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A QUANTITATIVE APPROACH TO COST MONITORING AND CONTROL OF CONSTRUCTION PROJECTS

By

Abdu Abubakar
(B.Sc., M.Sc., PGDCS, ANIOB, ANIQS, Licensed Quantity Surveyor)

A Doctoral Thesis submitted in partial fulfilment of the requirements for the award of Doctor of Philosophy of Loughborough University of Technology.

September 1992

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ABSTRACT

Existing literature and research findings indicated that cost monitoring and control of construction projects by contractors at the level of site operations has remained ineffective largely due to inability of existing control systems to accurately predict when, to what extent and why an on-going operation or project is to overrun its planned duration and cost. In most cases the information that would enable such advance detection becomes available to decision makers after the affected operation or project is completed. It is then hoped that the information could be used to 'control' future similar situations which in the case of construction projects hardly arise, at least never under identical circumstances. The existing cost control systems also fail to enable rational corrective decisions to be formulated. This resulted in total reliance on previous experience and personal intuition to make a guess of corrective measures. Most research efforts have focussed mainly on various aspects of project modelling and cost control using traditional accounting approaches that consistently fail to meet the requirements and schedule of timely cost control.

This research identified, from empirical evidence, construction and management science literature, the essential criteria and features of an effective cost monitoring and control approach for construction projects. The evidence from these three sources led to the formulation of an alternative approach based on quantitative analysis of cost data from construction projects. The cost monitoring and control process carried out on sites was formulated as a problem whose solution process is implemented using multiple regression and goal programming models and techniques that enable timely evaluation and prediction of costs and a rational computation of corrective decisions. This allowed cost deviations to be detected and optimum corrective measures calculated while the affected operation or project was still in progress.
The proposed approach employs an improved approach to data capture, processing, performance evaluation and corrective decision-making that avoids difficulties hitherto encountered and provides timely data for use in the cost control process. The proposed approach requires the use of a combined database and spreadsheet software along with any statistical package that contains the relevant models.

The proposed approach was tested with cost data from building and civil engineering projects and using mainly Quattro and SPSS-X software. The tests indicated that the approach is feasible and that, for the categories of projects used in the tests, the total costs of construction projects can be predicted and controlled on the basis of the costs of one or two of a project's cost components. It was specifically established that costs of residential housing projects can be predicted from the costs of labour and subcontracts, while costs of certain types of public building projects can be predicted from materials costs.
DEDICATION

To my father, the Late Abubakar Maigarin Unguwar Malamai, who set me on the course but did not live to witness the completion, and for being the greatest Daddy at all times!
DECLARATION

No portion of the research referred to in this thesis has been submitted in support of an application for another degree or qualification at this or any other university or other institution of learning.
ACKNOWLEDGEMENT

The undertaking and successful completion of this research was achieved with the assistance of many organizations and individuals to whom I owe a lot of gratitude. They include:

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- My supervisor Mr. Alan H. Tyler for the guidance, assistance, criticisms and suggestions he provided for the research.
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- The academic staff members of the Construction Management Group of the Civil Engineering Department who listened to me and made suggestions; especially Dr. A. Thorpe for his generous assistance and Mr. D. Johnson of LUT Business School for advice on statistical methods and analysis.
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- My fellow research students for their comraderie and sharing views and experiences during those inevitable moments when I needed some distraction from the research routine.

Finally I am most grateful to all members of my family for their understanding and support during the period of my stay in U.K., especially my brother Sufiyanu who ably held the fort and successfully conducted the affairs of the home following the death of our father.
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LIST OF ABBREVIATIONS

ITT	 Information turnaround time
LP	 Linear programming
GP	 Goal programming
IP	 Integer programming
RHP	 Residential housing projects
PBP	 Public building projects
CEP	 Civil engineering projects
PPBS	 Planning-programming-budgeting-system
AR	 Autoregressive models
MA	 Moving average models
ARMA	 Autoregressive moving average models
MARMA	 Multivariate autoregressive moving average models
R	 Coefficient of simple correlation
R2	 Coefficient of determination
D-W	 Durbin-Watson statistic
t	 Student t-distribution
PC	 Personal computer
U.K. 	 United Kingdom of Great Britain and Northern Ireland
SMS	 Site Manager System (software)
SPSS-X	 Statistical Package for Social Sciences No. 10
PR	 Performance Ratio

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 Introduction to the Subject
1.2 Background of A Problem
1.3 Research Justification and Hypothesis
1.4 Aim and Objectives of the Research
1.5 Research Methodology and Work Undertaken
1.6 Summary of Research Achievements
1.7 Guide to Thesis Presentation
GENERAL INTRODUCTION

Hypotheses are adventures of the mind - Medawar (1964)

1.1 Introduction to the Subject

The subject of the research presented in this thesis is cost monitoring and control of construction projects by contractors at the level of site operations. This refers to the activities carried out by contractors in order to effectively implement the various physical and financial plans and models of a project as developed at the estimating, planning, scheduling and budgeting stages of the project. A listing of such activities was given by Abubakar (1985) who defined the process for cost monitoring and control used by contractors as "the systematic recording, classifying and reporting of production quantities and utilization levels of the various construction resources; analysing performance levels from the various responsibility centres (i.e. cost codes) of the project, and the transmitting of all necessary information and exception reports to management as a basis for deciding on any corrective action that may be found desirable to ensure that planned project goals are realized".

The need to effectively monitor and control costs by contractors has been widely recognized and expressed in research works and construction literature. Kharbanda et al (1987), Clough et al (1979) and El-Rufai (1982), among others, have linked the success and survival of construction businesses to the effectiveness of their approaches to cost monitoring and control. Berny et al (1987) identified "the ability to accurately plan, monitor and forecast project expenditure and resources (as) critical to the management and corporate control of a company's well being". El-Rufai (1982) even suggested that failure to effectively control costs by contractors produces a negative snowball effect on project costs and level of business in the construction industry because "true cost control starts in the contractor's office". Following an investigation of profitability in construction companies, Mu'azu (1982) concluded that "to ensure success and profitability in their businesses contractors must establish effective cost control, monitoring and recording
In an investigation on construction business failure in the U.S.A. Kangari (1991) established a link between such failures and effective cost control and concluded that "construction companies capable of properly managing money and keeping close tabs on cost control are at an advantage"

Apart from a profit motive, other characteristics of the business have been identified among factors that call for comprehensive cost monitoring and control of construction projects. For instance, the degree of uncertainty involved in the design, planning and execution of construction projects led Ogunlana (1989) to conclude that "for construction works, the most comprehensive and realistic of all plans and estimates cannot anticipate all eventualities". Kangari (1991) cited what he called the fragmented nature of the construction industry, its sensitivity to economic cycles and the high level of competition occasioned by the large number of firms and the relative ease of entry into the business, as distinguishing characteristics of construction business which makes it susceptible to failure if not carefully monitored. Clough et al (1979) asserted that the construction process, once set in motion, is not a self-regulating one and requires expert guidance if events are to conform to plans. Abubakar (1987) identified some of the "peculiarities" that necessitate close cost monitoring and control of construction projects as follows:

1. Uncertainty is a common feature of most aspects of the physical realization of projects.
2. Planning and estimating which form the basis of cost monitoring and control are themselves imprecise acts.
3. Construction projects are generally one-off events which do not get repeated in absolute terms, thus experience on past projects has no absolute guarantee of validity.
4. Far too many parties are involved with project realization from inception to commissioning.
5. Thousands of work items have to be completed before a project is realized, and this means many sources of expenditure.
6. Large investments are involved over relatively long pay-back periods of time.

1.2 Background of A Problem

While the need for effective cost control of construction projects by contractors appeared to be clearly appreciated in literature, as cited above, recent researches, (see Kangari 1991, Fine 1982, Kodikara 1990 and Belivaeu 1984 among others), have indicated that companies still continued to fail in their cost control efforts. Despite the general recognition that successful and profitable construction business depends on effective cost monitoring and control, available research findings relating to various aspects of project management, (reviewed in chapter 2), have indicated that many problems faced by construction companies stem from ineffective monitoring and control efforts on projects. Problems such as cost and schedule overruns, insolvencies, bankruptcies, abandonment, and disputes have been partly attributed to failure of cost control systems employed by contractors. Clough et al (1979), for instance, attributed the failure of contractors' cost control efforts to a "historical dependence" of the construction industry on intuition and experience to secure successful realization of projects. Mu'azu (1982) concluded that "intuition and experience which, in the olden days, used to be a hallmark of the construction industry are no longer adequate to ensure success and profitability in the business of construction contracting".

On a more specific level, the failure of existing cost control systems has been attributed to their inability to accurately predict when, to what extent and why an on-going operation is going to start overrunning its planned duration and cost. Abdullah (1988) and Kharbanda et al (1987) suggested that the cost information systems employed in current cost control approaches produce untimely data that can not be useful to controlling on-going operations. Kodikara (1990) added that the data resulting from current approaches to performance measurement was often late and, consequently, only useful for controlling future operations; but then history, according to
Ogunlana (1989), has the unusual habit of not repeating itself in the construction industry.

Current approaches to evaluating performance data and making corrective decisions have been described as "unsatisfactory" by Kodikara (1990) and as "ineffective" by Balivaeu (1984). Yet Harris et al (1991), Mueller (1986) and Wilson et al (1988) identified timely evaluation of performance data and corrective decisions as essential to achieving effective control. The system of performance data capture on construction sites via designed forms/cards has also been identified by Rasdorf et al (1991) and McCaffer et al (1990) as contributing to the ineffectiveness of cost control systems. Abdullah et al (1988) concluded that current cost control systems are reduced to "mere accounting systems" by the data capture and processing processes used by contractors. In the light of these problems it is little wonder that Fine (1982) concluded that it was "practically impossible to find a project that was executed within the exact budget the contractor set for it". Another dimension to the problem of cost control was identified by Doughlas (1963) who contended that to effectively control costs we have to predict them accurately and that it is virtually impossible to forecast with absolute accuracy the cost of a construction project. Fine (1982) added a human dimension to the problem when he said that project costs depend on the way people behave, and predicting costs is, thus, like predicting human behaviour.

A survey of the major construction companies in the U.K. carried out as part of this research (see chapter 7) revealed that all the problems and inadequacies identified above with regard to cost monitoring and control efforts of contractors still exist in the construction industry. The survey also revealed that contractors still fail to effectively control costs due to the ineffectiveness of the methods used for capturing and processing performance information and the making of corrective decisions. The survey findings clearly revealed the need for a more effective approach to cost monitoring and control by contractors.
It is significant that most of the above catalogue of inadequacies of current approaches and systems to construction cost control were identified through researches that were not specifically aimed at the actual cost monitoring and control activities of contractors. Most of the cited works relate to different aspects of cost estimating, project modelling, systems integration and cost information systems. Indeed contractors' cost control efforts at the level of site operations have received relatively less research attention than they would appear to deserve. This was confirmed through a survey of some twenty U.K. research establishments, universities and polytechnics offering courses and research in construction engineering and management. It was found that between 1980 and 1990 no comprehensive research project was carried out covering all aspects of cost monitoring and control of projects.

The fact that earlier mentioned evidences of ineffective project control obtain in the construction industry despite a large amount of literature and research on estimating, planning and scheduling systems may lead to a conclusion that the lop-sided research emphasis has created a kind of "Emerton syndrome" in the industry. Emerton is reputed to have said, (Fine 1982), that "a nation that pays more regard to plumbing than philosophy will have both bad plumbing and bad philosophy".

1.3 Research Justification and Hypothesis

The foregoing brief definitions of the need for effective approach to cost monitoring and control of construction projects, and the evidence indicating that current systems and practices of cost control advocated in literature and employed by contractors are inadequate, provided the justification as well as the focus for this research. The motivation derives from the author’s experiences in a contracting organization as well as earlier studies carried out on the subject of the research.

The background described so far indicates the need for a cost monitoring and control approach that provides timely and suitably structured performance data to enable performance evaluation and necessary corrective decisions to be made while
the affected operations are still in progress. The approach required should also enable corrective decisions to be rationally computed, preferably based on actual data from the affected operations, instead of some subjective judgements and intuitions of project managers. These needs led to the formulation of the hypothesis that:

'Cost and performance data from construction operations can be quantitatively modeled to provide rational and effective measures of resource requirements and utilization levels/rates for the operations or projects in order to provide a scientific basis for computing appropriate adjustments to be made to on-going operations based on the observed performance levels and trends'.

