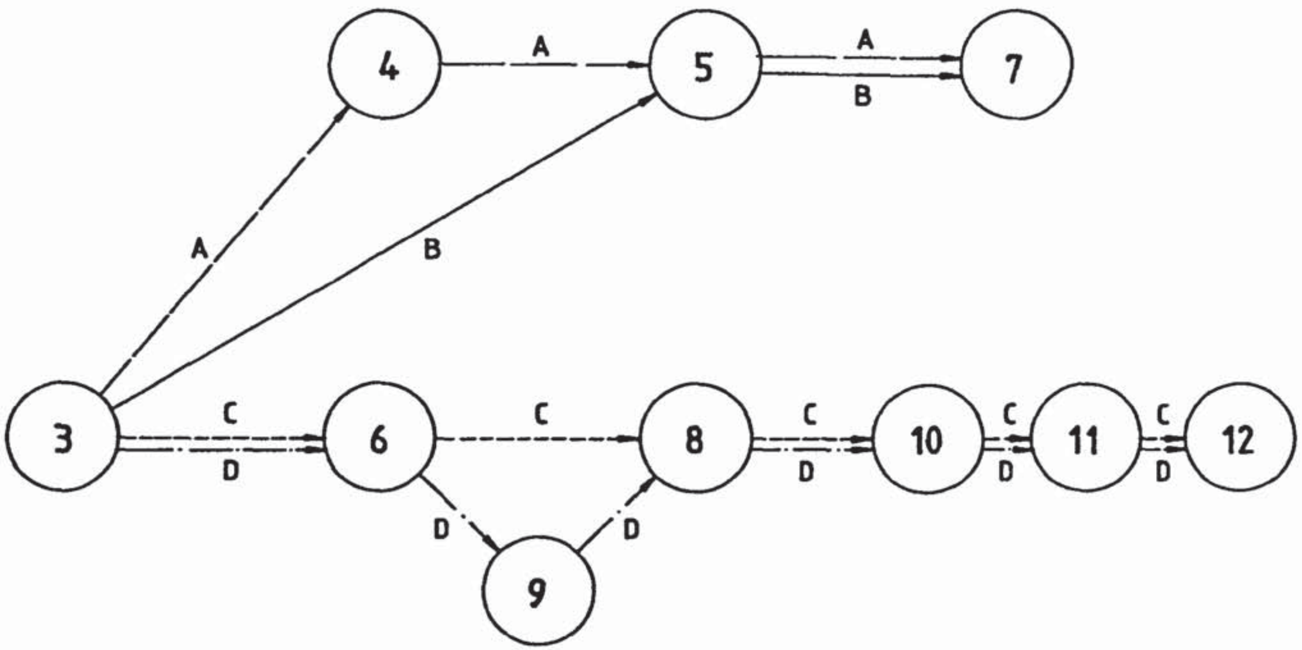


Fig 5·16 ALTERNATIVE FOUNDATION ROUTE THROUGH THE DURATION MODEL

There will be instances when an activity does not occur on a project, e.g. roof top plant room (15). The percentage value of the elemental cost plan category allowed for that activity is then apportioned equally throughout the other activities in the elemental category.

Because the duration model uses activities critical to the overall construction duration, some of the items in the cost plan are not included in the model, e.g. fittings, equipment and furniture. These must be incorporated in the cash flow analysis by selecting an appropriate time and period during the contract when the expenditure will take place. The method of achieving this is to link the affected elemental cost plan items to a particular activity in the network. The only instance where this should not be undertaken is with the preliminaries element which we discussed previously.

The assumption has been made that the rate of expenditure for each activity item will be constant throughout the duration of the activity with the following exceptions: activities 26 to 33 inclusive which are the mechanical and electrical services where, because of the high capital cost of the manufactured equipment initially delivered to site, it is assumed that 60% of the cost is expended in the first 30% of the activity duration and the remainder of the cost is spread equally throughout the duration thereafter.

The cash flow analysis system was tested by analysing the bills of quantities for a £1,500,000 project. A cost analysis was produced from the bills and then the values apportioned to the activities in the network duration model.

Figure 5.17 shows a plot of the results. The cumulative expenditure for the particular project shows an interesting trend. The plot does not show the pronounced S shaped curve that we anticipated. In the initial stages of the project the expenditure slope is not steep because of the low value of

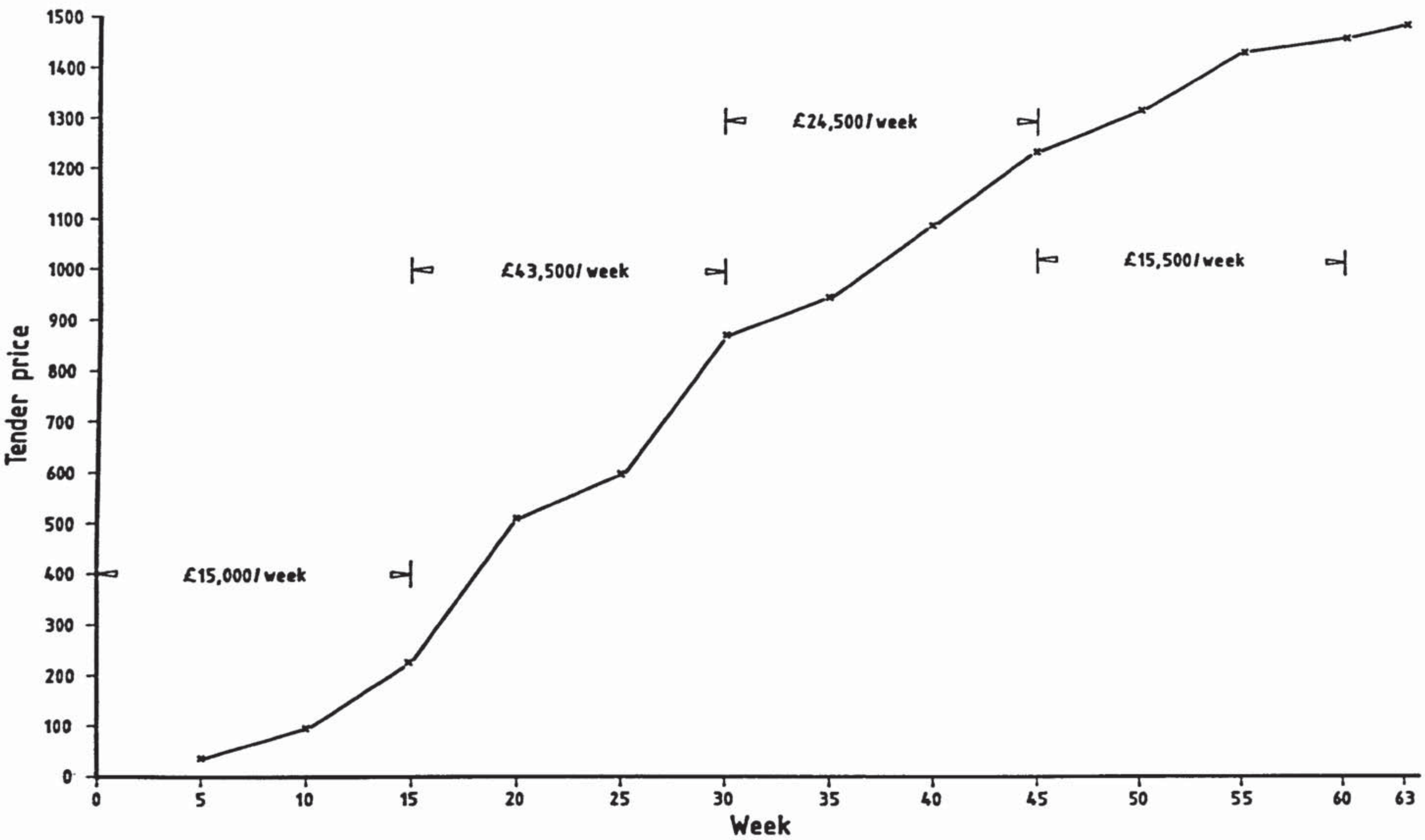


Fig 5·17 CUMULATIVE PLOT OF CASH FLOW

excavation work. When the work moves on to erecting the frame and cladding the building, the slope of the line increases. Towards the end of the project when the finishes are being applied the expenditure slows significantly.

The quantity surveyor can experiment with the results of the cash flow analysis by considering the effect of front loading the tender, or by introducing different expenditure curves for the activities.

The reliability of the cash flow analysis using the percentage values of the elemental categories is obviously open to criticism. However, at the present time the system of producing a cash flow analysis at the cost plan stage by using the proposed construction duration and sequence of operations, is likely to give a more reliable prediction of cash flow than any best guess system could hope to achieve.

5.13 Conclusions.

Conclusions have been drawn in the various sections of this chapter, but we feel that there is some merit in restating at this stage our major conclusions with respect to the time dimension of construction work.

The central theme of this chapter has been the role of individual activity durations as determinants firstly, of the total time to complete a particular project, and secondly, of the final price of that project. The adage that 'time is money' is nonetheless true in spite of its undoubted age, particularly in periods of financial stringency and depressed economic activity. Any mechanisms whereby we can improve the estimation of likely project durations, and outline the effects on duration of alternative design options is, therefore, of considerable benefit to the industry. We feel that the duration models developed in this chapter form a useful first step in the development of such a mechanism, in three major ways:

1) They serve the purpose of relating design and construction by encouraging the quantity surveyor and architect to consider what the consequences of the design are upon the time taken to complete operations on the site. Advice can be given to the client at the design stage on the construction time required for alternative design options. The quantity surveyor is not taking over the contractor's role of programming a project, he is moving towards the linking of price and time analysis. As Brett-Jones (1970) stated: "Quantity surveyors must know cost and price and they must know about productivity and the factors that influence it". The architect does not need to produce the drawings in an operational format and the use of the duration models in no way increases the architect's workload. The quantity surveyor's workload is marginally increased, particularly if the surveyor collects information on the output constants. Consideration must, therefore, be given to the feedback and analysis of the construction durations for the activities which we shall consider in Chapter 6.

2) Many of the preliminaries items were shown to be time related. By using the duration model in conjunction with Table 5C a more reliable basis of predicting the preliminaries price can be achieved. Furthermore, the large proportion of the project now represented by the preliminaries trade means that it must no longer be priced by the consultant quantity surveyor as a percentage of the total project value with very little understanding of the items allowed for in the price. The use of Table 5C will make the surveyor consider the method of construction which, hitherto, all the prediction systems have ignored.

3) The cash flow forecasting technique using the duration model permits a cash flow analysis for the proposed project at the design stage. In

the past this exercise has not usually been undertaken until the contractor's tender has been received and the construction programme could be related to the bill of quantities.

One of the reasons why duration modelling has not been attempted before is probably because the quantity surveyor has in the past received little or no education and training in construction programming and time control. This would appear to be a definite shortcoming, particularly when, as our research has highlighted, the activity duration times for building work are highly cost significant. The quantity surveyor must take a much greater interest in the time aspects of construction. We believe that our construction models provide a vehicle for such an interest to develop.

The involvement with duration models will mean acquiring a greater knowledge of how buildings are constructed. The need for a greater understanding of the interaction between the price, the duration, and the method of construction leads the research in the next chapter to the need for an operational approach to price prediction.

Chapter 6

Consideration of an operational approach to time and price prediction

6.0 Introduction.

In this chapter, we attempt to develop a price prediction technique that (a) uses the activity durations derived from the duration model developed in Chapter 5 and (b) takes account of both time and the operational factors that are embodied in construction prices. We shall consider prices in resource terms rather than as unit price rates.

All construction projects involve varying degrees of complexity, and each may require the use of a different construction method. As a result, price prediction techniques for building work which incorporate operational information are likely to provide a more reliable basis of prediction. In essence, this is similar to the operational bill approach postulated by the Building Research Establishment. The DOE in its "Structuring Project Information" report (1972) stressed that there should be an awareness of the contractor's method of work. It also proposed that the bills of quantities items should be arranged in small groups which contractors can relate to their own choice of operations.

Unfortunately, to date, the construction industry has not responded to the operational approach to estimating. The reasons for this mainly relate to the deep embodiment of the concept of unit price rates which exists throughout the contracting and sub-contracting industries. Any change would involve alterations in the collection of cost feedback data and to the conventional approach to estimating.

Bennett (1978) stated that "Operationally based price information will allow quantity surveyors to consider the construction implications of alternative designs. This will help quantity surveyors to distinguish between projects which generate a simple operational pattern ..... from those which generate a complex operational pattern". Apart from the operational bill of quantities there is no price feedback facility at the design stage whereby the contractor's price data can be considered to distinguish the operational pattern of a project.

There has been previous research (Fulkerson (1959), Fondahl (1962)) to identify the price implications of operational patterns in projects by pricing the activities of a network construction programme. From the quantity surveyor's point of view, the major shortcoming of this technique for the purpose of price prediction, has been that the cost planning elemental categories relate to the functional parts of a building, rather than to the network activities which are concerned with the building process on site.

In Chapter 5 we defined price in terms of an equation of the form $P = NM + t(L,K)$. The duration model allows us to consider t, and therefore we need a technique which can relate to the decisions the contractor makes when pricing M, L and K. Thus the first task is to analyse each of the activities from an operational standpoint and to consider those factors which will affect the duration and the price. In effect, this requires the construction of a flow chart or algorithm which simulates, as far as possible the decisions which the contractor must make in determining his price.

Once the algorithms are produced, a technique is required which can relate the items identified in the algorithm with the duration model to produce a price, thereby incorporating into the price information on the operational sequence, the method of construction and the duration.

As we have stated previously, a unit price rate comprises labour, material, plant, supervision, overheads and profit. The material allowance for any activity can be derived from the measurement of the area of finished work, making a suitable allowance for waste. Overheads and profit are generally considered as a percentage of the labour, material and plant value. The items under consideration for an activity are, therefore, labour, plant and supervision. The performance of labour is affected by a multitude of factors ranging from items that are within the control of the design team, such as the extent to which door sizes differ, to factors within the control of the contractor, for example, the extent of mechanical tools provided for a specific activity. What need to be considered in the algorithms, therefore, are items that will significantly affect the contractor's performance and thereby influence the price.

The items in the algorithm are then used to produce a factor table which embodies an operational approach to price prediction. The main factors that influence performance are listed in the factor tables together with a weighting factor for each item which takes account of variations in the labour productivity, supervision and risk. The underlying theory is that it is possible to weight the influence of an item on the overall performance of the labour and plant output for an activity. A base of 1.00 is established as the output base, and the criteria are defined which will achieve this base. Deviation in any of these criteria on a particular project will change the output base for that project and generate an adjustment factor to be applied to the output constants.

It would be possible to produce algorithms for all the activities, but we selected the following activities for inclusion in the thesis to illustrate the technique:

a) Demolition work.

b) Piling work.

c) Foundations.

d) Concrete frame and staircases.

Demolition and piling work were chosen because of their specialist nature. Foundations, and the concrete frame and staircases, were selected because of the existence of a heavy operational bias when prices are calculated by the contractor. The algorithms were produced empirically as a result of discussion with contractors, specialist sub-contractors and labour only sub-contractors.

The factor tables have also been produced by empirical judgment following discussion with estimators working for general contractors and specialist sub-contractors. It must be recognised that these factors are subjective in nature since no empirical data are available which would allow objective estimation. This means that the quantitative conclusions we can draw are limited, but it must be emphasised that our intention is to produce a methodology and to show how that methodology can be applied. Application of this methodology in "live" situations will generate experience and data which can be used to refine and extend these initial subjective factors.

We shall use the demolition activity to demonstrate the approach to the development of the algorithms and to show the operation of the factor tables.

6.1 Demolition Work.

To put the UK demolition industry into perspective, the turnover in 1976 was approximately £125 million, employing a labour force of approximately 7,000. Demolition techniques have changed dramatically over the past ten years.

Code of Practice 94 (1971) deals with various aspects of demolition work including safety and the recommended methods of demolishing buildings. Certain types of buildings are relatively easy to demolish, e.g. low rise load bearing brick structures. However, the increasing preponderance of the demolition of reinforced concrete structures means that the old methods of using a demolition ball and chain suspended from a lifting device, or pneumatic hammers, requires re-appraisal. Speed of demolition now necessitates the use of diamond drilling and sawing, hydraulic bursting, thermic lancing, flame cutting, Cardox, and explosive blasting. An understanding of the economics of using such specialist techniques is important.

When preparing budget prices for demolition work, the consultant quantity surveyor's current practice is to use a price per cubic metre of the volume of the enclosing structure where this price is taken from an historical observation. As a result the consultant quantity surveyor would only accidentally be taking into account the influence of factors such as site characteristics, building type and the availability of a market for demolished materials. We shall show below that each of these factors has significant time and price implications and so should be explicitly taken into account for price prediction.

Buildings to be demolished can be identified as follows:

a) detached building on an isolated site, being a building having a clear space on all sides of at least twice the maximum height of the section of building to be demolished;
b) detached building on a confined site;
c) attached building on an isolated site;
d) attached building on a confined site.

Table 6A shows the recommended methods of demolition. The site location and the type of structure dictate the method of demolition which, in turn, influences the time required and the price. For example, a 2-storey detached building on an isolated site can be demolished using mechanical plant and controlled collapse, whereas a similar 2-storey building on a confined site will be demolished using hand or mechanical means, and the duration will be longer because of the site position. Whilst the two buildings may be exactly the same size, the building on the confined site will be more expensive to demolish.

Figure 6.1 shows the algorithm that has been developed for estimating the price of the demolition activity. The price will be determined by the following factors:

1) the site and type of building that is to be demolished;

2) the age of the building, maximum number of storeys, and type of structure involved. The type of structure is important for two reasons: its influence on the method of demolition and the effect on the credit value of the materials arising from the demolition;

3) the existence of a local market for the sale of the demolished materials. Should all the demolished material need taking to a tip, the haulage cost and tipping fee will add considerably to the overall demolition price. The bill of quantities will normally state that the contractor is responsible for removing demolished material off site, and so the surveyor, when analysing the tender being used for prediction, has no means of knowing whether the demolition price in this tender allowed for the sale or tipping of the demolished material;

TABLE 6A : TYPE OF DEMOLITION RECOMMENDED UNDER CERTAIN CONDITIONS.

Type of Structure	Type of Construction	Location of Site			
		Detached building isolated site	Detached building confined site	Attached building isolated site	Attached building confined site
Small and Medium 2-storey buildings	Loadbearing walls.	ABCD	ABD	ABD	AD
Large buildings 3-storeys and over	Loadbearing walls	ABDE	ABDE	ABDE	AD
	Loadbearing walls with structural steel members	AE	AE	AE	AE
Framed Structures	Structural steel	ACE	AE	AE	A
	In situ reinforced concrete	ADE	ADE	ADE	AE
	Precast reinforced concrete	ADE	ADE	ADE	AE
	Composite structural steel and reinforced concrete	ADE	ADE	ADE	A
	Timber	A	A	A	A

Legend for Table 6A.

A. Hand demolition.

B. Mechanical demolition by pusher arm.

C. Mechanical demolition by deliberate collapse.

D. Mechanical demolition by demolition ball.

E. Demolition by explosive.

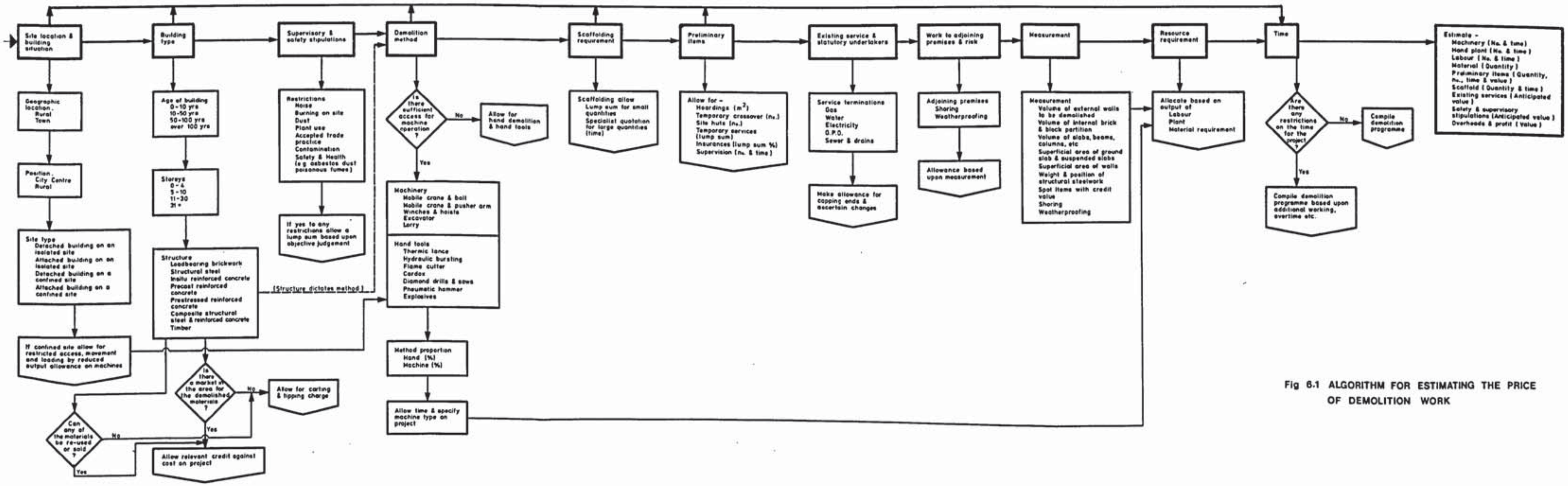


Fig 6.1 ALGORITHM FOR ESTIMATING THE PRICE OF DEMOLITION WORK

4) the restrictions which may be placed on the demolition work. In built-up areas the demolition contractor must consider the effect of noise and dust on the surrounding environment. He might well be forced to consider a slower demolition method in order to comply with any noise restrictions;

5) the most appropriate demolition method to adopt. The answers to questions 1 and 2 above will influence the choice of demolition method, but the demolition contractor will also attempt to optimise the time/cost relationship, should the client have stipulated a required duration at the tender stage. The most significant influence on price will be the extent of hand demolition that is required, as this is both costly and time consuming;

6) the extent of scaffolding required, which will be affected by the demolition method chosen. Temporary scaffolding will be required where there is extensive use of hand demolition;

7) the extent of preliminaries items required. When the demolition contract is let by the client to a specialist sub-contractor, certain preliminaries items must be allowed in the price. If the work is undertaken under the control of the general contractor, then the contractor will be responsible for most of the preliminaries items within the main contract;

8) the extent of the work to adjoining premises and in terminating existing services. The provision of waterproofing and shoring existing structures must be considered.

The measurements required by the contractor to determine a price are not the same as those provided by the quantity surveyor in accordance with the Standard Method of Measurement for Building Work (SMM). The bill of quantities gives a description of the items to be demolished, whereas the contractor needs to know the cubic volume of material to be removed from the site, the superficial area of scaffolding required and the superficial area of any temporary shoring required.

The last item in the algorithm gives the basis upon which the demolition contractor's estimate is formed. The time required to carry out the work is important because without a duration the measurement information is of limited applicability to the contractor. The contractor considers the sequence of activities, the factors that will affect productivity, the method of carrying out the work, the resources required, and the time for which the resources are required.

The algorithm was tested on a demolition contract, in order to consider the influence of the method of demolition on the total price. Guidance on prices (which were current to the second quarter 1977), labour productivity and plant performance was given by a demolition estimator. Table 6B shows the results of the analysis. The demolition prices varied by as much as 107% between the lowest and the highest price per cubic metre, dependent upon the selected method of demolition, the availability of a market for selling the demolished material, the number of storeys, and the project duration selected. The time taken to demolish the building was varied by incorporating two machines instead of one on site. This has the effect of making the price for the four-storey structure cheaper, and increasing the price on the eleven-storey building.

The algorithm highlights the importance of knowing how a building will be

TABLE 68 : COMPARISON OF DEMOLITION PRICES

Method	(A) 4 Storeys		(B) 11 Storeys		(C) 4 Storeys		(C) 11 Storeys	
	Total price of Demolition £	Price per m^3	Total price of Demolition £	Price per m^3	Total price of Demolition £	Price per m^3	Total price of Demolition £	Price per m^3
Mechanical demolition - materials sold by demolition contractor	12,890	1.19	14,450	1.34	11,290	1.05	15,350	1.42
Hand demolition - materials sold by demolition contractor	15,590	1.44	18,650	1.73	-	-	-	-
Mechanical demolition - materials removed to a tip	17,330	1.61	19,180	1.78	16,750	1.55	20,080	1.86
Hand demolition - materials removed to a tip	20,650	1.91	23,380	2.17	-	-	-	-

All the prices per m^3 are based upon the cubic volume of the enclosed building.

Data for model: 4 Storey building - 30m x 30m x 3m storey height
11 Storey building - 18.09m x 18.09m x 3m storey height
Volume (both buildings) 10800 m^3
Tipping charge (including cartage) £3/m^3
Selling price of hardcore 50p/m^3

Demolition Time

A - 15 weeks

B - 15 weeks

C - 10 weeks

Prices include all preliminary items, overheads and profit
Hire of crane and ball £10/hr including driver.

demolished, and whether there is a market available for the demolished material, whilst the SMM does not identify these cost significant features in a meaningful format.

Quantity surveyors have argued that the bill of quantities based upon the SMM provides the only reliable source of feedback for future prices. The algorithms help to show that this is not the case because the method of measurement describes only the extent of the work, whereas the contractor's task is to identify the cost significant factors involved in undertaking the work. The SMM does not identify these cost significant features of the trades in a meaningful format.

We now turn our attention to Table 6C, which is the factor table derived from the algorithm, and which is to be used in conjunction with the duration model to produce a price prediction for the demolition activity. We are considering the following five distinct areas in the factor table.

1) Output factors. These are based upon a factor of 1.00 which is the performance used in the duration model, with a stated gang size and specified plant as shown in Table 5C (Chapter 5). Table 6C shows a maximum and minimum value for each of the factors that affect output, thereby applying a weighting factor to the items in the algorithm. For example, the range for the influence of the site position is from 0.10 to 0.30; the value in the demolition being used for the base is 0.10. In effect, this is saying that 10% of the labour output will be affected by the site position.

   If the value bands are not considered appropriate for any particular type of project under consideration, they may be amended provided they are always related to the base of 1.00. It is worth re-stating that

TABLE 6C : DEMOLITION

TIME	FACTORS		BASE (Factors given in u below range)
·10 ·30 ·10	Site position	1	Rural location
·40 ·80 ·40	Site type	2	Detached building on an isolated site.
0 ·10 ·05	Building height	3	5-10 storeys. Storey height up to 2.80m.
·10 ·40 ·25	Structure type	4	Insitu reinforced concrete. (See Figure 6.1).
Dealt with in materials adjustment	Market for demolished materials	5	Local market available.
0 ·10 0	Restrictions	6	No restrictions.
·10 ·60 ·15	Machine/Hand demolition ratio	7	90% Machine use. 10% Hand demolition. (100% Machine use = 0.10).
0 ·05 0	Scaffolding	8	$200m^2$ scaffolding superficial area
Dealt with in preliminaries adjustment	Preliminaries	9	Standard - no peculiarities.
0 ·15 ·05	Work to adjoining property and to existing services.	10	Weatherproofing one adjoining structure. Standard disconnections. No shoring.
1·00			

OUTPUT BASE

1 Mobile crane and pusher arm)
1 Gang 5 men)

$200m^2$ of the demolished building per day.

Range within the time base

0.70 ——→ 2.50

i.e. $285m^2$/day → $80m^2$/day.

LABOUR AND SUPERVISION

Price base - January 1979.

All in hourly rate £3.00 per hour working a 40 hour week.

£0.60/m^2 of the gross floor area.

MATERIAL

25p/m^2 Weatherproofing. Credit for materials to be allowed.

PLANT AND EQUIPMENT.

1. Scaffolding £10 per week.
2. Mobile crane and pusher arm £100 per day.
3. Lorries £50 per day per lorry.
4. Mechanical shovel £50 per day (duration taken from time estimate).

OVERHEADS AND PROFIT

Range 5% - 20%.

these value bands are based on somewhat subjective criteria, but that they have been extensively discussed with experts in the industry. They do not constitute a definitive set of numbers but we feel they are a valid first approximation.

2) Labour and supervision. When an output base has been established, it is then related to the labour and supervision required for the activity. An 'all in' hourly rate per man hour is considered and by using the gang size specified in the output constant, a price per square metre of the demolished building can be produced together with the man hour requirements. This approach has the advantage that due allowance can be made in the labour rate for enhanced payments required in any particular geographical location. Furthermore, the sensitivity of the price can be considered by changing the hourly rate or by changing the extent of supervision required.

3) Material. The material content for demolition is obviously small, in this instance purely an allowance for weatherproofing an adjoining structure.

4) Plant. The plant price is derived by taking the duration of the activity from the duration model and applying the pricing factor shown in Table 6C. Prices for the plant can be obtained from the Contractors' Plant Association list of charges or from a plant hire company. Caution should be exercised when considering the duration, because the plant will not necessarily be required for the total duration of the activity.

5) Overheads and profit. The allowance for overheads and profit is based upon a percentage of the price of the labour, materials and plant.

Professional judgment must be used to anticipate the profit margin the market will bear. In effect, the market is being evaluated in much the same way as the contractor when preparing a tender.

We can best illustrate the use of Table 6C by a worked example for the demolition of a building.

a) Assume a 4-storey building of $3000m^2$ gross floor area is to be demolished.

b) All the factors in the table are examined and a factor of 0.90 is considered as being appropriate. The output for the demolition gang is taken from the output duration:

$$\frac{200}{.90} = \underline{220m^2 \text{ per day output}}$$

c) Labour = 60p x .90 = $54p/m^2$. (Assuming an 'all in' hourly rate of £3.00 per hour).

d) Material = $25p/m^2$.

Credit for sale of materials adjusted at end.

e) Plant = Duration $\frac{3000 \text{ (floor area)}}{220 \text{ (output)}}$ = 14 days x £200 per day.

(Assuming one mobile crane and pusher arm
one mechanical shovel
one lorry)

f) Overheads and profit allowance = 15%.

g)	Price =	Labour	1620	
		Material	750	
		Plant	2800	
			5170	
		Overheads and Profit 15% ...	775	
			5945	
	Less	Credit for sale of materials ...	1000	
			£4945	= £1.64/m^2

h) Resources = 70 man days
Duration = 14 days

Thus the use of the algorithms together with the factor tables permits an operational approach to price prediction for demolition work.

6.2 General Points on the Use of the Factor Tables.

Any system is of limited use unless there is feedback to determine the reliability of the results and to highlight any apparent shortcomings. The use of the factor tables requires consideration of the durations of activities and output constants. No feedback system currently exists which would provide the professional consultants with the information required for the factor tables.

The sensitivity of the factors used in the factor table must be considered. As the design proceeds, more is known about the project and more detailed information becomes available. Detailed measurements can then be made, thus allowing greater price exploration. For example, at the early design stage, the factor tables make an allowance for materials based upon a price per square metre of the superficial area. At the detail design stage the volumes and areas of specific materials can be priced, thereby allowing a detailed price analysis. This approach could also be adopted for the output constants by using the outputs stated in the sub-network routines of each of the activities in the duration model as was shown in Figure 5.10 (Chapter 5). The algorithm could then be used to examine the items that affect the productivity for each sub-activity.

6.3 Piling Work.

Consultant quantity surveyors currently estimate for piling work prices based upon a price per lineal metre of installed pile. The BCIS standard form of cost analysis requires the following information to be given in a cost analysis for the piling work of a completed project: the piling system, the total number of piles installed, the average pile length, and the average imposed and dead loads. The problems of applying these data in conjunction with the historical prices for piling taken from the BCIS are:

1) the time taken to complete the piling work is not stipulated, yet the duration affects the establishment charge for plant;

2) there is no requirement to state any imposed restrictions on the piling activity, such as noise restrictions or the close proximity of railways or roads;

3) that the site conditions are not stated;

4) that the extent of the grouping of piles in clusters is not given, although this affects the number of times the piling rig is moved;

5) that there is no soil classification system used by quantity surveyors capable of giving the impact of varying soil conditions on the price of piling;

6) that there is a seasonal effect on productivity of piling work. During the months November-February, allowance must be made for 'down-time' and reduced output.

Because of the specialist nature of piling work, estimating text books and price books give minimal guidance on pricing techniques. The pile design takes into account the total live and dead load of the building, the soil bearing capacity, the load distribution on the foundations and the number of piles. The use of precast, bored or driven piles, is based upon the proximity of adjacent buildings and the design pile diameters.

Figure 6.2 shows the algorithm and Table 6D the factor table for estimating the duration and the price of piling work. The principles involved in constructing the algorithm and the factor table for the piling activity are similar to the demolition activity, and therefore we have not discussed this aspect further.

As the piling contractor utilises expensive machinery, duration is an important consideration. The need to optimise machine use involves detailed programming considerations. If the output for driven piles is considered, a rig capable of driving up to 525mm diameter with a 7 or 8 man gang working a 50 hour week, will drive between 300 to 475 lineal metres of piles a week dependent upon ground conditions, pile layout and weather conditions. The piling estimator will use his judgment to select an output based upon the soil condition and the number of times the rig will be moved on site, the likely weather conditions, the diameter of the piles, the soil conditions, and the site conditions.