This hypothesis was informed by the existence and wide application of scientific management models and methods in manufacturing and other industries to forecast, monitor and control their activities. Indeed there is already a wide variety of computer software in the market developed for implementing many of the management models and methods.

1.4 Aim and Objectives of the Research

In view of the importance of cost monitoring and control to success in construction business and considering the problems identified earlier, this research was aimed at determining a more effective approach to contractors' monitoring and control functions. To achieve this aim it was necessary to thoroughly review existing literature and research findings, and investigate the current practice(s) employed by contractors in project cost management. The review and investigations were carried out with the following objectives:

1. Identifying from theoretical and empirical evidence the essential features of an effective cost monitoring and control system for construction sites.
2. Determining the level of effectiveness or otherwise of existing cost monitoring and control methods employed by contractors.

3. Identifying from theoretical and empirical evidence the aspects of existing approaches to cost monitoring and control that account for the problems identified earlier.

4. Assessing the suitability of contractors' approaches to project organization for cost monitoring and control.

5. Identifying a better procedure for acquiring and processing performance data to enable effective cost control.

6. Determining the applicability of statistical techniques and quantitative models to cost monitoring and control of construction projects.

7. Making recommendations for improving the effectiveness of cost monitoring and control efforts of contractors.

1.5 Research Methodology and Work Undertaken

Starting with the formulation of what were regarded as problems of cost monitoring and control for construction contractors, the research formulated specific and empirically meaningful aim and objectives, and attempted to realize them in the light of existing knowledge and investigation evidence. The theoretical knowledge that formed the basis for assessing the investigation evidence, proposals and test results arising from the research was obtained by reviewing available literature in construction and related disciplines such as operational research, cost accounting and production management, as well as previous research works related to the subject matter. The evidence, on the other hand, resulted from a study of current approaches to cost monitoring and control tasks by contractors, and was obtained through questionnaire surveys and oral interviews with top construction companies in U.K. via their staff who are directly involved in project management. The evidence collected was analysed and interpreted against the background of existing knowledge from reviewed literature and previous research findings.

The results and deductions from the analysis, coupled with the theoretical basis derived from literature led to the formulation of
an alternative approach to cost monitoring and control designed to improve the effectiveness of the process. The formulated approach was then tested using current and historical cost data of construction projects obtained from the industry. The work undertaken for the research can be summarized according to the stages shown in table 1.1.

The collection and processing of the cost data used in the test implementation of the proposed approach to cost monitoring and control presented some problems. The format and manner in which contractors capture and store cost and performance data, (as revealed in chapter 7), was not found to be conducive to timely processing and utilization of such data in cost control activities. Consequently, the most laborious and time-consuming part of this research was extracting the test data from the myriad of forms and other site documents provided by contractors and organizing the data in the way envisaged by the proposed cost monitoring and control approach. This problem, which for the projects profiled in Appendices III, IV & V took some 1300 man-hours, further confirmed and demonstrated the significance of the factors identified in chapter 2 as impediments to effective cost control by contractors.
### Table 1.1: Methodology and Work Undertaken

<table>
<thead>
<tr>
<th>Stage</th>
<th>Method</th>
<th>Aim</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Existing research works in areas related to cost monitoring and control were reviewed. Current and recent numbers from the construction press were reviewed.</td>
<td>To formulate a clear research problem</td>
</tr>
<tr>
<td>2</td>
<td>A postal survey of some U.K. institutions and research organizations was carried out.</td>
<td>To know extent of research on problem.</td>
</tr>
<tr>
<td>3</td>
<td>Books, journals and conference materials were reviewed. Discussions were held with practitioners and professionals in industry and academics.</td>
<td>To establish a firm theoretical basis for the research.</td>
</tr>
<tr>
<td>4</td>
<td>A questionnaire survey of top 100 U.K. construction companies regarding their approaches to cost monitoring and control was carried out.</td>
<td>To determine and assess the current approaches to cost control.</td>
</tr>
<tr>
<td>5</td>
<td>Interviews were carried out with project staff from some of the companies that took part in the survey.</td>
<td>To verify the findings and deductions from questionnaire survey.</td>
</tr>
<tr>
<td>6</td>
<td>An experiment on data capture methods was conducted among 20 P.G. &amp; research students of construction &amp; constrn. mangt.</td>
<td>To assess suitability of different methods of data capture.</td>
</tr>
<tr>
<td>7</td>
<td>An alternative cost monitoring and control approach based on quantitative techniques was formulated &amp; analysed</td>
<td>To provide more effective cost monitg. &amp; control method.</td>
</tr>
<tr>
<td>8</td>
<td>Data from past construction projects was collected from industry.</td>
<td>To test quantitative model on constrn. data</td>
</tr>
<tr>
<td>9</td>
<td>Data from on-going construction operations was collected from the same companies as in stage 8.</td>
<td>To test performance of the new method &amp; make recommendns.</td>
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1.6 Summary of Research Achievements

The achievements of this research can be summarized as follows:

1. Establishing that failure to effectively control construction costs by contractors was due to:
   
   - inadequate performance models,
   - inefficient cost information systems,
   - unsuitable approaches to performance measurement,
   - lack of rational procedures to decision-making.

   These were, in turn, found to be caused by:
   
   - Predominantly manual capture and processing of cost and performance data which resulted in late availability of information and corrective decisions.
   - Basing cost monitoring and control tasks on accounting principles and cycles which were unsuitable for the needs of cost control on site.
   - Use of unsuitable methods of performance evaluation such as profit and loss accounting and direct comparisons for detecting deviations.
   - Lack of a scientific basis for making corrective decisions in the event of performance deviating from plans.
   - Inability to make rational and accurate forecasts of future costs and performance based on actual trends from on-going operations.
   - Failure to adequately involve supervisory staff on site in preparing performance models and to make them accountable for expenditure at their corresponding responsibility centres.
   - Failure to set up suitable organizational structures at site level to enable effective communication and discharge of responsibilities.

2. Establishing that cost overrun (with its attendant effects) is one of the consequences of ineffective approaches to cost monitoring and control, and that the problem is very
widespread among contractors. It was for instance found that:

- 44% of contractors always suffered cost overruns on all their projects, while 16% always suffered cost overruns in 3 out of every 4 projects they executed.
- 60% of contractors overspent their budgets in 3 out of every 4 projects they executed, while up to 80% of them overspent their budgets in 1 out every 2 projects.
- All (i.e. 100%) contractors suffered cost overruns in at least 1 out of every 4 projects they executed.
- All contractors found that cost overruns on individual operations resulted in overruns on overall budgets in 92% of all cases. Thus effective cost control of the operations would leave only an 8% chance of overspending project budgets.

3. Identifying from theory and practice the essential criteria for effective cost control of construction projects.

4. Identifying some significant short-comings in the existing approaches to cost monitoring and control of construction projects prescribed in literature and as carried out in practice.

5. Identifying a scientific basis for achieving effective cost control and overcoming the problems stated in 1 above and the short-comings referred to in 4 above. The basis for achieving these was found to be quantitative techniques - namely regression and goal programming models for forecasting and optimization respectively. Their features were analysed against those of construction projects to find a framework for implementing the models.

6. Proposing an effective cost control approach by formulating the cost monitoring and control process of construction projects as mathematical equations that could be solved quantitatively to achieve effective control of the projects.

7. Prescribing a solution process for the formulated equations based on commonly available PC software that not only solve the equations but also, in the process, achieve speedy
and more accurate processing of cost and performance data from on-going operations in a computerized project library. This would provide timely information for making needed corrective decisions while the affected operations were still in progress.

8. Prescribing a speedy and rational approach to performance evaluation, forecasting and decision-making based on actual data from the affected operations.

9. Establishing through empirical evidence and analysis the applicability of quantitative techniques - namely regression and goal programming models - for cost monitoring and control of projects in contractors' organizations. The tests showed that only one or two key components needed to be identified and utilized for forecasting and controlling costs of construction projects.

10. Providing a simple and effective approach for cost control of construction projects by contractors on site.

11. Contributing to a better understanding of cost monitoring and control process carried out by contractors and the problems associated with the process.

12. Identifying areas in which further research was needed in order to enhance the above achievements and further the stated objectives of the research.

1.7 Thesis Presentation

The reporting of the research work comprising this thesis follows very much the same logical flow of the methodology that was outlined in table 1.1. For a better understanding of the 'story-line' of the thesis, the research can be considered as having three major components or phases as follows:

Phase I - Development of a focal theory for the research, which is presented in chapters 1 & 2.

Phase II - Development of a background theory and data basis for the research, presented in chapters 3, 4, 5, 6 & 7.

Phase III- Development of a contribution to the subject matter of the research, presented in chapters 8, 9, & 10.
Figure 1.1 shows what the various components of the research and how the material was organized into ten logically related chapters as summarized below:

**Chapter 1:** Presents a general introduction to the thesis comprising of brief definitions of the subject matter of the research as well as the specific problem under investigation. It also specifies the hypothesis, aim and objectives, the manner in which the research was carried out, as well as a summary of its achievements and structure of the thesis.

**Chapter 2:** Formulated the focal theory of the research by fully identifying, through a survey of existing research findings, specific short-comings inherent in current cost control systems as well as causes of cost and schedule overruns being experienced by construction contractors. This established the specific questions and or issues in cost monitoring and control activities that needed to be addressed by the research in order to improve the practice.

**Chapter 3:** Reviewed available management literature and established the essential features for an effective control process as prescribed by management pundits and scientists. Different control systems were reviewed and analysed to identify those features of the systems that could be effectively employed on construction projects.

**Chapter 4:** Reviewed available construction literature and developed from the review a theoretical model for cost monitoring and control by contractors as prescribed by experts and practitioners of the construction industry. The review identified the features required of an effective cost monitoring and control approach by construction literature.

**Chapter 5:** Sequel to the development of the theoretical model for cost monitoring and control in chapter four the crucial role of organizational structure to the effectiveness of the process was revealed. Thus chapter five reviewed other facets of the construction literature and identified the organizational features
that are necessary for the effective implementation of the theoretical model.

**Chapter 6:** The reviews presented in chapters 3 & 4 consistently revealed the necessity for a scientific and forward-looking approach to cost monitoring and control if the process was to be effective, and shows that available construction literature does not specify how to accomplish this feature for the process. Thus chapter six reviewed scientific management literature and identified quantitative models and methods that could be employed on construction projects to rectify the deficiencies identified with the theoretical model of the process.

**Chapter 7:** Presents a model of the current practical approach to cost monitoring and control by contractors in U.K. as developed through analysis of investigation evidence gathered from the industry. The investigation confirmed the continued existence of the problems identified earlier, threw more light on the nature of the short-comings associated with current approaches to cost monitoring and control, and indicated the improvements that needed to be made in the process.

**Chapter 8:** Collated the criteria for effective cost monitoring and control identified in chapters 3, 4, 5, 6, and 7 and employed them, against a background of the short-comings to process that were identified in the said chapters, as basis to formulate an alternative approach designed to effect improvement to the effectiveness of the process. The cost monitoring and control process was formulated as a problem that could be quantitatively solved and a solution process was prescribed.

**Chapter 9:** Presents the tests carried out to validate the proposals made in chapter 8. Historical and live construction cost data was employed to carry out the tests and the results were analysed to assess the effectiveness of the proposed approach.

**Chapter 10:** Presents the findings of the research, conclusions drawn from the findings and the recommendations for further research on the subject matter.
CH 1: INTRODUCTION
Introduces research problem, aim, objectives, methodology, achievements & structure

CH 2: EXISTING BACKGROUND TO THE RESEARCH PROBLEM
Detailed formulation of research problem & hypothesis based on evidence from existing knowledge & researches

CH 3
Systems and process of control as a management function

CH 4
Theoretical model for cost monitoring & control of constrn. projects

CH 5
Orgtnal. reqts. for effective monitr. & control of constrn. projects

CH 6
Exploring other required features of good practice in monitr. & control used in businesses other than constrn., to provide another basis for formulating reqd. improvement to current practice.

CH 7
Investigating the causes of problems identified in chs. 1 & 2; & establ. the nature & the success or failings of current practice in order to provide another basis for formulating improve ts.