Estimators for three piling companies were interviewed to establish the items considered in the estimating process. They stressed that as a basis for

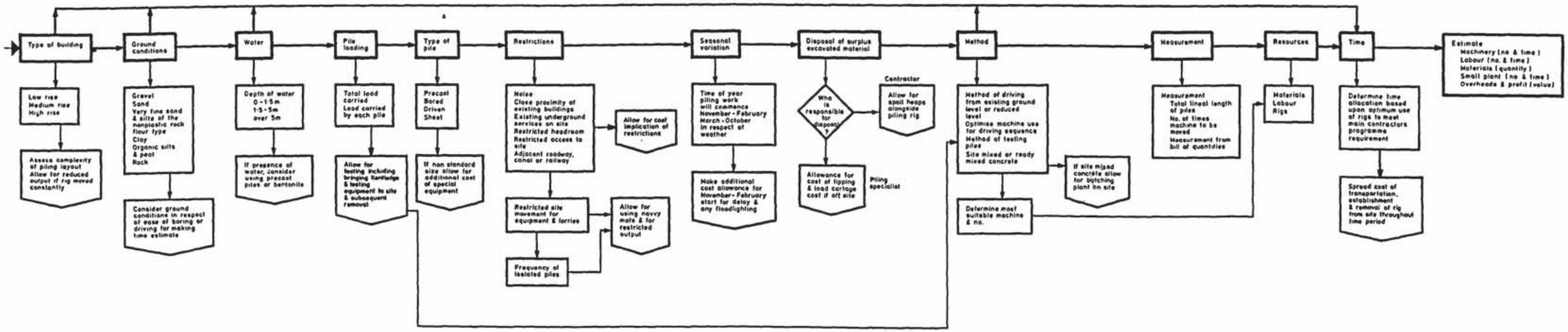


Fig 6.2 ALGORITHM FOR ESTIMATING THE PRICE OF PILING WORK

TIME	FACTORS		BASE
·10 ·30 ·15	Ground conditions	1	Clay
0 ·10 ·05	Water table level	2	Water table level over 5m deep.
·15 ·35 ·15	Complexity of pile layout	3	Allowance of 6 moves of the rig per day. No raking piles piling on slopes, or large clusters.
·05 ·30 ·10	Total number of piles to be driven	4	Time Up to 1000m = 0.05 1000 - 3000m = 0.10 Over 3000m = 0.30 (Consider total duration and number of rigs)
·15 ·25 ·20	Pile type	5	Driven cast in place concrete. Up to 400mm diameter.
0 ·20 ·05	Restrictions on piling work	6	Presence of adjacent roadway
·025 ·10 ·05	Seasonal allowance	7	February - May June - September 0.025 October - January 0.10
0 ·10 0	Disposal of excavated material	8	Main contractor to dispose surplus excavated material
·20 ·30 ·20	Method of piling	9	Driving on flat ground from existing ground level. Provision of navvy mats.
·025 ·10 ·05	Testing of piles	10	Standard test.
1·00			

OUTPUT BASE

1 Piling rig)
1 Gang 5 men)

80m of piling per day

or 20m²/day of the ground or basement floor area.

Range within the time base

0.70 ——→ 2.10

i.e. 115m/day ——→ 38m/day

LABOUR AND SUPERVISION

Price base - January 1979.

£10/m² of the ground floor area or £3/m of the pile length.

MATERIAL

£30/m² - £50/m² of the ground or basement floor area dependent upon intensity of piles

or £20/m of the pile length (based upon £400mm diameter pile).

PLANT AND EQUIPMENT

Establishment and removal charge charge for the rig	£1,800	(per rig) (up to 525mm diameter)
Equipment provision ... ... (includes dumper and lorry)	£100	per day per rig (duration and number of rigs taken from time estimate)

OVERHEADS AND PROFIT

Range 5% - 25%.

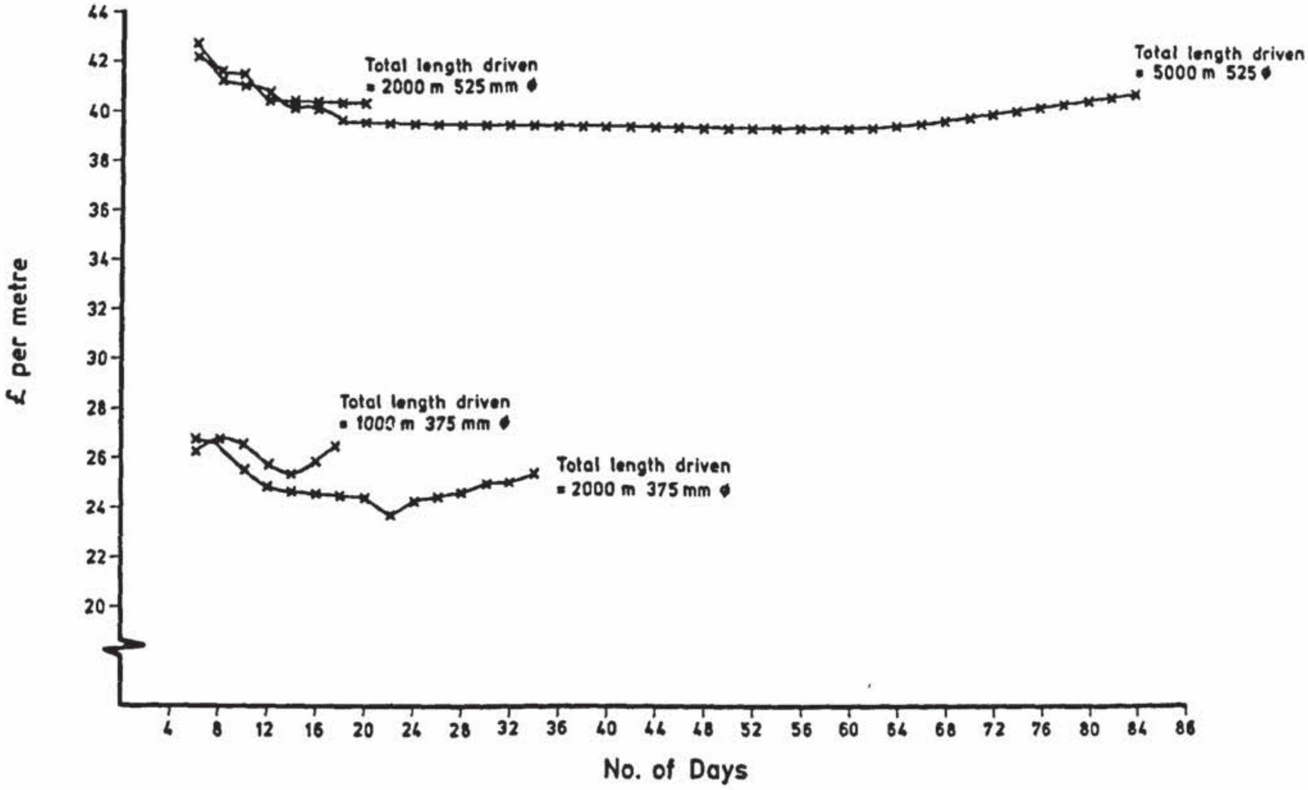
prediction the historical price per lineal metre of pile was misleading. A standard charge is made for the transportation, establishment and removal of the piling rig. In April 1976 this charge for a machine capable of driving piles up to 525mm diameter delivered to any site in Great Britain was £1,650; the larger machines carried a charge of £2,000. This charge is independent of location of the project and the number of piles to be driven. In addition, there is a hire charge for the rig per day which is determined by the number of days the rig is on site and the diameter of the piles.

Given this method of pricing, the total price of piling will be determined by the total number of lineal metres of piles to be driven, the diameter of the piles, and the number of days available for piling. It would be possible to identify for any given job an optimum number of rigs to have on site. This in turn, allows the determination of the price per lineal metre of piling for the project. It should be clear, however, that this price per lineal metre will not be constant for different projects.

To show this, a computer programme was used to vary the piling rig outputs on a contract model. Both 373mm and 525mm diameter shell piles with reinforced concrete filling were considered. The objective was to test the impact upon the price per lineal metre of the total number of piles on a project, the pile diameter; and the contract duration. The output of the piling rig was varied by commencing at an output of 300m per week and increasing in 10m stages up to a maximum output of 475m of piling per week. A second piling rig was also introduced to the work when the maximum output was reached, and when the work was outside the scope of one rig to complete within the contract duration. When the second rig was introduced, a maximum output from both rigs of 475 lineal metres of piling per week was assumed.

Figure 6.3 shows a plot of the results. Prices are current to January 1978.

Fig 6.3 THE COST OF PILING WORK



As we expected, the quantity of piles being driven in a stipulated number of days and the pile diameter affect the price per lineal metre. The algorithm and the factor table have also enabled us to make an adjustment for the establishment charge for the piling rig and the subsequent removal as a separate calculation.

6.4 Foundations.

The foundations and substructure items in Chapter 2 exhibited a high coefficient of variation. The reasons for this are perhaps obvious, in that work below ground level is affected by a large number of variables which are difficult to quantify reliably.

The structural engineer will consider the soil condition from a different viewpoint from that of the contractor. The presence of rock provides a stable foundation from a design viewpoint, whereas the contractor will consider rock difficult and expensive to work in. The presence of a high water table will create problems for both the designer and contractor. The designer will design to meet the worst possible condition whilst the builder will be faced with the difficulties of de-watering, reduced output and the consequence of increased activity durations.

Quantity surveyors are in need of a soil classification system which considers price as a parameter. A definition of the soil characteristics upon which a building is sited would give some basis for subjective comparison of foundation/subgrade conditions related to soil types. The Casagrande (1948) scale is used by engineers and CP 2001 (1957) and CP 101 (1972) give a detailed description of the classification of soils. Even when a site investigation report is in the surveyor's possession it is still difficult to relate it to the financial implications of a particular site condition.

Estimating text books still present the build-up for unit price rates in a fashion that is more pertinent to foundation work undertaken at the turn of the century. Construction method and duration are hardly considered, the assumption being that labour and machine output remain constant during a specific task.

This ignores the fact that at the tender stage the contractor will consider his method of working and then select the most appropriate plant. Decisions on the construction method take account of such items as the economics of using large capacity excavation equipment with a large lorry fleet to remove the surplus excavated material, or the employment of smaller plant with fewer lorries. The machine selection takes account of the capability of movement on the site topography, the rate of travel, the ability to strip soil, dig trenches, etc., the maximum reach below standing level, the minimum bucket width, the working space requirement, the maximum output capabilities and the hire rates.

Figure 6.4 shows an algorithm we developed for the foundations including the logic the contractor uses in deriving foundation prices.

Table 6E shows the factors to be considered for the price prediction. The value range for the soil type is 0.10 to 0.30, for example, gravel would be 0.10 and clay 0.20. The presence of a high water table level will affect performance in the digging and the loading of spoil into the lorries, as well as necessitating pumping. The pace of the excavation work is significantly affected by the extent of any excavation which has to be done by hand. Hand digging is both time consuming and expensive, and where it is required a suitable adjustment should be made to the plant and equipment item.

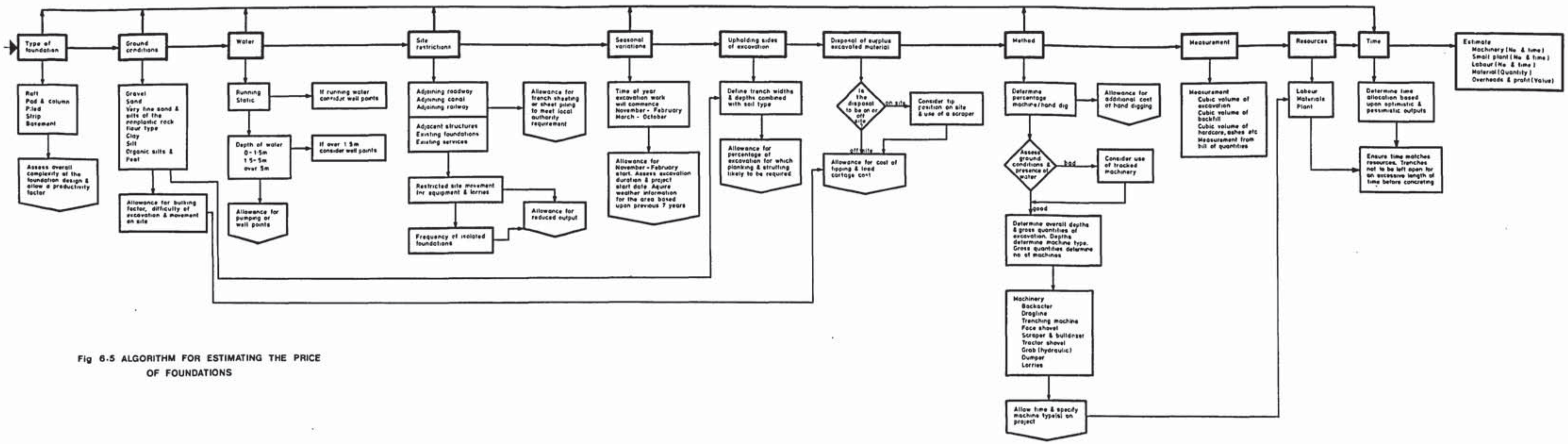


Fig 6.5 ALGORITHM FOR ESTIMATING THE PRICE OF FOUNDATIONS

TABLE 6F : FOUNDATIONS

TIME	FACTORS		BASE
·10 25 ·20	Foundation type	1	Raft with no basement. (Separate adjustment for basement)
·20 ·60 ·30	Foundation depths	2	Medium depth
·15 ·35 ·20	Complexity of foundation layout	3	Complexity based upon High, Medium and Basic. Basic assumed.
·10 ·30 ·20	Ground condition	4	Clay. (Price to take account of bulking).
0 ·20 0	Water table level	5	Over 5m average depth below ground level.
0 ·20 0	Site restrictions	6	No restrictions.
·10 ·30 ·20	Concrete and brickwork in foundations	7	Raft with no basement
·0 ·10 0	Seasonal allowance	8	March - October period during which work is commenced.
·05 ·15 ·10	Earthwork support	9	Low risk support required.
Make separate allowance for off site disposal	Disposal of excavated material	10	On site disposal
·05 ·25 ·10	Machine/Hand dig ratio	11	Assume 90% machine dig, 10% hand dig.
1·00			

OUTPUT BASE

2 Machines and 2 drivers)
1 Gang 5 men)
2 Lorries and drivers)

$30m^2$ per day of the ground floor area

Range within the time base

0.65 ——→ 2.35

i.e. $46m^2$/day ——→ $13m^2$/day

LABOUR AND SUPERVISION

Price base - January 1979.

£10/m^2 of the ground floor area.

Range within the price base 0.65 2.30 i.e. £6.50/m^2 - ——→ £23/m^2

MATERIAL

£12/m^2 - £42/m^2 of the ground floor area.

PLANT AND EQUIPMENT

Excavators £50 per day)
Lorries £50 per day per lorry) (duration taken from time estimate)

OVERHEADS AND PROFIT

5% - 15%.

6.5 Concrete Frame and Staircases.

The production of a concrete frame is increasingly becoming a role of three specialist trades. Formwork is usually erected by a specialist sub-contractor, reinforcement is fixed by a sub-contractor, whilst the placing of the concrete is becoming more specialised with the advent of more efficient and economical concrete pumping systems. With this increasing specialism is coming a greater cost awareness by the sub-contractors. Whereas in the past the contractor's costing system would consider placing concrete and erecting the formwork as two cost items, the sub-contractors will further sub-divide his costing system to capture cost information at a more detailed level.

The contractor is interested in the method of working, the number of men and the time taken to complete the task. He will calculate the beam to slab ratio and the column to wall ratio of the volume of concrete. He will also ask the following questions:

A) Are there any site restrictions likely to prevent the use of site mixed concrete?

B) Does the plan shape of the building permit large areas of repetition?

C) Will the plan shape create difficulties for the distribution of material?

D) What type of concrete frame will be used? If it is a flat slab system with no beams, this can lead to quicker construction and the possible use of table formwork.

E) Are all the storey heights reasonably constant?

F) Are there likely to be any precast concrete units weighing over 2 tonnes? (This will affect the crane requirements.)

G) What will be the required quality of surface finish to the concrete?

H) Will it be possible to cast a complete floor in one pour?

I) What will be the frequency of construction joints?

Formwork to suspended slabs over 300mm thick often necessitates propping a minimum of three floors below the slab whilst the concrete is curing, in order that the dead load is evenly distributed during construction.

Floor to ceiling heights are important when considering shuttering costs. There are five standard sizes of shutter support props, as shown below:

SHUTTERING SUPPORT PROPS

Size	Height closed	Height extended
0	1.05 m	1.80 m
1	1.75 m	3.12 m
2	1.97 m	3.35 m
3	2.58 m	3.96 m
4	3.20 m	4.87 m

If the design incoroporated varying floor to ceiling heights it could mean a greater number of props being kept on hire for the project. This was illustrated on a contract we encountered during the research. A four-storey office building had been designed with a ground and second floor storey height of 2.75 metres, while the first and third floors were 4.28 metres high. To enable the suspended slabs to be cast each in one pour, each floor required two thousand props to support the formwork. This necessitated both two thousand No. 1 props and two thousand No. 4 props being kept on hire. The impact upon the unit price per square metre of the formwork to the soffit of suspended slabs was to add twenty per cent to the unit prices.

Another example of the importance of understanding the method of working was encountered on a scheme where the designer specified a fair face finish to the concrete walls of a roof top lift motor room. All the formwork on the project had previously been sawn faced, and consequently only one use was obtained from the wrought faced shutters. Rather than declare an excessively high unit price rate, the sub-contractor distributed the additional cost of the wrought faced shutters throughout the unit price rates for all the formwork to vertical faces of wall items.

Figures 6.6, 6.7 and 6.8 show the algorithms we have developed for estimating the prices of concrete work, reinforcement, and formwork. We need to adopt a slightly different approach when combining these algorithms for the development of the factor table.

Table 6F shows the formwork, reinforcement and the concrete items considered separately. Many of the factors are common to all three items, hence the use of one table. The weighting of the three items is based upon a reinforced concrete flat slab system, but the factors will vary with the type of structural system.

The value range for the formwork items is very wide, thus highlighting the extent that productivity can be affected by such aspects as repetition and the extent of the beam to slab and column to wall ratios.