CH 8: PROPOSING A NEW COST MONITORING & CONTROL APPROACH
Formulating the cost monitoring and control problem as a quantitative process & proposing a solution process designed to improve the effectiveness of the process

CH 9: TESTING THE PROPOSED COST MONITORING AND CONTROL APPROACH
Validating & testing the proposed solution process with data from construction projects in order to assess its effectiveness

CH 10
Conclusions & recommendations for further research

Figure 1.1: Guide to the Thesis
CHAPTER TWO

REVIEW OF EXISTING BACKGROUND TO THE PROBLEMS OF
COST CONTROL OF CONSTRUCTION PROJECTS

2.1 Introduction
2.2 Survey of Existing Researches on Cost Control
2.3 Cost Monitoring and Control Problems
2.4 Summary
REVIEW OF EXISTING BACKGROUND TO THE PROBLEMS OF
COST CONTROL OF CONSTRUCTION PROJECTS

A wise man learns from his own mistakes; yet a wise man learns
from other people. ---- Sir Rex Hunt (1992)

2.1 Introduction

While defining the subject of the research reported in this thesis
and the nature of the specific problem under investigation, in
chapter one, a few instances were cited of other researches that
either established or indicated flaws in various aspects of
current approaches to cost monitoring and control of
construction projects. In order to make a clear formulation of
the problem for this research and to fully identify the precise
shortcomings of existing cost control systems, this chapter
presents a review of some of the research findings that were
either directly geared towards contractors' cost monitoring and
control process or which have significant bearing on the
process. This was aimed at enabling this research to establish,
from the on-set, the 'right questions' to which answers need to
be sought in order to improve the effectiveness of the cost
monitoring and control efforts of contractors. Furthermore the
review should help identify some of the causes of cost and
schedule overruns suffered by contractors, (as found by this
research and revealed in chapter 7), so that the search for an
improved approach to cost monitoring and control would keep
such factors under consideration.

The research works available in the area of cost control of
construction projects are, by no means, limited to those
reviewed in this chapter. In addition to the seven works
reported in this chapter other researches reviewed include (but
are not limited to) Langford et al (1987), Barakat et al (1987),
Anatavichius (1987), Baxendale (1990), Jagboro (1991), Ibbs
2.2 Survey of Existing Researches on Cost Control

Different aspects of the cost monitoring and control problems encountered by construction contractors have been revealed by various researches. The problems identified can be classified according to the major components of project management process listed below:

- Project modelling.
- Cost information systems.
- Data capture systems.
- Performance evaluation & decision-making systems.

2.2.1 Researches Related to Project Modelling

Several researches have been made into the problems of modelling construction projects and the effect of the models on the control of projects. A research by Berny et al (1987) stated the problems that were generally identified by other researches and initiated the development of possible solutions. The research, which was designed to apply growth curve models to budgeting, monitoring and forecasting for construction projects as an aid to management control, observed that "existing project control systems suffer from inadequate feedback and a shortfall of accurate enough information to give adequate corrective measures". This was attributed to failure of the control systems to enable "reliable forecasting and contingency planning" of the overall financial and monitoring facets of individual projects and of companies in general. The research, accordingly, identified a need for "more reliable and flexible aids which go beyond currently available project and financial modelling devices" to ensure effective project controls.

To meet this need the research proposed different monitoring and forecasting models designed to improve the accuracy with which traditional project modelling techniques could represent actual projects and provide "a corporate and project financial planning aid with a comprehensive quantitative and analytical basis hitherto not provided by previous systems". The extent to which the proposed models can fulfil this function is however
unclear since the results of their applications would have to be statistically inferred. In any case, however, the models proposed by the research are not (yet) applicable by project managers for real time cost monitoring and control of projects because, as pointed out by the researchers, they (the models) do not "incorporate procedures which equate to everyday use by project managers to assist all aspects of their financial budgeting, monitoring and control". Furthermore, the formulation of the models does not appear to anticipate the needs of such essential monitoring and control tasks, (as will be seen in chapters 3 & 4), as performance evaluation, prediction and corrective decision making. Thus the models do not appear to be able to provide a basis for forward-looking control. The research was, however, significant both in identifying the problems mentioned earlier and in contributing to the search for a scientific approach to solving the problems.

2.2.2 Researches Related to Cost Information Systems

Balivaeu's Accounting Approach to Cost Control

In a doctoral research titled "A Cost Control Model for On-site Works Activities for Construction" carried out at Purdue University, Balivaeu (1984) set out to "present an integrated cost control system" with the aim of providing an insight into the various "segments" of a cost control system and a "readily adaptable model that can be referenced for computer application". The research made a comprehensive review of project cost coding systems and cost accounting processes on construction sites, as well as the estimating component of cost control systems with particular regard to estimating process and database formats.

One of the outcomes of the research was collating, into a single comprehensive mass, the various forms for data gathering and classification on construction sites. While this, (as revealed in chapter 4), is essential for project cost modelling and historical data banking both of which are useful ingredients of the cost control process for construction projects, the research did not establish how effective cost control could be achieved using the
documents reviewed. The process defined by the research did not address such essential aspects of cost control as project performance modelling, performance evaluation and forecasting, and the making of corrective decisions. The issue of timeliness with which information would need to be exchanged between components of the defined process in such a way that it does not become another vehicle for exchanging historical data was also not resolved. These deficiencies would appear to render the results of Beliveau's study as just another accounting system as opposed to a cost control system.

Rasdorf's Work-packaging Model

In a research carried out at North Carolina State University, Rasdorf et al (1991) identified "quality, integrity and timeliness of data" that flow through control systems as being critical to achieving effective management of construction projects. In addition to these factors the research attributed lack of adequate effectiveness in control of projects to inefficient flow of information which, in turn, was occasioned by lack of integration of cost and schedule control functions. This lack of integration was shown to result from the traditional dependence of cost control and schedule control functions on the cost breakdown structure (CBS) and work breakdown structure (WBS), respectively, of construction projects with the former being performed at considerably less detail than the latter. This, the researchers claimed, required project managers to relate data coming from two sources which, in turn, led to reduction in the efficiency with which meaningful information was obtained.

Accordingly, the research sought the solution of these problems in integrating the cost and schedule control functions of projects and decided that the desired integration could be achieved by acquiring and maintaining cost and time data "at an established common-denominator control account defined at a sufficiently detailed level". The research proposed a work-packaging model to integrate the essential features of the CBS and WBS as the possible common-denominator control account that would solve the problems. The effective implementation of
the proposed model would however require an automated method of acquiring and storing data that support the model's concept and level of detail. Towards this end, the research considered several automated data acquisition systems currently being developed in the construction industry based on such technologies as bar coding (BC), magnetic stripes (MS), radio frequency (RF), optical character recognition (OCR), voice recognition (VR), and magnetic-ink character recognition (MICR). The review led to the view that automating data acquisition to support different management functions is evolving as a key in the design of future project management systems. But in their current states of development and evaluation the reviewed technologies have not yet established adequate acceptability in the construction industry.

According to the researchers, the actual implementation of the proposed work-packaging model coupled with an automated data capture system "remain to be completed, and the interactions that would result between the data acquisition and storage remain to be investigated". While the Rasdorf proposal would appear to have the potential for reducing the inefficiency of data exchange between the components of the control process there was no indication that it would have the predictive and optimisation components that could transform acquired data into performance forecasts and suggest directions and optimum measures of needed corrective actions.

2.2.3 Researches Related to Data Capture Systems

The PAVIC System

Bentsson et al (1987) identified the need for "an appropriate system for data collection and analysis" to provide timely and accurate data for planning and control of construction projects. They dismissed "traditional methods" of data gathering as "time-consuming and often expensive", and resulting in incomplete company databases consisting of outdated and difficult-to-retrieve data. An appropriate system, they claimed, "has to be computerized, must facilitate statistical analysis and make different kinds of data presentation feasible", in addition to
allowing for storage of data in easy-to-retrieve databases. To meet these requirements, the study prescribed the use of the PAVIC system (Productivity Analysis with Video and Computer) developed at the Department of Construction Engineering and Management of Chalmers University of Technology in Sweden.

The PAVIC system entailed video recording of work operations and analysing the film by connecting it to a specially coded computer which was programmed to imprint time marks on the sound track of the video tape and transform the recorded information into statistics such as means, maxima, minima and standard deviation for each operation studied. Further analysis of these statistics generated performance distributions that were used to simulate the production system and sub-systems studied.

A major flaw of the system, (at least at its current state of development), was that the data generated would appear to be of purely academic value as it cannot aid cost and or schedule control of operations. This was because the data generated was not related to any bench-mark derived from the operations being controlled. The system's capacity to predict and the value of any such predictions would also be doubtful since it simulated operational progress as opposed to the consumption of construction resources. This means that the system would not provide a reliable basis for cost control of operations in progress.

The Site Manager System

A study carried out by Charles Gregory (Civil Engineering) Ltd in conjunction with the Department of Civil Engineering of Loughborough University of Technology under a Teaching Company Scheme identified the following as some of the problems inhibiting effective financial control of projects by construction companies:

- Inefficient cost reporting comprising:
  - untimely reporting of cost and performance data between sites and headoffice,
  - incomplete cost reports reaching headoffice in trickles,
- ad hoc reporting systems on sites led to problems of understanding for head office staff,
- consequent crisis of confidence with head office doubting the accuracy of incoming reports.
- Lack of efficient project records/library for:
  - storage of historical information in a logical and retrievable form,
  - retrieval of current and historical data for the assessment of claims and defects.
- Need for effective use of cost data on site to:
  - improve efficiency,
  - reduce clerical effort in data capture in a structured and prompted manner,
  - maintain a site data library for use on the site.

The study set out to achieve the following objectives which were, in turn, aimed at improving the efficiency of the company's data exchange system and consequently the effectiveness of its cost monitoring and control efforts:

- The development of a site records/information system for storing, retrieving and manipulating site data.
- The development of routines to access the site data to enable:
  - speedier processing of invoices;
  - up to date cost reporting;
  - improved flow of information between project sites and company head office;
- Interfacing of these with existing company softwares.

To accomplish these objectives the study extensively reviewed and analysed existing procedures employed on sites and the company head office and developed a program - the Site Manager System (SMS) - to solve the identified problems. The SMS allows site staff (agents, engineers and foremen) to record site cost data for the following:

- Labour details
- Plant hired
- Materials/goods received
and prepare valuations, namely:

- Contract progress (initial valuation), and
- External valuation.

The SMS software was designed to be used on portable (laptop) type computers. The design philosophy was that the user could take his data with him/her wherever he/she went. The site machines were coordinated by a central PC at headoffice. This machine ensured that all sites were kept up to date with the latest software and data. Communication between site and headoffice was achieved via the exchange of floppy disks, usually on a weekly basis.

The site system was composed of three sub-systems, namely libraries, sheets and archives, (see figures 2.1 & 2.2). The head office machine had access to libraries and archives only. There were sheet and archive files for each of the site data types outlined above. The libraries were used to maintain details of suppliers' rates, work items, abbreviations etc and may be maintained on site or centrally from the head office machine. The sheets, which form the basic data recording area of the system, were completed on site on a regular basis. When the week's work had been completed the data was filed to the archive. The archives allowed the historic sheet data to be viewed on site or at headoffice. Searching facilities were included which enabled precise deliveries, work items etc to be found quickly and easily.

Following test implementation of the SMS software over a period of 4 years by 25 users on some 40 contracts the study identified the following benefits and advantages of the system:

- The system is cheap to implement, with laptop computers costing as low as £700. Furthermore a single stand-alone version of the system is available for use on autonomous sites
that do not require the coordinating facilities of the head office computer.

- The system achieved a 50% to 70% saving of time spent on booking of weekly sheets.
- Increased accuracy in booking and exchange of performance data.
- Volume of site paperwork is greatly reduced with the result that site agents have all their records for two to three years stored on 40Mb laptops.
- The archive search facility of the software allows for easy and quick retrieval of information.
- The system achieved more than 50% reduction in invoice queries due to improved accuracy with which sheets are recorded.
- The system imposed a discipline of standardizing data formats across all contracts and project management functions.
- Improved communication of information between sites and head office because the system reminds staff at both site and head office of information not communicated and enables the exchange to be done automatically.
- Timely cost reporting was achieved because all site information was available within a week as opposed to two months delay that was being encountered under the former accounting system. This allowed the site information to be used for contract control purposes.

While the SMS does not constitute a cost control system by itself, it would appear to provide a satisfactory approach to the seemingly intractable problem of integrated capture and timely processing and reporting of performance data for use by the cost control process. When coupled with effective prediction and decision-making models the system should facilitate effective monitoring and control of construction projects. This was found to be the case when the SMS was used to capture and process data for use in the trial run of an alternative approach to cost monitoring and control which was proposed and tested as part of this research, (see chapters 8 & 9). But the SMS does not have predictive and optimisation capabilities which, (as revealed
in chapters 3, 4 and 6), are essential for achieving effective cost control.
Suckarieh's Cost Control Software Configuration

In a research at the University of Cincinnati in Ohio, U.S.A., Suckarieh (1987) set out to solve what was identified as a "major problem in the construction industry" namely project budgeting and cost control. Because the study identified the "intensity and size of the data needed for adequate control" as the cause of the problem, it sought the solution in the use of specialized data handling software that could be used on microcomputers. The research prescribed a cost control model that employed three microcomputer programmes; namely spreadsheet, database management and time management programmes; that were available for most microcomputers at modest cost. When linked together, the programmes provided construction firms with "the means to estimate projects, plan their schedule, control their cost and build a database for future projects".

Figure 2.3 illustrates the flow of data among the programmes used in the model. The database management programme is used for storing data and for reporting. It accumulates and updates such data as material costs and outputs, crew sizes and outputs, equipment costs and outputs, activity codes and descriptions etc which it uses to provide estimates for bidding and cost control, as well as scheduling inputs to the time management programme. The time management programmes and the spreadsheet employed data from the database for estimating and scheduling; as well as receiving input data during construction operations to compute cost and progress reports for the purpose of cost control.

While the Suckarieh model would appear to solve some of the problems related to data handling and processing in cost monitoring and control activities, it does not address the important tasks of performance prediction and corrective decision making. It only provided cost reports that indicated whether or not cost and physical progress were on course. It also identified the specific activities that were either running behind schedule or incurring cost overruns. But the model
neither explained the cause of the cost and or schedule overruns nor specified the quantity and direction of adjustments to ongoing operations that were optimally needed to return performance to desired levels. These determinants of rational corrective decisions were left to the intuitive judgement of project managers.

As will be revealed in subsequent chapters of this thesis, any control system that fails to anticipate and predict future events and rationally compute appropriate corrective measures in advance of the occurrence of unwanted events will not be adequate or suitable for construction projects because it would only provide historical evidence that losses have been incurred. Nevertheless the Suckarieh model was found useful for this research in that it suggested a framework for proposing an alternative approach to cost monitoring and control, (given in chapter 8), which would correct the identified deficiencies.

Predictive Cost-Time Profiles of Construction Activities

Starting with the premise that ineffective financial management by construction companies was one of the factors responsible for financial and thus company failures, Christian et al (1990) investigated "the characteristic cost-time profiles for different construction activities associated with educational, office and
apartment building projects" in the province of New Brunswick, Canada. The investigation stemmed from a realization that modelling cost-time profiles for major construction activities could be "extremely useful to the project owners and contractors in their financial planning". The aim was to obtain predictive cost patterns that could be used to establish management action plans that would "reveal the amount and timing of future financial resource requirements" and provide a basis for decision making.

The major construction trades involved in the categories of buildings under investigation were identified to be:

- Site-work
- Concrete
- Masonry
- Steel and Metals
- Wood and Plastics
- Thermal/Moisture protection
- Doors and windows
- Finishes
- Mechanical services
- Electrical Installations

Cost and time data concerning the various activities in the buildings was collected from the progress reports of educational, office and apartment buildings. Monthly cumulative totals of activity costs and time elapsed were standardized to percentages of the total activity cost and time respectively, in order to reduce the data to a common scale. Regression analysis was employed to establish the appropriate models for the data relationships. By modelling completion cost as response variable against the time elapsed, the study examined exponential, geometric, reciprocal, hyperbolic and polynomial relationships. Cost-time profiles were found to vary with the kind of construction projects even for similar activities. The best fit function was decided from its high value of coefficient of determination and low value of standard error of estimate.
The research claimed to have achieved a "fast, inexpensive and reasonably accurate method to forecast the distribution of the cost of individual activities over their duration". This should provide contractors with a "more extensive tool for pre-planning future cost-flows of forthcoming building operations". In addition to aiding effective cost planning for contractors, the research has highlighted the great potential of quantitative methods as tools of construction project management and reinforces the need for this research to investigate the hypothesis defined (see chapter 1) to cost control activities on construction sites.

2.3 Cost Monitoring and Control Problems

2.3.1 Matters Arising from Existing Researches

From the foregoing review of existing research works, some of the problems that hinder effective cost monitoring and control of construction projects by contractors can be summarized thus:

1. The preparation of project performance models which, as pointed out in chapters 3 and 4, are essential for cost monitoring and control does not appear to adequately anticipate the needs of subsequent monitoring, evaluation and forecasting of cost and performance data as part of the project control function. The models apparently fail to provide a suitable framework for generating accurate and timely feedback that would enable adequate corrective measures to be found for deviating operations on the projects. Thus, in addition to accurately representing a project, a good model should, as suggested by Berny et al (1987), include some "comprehensive quantitative and analytical basis" that would enable subsequent monitoring and control tasks to be effectively carried out.

2. The cost information systems - that is the systems for the capture, processing, and transmitting of performance and cost data to higher levels for management decisions - operated by construction companies do not appear to generate cost data of the required quality, (in terms of format and detail), and timeliness to enable operations to
be controlled while the operations are still in progress. This inefficient flow of information appeared to result from the accounting approach of the cost systems and the lack of integration between cost and schedule control functions which, in turn, is occasioned by the differences in sources of data for the two functions. Thus cost data would be late and unsuitable for immediate use for cost control.

3. The systems of processing cost and performance data do not appear to be capable of clearly isolating the actual causes and or sources of cost/schedule overruns let alone explain such causes in a way that would direct the corrective efforts of management. Furthermore there appeared to be no evidence to suggest that the methods used for processing performance data were capable of predicting future levels of performance to allow advance corrective measures to be taken.

4. No evidence was found to suggest that current cost control systems contain rational procedures for making corrective decisions in the event of unfavorable performance. Indeed when feedback data is late and of unsuitable quality, any hope of making rational and effective corrective decisions would be unrealistic.

2.3.2 Questions Arising for this Research

In the light of the hindrances to effective cost monitoring and control identified in this chapter, the questions that needed to be answered by this research in order to realize its aim of improving the effectiveness of contractors' cost monitoring and control efforts included, (but were not limited to):

1. What are the actual causes of the problems? This may be answered via a comprehensive investigation and analysis of contractors' cost monitoring and control tasks on site as presented in chapter 7.
2. How should cost and performance data be acquired and transmitted to provide timely and accurate information in
a suitable format and detail to enable adequate corrective measures be found by management?

3. How should captured cost and performance data be processed to enable the causes and sources of unfavorable performance to be isolated and explained so that management could know what corrective measures to adopt and where to direct them?

4. How could processed performance data be utilized in conjunction with a project's performance models to predict future cost and performance levels on an on-going operation?

5. How could processed performance data from an on-going operation be utilized in conjunction with a project's performance models to compute required adjustments that would be needed to that operation in order to either avoid a predicted overrun or correct those that have arisen?

**Chapters 3, 4, 5 and 6** of this thesis provide the theoretical framework that is necessary to answer the above questions, while **chapters 7, 8, and 9** provide actual evidence collected, proposals made and tests carried out by this research in an attempt to answer the questions.

In addition to the above problems related to cost monitoring and control approach other causes of cost and schedule overruns mentioned in literature include:

1. Design factors especially where contractors at tendering stages have not fully understood or anticipated the full ramifications of a project’s design.

2. Technical factors such as in situations where a contractor's proposed construction method(s) proves to be more difficult or expensive than was anticipated at planning stages.

3. Managerial factors such as poor planning, organization and coordination of resource acquisition, utilization and control.
4. Legal and social factors such as trade union requirements and disruptions.
5. Contingency factors such as weather and unfavorable changes in market and industry situations.
6. Roles of consultants, subcontractors and clients.

2.4 Summary

The review of some existing researches presented in this chapter has revealed some of the problems or factors that were identified as hindrances to effective cost monitoring and control of construction projects by contractors. The main problems identified were:

- Inadequate project performance models.
- Inefficient cost information systems.
- Unsuitable and inadequate methods of processing performance data.
- Lack of rational decision-making procedures within existing cost control systems.

The review also revealed some of the attempts and or proposals made towards solving the problems. The deficiencies of such attempts and proposals were identified vis-a-vis the defined problems. Consequently, specific questions were identified that needed to be answered by this research in order to improve the effectiveness of contractors' cost monitoring and control tasks. The main thrusts of the questions raised for this research were to specifically ascertain the nature and causes of the above problems, and to seek a more effective approach for acquiring and processing cost data from on-going construction operations in such a way that performance could be predicted and corrective measures taken while the operations were still in progress. In other words, timeliness and rationale are some of the essential attributes of any approach that should be proposed by this research.
CHAPTER THREE

THE PROCESS AND SYSTEMS OF CONTROL FROM
MANAGEMENT SCIENCE

3.1 Introduction
3.2 The Process of Control
3.3 Systems of Control
3.4 Requirements for Effective Control
3.5 Controls and Responsibility Accounting
3.6 Summary
3.1 Introduction

In order to provide a comprehensive basis for viewing current approaches to cost monitoring and control of construction projects by contractors and rationally analysing the investigation evidence that would be generated during the research, it was essential for the research to review and collate relevant theoretical knowledge on the different approaches to control as a management function. The review should also help to identify the essential components or features of the control process as seen by management science. Accordingly, this chapter presents the review of theoretical framework for the process of control as well as various systems and or approaches to control.

The control process is presented logically via its constituent elements which were identified as:

1. Setting standards.
2. Recording performance.
4. Corrective action.

The above elements of the control process are, in this chapter, treated on a general level as managerial activities that would be applicable to any given system. The specific manner in which these elements are carried out on construction projects is reviewed in chapter 4.

This chapter also presents a review of various classifications of, or approaches to managerial control developed by management pundits and which are in use in other industries. This entailed identifying the essential elements and considerations of the following control types:

1. Open-loop controls.
2. Closed-loop controls.
3. Feedforward controls.
4. Feedback controls.
5. Tocher's cybernetic approach.
6. Hofstede's contingency approach.

Finally the chapter reviews the concept of responsibility accounting and its application to construction project management, showing how such concepts could be used to design and install responsibility accounting as a component of project cost monitoring and control system on site.

3.2 The Process of Control

There is no dearth of definitions of control in scientific management literature. The common and essential message in all available definitions is that control is about preventing mistakes or correcting those that have arisen in the course of achieving some specified goals or objectives. The 1975 edition of Webster's New Collegiate Dictionary defines control in two ways:

1. To check or verify by comparison with a duplicate register or standard.
2. To regulate, exercise authority over, direct or command to take corrective decision.

Parker et al (1991) have observed that this definition, when coupled with the term 'cost', gives no indication or solace that costs would not rise if cost control were practiced. That is to say cost control does not promise the end to the problems of management be they inflation, wastage, or anything else. What the definition shows is that to control one must have a baseline against which to compare so that deviations can be spotted in time to take corrective action. The process of exercising control in any given system, according to Adamu et al (1988), should not be erratic, but entail a logically mapped out strategy to ensure the attainment of system objectives. Abubakar (1985) described control as "the implementation of rationally calculated decisions to adopt a different method of doing the work at hand in order to eliminate difficulties or short comings that have arisen in the course of the works being carried out so that performance is returned to the desired level".
The activities that constitute the control process have been identified in different ways. Scanlan et al (1979) and Koontz et al (1980), giving the views of general management science, identified the following as the "essential elements" of the control process:

1. Establishment of a standard or plan for desired results.
3. Comparison of the results with the plan, and evaluation.
4. Direction of needed corrective actions.

While considering control as a tool of financial management, McEntegart (1980) classified the process into budgeting, responsibility accounting, reporting and corrective decisions. It is worth noting that McEntegart refers to corrective decisions instead of actions, perhaps, because the nature of management accounting procedures is such that feedback information is mostly useful for 'controlling' future operations since the data is generally historical. When applied to construction projects, NCC (1979) and Musa et al (1988) classified the process of control into four phases, namely:

1. Recording or capture of performance data.
3. Reporting.
4. Corrective action.

Harris et al (1991) expressed the view that the "paperwork" that accompanies any control process and which forms the essential medium for reporting is not a part of the control system. According to them, the elements of any control system are:

1. Observation (i.e. performance recording).
2. Comparison of observations with some desired standard.
3. Corrective action to take if necessary.