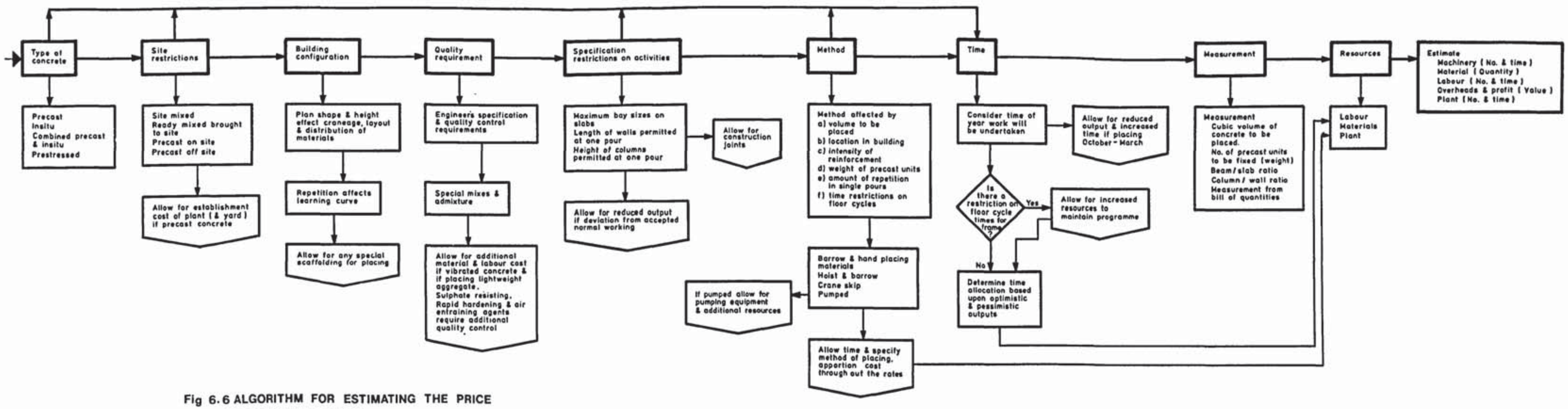


Fig 6.6 ALGORITHM FOR ESTIMATING THE PRICE OF CONCRETE WORK

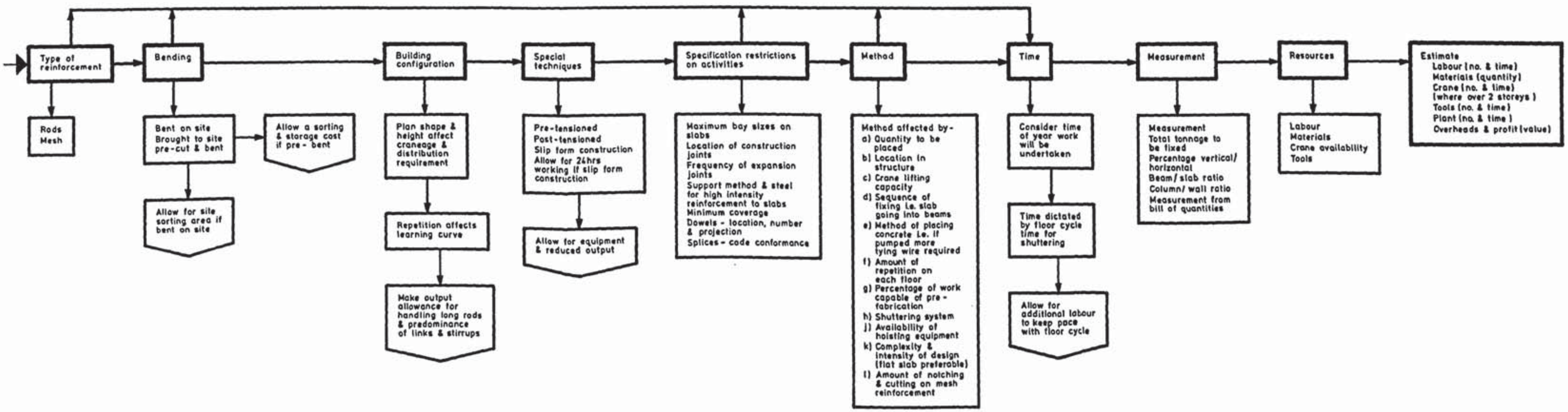


Fig 6.7 ALGORITHM FOR ESTIMATING THE PRICE OF REINFORCEMENT FOR CONCRETE

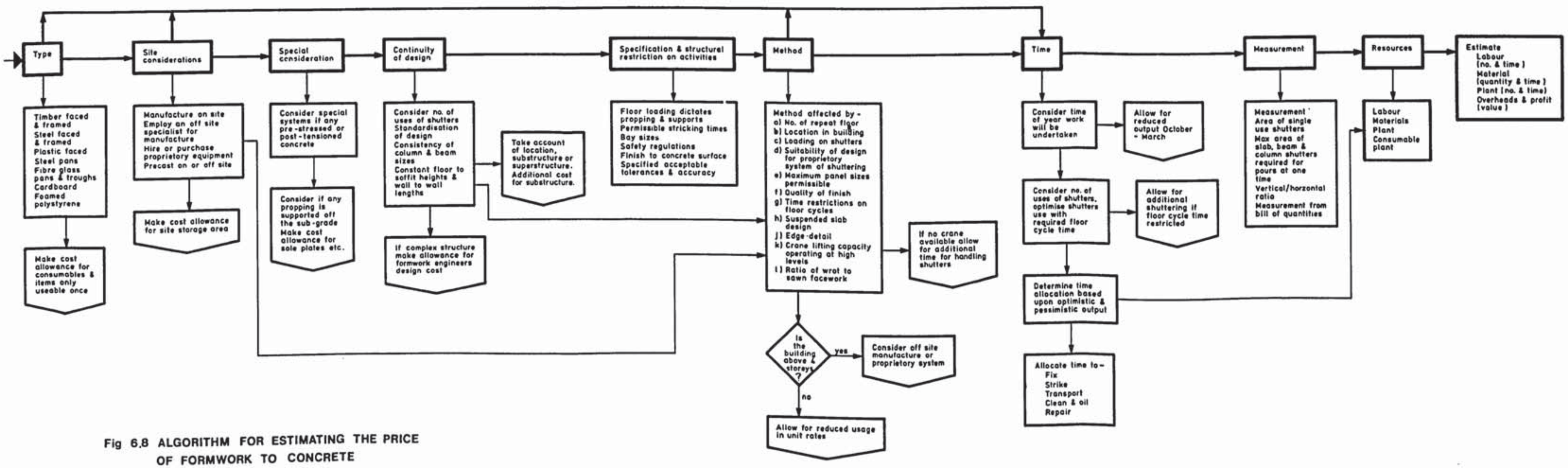


Fig 6.8 ALGORITHM FOR ESTIMATING THE PRICE OF FORMWORK TO CONCRETE

TABLE 6F . CONCRETE FRAME AND STAIRCASES

FACTOR	FORMWORK	REINFORCEMENT	CONCRETE	BASE
Type of formwork	0 / ·05 / ·025			Timber faced and framed
Type of concrete			·05 / ·10 / ·075	Reinforced concrete flat slab. Allowance of 4 staircases per floor.
Type of reinforcement		0 / ·05 / ·025		Pre-bent rods
Building configuration with regard to distribution of materials	·05 / ·15 / ·05	0 / ·10 / 0	·05 / ·15 / ·05	Single block, crane availability.
Quality of concrete (special requirements)			0 / ·05 / ·025	Good quality exposed finish required.
Quality of formwork (special requirements)	0 / ·20 / 0			No special requirements.
Special pre or post tensioned reinforcement requirement	0 / ·10 / 0	0 / ·20 / 0	0 / ·10 / 0	No pre or post tensioned reinforcement.
Repetition of plan shape and storey heights	·30 / ·60 / ·30	·025 / ·10 / ·025	0 / ·10 / 0	Repetitive floor plans (8 storeys)
Sawn/wrot formwork ratio	0 / ·20 / ·075			90:10 ratio.
Slab/Beam ratio	·05 / ·15 / ·075	0 / ·10 / ·025	·025 / ·10 / ·05	95:5 ratio.
Wall/Column ratio	·05 / ·15 / ·075	0 / ·10 / ·025	·025 / ·10 / ·05	90:10 ratio
Seasonal variation	0 / ·05 / 0	0 / ·05 / 0	0 / ·15 / 0	March - October construction period
Floor cycle time restrictions	0 / ·20 / 0	0 / ·05 / 0	0 / ·05 / 0	Minimum 12 day floor cycle time
Special finishes to concrete	0 / ·10 / 0		0 / ·10 / 0	No special finishes
	0·60	0·10	0·30	
Range =	0·45 → 1·95	0 → 0·75	0·125 → 1·00	

OUTPUT BASE

5 men placing
10 men formwork
4 men reinforcement

Using weighting with a minimum 12 day floor cycle

0.60 Formwork
0.10 Reinforcement
0.30 Concrete

35m^2/day of the superficial floor area of the frame

Range within the time base

Formwork	0.45	1.95
Reinforcement	0	0.75
Concrete	0.125	1.00

i.e. 60m^2/day ——— 13m^2/day

LABOUR AND SUPERVISION

Price base (Factor 1.0)

£6.00/m^2 of the slab area.

MATERIAL

Concrete (300mm slab)	...	15.00/m^2
Reinforcement·.05T/m^2	...	10.00/m^2
Formwork (assume 6 uses)	...	6.00/m^2
		31.00/m^2

Range £20 - £55/m^2 dependent upon column intensity and slab thickness.

PLANT AND EQUIPMENT

Pumping equipment - £100 per day during placing (duration taken from time est
Vibrators - £5/day
Power saws - £2/day
Small tools - £10/week
(Cranenge and hoists with preliminaries)

OVERHEADS AND PROFIT

Range 5% - 25%.

Table 6F would be used at the sketch design stage where there is insufficient design detail to measure the detail quantities. A factor table on the lines we suggested above could be used as more detailed information becomes available.

6.6 Testing the Algorithms and the Price Prediction Technique.

The algorithms will hopefully provide an insight into the logic used by the specialist sub-contractor and general contractor when pricing. Even at the pre-cost plan stage the surveyor must consider how the proposed building will be constructed. One outstanding question is, however, whether the algorithms do represent actual construction practice.

We considered the most rigorous test for our estimating algorithms was to gain the reaction from estimators in specialist sub-contract organisations undertaking demolition, piling work, excavation, formwork erection, concrete placing and steel fixing. We also gave the algorithms to the chief estimators from five national contractors. All the organisations approached were very co-operative. Their attitude was that the algorithms could help consultant quantity surveyors to be aware of the 'real' problems the specialist faces on construction projects. They felt that the long term objective must be to develop an operational approach to pricing for the construction industry.

No empirical tests could be conducted on the factor tables, but advice was sought from quantity surveyors in practice. They felt that the approach was useful, but also felt that there would be some difficulty in obtaining reliable feedback about durations, because the bill of quantities in its present form does not permit the type of analysis the prediction system requires.

6.7 Conclusions.

In this chapter we have investigated the contractor's logic used in pricing, and by simulating his decision process we have produced algorithms showing the impact of operational factors and the method of construction on site performance. We have used this information to produce an operational price prediction technique that takes into consideration both the construction method and the construction duration.

The use of the algorithms and factor tables represents a departure from the conventional approach to price prediction. The system does not use unit price rates, which currently represents the main source of price data for the quantity surveyor. Unit price rates reveal the weakness of bills of quantities in their current form, which results from an insufficiently sensitive SMM. The theory that any item of construction can be related to a unit of finished work is an outdated approach to prediction.

An understanding of the requirement and usage of the resources involved in any task in the building process is obviously important, and the often quoted statement, "The quantity surveyor should not concern himself with the method of construction - that is the contractor's problem," shows a total lack of understanding of how prices for building work are derived.

Price prediction which simulates the contractor's approach takes account of both the buildability of the project and the variables which will influence performance.

The factor tables and algorithms can be easily updated and revised as more knowledge becomes available. When wage rates change or a new type of plant or technique becomes commonly used, the required changes to the factor table can be easily made.

Chapter 7

Conclusions

7.0 Introduction.

The price prediction for a proposed project is probably one of the most important tasks performed by the quantity surveyor. Despite its importance, price prediction techniques have changed very little over the past 25 years. There appears to have been a lack of fundamental research to consider how price forecasting techniques could be improved.

Price prediction is characterised by a reliance upon unit price rates from completed projects. The underlying assumption has been that prices should be related to a unit of measurement of the finished building.

This thesis, therefore, has the overall objective of gaining a greater understanding of the price prediction process. Having drawn conclusions during, and at the end of, each chapter, we now summarise those which appear most important. Initially we shall be looking at changes to the existing techniques of price prediction before making some comments about the changes we feel are necessary for the future development of price prediction techniques.

7.1 The Variability of Building Prices.

Unit price rates contained in tenders exhibit considerable variability. Prices for individual measured items of work on different projects showed variations of up to eight times those of tender totals. Even when tenders submitted by different contractors for the same project are considered, there is wide variation.

The trades exhibiting the greatest price variability are preliminaries, and excavation and earthwork. The preliminaries trade is influenced by the contractor's approach to pricing, by the construction complexity of the project, and by its duration. We can ascribe the high variability of the excavation and earthwork to the different construction methods and to the contractor's evaluation of risk associated with the trade.

There was much smaller variation in the unit price rates submitted by specialist sub-contractors than in those exhibited by general contractors. The often narrowly defined nature of the specialist's work has meant that many firms have been able to develop more refined costing systems than is possible by a general contractor who is covering a wide range of work. This situation has led to the availability of cost feedback and a more detailed approach to estimating.

In order to take account of price variability when using a sample of historical prices as a basis for price prediction, both the sample size and the homogeneity of the sample are important. It will often be better to use a small homogeneous sample, rather than a large heterogeneous sample.

7.2 The Adequacy of Current Price Prediction Techniques.

The reliance on historical unit price rates has meant that quantity surveyors have placed too much emphasis on considering the effect of, rather than analysing the factors that cause, price differences for building work. For example, for the purposes of cost planning, the building price is analysed into functional elemental categories, but these are of little help in the identification of factors affecting prices.

Unit price rates say nothing about the resources included in the rate, or the method of using the resources or the duration for which the resources are required.

None of the prediction techniques directly considers the influence of the construction duration, the resources involved in the construction process, the operational sequence of the construction work, or the complexity of the project. New approaches at the early design stages are required which identify the cost significant aspects of design and construction. One such approach is the use of simulation cost models.

We demonstrated in the thesis the use of a simulation cost model for lift installation. The main advantage of this technique is that the designer can be advised of the financial implications of conceptual design options prior to the commencement of detailed design. However it requires an appreciation of the technology of design problems which not all quantity surveyors have in the past been prepared to consider.

Simulation cost models could be developed for all construction activities, with advice on price data being given by the specialist sub-contractors, material and component manufacturers, and contractor's estimators.

We feel that site activities lend themselves more readily than do the elemental categories to a modelling approach, which can take into consideration factors which influence the contractor's approach to pricing.

As a first step, the operational activities in our duration model (Chapter 5, Figure 5.9) could be used as the framework for the development of the models.

Of fundamental importance to all existing price prediction techniques is the use of price data taken from the low bids of historical projects. Whilst we concluded that the low bidder's price data should be used as the basis for forecasting, consideration should be given to the relationship between the lowest and second lowest bids. We suggested that where the low bid is more than 5% of the contract value below the second lowest bid, then the lowest bidder's prices should be treated with caution when used as price data for prediction.

7.3 The Accuracy of the Quantity Surveyor's Price Predictions and the Contractor's Estimates.

(a) The Quantity Surveyor's Price Predictions.

The case study in Chapter 4 of two County Councils showed that, despite their commissioning similar types of projects, there were significant differences in estimating performance. We concluded that on the larger projects the estimates differed from the low bids in a consistent fashion. There is, therefore, a need for a quantity surveyor to monitor performance constantly in order to identify any estimating patterns which emerge.

We produced trend and deviation control charts which aid the quantity surveyor by indicating any consistent bias in estimating performance. Complete accuracy is unattainable, but consistent errors can and should be avoided.

We applied risk analysis to cost planning to show the relationship between a price prediction and the chance or probability of the tender price deviating from the price forecast, and to indicate the most likely range within which the contractor's price will lie. The technique does not improve the accuracy of predictions, but it does permit the systematic consideration of potential errors.

A price prediction within a value range is more meaningful to the client than a single figure forecast, which lacks the means of gauging the chances that the tender price will either exceed or be less than the price forecast.

(b) The Contractor's Estimates.

Very little published data are available to give an indication of the accuracy of contractor's estimates. We examined one contractor's estimating performance which showed that on individual projects there was a low level of accuracy. However, the overall accuracy on all the project estimates showed that 'on average' the contractor achieved his desired level of profitability.

The analysis supports our view that the quantity surveyor should always use more than one historical project as the price data for prediction.

7.4 The Use of the Construction Duration in the Price Prediction Process.

In Chapter 3 we criticised existing price prediction techniques for not taking due account of the impact of construction duration on the price of building work. Many of the items in a bill of quantities are time related, yet no technique exists by which the duration can be adequately considered. We developed a duration model which serves three purposes:

a) it allows the construction duration of alternative design solutions to be evaluated at the design stage;

b) in conjunction with a list of time related preliminaries items, it permits a systematic evaluation of the preliminaries prices for a proposed project;

c) when linked with the cost planning elemental categories it allows the production of a cash flow analysis at the design stage.