The various classifications of the control process discussed above agree in principles and can be represented as shown in figure 3.1.
In order to appreciate the scope and interrelationships of the identified elements of the control process a brief review of the activities that constitute each of the elements is now considered.

### 3.2.1 Standards

Standards, according to Koontz et al (1980), are the yardsticks against which controls are devised. They are the plans for output and expenditure levels for the various responsibility centres which contribute to the accomplishment of the overall goals of the project. In a construction project control scheme, standards are the budgeted inputs and expected outputs for the different responsibility centres. According to Beliveau (1984), and Abubakar (1985) a contractor’s cost control standard would normally include, but not be limited to, the following:

1. Labour costs and outputs.
2. Material quantities and costs.
3. Plant costs and outputs.
4. Quality and quantity of outputs.
5. Subcontractors' resumption and finish dates.
7. Levels of general and project overheads.
8. Profit levels.
9. Establishment costs.
10. Periodic expenditure forecasts.
11. Schedule of expected revenue.
A careful consideration of the above list of performance standards shows that they can be categorized according to four main objectives of any construction project; namely quality, cost, time and output. Other inherent components of established standards for projects were identified by Thierauf et al (1977) as:

1. Guidance to subordinates as to accomplishing the set standards.
2. Determining where or at what point in the process the standards are to be measured, i.e. the control points.
3. Timing for comparing actual results against standards.

Thierauf et al (1977) also suggested that identified control points need to be comprehensive, economical and balanced. They are comprehensive when they include all major operations that are capable of being measured, while economy requires that only critical points that have an important impact on cost and quality are scheduled as reference points. Balancing of control means not overlooking quality factors in favour of only quantitative and other cost factors, a situation that can easily be encouraged by inexperienced project management. Thus, standards should provide not only the basis but also the framework and guide-lines for the monitoring and control of a project.

3.2.2 Performance Recording

Recording, according to NCC (1979), refers to the process of "accumulating, on a regular basis, the necessary information so that progress on a project can be measured, both as regards time and cost utilization, and also the completion status of current activities". While recording refers to the capture of raw performance data, measurement involves the quantification or expression in discrete terms of the plans and performance in order to allow a comparison between them to be made. Thus, for the measurement process to be effective, it needs to express corresponding plans and recorded achievements in like formats and units or measures. In other words the formats for data capture should, as much as possible, be similar to those in which
not only the plans were established, but also those in which recorded performance would be subsequently processed, utilized and stored. This, according to Kratt (1989), will ensure efficient flow of information of suitable quality within the control system. Clough et al (1979), and Beliveau (1984), among others, identified typical formats for the recording and monitoring of performance on construction projects as:

1. Work sections (as in standard methods of measurement)
2. Functional elements
3. Trades
4. Operations
5. Individual resources
6. Company-designed cost codes
7. Subcontract packages
8. Activity gangs

Clough et al (1979), Forster (1989) and McCaffer et al (1990) have identified designed forms/cards as the most popular means of capturing data on construction sites. Such forms include, but are not limited to:

1. Time sheets for labour, plant and subcontractors
2. Site diary
3. Equipment utilization register
4. Work quantity summaries
5. Stores indent forms

Rasdorf et al (1991) discouraged manual data capture because the system is "subject to human errors during filling out forms by hand, summarizing the paper forms onto others and keying information into computer work stations". They advocated a system of bar-coding similar to one developed by Ontario Ministry of Transport (1990). The works of Bell et al (1988) and Bernold (1990) appear to indicate that the practicability of employing bar-coding technology on construction sites has not been satisfactorily established and may, in any case, be economically affordable by only a small section of the construction industry. McCaffer et al (1990) criticized manual data capture via the use of forms/cards for being inaccurate,
laborious and containing only limited details to enable effective monitoring and control of projects. To overcome the problems, they proposed a computerized data capture system using portable laptop computers. The system was developed by the Department of Civil Engineering, Loughborough University of Technology in association with Charles Gregory (Civil Engineering) Ltd. and named **Site Manager System** (see [chapter 2](#)). While the system does not completely eliminate the use of forms except on relatively small projects that require small number of operations and thus fewer supervisors it achieves speedy processing and communication of information between the site and company headoffices.

Intangible factors such as labour relations and job satisfaction which could affect the progress of a construction project would, according to Scanlan et al (1979), warrant a project manager to employ "some subjective measures of success". Failure to do this could cause goals and objectives that are not measurable to be overlooked in favour of measurable ones.

### 3.2.3 Performance Monitoring

It is common in literature to find this phase of the control process being equated to the preceding one because both relate to assessing the status of the works being controlled. Thierauf et al (1977) and NCC (1979) among others believe that the two phases are not the same because recording occurs as the work is being performed while monitoring or status evaluation occurs later and is concerned with the finished results. Abubakar (1985) identified the monitoring phase with comparing the recorded performance with the standards set for each responsibility centre in order to determine if deviations have occurred. The monitoring process was identified by Davis (1951) and Koontz et al (1980) to consist of the following phases:

**Receipt of raw data**

This refers to the upward communication of the captured production information by the lines foremen to the level of
Data processing

This is the accumulation, classification and recording of received information into some recognized and meaningful manner to facilitate identification of significant deviations from plans and or standards.

Performance evaluation

This is the periodic evaluation of completed action to date to actually measure the degree of deviation between completed activities and plans. Thierauf et al (1977) and Wilson et al (1988) among others identified three methods for performance evaluation as follows:

- Computational methods which are used when deviations, whether favourable or unfavorable, are results of routine activities which are specific in nature, e.g. concreting. Such methods include profit and loss accounting, job costing, direct comparisons, variance analysis, and ratio analysis.

- Judgemental approach; employed when deviations result from activities that are difficult to define with any reasonable degree of precision, e.g. supervision. In such cases rationality would be applied and deviations would be measured against organization policies, rules and so forth. Judgements are made concerning whether actions are in conformity with generally accepted organization guides.

- Whenever there is a clash of judgemental values, Thompson (1967) ruled that compromises should be used to determine the deviations.

An important question in performance evaluation is the proper frequency of the evaluations. Abubakar (1987) pointed out that while widely spaced evaluations could be dangerous to profit margin, too frequent ones may be defeatist to
progress and equally dangerous. Working conditions, type of project and site organization should have a bearing on the frequency of evaluations.

**Status reporting**

In this phase, significant deviations are reported to the project manager. Where the project management group have ample authority, the reporting stops here. It is, however, common to have an overall project manager or higher level executives who require information on current performance so as to redirect the courses of action on the project both on short and long range basis. An important question in this phase of project monitoring is the level of detail that reports should contain at each stage. According to Koontz et al (1980), each level of management should receive only concise information that is relevant for the full and proper discharge of its functions.

Figure 3.2 shows a schematic illustration of the monitoring phase of the control process. More detailed aspects of the monitoring process as it relates specifically to construction activities will be considered in chapter three.
3.2.4 Corrective Action

This is the final phase of the control process and, according to Abubakar (1985), consists of the following steps:

1. Analysing reported performance data so as to determine the cause(s) of any identified loss of performance.
2. Making rational decisions as to what action to take to correct the deficiency and to attempt to return performance to the desired level.
3. Communicating the corrective decisions to the right level and at the right time, (usually as soon as possible), for implementation.
4. Implementing the corrective decisions by instructing staff and management of the new approach.

Two key questions arising from the above steps for the project manager are, in this order:

1. What must be done immediately to restore performance to desired levels or correct standards?
2. What are the basic causes of the deviations?

Although a reverse ordering of these questions might appear more logically appealing, economic expedience would require them to be tackled in the above order. It is generally agreed in literature that corrective decision making should have a dominating input from, (but not be entirely carried out by), project managers. Gunning (1984) ruled that site managers should be responsible for decision making concerning production and corrective effort but should not be involved in actual performance measurement and evaluation. Figure 3.3 shows a schematic representation of the decision making process along with the various requirements and considerations that influence the making of corrective decisions. The process is considered so important to the control system in literature that it has often been regarded as the ultimate determinant of the effectiveness of the system. Harris et al (1991), for instance, concluded that "ultimately the decision of the manager that something should be done differently, and the transformation of
that decision into practice, are the actions which achieve control". But they have not prescribed how the manager should approach this important task beyond indicating that the paperwork or cost information system can "provide guidance on what control actions should be taken". And this appeared to be a common feature with most literature on construction cost control for which Fine (1982) provided the excuse that even prophets who had a direct line to God kept well away from forecasting and controlling costs!

3.3 Systems of Control

There are different ways of effecting controls on any given system. Indeed several control systems have been proposed and developed in practice to suit the peculiarities and needs of different management situations. Scanlan et al (1979) and Koontz et al (1980) pointed out that the mode of executing the various steps of corrective action outlined in section 3.2.4 differ according to the management's approach to planning and the type of control in operation. For instance, where a participative
approach is adopted to goal setting, like the case in MBO, then the goal becomes a means of self-control because its regular review and updating continuously provide a current and relevant standard. A brief review of the various systems and approaches to control, together with the essential elements and considerations of each type should enable this research to identify one that would best serve the purposes of cost monitoring and control of construction projects by contractors. The review should also provide a basis for assessing existing practical approaches to project control by the contractors to enable suitable improvements to be sought.

3.3.1 Open-loop Controls

Roche (1982) defined open-loop control as one in which "remedial or corrective action is not automatic but depends on intervention from outside the system". In other words control action is implemented without reference to the actual state of the production (construction) process. When applied to construction projects, the open-loop control implies that the inputs to any construction activity or operation are considered as unaffected by the state or process of the activity or operation itself. Wilson et al (1988) likened open-loop control to the case of a golfer hitting a golf ball. His aim is to get the ball into the hole and, with this in mind, he will take into account the distance, the hazards and so forth, prior to hitting the ball. Once the ball is in the air there is nothing that the golfer can do but hope that he did things right. This example accurately captures the nature of open-loop control and it is obvious that this system will be least desirable on construction projects because there is always some possibility for even the best of plans to go wrong, and it will be foolhardy to have to helplessly watch the objectives of the project land on the rocks. Thus the essential feature of open-loop control is the taking of corrective decisions and actions by management as opposed to the control process itself.

3.3.2 Closed-loop Controls

This system corrects the deficiency of open-loop controls where errors can not be corrected as the process goes along. Roche
(1982) defined closed-loop controls as those in which "the output is fed back to the input so that the system's output can affect its input as a result of control action emanating from a comparison between the desired value and the actual state of the process being controlled". This form of closed-loop control is known as feedback control and is, in turn, of two types; namely:

1. Positive feedback where outputs warrant a control action to reinforce a preceding change of the actual process.
2. Negative feedback where the outputs warrant a control action to oppose a preceding change of the actual process.

Another form of closed-loop control, identified by Wilson et al (1988), is feedforward control. In this case a monitoring device is introduced to continually scan both the environment and the transformation process of the system, (i.e. the process by which the system converts inputs into outputs, e.g. construction activities). This provides a basis for modifying either the initial plans or the transformation process itself if it appears that circumstances are likely to change before the plan has run its course and the goal realized. It is tempting to conclude at this juncture that since feedforward controls are preventive as opposed to feedback controls which are curative, and the desire of project control is to prevent outputs from deviating from plans, then feedforward control is more suitable for construction projects. Such conclusions should, however, better be reserved until a fuller review of the two forms of control is made. Meanwhile it is significant to note that both forms of control entail linking outputs with other elements within the system, (i.e. construction process), and this would explain why they are termed closed-loop control systems.

Feedforward Controls

According to Bhaskar et al (1985), feedforward control is a "measurement and prediction system which assesses the system and predicts the output of the system at some future date". It differs from a feedback system in that it seeks to anticipate, and thereby to avoid, deviations between the actual and the planned
outcomes. Figure 3.4 gives a schematic representation of the feedforward control system.

Cushing (1982) identified the components of feedforward control systems as:

1. An operating process which converts inputs into outputs.
2. A characteristic of the process which is to be the subject of control, e.g. time, cost, or production quantities.
3. A measurement system which assesses the state of the process and its inputs, and attempts to predict its outcomes.
4. A set of standards or criteria by which the predicted state of the process can be evaluated, e.g. construction schedule, budget or other performance models.
5. A regulator which compares the predictions of process outputs to the standards, and which takes corrective action where there is likely to be a deviation.

Wilson et al (1988) gave one of the preconditions to the effective functioning of feedforward controls as the existence within the process to be controlled of a reasonably predictable relationship between inputs and outputs.

Feedback Controls

This control system seeks to ensure self-regulation of the process in the face of changing circumstances once the control system has been designed and installed. It attempts to maintain key system variables in a state of equilibrium even when there are environmental disturbances. For instance construction process interactions or site organizational structure and lines of command can be maintained constant while the mix of resource inputs is varied in the light of recorded outputs.

Wilson et al (1988) identified the components of a feedback control system as:

1. An operating process which converts inputs into outputs.
2. A characteristic of the process which is the subject of control.
3. A measurement system which assesses the state of the characteristic, e.g. the monitoring devices.
4. A set of standards or criteria by which the measured state of the characteristic is evaluated.
5. A regulator whose functions are to compare measures of the process characteristics with the standards, and to take action to adjust the process if the comparison reveals that the process is deviating from plans.

Cushing (1982) suggested some of the principles for the proper functioning of feedforward control systems as:

1. The benefits from the system should be, at least, as great as the cost of developing, installing and operating it.
2. Variances, once measured, should be reported quickly to facilitate prompt control action.

3. Feedback reports should be simple, easy to understand and highlight the significant factors requiring managerial attention.

4. Feedback control systems should be integrated with the organizational structure of which they are a part; the boundaries of each process subject to control should be within a given manager's span of control.

Figure 3.5 shows a schematic representation of the feedback control system.

![Figure 3.5: A Feedback Control System](source: Wilson et al [1988])

Feedforward Vs Feedback Controls

Table 3.1 gives a comparison of some of the significant features of feedforward and feedback controls. Feedback systems are typically cheaper and easier to implement than feedforward systems, and they are more effective in restoring a process that has gone out of gear. Their main disadvantage, however, is that they can allow deviations to persist for as long it takes to detect and correct them. Feedforward controls, on the other hand, depend critically for their effectiveness upon the forecasting
ability of those who must predict future process outputs. And we all know what a dangerous vocation predicting can be.

The most effective approach to control was said, by Wilson et al (1988), Summers (1974) and Lynch et al (1983), to come from using a combination of feedforward and feedback controls to complement one another because few, (if any), processes could be expected to operate effectively for any length of time if only one type of control is in use. This view stems from the fact that both feedforward and feedback controls are intertwined with the design of managerial accounting systems which provide the necessary ingredients for their implementation. Table 3.2 gives the functions that managerial accounting provides to feedback and feedforward control systems.

**Table 3.1: Comparison of Feedforward and Feedback Controls** [Cushing(1982)]

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Feedforward</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low cost</td>
<td>--</td>
<td>Yes</td>
</tr>
<tr>
<td>Ease of implementing</td>
<td>--</td>
<td>Yes</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>--</td>
<td>Yes</td>
</tr>
<tr>
<td>Minimal time delays</td>
<td>Yes</td>
<td>---</td>
</tr>
<tr>
<td>Self-regulation</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Table 3.2 Accounting Functions to Feedforward and Feedback Controls**

<table>
<thead>
<tr>
<th>Function</th>
<th>Feedforward</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Setting standard</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Performance measurement</td>
<td>---</td>
<td>Yes</td>
</tr>
<tr>
<td>Reporting of results</td>
<td>---</td>
<td>Yes</td>
</tr>
<tr>
<td>Monitoring process inputs</td>
<td>Yes</td>
<td>---</td>
</tr>
<tr>
<td>Monitoring operations</td>
<td>Yes</td>
<td>---</td>
</tr>
<tr>
<td>Predicting process outputs</td>
<td>Yes</td>
<td>---</td>
</tr>
</tbody>
</table>

It is, thus far, clear that time is of great importance to the effectiveness of both feedforward and feedback controls. While feedback controls rely on *periodic* outputs from on-going and completed activities of the process to alter or reinforce the
inputs to the process, feedforward controls rely on continuous predictions of periodic outcomes of on-going activities of the process to direct and/or control the overall project goal. It is not within the scope of this research to investigate the relationships between various construction activities and the optimal timing for reporting performance on the activities. But it is clear that a knowledge of appropriate or optimum time intervals, stages or periods for issuing performance reports or making performance predictions would be vital to project control, and must sooner than later command more research attention from construction managers. The problem is, however, more complicated than might appear from this brief mention because it bears on a whole range of factors such as:

1. Type and peculiarities of project being controlled.
2. Site organizational structure.
3. Construction methods.
4. Methods of project planning and scheduling used.
5. Type of project management and staff competence, e.t.c..

3.3.3 Tocher's Cybernetic Control Model

Tocher (1970, 1976) proposed a cybernetic model for control of essentially simple systems or processes. The significance of his model lies in identifying the conditions that must be fulfilled in order that an operation, process or situation might be said to be in control. According to Tocher there are at least four necessary conditions that must be satisfied before a process can be said to be controlled, and these are:

1. An objective for the system being controlled.
2. A means of measuring the results along the dimensions in which the objective has been specified.
3. A predictive model of the system being controlled.
4. A choice of relevant alternative actions available to the controller.

Otley et al (1980) gave a schematic representation of Tocher's model, see figure 3.6, which shows that Tocher's approach to control requires:
1. Clear advance knowledge and understanding of the objectives of the process.
2. Advance knowledge or, at least, a reliable anticipation of the outcome or result of actions taken.
3. That expected outcomes or results are measurable.
4. That once actual and desired outcomes are compared, a mismatch signal be readily transmitted to those required to act.
5. A predictive model that uses the process' inputs, outputs and transformation process to predict likely outcomes of various alternative courses of action to enable corrective decisions to be made.

Tocher's model also identifies the various forms of corrective action that may be taken, and these include:

1. Changing the inputs to the system.
2. Changing the objective.
3. Amending the predictive model of the process to be controlled.
4. Changing the nature of the process itself.

Figure 3.6: Tocher's Control Model [source: Otley et al (1980)]
A major set-back to Tocher's approach to control appear to be its critical dependence on the predictive model for its effectiveness. Otley (1980) pointed out the following features of predictive models which are of particular importance and which would either completely prohibit the use of Tocher's model or else confine its application to only very simple processes:

1. Available models are usually imprecise and inaccurate so that predictions made with them are often inaccurate or result in unintended consequences.
2. Within organizations, there are usually multiple and partly conflicting predictive models because uncertainty leads to generation of several small, partial models and application of individual experiences and insights of personnel to the models.

In the case of construction projects it might still be possible to apply Tocher's approach to control when the predictive model is based on parameters and decision rules emanating from reliable historical evidence. This means uncertainty would have both been recognized and taken into account in constructing the predictive models, (details of how this could be done will be reviewed in chapter 6 and demonstrated in chapters 8 & 9).

3.3.4 Hofstede's Contingency Approach to Control

Hofstede (1981) provided a typology of controls ranging from routine to political but without having recourse to the feedforward- feedback classification. He began his argument on essentially the same premise as Tocher by stating that controlling a process is easiest, (that is a matter of routine), in situations where:

1. Objectives are unambiguous.
2. Outputs are measurable.
3. The effects of interventions are known.
4. The activity is repetitive.

When one or more of these factors are missing, then various control options present themselves to the process depending on
the missing factor. Accordingly, Hofstede provided six types of controls, as shown in figure 3.7, to be employed in the various situations shown in the figure. The control types are:

1. Routine control.
2. Expert control.
3. Trial and error control.
4. Intuitive control.
5. Judgemental control.
6. Political control.

Figure 3.7: A Contingency Classification of Controls
[source: Hofstede (1981)]
Wilson et al (1988) identified the significance of Hofstede's contingent classification of controls as follows:

1. It emphasizes that there is a range of control alternatives that are more or less appropriate depending on the problem situation. This is useful because traditional managerial accounting control systems have invariably assumed that it is possible to always set clear objectives, (e.g. budget targets), measure outputs and compare performance against budget, and to take corrective action if deviations occur and the activity is repetitive. These assumptions are not always met in practice and even where met, the act of controlling is compounded by the unpredictability of any process that interacts with people.

2. It focuses attention to the interactions of people in controlling organizations. The notions of intuitive, judgemental and political controls focus on the social process surrounding managerial systems instead of continuous reference to abstract categories and systems.

It would appear, from the foregoing review of control types, that for a contractor to achieve effective cost control the company must operate a system that is an aggregate of several aspects of all the above control types with the possible exception of the open-loop system. This is because, if not expertly implemented, the open-loop system can lead to unnecessary delays which are both expensive and embarrassing to the general conduct of a project. An instance of this would be a situation where many staff and line functions get stranded waiting for management to make decisions on matters which a reasonably able foreman or site engineer can resolve.
3.4 Requirements for Effective Control

Thierauf et al (1977) summarized the requirements for effective control in the following 'ten commandments':

Controls should:

1. Reflect the job they are designed to perform.
2. Report deviations promptly.
3. Be forward looking.
4. Point out exceptions.
5. Be objective.
7. Reflect the organization structure.
8. Be economical.
10. Lead to corrective action.

3.5 Controls and Responsibility Accounting

3.5.1 Principles of Responsibility Accounting

The development of responsibility accounting concepts as a cost control tool was, according to Roche (1982), necessitated by three basic facts, namely:

1. That feedback controls require the identification of errors and or variances between the expected and the actual performances, and the taking of appropriate corrective actions to steer the production process and organizational members towards a more desirable path.
2. That an organization is an abstract theoretical construct that is not capable of acting, in a literal sense, by itself but necessarily requires specific persons to act.
3. That of the three major objectives of cost accounting, namely:
   - cost control,
   - product costing (or estimating), and
   - inventory pricing,
contemporary cost systems and accounting procedures meet only the last two objectives but for the most part fall
on their faces when it comes to the objective of real-time cost control.

Responsibility accounting addresses these issues by identifying those cost elements in a certain area of activity which form a controllable set and appointing a person to be responsible for managing this set of cost elements. Thus responsibility accounting requires that particular costs and or revenues be identified as the responsibility of certain individuals or groups in an organization. This implies the classification and reporting of accounting information by areas of responsibility, e.g. concreting, glazing, e.t.c.. Roche (1982) and McEntegart (1980) identified three premises that constitute the concept of responsibility accounting thus:

1. If a person has authority over both the acquisition and the use of the services, (or resources), he should be charged with the cost of such resources.
2. If the person can significantly influence the amount of cost through his own actions, he may be charged with such costs.
3. Even if the person can not significantly influence the amount of cost through his own action, he may be charged with those elements with which the management desires him to be concerned, so he will help to influence those who are responsible.

It is evident from the above premises that, in addition to providing a practical method for implementing feedback control, responsibility accounting also has implications for feedforward control. An operational foreman, for instance, would need to predict the environment for his activities for his operation to grasp opportunities for growth, expansion and/or flexibility within available alternatives. If the foreman only responds to existing challenges from the environment, he may not be able to effectively control the environment.
3.5.2 Responsibility Accounting Applied to Construction Projects

Though basically developed for the manufacturing industries, the concept of responsibility accounting has been widely applied for cost control of construction projects. The technique fits as an extension or a part of the project cost recording, monitoring and evaluation framework employed on construction sites. In this case responsibility centres would be akin to project cost codes, [see Clough et al (1979)]. Furthermore the three main levels of responsibility used in responsibility accounting could correspondingly be applied to the hierarchical structure used for managing most medium to large construction projects thus:

1. A cost centre, (or cost code), where managers would be accountable for the expenses which are incurred would correspond to the levels of general or trades foremen, depending on the size of the project.
2. A profit centre where managers would be accountable for revenues or funds and expenses would correspond to the level of a project manager.
3. An investment centre (or level) where managers would be accountable for revenues or funds, expenses and capital investment decisions would correspond to the level of general manager or managing director of the company.

The concept of responsibility accounting has been widely employed by the construction industry in recent researches that were aimed at formulating an integrated framework for cost and schedule control of projects. For instance the thrust of proposals for integrated cost and schedule control made by Hendrickson et al (1989), Teicholz (1987) and Ibbs et al (1989) all revolve around comprehensive cost and schedule coding of construction projects and closely relating performance monitoring and control around the coding structure. Perhaps the most comprehensive application of responsibility accounting to monitoring and control of construction projects is illustrated by the work-packaging model developed by National Aeronautics and Space Administration (NASA) and Department of Defence (DoD) of U.S.A. in "Project Control (1987)". The model imposes
new disciplines in project planning and budgeting that create a unified view of time and cost data from construction operations through "control accounts" which are akin to budgetary codes used in financial management but with the distinction that they have a two dimensional definition combining cost as well as work breakdown structures of the project, (see also Rasdorf et al (1991) reviewed in chapter 2).