The use of the duration model requires consideration of the project in terms of construction activities and the sequence of operations. Ultimately, this will mean the design team acquiring a greater knowledge than they currently have of the method of constructing buildings.

7.5 An Operational Approach to Price Prediction.

An operational approach to price prediction was researched by identifying the cost significant features of a number of construction activities. We simulated the decisions made by the contractor at the stimating stage to produce algorithms showing the major items which influence the contractor's site performance.

The use of the duration model, the algorithms, and the factor tables enables items to be considered which are currently ignored by prediction techniques.

This approach is not in keeping with the current methods of using the unit price rates contained in bills of quantities as the basis for prediction and would require some radical changes to be made to the methods of cost planning and pricing construction work.

7.6 Changing the Basis of Price Prediction - the Way Ahead.

One of the fundamental difficulties when considering prices is the separation of design and construction. This has led the design team to consider prices in relation to the built project, whereas the contractor considers prices in relation to the construction activities and their inter-relationship which lead to the built project. Furthermore, the bill of quantities requires contractors to display prices in a manner that relates to the finished design.

We showed in Chapter 2 that contractors consider costs in resource terms, yet they communicate prices by converting the resources to unit price rates.

The initial task is to convince the contracting and sub-contracting industries and the quantity surveying profession that it is pointless to use these two levels of information. If there were a common language for prices based upon resources, the design team would eventually acquire a greater awareness of the contractor's operational and sequencing problems associated with construction tasks.

In Chapter 3 we criticised the cost planning elemental categories as being concerned purely with the functional part of a building. The elemental categories were developed to allow a means of cost control during the design phase and to ensure a balanced spread of expenditure throughout the building. The elemental categories do not match the format of a trade bill of quantities, and therefore the elemental bill was developed to enable unit price rates to be analysed by elemental categories. These bills have never been popular with contractors' estimators because they serve no useful purpose for the contractor.

A major revision of elemental cost planning is long overdue. The objectives of design cost planning are still applicable, but the categories should reflect the resource inputs. Cost planning should involve considerations of the construction duration, the quantity and extent of the work, the complexity (buildability) of the project, the method of construction and the operational sequence of the work, thereby satisfying Bennett's (1978) criterion of distinguishing projects which generate a simple operational pattern from those that generate a complex operational pattern.

Our research has shown the possibility of modelling a building using activities. We suggest that this concept could easily be applied to cost planning by using price models based upon activities employing a precedence network for particular building types. Algorithms can be developed to reflect the operational significance, and factor tables to consider the price implications and resource requirements.

In Chapters 5 and 6 we emphasised that in order to use an operational approach to price prediction, feedback on activity durations and outputs would need to be collected. In the past, these areas have been outside the surveyor's scope of interest. Hence, no formal education and training has been given in construction programming and measurement of performance. We are not suggesting that the surveyor should become involved in work study measurements on site; this would not be practical or acceptable to any of the parties.

The current bill of quantities provides little or none of the data that have been described as being a requisite for the price models. Therefore, an adequate feedback system is required which is capable of capturing information in the defined format. This would require major modification to the SMM and the bill of quantities.

The seventh edition of the SMM is being considered at present. We recommend that items in bills of quantities should be classified as being time related, method related, or quantity related. Furthermore, we feel that resource prices based upon site activities should be used as the common language of the construction industry. This means the quantity surveyor would require a more detailed knowledge of the construction process than he currently possesses.

There are limitations to the reliance on the bill of quantities as the main source of price information. The use of resources would enable price data to be obtained from material manufacturers and suppliers, and plant hire specialists, thereby allowing a more meaningful analysis of prices to be undertaken.

This leads to an overlying qualification of the whole work, namely that the various conjectures and proposals have been tested only to a limited extent. Whilst they are plausible, their relevance to building will need to be further tested. The thesis indicates how this may be attempted through further research which was not possible in the present investigation. In brief, the thesis points to possible rather than final solutions.

APPENDICES

APPENDIX 1.

THE IMPACT OF GEOGRAPHICAL LOCATION UPON CONSTRUCTION PRICES.

8.0 Introduction.

The main factors of production in construction are labour, materials, transport and plant. The prices of all these factors can vary regionally by interaction with other economic forces. Regional patterns exist as a result of economic activity, availability of labour, ease of transportation, climate and a host of other factors. Stone (1967) said "the extent and reasons for regional differences in price are at present very imperfectly understood". Despite eleven years having elapsed, our research findings support Stone's viewpoint.

Very few research projects have been carried out to determine the effect on price of regional location. Reiners (1958) concluded that construction prices for the erection of three to five storey flats in inner London were 20% to 30% higher than in the provinces. The Phelps Brown Report (1967) did not concern itself directly with construction prices, but it did point to the lack of uniformity in average earnings of skilled workers between different regions. Any variation in wages paid by the contractor will, ultimately, lead to a difference in construction prices between regions. The Scottish Housing Advisory Committee (1970) found that the average cost in Scotland in 1970 to construct a housing unit with the same floor area was £717 more than in England. They concluded that part of the difference could be accounted for by higher wage rates, higher material costs, the effect on productivity of more severe weather conditions, and higher profit margins in Scotland.

Certain UK government bodies have attempted to measure the price effect of location. The Housing Cost Yardstick issued by the Department of the

Environment makes regional cost allowances for the effect of location on residential development. The DQSS have produced a location index which is applicable to public sector work undertaken by PSA.

To consider the location effects upon cost, we obtained data from a contractor relating to his construction costs for various projects located throughout Great Britain. To our knowledge, all the previous research on the impact of location has concentrated purely on price, but we were considering costs to the contractor.

8.1 Analysis of the Impact of Location upon Cost.

We were given access to a national contractor's cost book for a completed office block located in the Barbican, London. The project was finished in 1974 at a cost to the contractor of £1,225,040. The contractor's actual profit margin on the final account value was 6.08%, and because this was acceptable, we felt there was validity in using the data for the project.

We analysed the project cost to the categories shown on Table A1.A. The aim was to use the project as a model to test various aspects of the cost of regional location. Our assumption, in using the model, was that the same amount of labour, materials and plant would be used if the building were constructed in different locations.

8.2 Labour.

The first consideration was the cost of labour. The National Working Rule Agreement (1978) gives the agreed minimum wage rates and additional payments payable to operatives on construction sites. However, it is unlikely that the vast majority of the labour force would be prepared to work for the stated rates, especially when there is high construction market activity in an area. It would be necessary to offer a rate above the basic wage rate as an inducement.

TABLE A1.A : CONTRACT MODEL ANALYSIS (COST TO CONTRACTOR)

ALLOCATION	MAIN CONTRACTORS WORK		NOMINATED SUB-CONTRACTORS AND SUPPLIERS WORK		DIRECT SUB-CONTRACTORS WORK		TOTAL AS A PERCENTAGE OF CONTRACT VALUE	PERCENTAGE OF TOTAL CONTRACT COST WITH ON COST PROPORTIONS
	£	% of contract value	£	% of contract value	£	% of contract value		
Craftsmen	57 008	4.654	105 318	8.597	53 308	4.352	17.603	20.443
Labourers/Mates	54 592	4.456	56 620	4.622	53 022	4.328	13.406	15.570
Labour only Craftsmen	21 886	1.786	-	-	-	-	1.786	2.074
Labour only Labourers	24 154	1.975	-	-	-	-	1.975	2.294
Site staff	60 740	4.958	-	-	-	-	4.958	5.758
Materials	163 620	13.356	271 550	22.166	35 830	2.925	38.447	44.650
Plant hire and fuel	72 118	5.886	17 372	1.418	648	0.053	7.357	8.544
Plant spares	1 906	0.155	-	-	-	-	0.155	0.180
Non-mechanical plant	3 516	0.287	-	-	1 622	0.132	0.419	0.487
Prime cost	459 540	37.513	450 860	36.803	144 430	11.790	86.106	-
Head Office overhead apportionment	61 571	5.026	94 124	7.684	14 512	1.184	13.894	-
TOTALS	521 11[illegible]	42.539	544984	44.487	158 942	12.974	100.000	100.000

(Note: Nominated Sub-contractors breakdown on a percentage basis only).

The gross cost of labour comprises fixed and variable costs. The fixed costs include the basic wage rate, payments required under the National Working Rule Agreement, insurances, guaranteed time, severance pay, sick pay scheme, death benefit scheme, holidays with pay, graduated pension and industrial training board levy. The variable costs are fares, travelling time, lodging allowances, unearned bonus, inducement money to attract labour, non-productive overtime and non-production because of inclement weather.

The contractor made available to us the wage sheets for all the projects he had under construction during February 1974. Column B of Table A1.B shows the average gross wage rate per hour including guaranteed bonus, before any statutory deductions, earned by the contractor's craftsmen in various locations throughout Britain. The rates represent a mean hourly rate for all the various trades over the four week period. The wage rates in the table exhibit surprising variability. We would expect a higher labour rate to be prevalent in London than the provinces, and this is confirmed by the wage rates. However, the distance from Brighton to Worthing is ten miles, yet different hourly rates were being offered in the two locations. We approached the contractor to find out why this was so; the reason given was that many of the site force at Worthing were recruited from the Brighton area, where there was availability of labour. Consequently, a higher hourly rate was being paid at Worthing to attract labour.

We used sensitivity analysis on the contract model to test the effect on the overall construction price of applying the wage rates in the various locations, comparing the supposed cost of the Barbican building in the other locations using the different wage rates. Column C of Table A1.B shows the results of the analysis, and Column D gives the indexed value. The base index (100) was the Barbican, whilst the lowest index number was Southampton (93.8).

TABLE A1.B : HOURLY WAGE RATE AND CONTRACT MODEL COST

Location (A)	Hourly rate (£) (B)	Cost based upon contract model (£) (C)	Cost index based upon contract model (D)
SOUTH			
Barbican, London EC1	1.89	1,225,040	100
London EC1	1.82	1,219,200	99.5
London SW3	1.63	1,203,353	98.2
London E1	1.61	1.201,685	98.1
London WC1	1.55	1,196,680	97.7
London SE3	1.44	1,187,506	97.0
Shepperton, Middx.	1.43	1,186,672	96.9
London W1	1.40	1,184,170	96.7
Worthing	1.38	1,182,502	96.5
London SW1	1.26	1,172,493	95.7
Brighton	1.25	1,171,659	95.6
Hove	1.22	1,169,156	95.4
London SW7	1.17	1,164,986	95.1
Wallingford, Oxon.	1.07	1,156,645	94.4
Southampton	0.98	1,149,138	93.8
WEST			
Blackdown, Dorset	1.24	1,170,825	95.6
Newport, Gwent	1.21	1,168,322	95.4
Bristol	1.12	1,160,815	94.8
EAST			
Hull	1.19	1,166,654	95.2
York	1.03	1,153,309	94.1
Pontefract	0.99	1,149,973	93.9
NORTH			
Manchester	1.74	1,212,528	98.9
Edinburgh	1.44	1,187,506	96.9
Inverness	1.18	1,165,820	95.2
Aberdeen	1.14	1,162,484	94.9
Glasgow	1.12	1,160,816	94.8

We can conclude two things from the analysis. Firstly, wage rates exhibit very wide variability. London wage rates are somewhat higher than other rates paid in the South, but the sample is too small to show conclusively what regional trend exists. Secondly, despite the fact that the value of the labour represented only 35% of the total value of the construction cost, the cost index (Column D) shows that the variability in wage rates can lead to a variation in the overall contract sum of 7%.

8.3 Materials and Plant.

We than moved on to consider the effect of the costs of certain construction materials.

Norman (1979) suggests the greatest regional price influence on materials is the impact on transportation costs.

We decided to concentrate the study on certain primary building materials. The quantities of materials used in the contract model were taken from the records and used to test the price difference.

The materials considered were common bricks, clinker concrete blocks, mild steel rod reinforcement, and ready mixed concrete. These materials were selected on the basis that they represent a significant part of the expenditure on a project. Quotations were sought from national suppliers and prices were calculated using a time base of February 1976.

In the cases of bricks, blocks and mild steel rod reinforcement, there is a basic price list applicable to all parts of Great Britain, but to the list is added the transportation or delivery charge. For the purposes of estimating the rod reinforcement transport charge, the basing point was Scunthorpe.

To maintain consistency of prices, only one major supplier of ready mixed concrete was approached. There is a wide variation throughout the industry of the price of ready mixed concrete delivered to site, which is dependent upon the location of the batching plant to the site and the total volume of concrete to be supplied.

We consolidated the study on material prices by grouping certain cities to give a representation throughout the country, thus avoiding unnecessary duplication of prices. We applied the prices of materials to the quantities derived from the model; Table A1.C shows the results. Column F highlights two interesting results. Firstly, London is the most expensive area for the purchase and delivery of materials, in this case influenced mainly by the high price of ready mixed concrete. Secondly, the regional variation in the price of materials has very little impact on the overall construction price.

To take account of the plant costs we asked plant hire companies if any regional pattern existed in the cost of plant hire. All the organisations were unanimous that geographical location had no effect on plant hire charges.

8.4 Temporary Services.

One aspect of building work for which we could find no published information was the cost of power and water consumed during construction work. We therefore considered this aspect further.

The contractor is faced at the estimating stage with an unquantified variable when calculating the cost of temporary electricity and water for a construction project, because he must predict the quantity of power and water likely to be used on the proposed project.

Every electricity board and water board in Great Britain was contacted to

TABLE A1.C : PERCENTAGE ADDITIONS TO CONTRACT MODEL FOR MATERIALS

LOCATION (A)	% ADDITION OR DEDUCTION TO TOTAL VALUE OF CONTRACT MODEL USING LONDON AS BASE				
	Bricks (B)	Blocks (C)	Rod Reinforcement (D)	Ready mixed concrete (E)	Total adjustment (F)
London	-	-	-	-	-
Brighton	+0.09	-	+0.05	-0.35	-0.21
Wallingford	+0.03	-	-0.02	-0.70	-0.69
Southampton	+0.13	-	+0.04	-0.35	-0.18
Newport	+0.16	-	+0.02	-1.12	-0.94
Hull	+0.22	+0.02	-0.22	-1.26	-1.24
York	+0.22	+0.01	-0.19	-1.12	-1.08
Manchester	+0.21	-	-0.18	-1.19	-1.16
Edinburgh	+0.27	-	+0.05	-1.47	-1.15
Glasgow	+0.27	-	+0.08	-1.47	-1.12
Inverness	+0.32	+0.02	+0.20	-0.70	-0.16

ascertain their charges for temporary water and power supplies. No national uniform scale of charges exists for either power or water.

Most of the water authorities offer the alternatives of being charged either on a metered quantity of water consumed during building work, or on a fixed percentage of the contract value. Certain authorities add further complications by charging on a percentage value of the wet trades items on a construction project. We ascertained from the contract model records that approximately 1,500,000 gallons of water were used during construction work. Figure A1.1 shows the overall effect on total value of the contract model for the cost of water, assuming the project was built in the location of the various water authorities. The analysis highlights considerable inconsistencies that currently prevail. The Fòlkestone Water Authority and the Mid-Kent Water Authority are closely located, yet Folkestone charge over three times the Mid-Kent price for water. Similarly, if the model were built in the Bournemouth area, the cost of water would have represented 0.02% of the contract value, whilst the adjoining water board, the South-West, would have charged 0.42% of the project value; in money terms this represents a difference of £27,000 on the model. In Chapter 3 we discussed the accuracy of the quantity surveyor's predictions; it would be extremely difficult for the quantity surveyor to capture this price difference on water when preparing a price prediction.

In many instances the contractor must select, at the commencement of the contract, the basis upon which he wishes to be charged for the water for building work. The table indicates that it is usually preferable to pay for the water by a meter which measures the quantity of water actually consumed.