3.5.3 Design of Responsibility Accounting for Construction Sites

The details of this purely accounting function has been discussed in detail by Wolkstein (1967), Goldhaber et al (1977), Tenah (1985) and Wilson et al (1988). The task comprises:

1. Identifying relevant cost centres taking due cognizance of site organization, nature of works, previous experiences, e.t.c.. In any case it is necessary to assign every foreseeable activity or expense to one cost code or another.
2. Designing suitable performance reports that are relevant with respect to content, frequency of reporting, and level of detail required at each level of responsibility. The rule is reports must be simple but comprehensive enough with regard to content and details, and yet report only relevant information to each level of authority.

The design of construction cost codes has been extensively treated by Adrian (1981), Clough (1979), Ng (1985) and Beliveau (1984). Abubakar (1985) recommended the format of the Standard Form of Cost Analysis designed by the Building Cost Information Service of the Royal Institution of Chartered Surveyors. Each project team would, of course, choose a classification it considers most suitable to the job at hand.
3.6 Summary

The review of literature presented in this chapter has revealed the various classifications of the control process depending on different management viewpoints. The control process was shown to entail pre-determining the goals of a given system or organization, the courses of action to achieve those goals, and taking appropriate steps to ensure that the goals are realized. The various steps involved in recording, processing, evaluating and reporting performance data, as well as taking corrective actions were reviewed along with such important considerations as format, content, frequency and degree of details of performance reports.

A review of various approaches to control revealed that while many of them agree in general premises, they differed in the way to handle such grey areas as controlling intangibles. Open-loop controls were found to be particularly unsuitable for construction projects, while the other control types were each found to have some positive aspects that could be employed to ensure effective control on construction sites. While Tocher's cybernetic model would be useful for controlling mainly simple systems, its concept (which is essentially feedforward) could still be employed on construction sites with suitable precautions. Hofstede's contingency approach to control provides useful framework for managing the social aspects of controls in organizations.

It was shown in the review that most approaches to control available in literature have stemmed from, and thus follow the structures of, management accounting. Responsibility accounting concepts were found to have been developed to aid a more effective implementation of the control systems while at the same time furthering the course of those objectives of management accounting which are not realized through routine accounting procedures.

It was also shown that the main responsibility centres used in responsibility accounting could correspondingly be applied to
the hierarchical management structures of most construction companies through to the project levels.

Effective cost monitoring and control by contractors was shown to require a combination of various managerial control models; (e.g. feedforward, feedback, cybernetic and contingency models); using performance exception reports as inputs to the models to alter the observed levels of performance. A common requirement that featured in all the control models reviewed in this chapter was found to be the prediction of future courses of events based on on-going trends and using results of such predictions to appropriately adjust the course of current and future activities in order to realize the desired objectives of a project. The various techniques available for analysing current performance levels, forecasting future performance levels and determining rational decision-making parameters have been considered in detail in chapter 6. Meanwhile let us consider the cost monitoring and control function with specific reference to construction contracting organizations and as advocated in technical literature and previous research works related to the function.
CHAPTER FOUR

THEORETICAL BASIS FOR COST MONITORING AND CONTROL OF CONSTRUCTION PROJECTS

4.1 Introduction
4.2 Framework for Project Monitoring and Control
4.3 Measurement of Performance
4.4 Corrective Decision-making
4.5 Summary and Deductions
4.1 Introduction

This chapter presents a general review of theoretical knowledge on the approaches to construction project management with particular emphasis on cost monitoring and control activities by contractors. The object of the review was to define the complete framework of technical and managerial functions within which site cost monitoring and control is carried out. This definition was a necessary prelude to complete realization of the aims and objectives of this research. The review also covered the essential considerations and significance of the functional elements, (and the constituent activities), that constitute the framework for managing construction projects by contractors. These include:

1. The relevance of a contractor's functional organization as a basis for cost monitoring and control.
2. The components of company and project cost information systems as essential basis for cost monitoring and control.
3. The relevance of project estimating and planning to cost monitoring and control.
4. The philosophy, procedure and systems of cost budgeting by contractors as framework for cost control.
5. The principles and methods of performance measurement, evaluation, forecasting and corrective decision-making.

The monitoring and control activities on construction projects, comprising performance measurement and decision-making, are reviewed in detail via the various steps and or methods used for recording, processing and evaluating actual performance levels. Decision-making options available to project management in the event of various situations of unfavorable performances are also reviewed. The budgeting function was reviewed in considerable detail because of its critical importance to the effectiveness of cost monitoring and control efforts.
4.2 Framework for Project Monitoring and Control

Contractors' cost monitoring and control tasks on construction projects are, according to Clough et al (1979), Mueller (1986) and Abubakar (1985, 1987) among others, carried out within the framework of an overall project management system which consists of the following functional elements:

1. Contractor's functional organization.
2. Cost systems.
4. Planning and scheduling.
5. Budgeting

The various activities that constitute the above elements provide the essential basis for monitoring and control of construction projects on site. Thus it was pertinent for this research to briefly review the essential considerations relating to the activities in the framework to enable a proper evaluation and appreciation of the characteristics of the theoretical approach to monitoring and control of construction projects.

4.2.1 Contractor's Functional Organization

The functional departments of a construction company provide the essential framework for implementing the policies of the company and realizing its corporate objectives in general. They provide the basis as well as directives for accomplishing specific activities towards realizing the overall objectives of the company. Available literature, see Forster (1989) and Stallworthy et al (1987) among others, identifies five functions that generally define the functional organization of construction companies, and these functions are carried out by the following departments:

1. Administration department which is responsible for interpreting company policies with regard to finance, personnel, contracts, purchasing, sales, e.t.c.
2. Personnel department which is responsible for recruiting, training and administering the staff and labour force of the company.

3. Finance/Accounts department which is responsible for administering the financial affairs of the company.

4. Purchasing/Procurement department which is responsible for acquiring all the necessary materials, equipment, components and or services required by the company to carry out its activities.

5. Engineering/Contracts department which is responsible for the actual planning and execution of projects being handled by the company.

These are, by no means, the only departments of a construction company as they could be further split into more specific functional units which, in big organizations, could be full departments. The functional areas outlined above, however, are the most essential for the purpose of cost monitoring and control of projects. They provide the necessary basis and inputs for the company's monitoring and control activities on site. The essential features and organizational requirements for effective cost monitoring and control of construction projects have been reviewed in detail in chapter 5 of this thesis.

4.2.2 Contractor's Cost Systems

It was pointed out in chapter 3 that the various types of control and the actual control process depend almost entirely on organized and comprehensive information in the form of standards and performance reports. Gunning (1984), Sidwell et al (1984) and Rasdorf et al (1991), among others, have shown how the entire project management functions of estimating, planning, scheduling, budgeting, controlling and directing depend on a comprehensive management information system. Such a system supplies the inputs to each phase of project management activities, and channels output data through other phases and to a central data pool for further reference. In construction business organizations, such information system is
generally known as a cost system, (see Clough et al 1979), and comprises two levels namely:

1. The overall company cost system, based at the headoffice, consisting of all records relating to the operations of the company, including the financial management system run by central accounts departments.

2. The project cost system which deals with information on operations of individual projects handled by the company, and this is usually based with the respective project managers.

The project cost system, in addition to providing the basis for physical and cost control of individual projects, also provides input data to the records of the overall company cost system. This research was more concerned with the project cost system because it is more directly relevant to cost monitoring and control on construction sites. The overall company cost system is more of historical value than any practical significance to controlling on-going activities on site.

A cost system is a library of organized information on the various resources employed by a contractor with regard to their costs, utilization and outputs. The information is organized in the sense that it has to be structured in such a way as to allow prompt estimating, monitoring, reporting and evaluation of project costs. According to Clough et al (1979), the cost system has its limitations because it is only a means to an end and not the end itself. As such it can only be justified where its contribution is worth more than the cost of its development. But, if well developed, a cost system would be an asset rather than an expense. Clough et al (1979) also gave the principles that should guide the development of good cost information systems for construction projects, thus:

1. Excessive detail should be avoided because it could create problems in allocating field expenses and render resulting data unsuitable for estimating and cost control.

2. The scope of the cost system should reflect the type of contract and the characteristics of the job.
3. The information gathered should be geared towards aiding estimating, cost control and effective supervision by highlighting problem areas.

4. The cost system should be cheap to maintain and, as much as possible, closely relate to the organizational structure of the project.

Clough et al (1979) also cautioned that a cost system should only field supervision not replace it because "in the final analysis, the best cost control system that a contractor can have is skilled, experienced and energetic field supervision".

Elements of a Project Cost System

Figure 4.1 shows a schematic representation of a typical project cost system. The diagram has been simplified to reveal just the various classes of cost that constitute the salient sources of expenditure on a construction project.

The principles and procedures for computing the cost components of the various elements of a project cost system have been adequately treated in classics by Enterkin et al (1972), Wood (1982), Geddes (1985) and Hardie (1987), among others. Table 4.1 shows some of the types of information that would normally be contained in the various elements of a cost system. It is evident from the table that a comprehensive cost system would be essential to realistic estimating and preparation of performance models for a project.
Figure 4.1: Elements of a Project Cost System

INPUT FROM COMPANY COST SYSTEM

- Overheads
- S/C's Attendance
- Preliminaries
- Plant
- Materials
- Labour
- Permanent
- Casual
- Non-consumables
- Mechanised
- Hand tools
- Fixed
- General
- Variable

COST ELEMENTS

INPUT FROM PROJECT OPERATIONS

- Basic wages
- Statutory contributions
- Trade agreement charges
- Basic cost
- Hire rates
- Maintenance
- Operating
- Running
- Basic cost contributions
- Transport & delivery
- Off-loading & storage
- Waste allowance

FEEDBACK

EFFECT TYPES

COST TYPES
Table 4.1: Contents of Cost Information Systems (source: Gunning 1984)

<table>
<thead>
<tr>
<th>Elements</th>
<th>Records</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>Mats. scheds., Stock holding levs., Wastage allows., Storage reqts., Insptn procds., Delivery progms.,</td>
</tr>
<tr>
<td>Subcontractors</td>
<td>Programme, Subcontract conditions, Attendance requirements, Payment procedures.</td>
</tr>
<tr>
<td>Costs</td>
<td>Bill rates, Unit cost estimates, Turnover budget, Cash flow forecast, Financial ratios.</td>
</tr>
<tr>
<td>Time</td>
<td>Programme and productivity data, Variation agreements, Client requirements.</td>
</tr>
<tr>
<td>Quality</td>
<td>Spectns, Drwgs, Brit. stands., Samps, Bdg regtns, Manufacturer's data, Exptns. in wkmanship, etc.</td>
</tr>
<tr>
<td>Safety &amp; security</td>
<td>Legislation on safety, Health and welfare, LA reqts., TU agreemts, Co. policy, Estabd. good practice.</td>
</tr>
<tr>
<td>Information</td>
<td>Information schedules, Programme, Contract and s/c requirements, Co. policy on record keeping.</td>
</tr>
<tr>
<td>Methods</td>
<td>Method statements, Productivity data, Work study information, Previous experience.</td>
</tr>
<tr>
<td>Management</td>
<td>Contract requirements, Job descriptions, Management development programmes.</td>
</tr>
</tbody>
</table>

4.2.3 Estimating

Estimating the costs of construction projects within contractors' organizations, according to Saunt (1979), starts pre-tender and continues through the post-contract stage of a project. At the
pre-tender stage, the estimator determines how much to bid for a project of a given quantity and specification. The company management would then adjudicate on the figure arrived at by the estimator and make an allowance for overheads and profit to arrive at the tender sum. At the post-contract stage the estimator, together with other members of the project team, scrutinizes the project more closely and establishes the most economical resource mix and method of construction to achieve a profitable contract completion. This latter stage of estimating is the one that culminates into the project budget.