We then considered the cost of electricity used in building work. From the contract model records, we calculated that an average of 37,500 units of

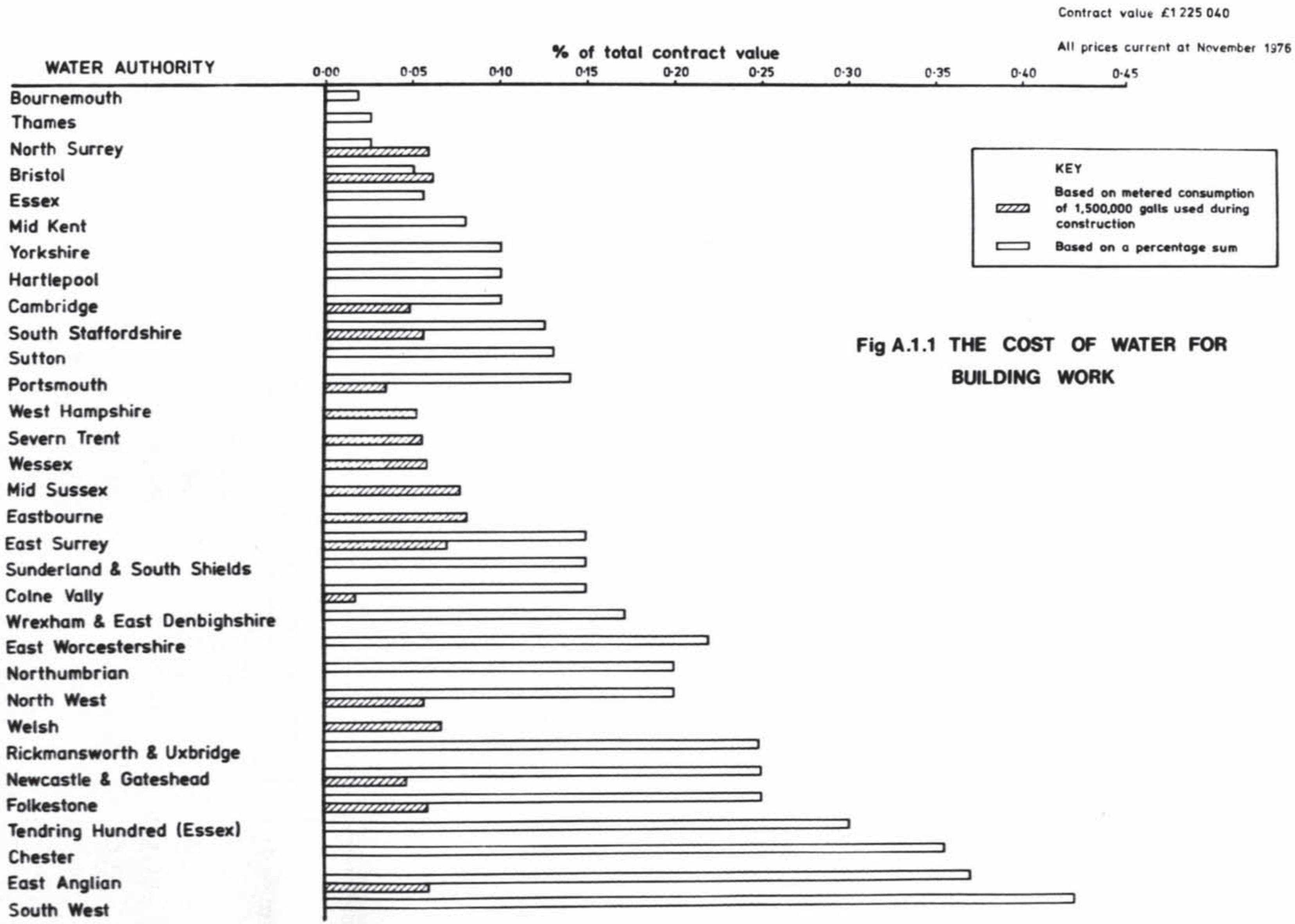


Fig A.1.1 THE COST OF WATER FOR BUILDING WORK electricity per month were consumed throughout a twelve month period. We applied the tariffs and basis of charging for each electricity board to the contract model. Table A1.D shows the results. The percentage value for electricity of the total contract value has been expressed for each board.

The method of charging for the units of electricity consumed was totally different for every board, as was the price charged per unit of electricity. Anomalies occur in the regions, for example, the north of Scotland charge under half that of the south of Scotland electricity board.

None of the prices in Table A1.D or Figure A1.1 includes for the cost of installing and removing the services, nor any allowance for the main contractor's attendance, overheads and profit. It is evident that when all the charges are combined, temporary power and water are now a significant cost factor.

If we combine Figure A1.1 and Table A1.B and apply the values to our contract model in the locations used for the material price analysis, we get the results shown in Table A1.E.

TABLE A1.E : THE COST OF TEMPORARY SERVICES FOR BUILDING WORK

Location	% of total value on contract model represented by electricity and water charges	Index
London	0.912	100.0
Brighton	0.844	92.5
Wallingford	1.185	129.9
Southampton	0.889	97.5
Newport	0.985	108.0
Hull	0.955	104.7
York	0.955	104.7
Manchester	1.053	115.5

Note: No replies were received from the Scottish water authorities. Water cost based upon metered consumption.

TABLE A1.D THE COST OF ELECTRICITY FOR BUILDING WORK

Electricity Board	Percentage of contract model value
North of Scotland	0.471
Southern	0.749
South Eastern	0.762
Eastern	0.822
Merseyside and North Wales	0.831
Norweb	0.853
Yorkshire	0.855
South Wales	0.918
Midlands	0.993
South of Scotland	1.023
East Midlands	1.069
South Western	1.159

(All prices current: November 1976)

The results highlight the wide variation that exists. For example, the cost of temporary services in Wallingford is 30% higher than in central London, yet the distance between the two locations is under fifty miles.

Our investigation into the impact of location upon cost has shown that variability of cost does exist, the main influence being the labour cost. We have assumed that the contractor will reflect the regional differences in cost in his prices.

Our research has shown the need to make an adjustment system (based upon an index) for the effect of location upon construction prices. The data used for our analysis are not sufficiently detailed for us to construct such an index, and it was not possible within the scope of this thesis to set about the task of developing our own index. However, our further research in the future will examine this aspect of building economics in greater detail.

APPENDIX 2.

COST AND PRICE INDEXES.

9.0 Introduction.

Our research into cost and price indexes took two forms. Firstly, we considered the characteristics and types of indexes together with the way they are constructed. Secondly, we analysed a number of published indexes to identify the degree of uniformity in index movement.

9.1 Characteristics of an Index.

An index number is a statistical measure designed to show changes in a variable or group of related variables with respect to time. Indexes are nearly always inexact, but serve as indicators of general trends. No one index can ever precisely describe all variations, but as the alternative is the use of many indexes, this is seldom warranted.

An index is useful only if it can be made available easily and quickly for use. Index users not only require up to date information, but also a predictive capability. No index currently supplies forecasts; users must infer future trends.

Indexes may be either:

1) Input indexes which measure price change based upon a sample of labour, material and equipment inputs, suitably weighted one to the other to reflect the effect on total cost, i.e. the cost actually incurred by the contractor.

2) Output indexes which measure price change at the transaction level, usually the purchase price paid for complete buildings. These indexes reflect price change resulting from variations in labour and material

prices and also take into account productivity, market conditions, interest rates, technological change and other intangibles, i.e. the tender price submitted by the contractor to the client.

9.2 Time Cost Indexes.

Time indexes measure cost changes over time and are often called inflation or escalation indexes.

In the construction industry we use the terms "building cost indexes" to represent input indexes and "tender price indexes" for output indexes. Both types of index fulfil a useful but different function.

The building cost indexes are compiled by official bodies. They rely on a model which uses data on material prices supplied by the Department of Trade and Industry, and indexes of wages compiled by the Department of Employment. Specialist organisations, such as the National Association of Lift Manufacturers, also publish cost indexes for the more specialised aspects of construction where a general building cost index would be inappropriate. The structure of an input index model is shown in Figure A2.1. If the weighting of the model is incorrect, the index will be distorted.

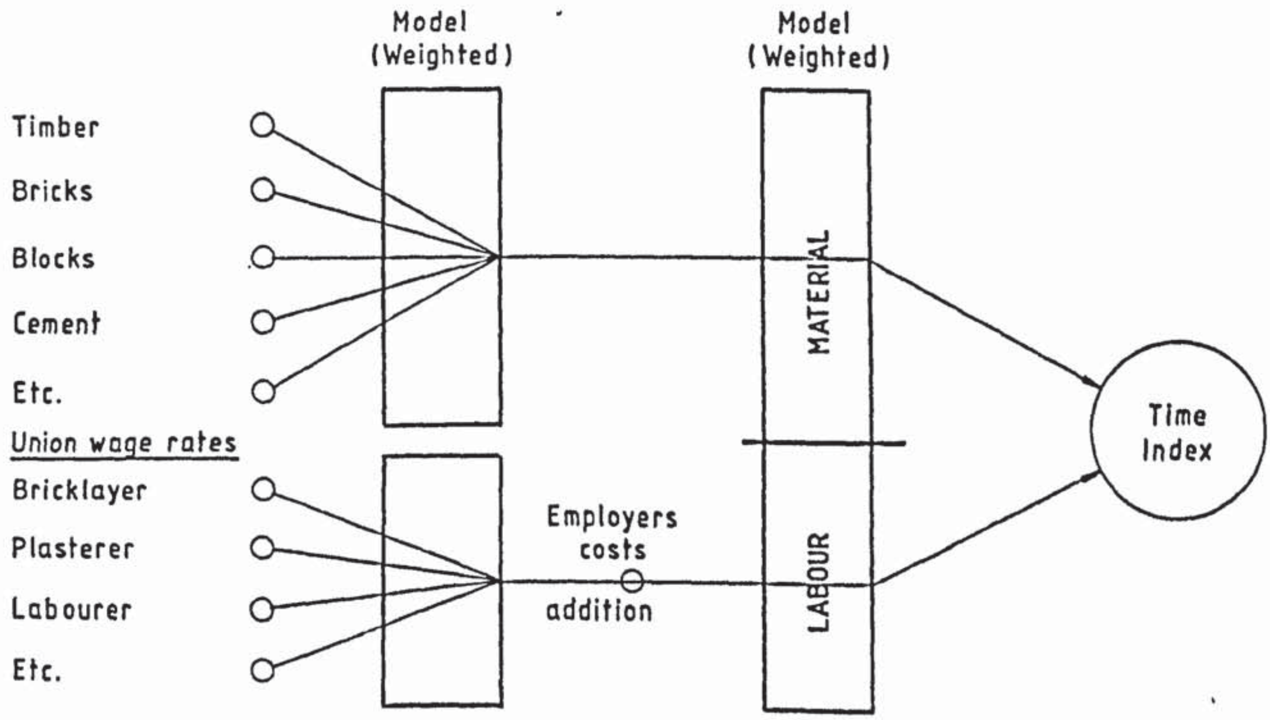


Figure A2.1

Tender price indexes are more widely used in the construction industry. They are compiled by both government bodies and private organisations.

The method of compiling tender price indexes was investigated by Bowley and Corlett (1970), who undertook a study for the MPBW and concluded:

> 'Indices based upon short lists of items selected from bills of quantities reflect reasonably well the trend in prices shown in indices based on the full bill ..... The most promising prospect for improving building price indices seems to be in the use of price data from the bill of quantities'.

The DQSS pioneered a method of preparing an index of building tender prices. It is worth investigating further the technique developed by DQSS, because the BCIS tender price index also applies the same methodology,

The indexes are prepared by selecting unit price rates for measured items from bills of quantities where the contract value is over £30,000 and the project was obtained by competitive tender. The largest items by value from each trade or work section are chosen until the value of 25% of the total for the trade is reached. The method of selection is to take the highest extended value item first, and then in descending order until the 25% level is reached. The items selected are then re-priced using the MPBW (DOE) Schedule of Rates (1973), which is used as the base of 100. After an adjustment for preliminaries, the total of the items repriced at base rates is compared with the value of items selected for analysis.

Further adjustments are undertaken to take account of prime cost and provisional sums, and an index number is calculated for the lowest overall tender. The indexes for all the tenders which have been sampled are summarised every three months and the geometric mean is computed. The difference between the geometric mean of the current and preceding quarters is used to gauge the movement in tender prices.

The indexes reflect the conditions and circumstances for each project analysed; they are the product of the competitive situation with its difficulties and uncertainties. Variation must be expected owing to the differing regional cost patterns.

There will obviously be shortcomings in any indexing system, but the detailed approach developed by DQSS has refined the methodology of developing tender price indexes.

9.3 Differences in Movement between Indexes.

The purpose of an index is to up-date historical prices to a common time base. The index is also used to extrapolate to a future time base.

It would not be economically viable or technically feasible for each quantity surveyor to construct an index for his own use, and therefore existing time indexes must be evaluated with a view to adoption. The first consideration was the choice of either an input or an output index.

Fleming (1965) and Bowley (1970) recommended the use of a tender price based index when cost planning. An output tender price index is considered preferable for the following reasons:

1) The index considers price to the client, which is the purpose of a price prediction system.
2) The building cost indexes make use of indexes prepared by other bodies, and therefore represent an average of an average; this could have the effect of compounding any inaccuracies.

3) Economic market trends are measured in the tender price index. The construction industry is significantly affected by market trends.

4) The published tender price indexes prepared by the BCIS and DOE are used uniformly and accepted throughout the construction industry.

5) Tender price indexes take account of the contractor's method of undertaking the work; technological and human innovation is therefore considered.

6) Tender prices incorporate the economies of bulk purchase schemes for construction materials.

7) An input index, because of the use of models, will tend towards obsolescence.

We compared the difference in movement between the BCIS tender price and BCIS general building cost index for the period 1974 to 1978 to gain an understanding of the differences in price movement.

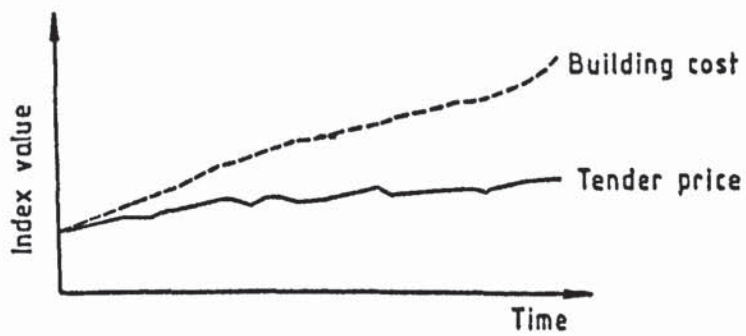


FIGURE A2.2 : COMPARISON OF BCIS TENDER PRICE AND BUILDING COST INDEXES.

Figure A2.2 shows that the input index has inflated much faster than the output index. This has occurred primarily because of the dramatic downturn in construction activity from 1973 to 1977, when contractors were prepared to absorb some of their increased costs in order to maintain their workload. As a result, the tendency has been for the quantity surveying profession to rely heavily on the use of output indexes.

The next consideration was the differences displayed by the published output indexes. Available indexes are:

A) DOE DQSS all-in index of building tender prices;

B) BCIS tender price index (combined, firm and fluctuating price);

C) David, Belfield and Everest tender price index (published in 'Spons Architects and Builders Price Book' and the 'Architect's Journal');

Figure A2.3 shows indexes A), B) and C) re-based to the first quarter 1974 and plotted on a graph. The indexes exhibit some consistency until the second quarter 1976, when the BCIS index rose sharply when compared with the other indexes. There is no apparent reason for this, nor is there any indication that the index is wrong. The BCIS index comprises a combination of public and private sector projects whilst the DQSS analyses only public sector work. The Davis, Belfield and Everest index also uses both public and private sector work.

This analysis shows the inconsistency which exists between the three price indexes. The quantity surveyor places extensive reliance on price indexes as the basis for adjusting historical prices, yet very little is known or published about the accuracy of an index.

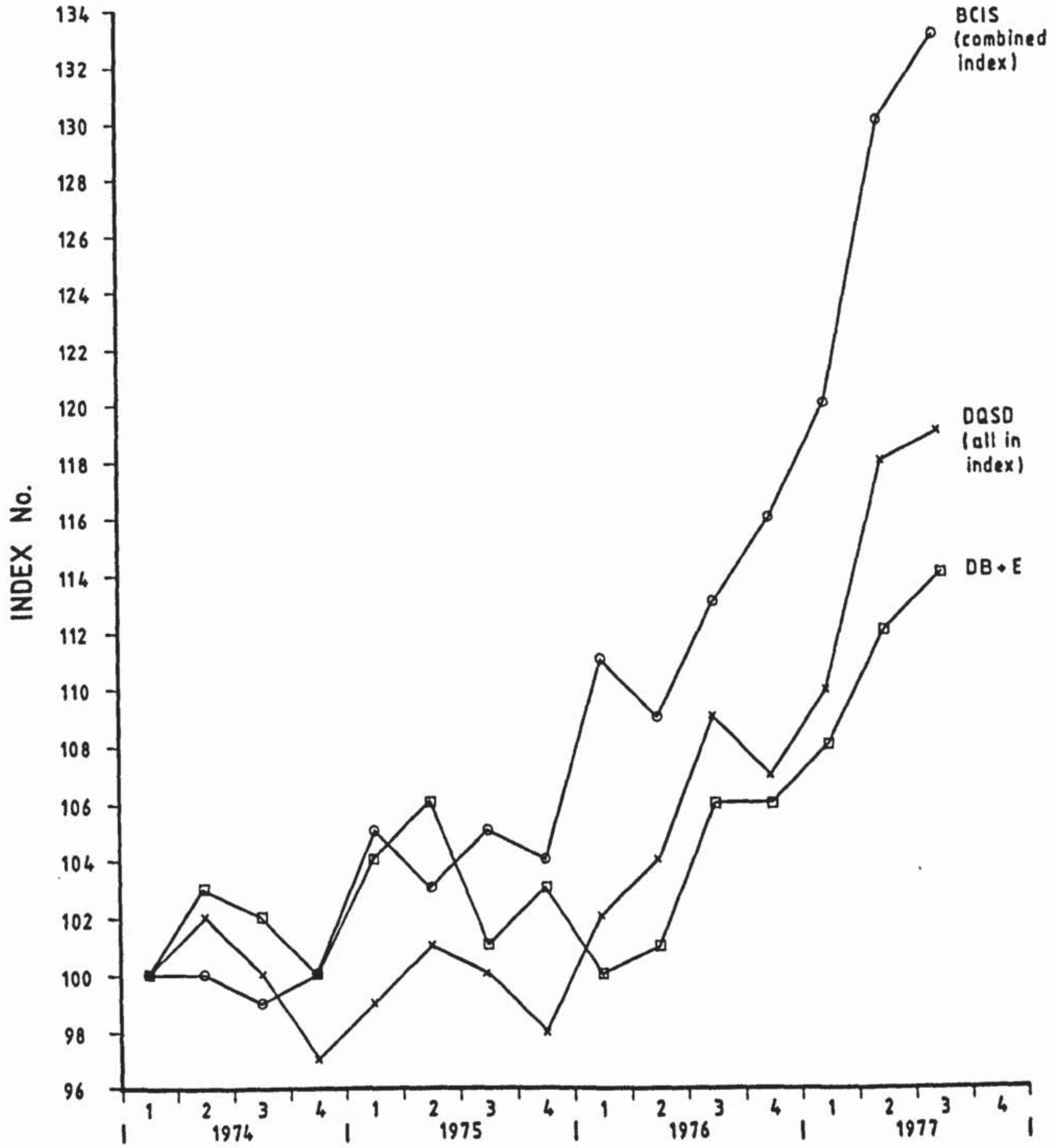


Fig A2.3 COMPARISON OF TENDER BASED PRICE INDEX

(Prices re-based to 1974 1st Quarter)

APPENDIX 3.

THE EFFECT OF HEIGHT UPON CONSTRUCTION PRICES.

10.0 Introduction.

There is a generally held view that for the same gross floor area, tall buildings are more expensive to construct than low-rise buildings. The height facet of building economics is generally not well understood.

Our objectives are firstly, to propose the kind of relationship we could expect to find between price and height, and secondly, to examine the cost analysis for a number of offices constructed over the period 1964-75 to see whether expectations are supported by observations.

The prices considered are construction prices for completed projects, excluding external works, expressed as a price per square metre of gross floor area. These have been indexed to January 1970 using the BCIS index.

What then is the current expectation of the relationship between £/m^2 and the number of storeys in a building?

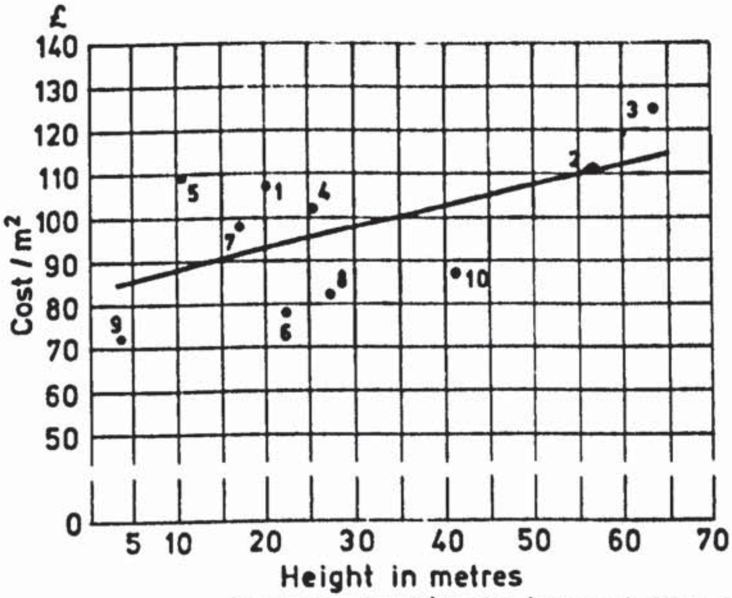
There have been numerous UK studies analysing the association between height and price. Most of these have concluded that the price per square metre of gross floor area will rise linearly with the number of storeys. The RICS Cost Research Panel (1958) and Craig (1956) found this to be the case with multi-storey housing. The Department of Health and Social Security (Capricode) and the Department of the Environment (Housing Cost Yardsticks) both use a linear relationship to take account of the price effect of height in calculating their cost allowances.

Tregenza (1972) cost analysed ten office buildings ranging from one to eighteen storeys high. They were all re-based for time to January 1971, and some adjustments made for the varying quality by applying mean values to some of the elemental prices. A linear regression line was fitted which suggested that the average price per square metre of internal gross floor area increased from £88 for a 10m high building to £112 for a building 60m high, as shown in Figure A3.1.

Professors Jarle (1972) and Poyhonen (1969) in Finland looked separately at the effect of height on the price of multi-storey housing. Figure A3.2 shows the conclusions reached in these studies. It is interesting to note the rejection of a linear relationship.

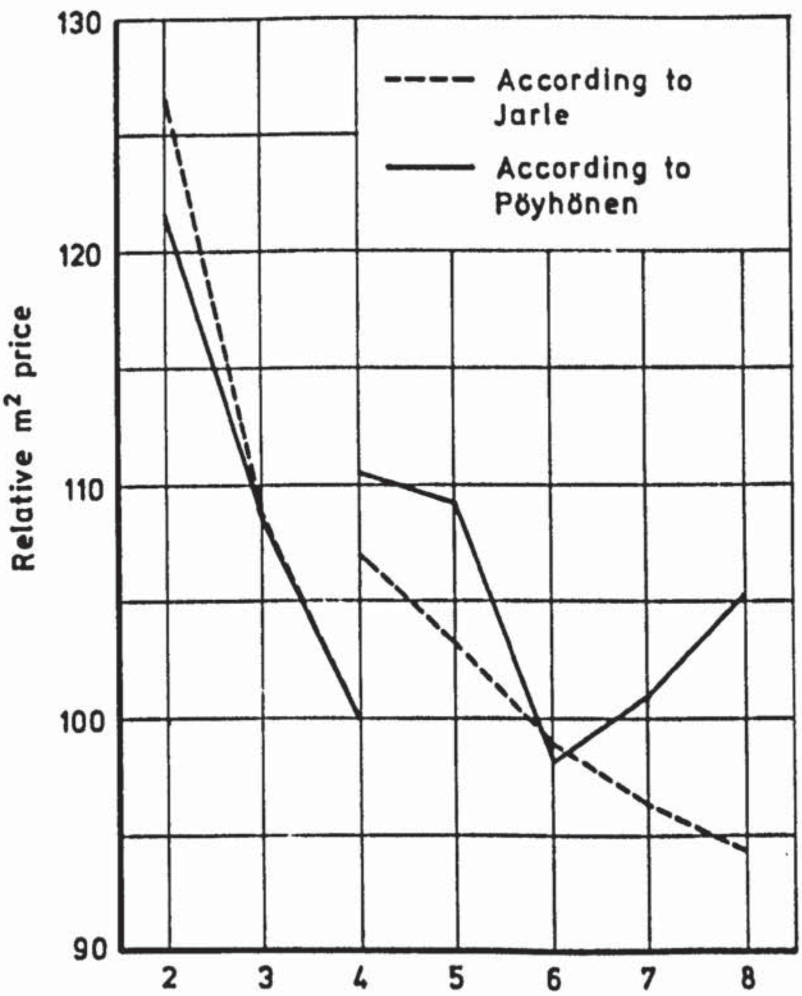
A theoretical study by Steyert (1972) in the USA using modelling techniques should also be considered. A static model is capable of adjusting variables only in a fixed manner. For example, if an architect wants to increase the storey height of his building the static model will adjust the design variables in arithmetic proportion. The dynamic model considers simultaneously the induced effects on the individual components of the building.

One of Steyert's conclusions was the suggestion that the prices of the various elements of a building will respond differently to changes in the number of storeys. Structural frame and lift installation prices will increase with height but a number of elemental cost categories will decrease with height. The reason for this latter effect is two-fold. Firstly, there is a learning curve effect, or improvement curve as it is sometimes called, with respect to labour output. Secondly, the total cost of such items as the roof and to some extent foundations, will increase less than proportionately with gross floor area [(1)].



Source: Architects Journal November 1972

Fig A3.1



Building costs according to number of storeys

Source: Build International June 1969

Fig A3.2

Steyert further showed that column prices and the price of withstanding wind load both rise rapidly with building height. He concluded that the price implications of carrying the gravity load of the higher floors are more significant than the problem of design for wind.

The main conclusions to be drawn from this brief literature survey is that UK practice appears to be at variance with overseas research findings. Clearly, international experience cannot be applied directly to the UK situation, e.g. North American contractors have greater expertise than European contractors at building high rise structures and this is reflected in the pricing strategy of bids. There seems to be no good reason, however, for the assumption that £/m^2 for UK buildings should increase linearly with height.

Theory would suggest that the elemental cost components of a building can be split into four categories:

a) those which fall as the number of storeys increases, (e.g. roofs, foundations);

b) those which rise as the number of storeys increases (e.g. lift installations);

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(1) This has to be qualified with respect to foundation costs; these will be influenced by total dead and live load to be carried, the soil bearing capacity of the site and the foundation perimeter to ground floor area ratio.

c) those which are unaffected by height, (e.g. floor finishes, interior doors);

d) those which fall initially and then rise as the number of storeys increases, (e.g. exterior closure).

A hypothetical example of each of these is illustrated in Figure 7.10. Adding these curves together would imply that the relationship between £/m^2 and the number of storeys would be U-shaped as indicated by the (hypothetical) total cost curve in Figure A3.4.

Learning curves have been mentioned previously and these can be considered in more detail to lend further support to our theoretical expectations.

Repetition of site operations will lead to a decrease in operational costs on the one hand, and to indirect cost savings caused by the reduction of construction time on the other, as the United Nations (1965) studies have shown. The direct savings in operational costs depend on the gradual decrease in operational time attained in repetitive work. The learning curve theorem states that every time the number of repetitions doubles the output time declines by a fixed percentage, this fixed percentage identifying the improvement achieved; a typical learning curve is illustrated in Figure A3.3.

If we consider a two-storey and a five-storey building with the same floor area, there is some reason for thinking that the learning curve effect would introduce cost savings to the taller building. In the context of an individual building there is a limit to this process, however, in that savings in some elemental prices brought about by the learning curve will not be sufficient to offset increases in prices of other elements of the construction process

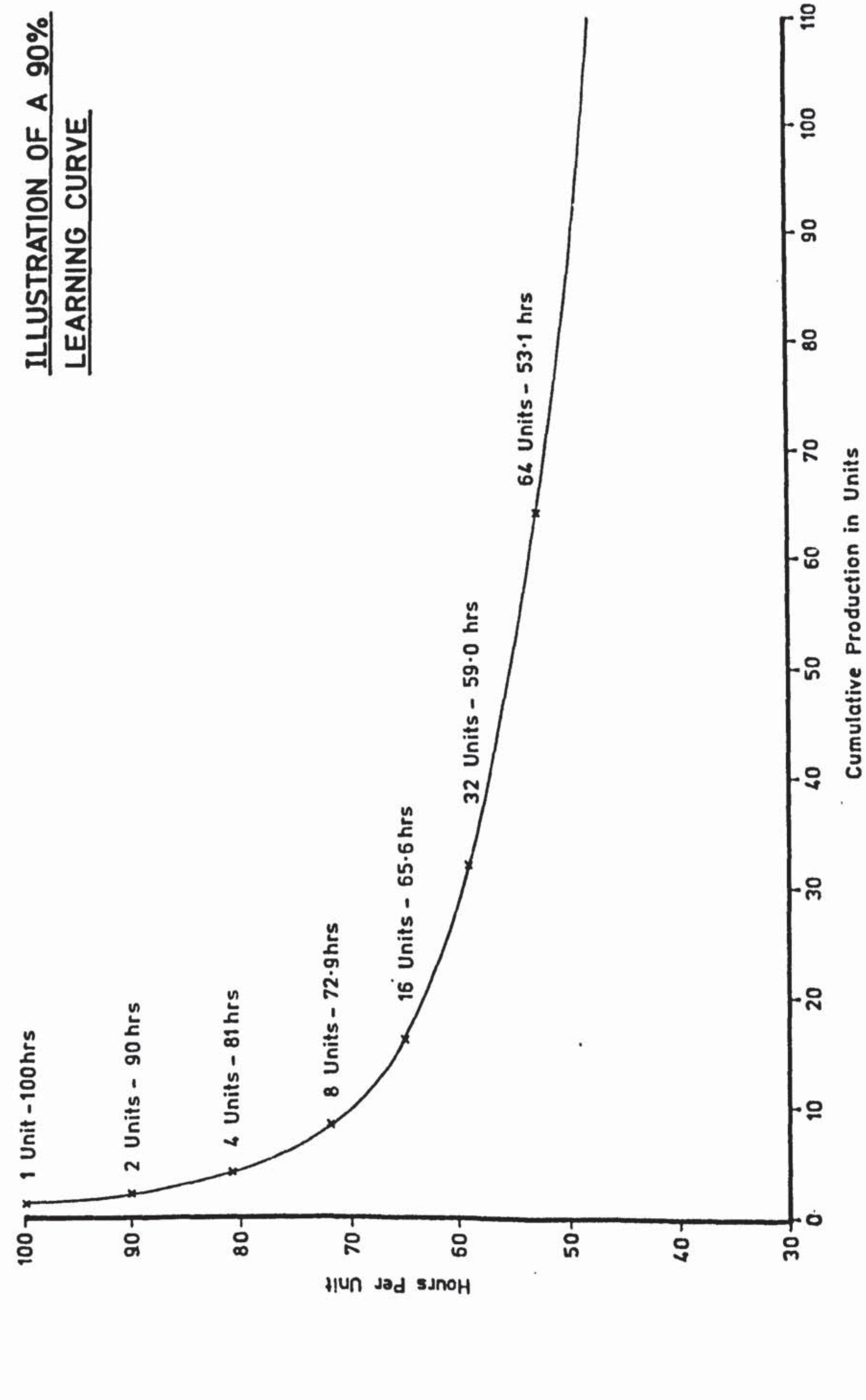
ILLUSTRATION OF A 90%
LEARNING CURVE
1 Unit -100hrs
2 Units - 90 hrs
4 Units - 81 hrs
8 Units - 72·9hrs
16 Units - 65·6 hrs
32 Units - 59·0 hrs
64 Units - 53·1 hrs
Hours Per Unit
100
90
80
70
60
50
40
30
0
10
20
30
40
50
60
70
80
90
100
110
Cumulative Production in Units

Fig A3.3

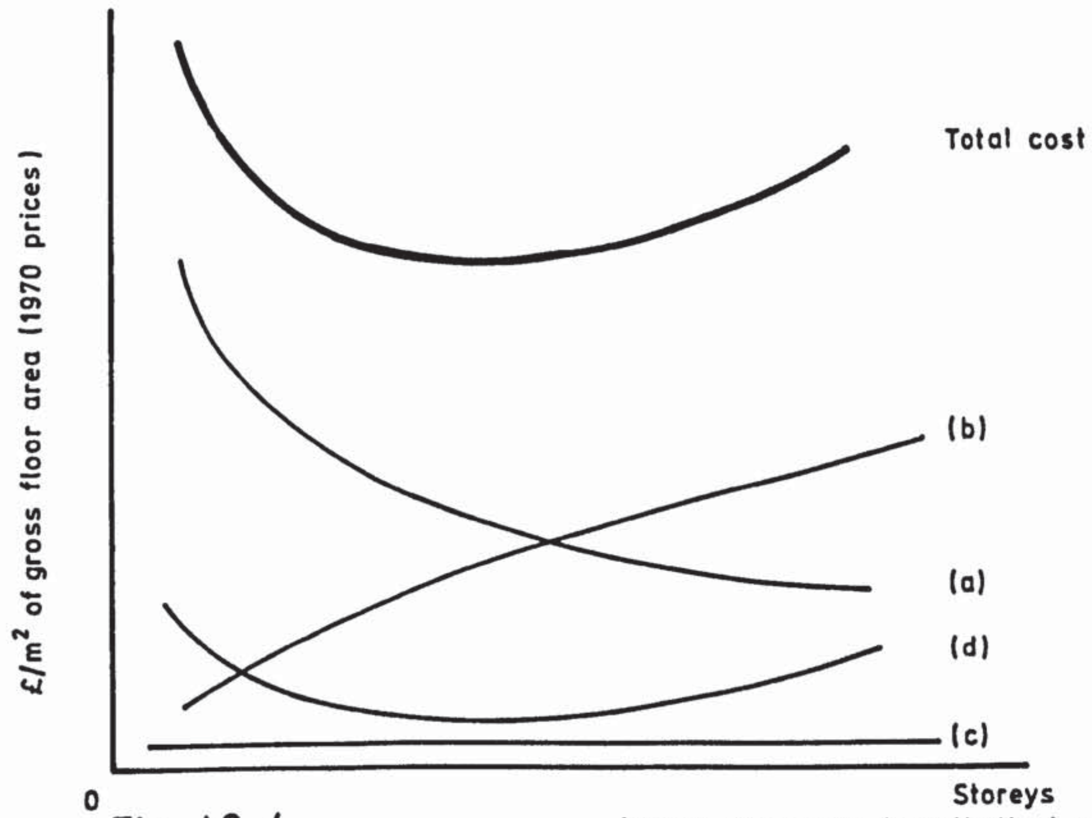

Fig A3.4 (Note:- these are hypothetical curves)

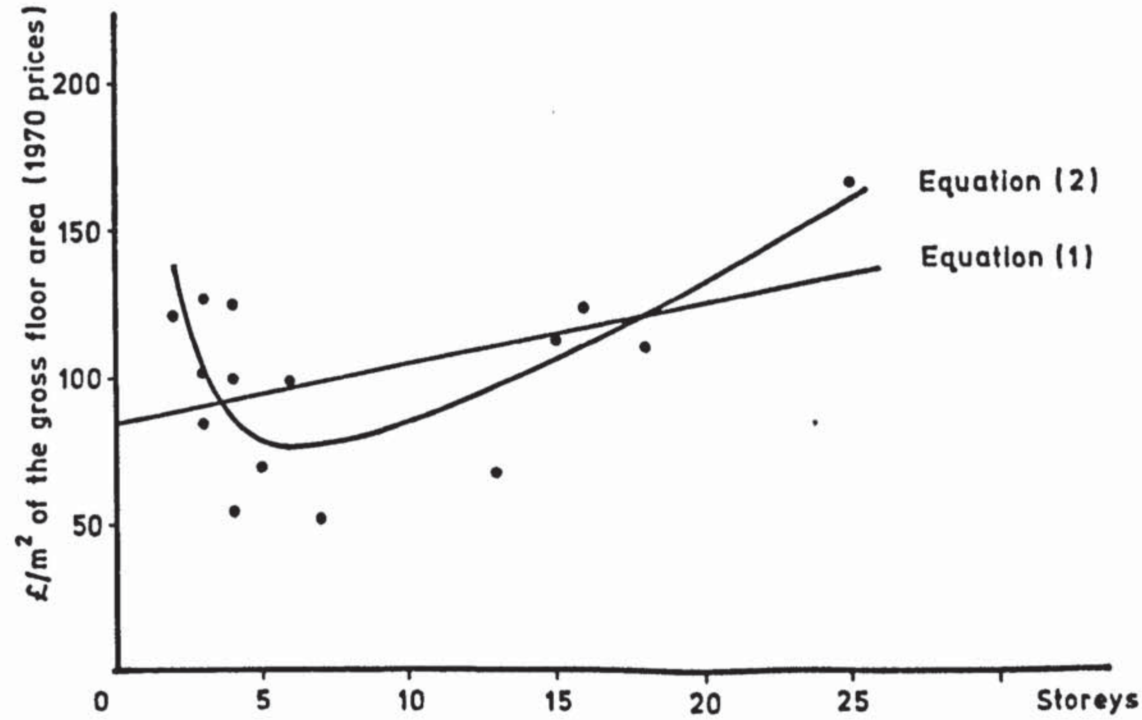

Fig A3.5

Our hypothesis is, therefore, that £/m^2 will decline initially as the number of storeys increases, but will eventually rise.

To test this hypothesis, we considered data on fifteen offices with two or more storeys, reported in the Architects Journal over the period 1964-75. (Single storey buildings have been excluded since these are liable not to exhibit the characteristics of multi-storey buildings). They include the ten observations used by Tregenza. The data are plotted in Figure A3.5.

As a first exercise, we assumed a straight line relationship between £/m^2 and the number of storeys. Regression analysis was used to find the relationship between height and price.

The relationship obtained from the data was:

$$£/m^2 = 84.29 + 1.97 \times \text{Number of storeys} \quad (1)$$

This equation is graphed as the straight line in Figure A3.5.

Equation (1) states that £/m^2 is £84.29 plus £1.97 for each floor (including the ground floor). In other words, adding a storey will increase £/m^2 by £1.97.

Whilst the relationship in equation (1) is the best straight line approximation to the data, it is only just statistically significant in that it explains less than 20% of the variation in construction prices. Looking at the equation in more detail, it can be seen that the straight line does not reflect at all the pattern of variation of £/m^2 for buildings under ten storeys, and underestimates the increase in £/m^2 for the high rise buildings.

The next step, therefore, was to try an equation which would give an initial decline in £/m^2 as the number of storeys increased, followed by a subsequent rise. The equation estimated was:

$$£/m^2 = 5.94 \times \text{Number of storeys} + \frac{248.59}{\text{No. of storeys}} \quad (2)$$

This equation is shown in Figure A3.5 as the U-shaped curve. The interpretation of the equation is illustrated in Table A3.1.

TABLE A3.1 : ILLUSTRATION OF EQUATION (2)

No. of storeys (A)	First term of (2) 5.94 x number of storeys (B)	Second term of (2) 248.59 ÷ number of storeys (C)	Predicted $£/m^2$ (B) + (C) = (D)
2	11.88	124.30	136.18
4	23.76	62.15	85.91
6	35.64	41.43	77.07
8	47.52	31.07	78.59
10	59.40	24.86	84.26
15	89.10	16.57	105.67
20	118.80	12.43	131.23
25	148.50	9.94	158.44

(January 1970 prices)

As can be seen from this table, while the second term in equation (2) declines with the number of storeys, the first term increases, and eventually becomes dominant above six storeys.

Equation (2) is statistically significant, explaining 50% of the variation in construction costs of the various offices. It approximates the data in

Figure A3.5 much more closely than equation (1). The data would therefore appear to support our hypothesis as illustrated by the total cost curve in Figure A3.4.

As has been pointed out many times in the thesis, there are many other influences, e.g. quality, geographical location, size of project, site characteristics, plan shape, etc., in addition to height, which will affect construction prices.

Further, equation (2) is one of many possible equations which would give rise to a U-shaped curve. Its main attraction is its simplicity, but this is obtained at some loss of accuracy in its approximation to the data. These considerations result in 46% of the variation in construction costs being unexplained by equation (2). Looking at Figure A3.5, it can be seen that there is a wide variation in costs of construction for the three four-storey buildings in the sample. An analysis of the costs for these buildings indicates that the differences in costs arise mainly from the preliminaries and superstructure elements.

A further point is worthy of note. We have concentrated on the relationship between £/m^2 of gross floor area and the number of storeys. In commercial office buildings there is some suggestion that the amount of lettable floor area will decrease as additional storeys are added because of the need for circulation space, lift shafts, etc. This is illustrated in Figure A3.6. After an initial steep fall the rate of reduction in the proportion of lettable floor area is shown to decline. It should be emphasised that the curve as drawn is hypothetical but is supported by the data used by Tregenza. These are plotted in Figure A3.7 with a suggested correlation between lettable floor area and the number of storeys (this has been fitted by eye).

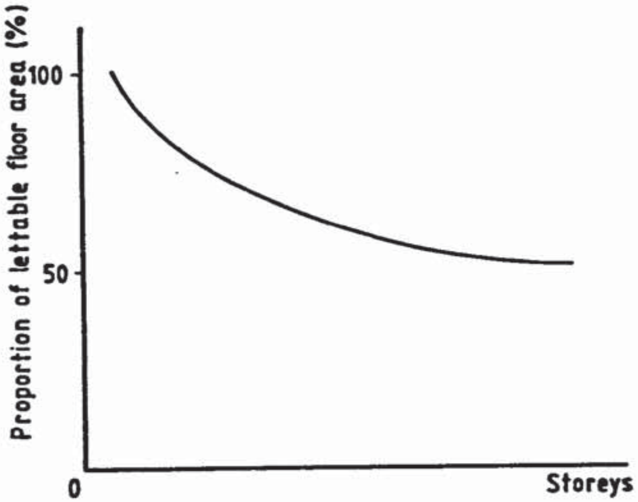

Fig A3.6

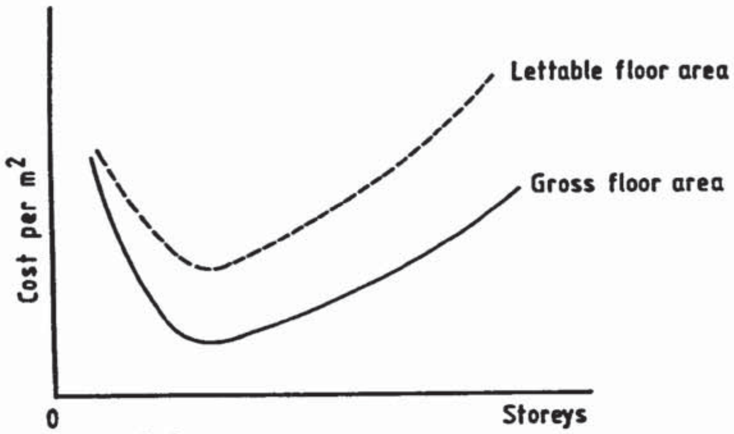

Fig A3.8

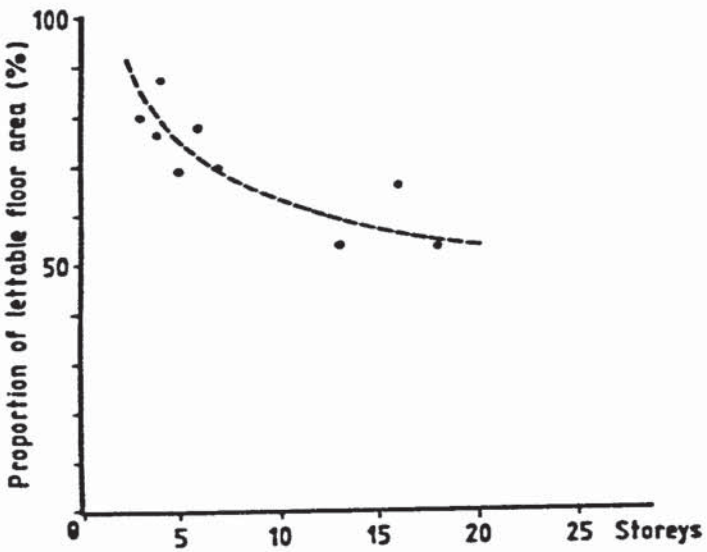

Fig A3.7

If consideration is given to the price per square metre of the lettable floor area as opposed to the gross floor area, a different cost curve will be obtained. This has significant implications for commercial office building developers. The effect will be to shift vertically the curve relating £/m^2 and the number of storeys, the move being greater the more storeys there are. Figure A3.8 illustrates this point. The solid curve relates £/m^2 and number of storeys and the dotted curve relates £/m^2 of lettable floor area to number of storeys. While the dotted curve is flatter than the solid curve, there is no reason to believe that the U-shape will disappear completely.

In conclusion, while equation (2) must be treated with some caution if used as a predictive equation, we feel the initial hypothesis has been justified. The relationship between £/m^2 and the number of storeys in an office structure can be expected to be U-shaped. It will exhibit an initial decrease in £/m^2 as the number of storeys is increased, before eventually rising.

It must be stressed that an equation can only be as good as the data from which it is generated.

We wanted to test our hypothesis further by considering costs to the contractor of building high structures. We approached five national contractors with a view to obtaining evidence from either a cost feedback or estimating system. No records whatever were available to show the effect of height upon cost. The estimators felt that an allowance was made intuitively at the tender stage.

The precise nature of the impact of height on construction prices needs further investigation. This study has outlined a basic theoretical structure and has adduced supportive evidence but we feel the equation (2) we have developed is not sufficiently reliable for use in a practical situation.

APPENDIX 4.

PRICE PREDICTION FOR LIFT INSTALLATIONS.

11.0 Introduction.

In Chapter 3 a cost model was developed for the price prediction of a lift installation. The model has been computerised together with the design criteria for a lift installation and incorporated to provide a system that selects and prices a lift installation for a building. The objective was to produce a computer programme that could be used by a quantity surveyor at the early design stage, knowing only the gross floor area of the proposed building, the total number of storeys and some indication of the required overall quality level. The programme also serves as a design tool for the architect, by considering the design and cost implications of alternative types of installations.

The following sequence was followed when developing the programme.

1) The design criteria defined in Table 3K (Chapter 3) were documented. The minimum input for the lift design selection tables were established, being: the overall number of storeys, the gross floor area, the design population and the average floor to floor height. The programme has two default functions: the machine makes an assumption if the design population of the proposed building is not known, and if the average floor to floor height is not stated, the machine uses 3.30m.

2) Three quality parameters to define the overall quality of the building were used. These were high, medium and low. The quality parameter will affect the handling capacity of the lifts. This relates to the quantity of traffic to be handled, which is expressed as the percentage of the

building population to be transported in five minutes; also the quality of service, expressed as the expected average interval in seconds between arrival of lifts at the main floor (i.e. the round trip time of one lift divided by the number of lifts in the group). From the waiting interval is derived the group grade information, a waiting interval less than forty five seconds is excellent, between forty five and fifty five seconds would be classified good, between fifty five and sixty five seconds is fair, and over sixty five seconds is casual.

3) The cost model equation and prices developed in Chapter 3 were incorporated. As an example of the output from the programme, Figure A4.1 shows a copy of the computer print-out for a proposed six-storey, high quality office building where the input parameters have been identified. The total price calculated by the machine is marked Z. The parameters were then changed by retaining the same proposed building but altering the quality level from high to low. The results are shown in Figure A4.2. The reduction in total cost reflects the quality change.

We can conclude that the lift selection programme provides a useful tool for the quantity surveyor at the design stage. The small amount of input information required, allows the surveyor to show the impact of various design alternatives prior to any design work being undertaken.

LIFT [illegible]
UNIV. OF [illegible]

ENT[illegible] [illegible]ILDING TYP[illegible], [illegible]ALITY, [illegible] FINISHES.

ENTER # STORIES, NET AREA, DESIGN POP, AND FLOOR-FLOOR HEIGHT.

BUILDING TYPE: OFFICE
BUILDING QUALITY: HIGH
FINISH [illegible]: HIGH / HIGH
LIFT [illegible]IVE: SINGL[illegible]
LIFT CONTROL: COLLECTIVE
NUMBER OF FLRS: [illegible]
TOTAL FLOOR AREA: [illegible]
TOTAL DSGN POP: 45[illegible]

FLOORS: 6 DESIGN AREA: [illegible] DESIGN POP: 454

	AREA SERVED	NUM LIFTS	CAPACITY PERS	CAPACITY KG	SPEED M/SEC	HC 5MIN PERS	HC 5MIN %	WAITING INTERVAL	GROUP GRADE
1	3760	2	8	[illegible]	1.[illegible]	6[illegible]	13	47 SEC	EXCEL
2	348[illegible]	[illegible]	10	750	1.[illegible]	46	10	5[illegible] SEC	GOOD
3*	[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	45	[illegible]	[illegible] SEC	FAIR
4*	5[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	57 SEC	FAIR
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] SEC	FAIR
6	654[illegible]	2	[illegible]	[illegible]	1.50	4[illegible]	1[illegible]	74 SEC	CASUAL
7	7[illegible]	[illegible]	16	[illegible]	[illegible]	45	1[illegible]	86 SEC	CASUAL
8	9[illegible]	[illegible]	1[illegible]	[illegible]	1.[illegible]	49	1[illegible]	59 SEC	CASUAL
9	1[illegible]	[illegible]	[illegible]	[illegible]	1.[illegible]	45	1[illegible]	64 SEC	CASUAL
10	[illegible]	[illegible]	16	[illegible]	[illegible]	[illegible]	15	7[illegible] SEC	CASUAL

COSTS COST BREAKDOWN

	COST TOTAL	SPEED	CONTROL	LIFT CAR	CAR FIN	LANDING
1	56[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	5[illegible]	17[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
9	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NOTES:

ALL [illegible] ARE [illegible] AND SECONDS.
ALL COSTS [illegible]
HC - [illegible] CAPACITY OF THE LIFTS
[illegible] PEOPLE
[illegible]
WAITING INTERVAL IS THE [illegible] WAITING TIME FROM
THE LIFT CALL [illegible] LIFT ARRIVAL.
GROUP GRADE IS [illegible]
[illegible]
SPECIAL COSTS [illegible]

Fig A4.1

[illegible]

[illegible]

ELEVATING TYPE: [illegible]
BUILDING [illegible]: [illegible]
FIRE [illegible]: [illegible]
LIFT [illegible]: [illegible]
LIFT CONTROL: [illegible]
NUMBER OF FLOORS:
TOTAL FLOOR [illegible]: [illegible]
TOTAL [illegible]: [illegible]

FLOORS: [illegible] DESIGN [illegible]: [illegible] DESIGN [illegible]: [illegible]25

	AREA SERVED	NUM LIFTS	CAPACITY PERS	CAPACITY KG	SPEED M/SEC	HC- 5MIN PERS	HC- 5MIN %	WAITING INTERVAL	GROUP GRADE
1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	9	[illegible] SEC	EXCEL
2	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible] SEC	GOOD
3*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible] SEC	FAIR
4*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] SEC	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible] SEC	FAIR
6	654[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	74 SEC	CASUAL
7	73[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible] SEC	CASUAL
8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible] SEC	CASUAL
9	[illegible]	3	[illegible]	[illegible]	[illegible]	[illegible]	7	[illegible] SEC	CASUAL
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible].50	[illegible]	11	[illegible] SEC	CASUAL

COSTS COST BREAKDOWN

	COST TOTAL	SPEED	CONTROL	LIFT CAR	CAR FIN	LANDING
1	54[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2	54[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
3*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
4*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
7	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
8	[illegible]	[illegible]	[illegible]3.45	[illegible]	[illegible]	[illegible]
9	[illegible].45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
10	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NOTES:

ALL MEASUREMENTS ARE IN METRES AND SECONDS.
ALL COSTS ARE IN POUNDS.
HC - 5MIN IS THE HANDLING CAPACITY OF THE LIFTS
IN PERSONS [illegible] AND THE PERCENT OF PEOPLE
IN THE BUILDING.
WAITING INTERVAL IS [illegible] WAITING TIME FROM
THE LIFT CALL [illegible] THE LIFT ARRIVAL.
GROUP GRADE IS THE [illegible] APPLIED
TO THE SERVICE [illegible] BY THE GROUP.
SPECIAL COSTS INCLUDES COST FROM [illegible] CONSTRUCTIONS.

Fig A4.2

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