The following definition by Clough et al (1979) reveals not only the dependence of estimating on a comprehensive cost system and skilled staff but also an indication of its significance to subsequent monitoring and control efforts:

"Construction estimating is the process of identifying and compiling the many items of cost that will enter into a construction programme. This is a procedure that requires very detailed study of the project itself, combined with an intimate knowledge of the availability, characteristics and costs of materials, equipment and labour. A good estimator is a highly skilled artisan who has an encyclopedic knowledge of production costs and rates, and he practices a craft unlike that of any other on earth. Estimating a project is a curious combination of precise facts, management decision, hard-headed realism, a great deal of work, hunch and an element of cold blooded guessing. ..... The contractor's ability to estimate accurately largely determines the profitability of a job long before construction starts".

The importance of estimating to the success of construction projects is further underlined by the vast amount of literature and research works available on various aspects of the function. Indeed estimating has become a specialized discipline within the construction industry. Detailed insights into the estimating process on construction projects and its contribution to the cost monitoring and control efforts of contractors can be found in the
works of Kerzner (1983), Hardie (1987), McCaffer et al (1991) and so on. The general picture from these literature, in relating estimating to monitoring and control of construction projects, is that the first phase of project estimating is the determining of work quantities required to complete the project. The quantities are then analysed into the amounts of labour hours, plant hours, materials quantities, and subcontracting required to accomplish them. When the analysed resource requirements are priced the result is the estimated project cost, which is then divided into various responsibility centres to give the budget. Conversely, to control the budget, the actual work quantities completed on site are systematically measured at regular intervals, analysed into the resource levels required to produce such quantities, and then compared with actual recorded labour, materials and plant requirements that were used. This would then signal whether performance is in keeping with the budget or not and, if not, where the discrepancy arose from. In this way corrective action can be directed to the defaulting activity or cost centre.

4.2.4 Construction Planning and Scheduling

Since planning is a relatively well-beaten track in researches pertaining to the construction industry it is not necessary here to argue a case for the role and techniques of project planning and scheduling in the management of a construction project, including cost monitoring and control on site. This has been adequately covered in existing researches and literature, see Abubakar (1987), Jackson (1979), Milligan (1979), Kharbanda et al (1987), Mueller (1986) to mention just a few. The general view in these works is that:

1. Planning entails the provision of a logical and complete method statement of how the various work operations contained in the project will be carried out within the agreed contract period and cost (subject to any subsequent changes under the contract) while leaving the contractor's planned profit margin untouched.
2. The effectiveness of any control system depends on the quality of the plan on which it is based and the feasibility of the monitoring devices incorporated into the plan.

It is sufficient for the purpose of this research to summarize the objectives, essential considerations and procedural steps for sound construction planning by contractors. Abubakar (1987) identified the objectives of a construction plan as:

1. Establishing the project's cost budget based on individual responsibility centres.
2. Establishing a procurement schedule for labour, materials, plant, subcontractors and utilities.
3. Establishing a construction schedule possibly by way of a critical path network or bar charts.
4. Establishing the organizational and staffing structure of the project, as well as command chains and communication channels.
5. Establishing cash-flow forecasts to fit (any) earlier reached financing decisions and/or agreements.

These objectives, which are often expressed as performance models, provide the feasible framework for achieving project goals and serve as the basis for monitoring and controlling actual progress during the implementation of the plan. The following are some of the essential considerations for sound planning of construction projects:

1. Aims and objectives of the project.
2. Location of the project.
3. Financing arrangements; i.e. whether owned or loan capital will be used.
4. Form of construction, tendering and contracting.
5. Method of construction and desired project duration.
6. Availability of labour, materials and plant.
7. Need or otherwise of mechanical plant and subcontractors and their types.
8. Present work load of the contractor.
The process of construction planning progresses through a series of well defined phases, namely:

1. Pre-bid and bid.
2. Contract award and pre-construction.
3. Weekly job cycle.
5. Substantial completion (or practical completion).
6 Final completion and job close-out.

The planning associated with the contract and pre-construction phases of the project is, according to Mueller (1986), the most important because it controls all the subsequent actions with respect to the project and establishes the expected boundaries of performance. In addition to other issues particular to a contractor's organization, abilities and project limitations, the various phases of construction planning seek to answer the following primary and accumulative questions; accumulative in the sense that the answer to each defines a major logical step in realizing the project's performance models and leads to the answer for the next question. The questions are:

1. How will the job be constructed? (the plan).
2. When will it be constructed? (the schedule).
3. What is it expected to cost? (the budget).

Construction planning, according to Abubakar (1985), answers these questions through the following logical steps:

1. Defining all the activities that must be carried out to secure the completion of the project. This is done through careful analysis of contract drawings, contract bills, specifications, site investigation reports, e.t.c..
2. Identifying the physical relationships between the activities, or choosing an optimum logical sequence for the activities where there are no physical relationships. This yields a logic network or some other diagrammatical representation of the work items contained in the project and provides a basis for resource planning.
3. Identifying or deciding who will physically perform each activity and what resources are available for the performance of each activity.

4. Based on the resource allocation from the previous step and the rate at which the resources will be applied, determining how long it will take to perform each activity. This is the activity scheduling step.

5. Schedule computations based on activity durations to determine the time boundaries for each activity, the critical path for the overall project and the available activity floats.

6. Review of project schedule by identifying multiple activities requiring the same resources at the same time and eliminating such conflicting demands by seeking alternative resources, relationships or priorities among the activities. This step finally yields the project plan which, when dated provides the project schedule.

7. Establishing the cost budget for the project from the results of steps 3 to 6 above. The outcome of this step may lead to a review of some or all of steps 2 through step 7 itself. This step, thus, provides the first opportunity ever for a very close scrutiny and review of the entire project plan and schedule even before the commencement of site operations.

The foregoing steps of the process of construction planning result into the two primary performance models for the project, namely construction budget and construction schedule. Other performance models which are necessary pre-requisites to effective cost monitoring and control on site can then be derived from the primary models, see Mueller (1986). The secondary or derived models are:

1. Cost curves.
2. Production curves.
3. Schedule of values curves.
4. Cash income or schedule of expected revenue curves.
5. Cash requirement curves.
This research did not consider it necessary to go into the details of the procedures for deriving these models because once the primary models have been established, the rest is mainly clerical and drafting jobs. It should surface to give the contents and relationships of the models as in table 4.2.

Table 4.2: Contents of and Relationships between Performance Models

<table>
<thead>
<tr>
<th>Models</th>
<th>Presentation</th>
<th>Content/Use</th>
<th>Data Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Budget</td>
<td>Tabular</td>
<td>Cost control</td>
<td>Refined estimate</td>
</tr>
<tr>
<td>Schedule</td>
<td>Logic network or time scale</td>
<td>Calendar dated schedule</td>
<td>Roster of activities and project plan</td>
</tr>
<tr>
<td>Cost curve</td>
<td>&quot;S&quot; curve</td>
<td>Cost/time</td>
<td>Budget and schedule</td>
</tr>
<tr>
<td>Prodtn. curve</td>
<td>&quot;S&quot; curve</td>
<td>Production values</td>
<td>Cost curve plus budgeted overhead and fee</td>
</tr>
<tr>
<td>Schedule of values curve</td>
<td>Modified &quot;S&quot; curve</td>
<td>Values for requisitions</td>
<td>Weighted cost and/or production curve</td>
</tr>
<tr>
<td>Cash income curve</td>
<td>Histogram</td>
<td>Accounts receivable</td>
<td>Schedule of values plus contract payment terms</td>
</tr>
<tr>
<td>Cash reqt. curve</td>
<td>Modified histogram</td>
<td>Accounts payable &amp; P/R</td>
<td>S/C &amp; vendor payment &amp; P/R cycle</td>
</tr>
</tbody>
</table>

4.2.5 Construction Cost Budgeting

It has already been pointed out that planning provides a basis for control. From the definition of planning given in section 4.2.4, that is providing a complete method statement of doing the work in advance of its execution, it is clear that a project plan can not by itself enable costs to be controlled. To achieve cost control, in accordance with the concept of control defined in chapter 2, the plan must be expressed in quantitative terms. This would require presenting each proposed activity on the project in pecuniary terms so that comparisons can be made with actual expenditure on each activity to determine any deviations. This quantitative expression of the plan in monetary terms is called a budget. This concept of budget agrees with definitions due to Roche (1982), Degen et al (1980), and Wilson
et al (1988). Thus budgeting involves assessment of the likely cost expenditure in respect of the various responsibility centres of a project and making due allowance for them in the financial plan of the project. Knight et al (1964) and Abubakar (1985) showed that though budgeted costs are related to the method statement prepared at the contract planning stage, budgeting is more than just planning: "it is the pricing of the plan".

Due to the identified significance of budgets as essential basis for cost monitoring and control, it was essential for this research to include a detailed review of the different facets of the budgeting function that could affect the effectiveness of cost control efforts.

**Objectives of Budgets**

From the view of management accountancy, as represented by Wilson et al (1988), Hongren et al (1982), Patillo (1977) and Smith et al (1988), among others, a comprehensive project budget provides the contractor with the following objectives:

1. Informs of the most economical, yet feasible cost of completing the project.
2. It represents the permitted level of expenditure within which the work must be completed in order to provide an acceptable profit margin for the contractor.
3. It serves as a control device because monitoring processes relate the budget to actual expenditure on the project to reveal areas of overspending.
4. Allows management to periodically appraise the financial progress of the project during the construction phase.
5. Provides a rational basis for review of existing working methods and considering the introduction of new ones.

These objectives would make budgets appear to provide a panacea for the management function of profit planning and control. This is only true to some extent because the approach to the development and implementation of the budget largely determines the success of the budget in realizing the above objectives. For instance, although the project manager is ultimately responsible for the preparation and agreement of the
budget and ensuring that it is prepared at the right time, it is unwise (if at all possible) for him to do so without consulting and seeking the inputs of other key project staff. Non-participative budgeting could create human relations problems such as misconceptions, resentments, misinterpretations, speculations e.t.c. by all levels of personnel concerned with its operation. Henke et al (1978) added that an improperly developed budget may weaken general morale, inhibit individual creativity, create laxity and develop pressures where goals are unrealistically high. It will be unrealistic for any project manager to expect profitable operations under such an atmosphere. In order to minimize these problems Henke et al (1978) suggested the following measures:

1. Involving all levels of personnel in the preparation of the budget.
2. Developing a positive and enthusiastic attitude among management personnel toward the budget.
3. Communicating the purposes and uses of the budget to all personnel.
4. Establishing realistic and achievable goals in the budgetary plan.

Budgeting Procedure

The process of preparing budgets for construction projects can be broken into the following phases:

Pricing the Plan

The operations that have been identified at the planning and programming stage of the project and detailed in the contract plan are priced by estimating their anticipated cost when performed in the method in which they are planned to be executed. The estimate must take into account the overall resource requirements in terms of labour, materials, plant and subcontractors for each operation. To achieve this, Clough et al (1979) stressed the importance of entrusting this function only to people familiar with work quantities and field procedures who are much better equipped to compute production rates and unit
costs. This would clearly negate the notion held by Wolkstein (1967) that since budgeting is an accounting function it can generally be fused with the conventional responsibilities of the accounting department of a contractor's organization. Abubakar (1987) opined that estimating, budgeting and accounting for construction works are delicate and highly specialized functions that are best handled by experts with relevant training and experience such as quantity surveyors and engineers.

**Checking Tender Allowance**

The estimated operation costs obtained from the previous phase are then checked against the financial allowances made for these operations in the tender. This is not a straightforward issue since the monies included in the bills of quantities, (which are the main source of budgeting data), are the revenue that is to be received for carrying out specific items of work, which are rarely on the basis of operations or budgetary formats. This means a quantity surveyor (or project manager) will have to cost-analyse the bills of quantities in order to convert the items of work, quantities and prices contained therein to a format that is comparable to the format of the budgetary estimates. The purpose of this phase is to ensure that the tender allowance is not exceeded by the estimate based on the planned methods of construction.

**Tender-Budget Reconciliation**

In the event of the budget exceeding the tender allowance, it is necessary to check the budget and the plan and, if possible, to reduce the budget cost to that allowed for in the tender or, preferably, a lower value by altering the planned method of construction. This may not be possible where an error in the tender becomes apparent. This reconciliation of tender and budget enables the project management to ensure that the planned profit margin on the project is not eroded, as well as providing the first major review of a contractor's work plan.
**Finalizing the Budget**

Having completed the budget and any necessary checks and adjustments to contain it within the tender allowance, it must be finally agreed by the project manager and his departmental heads. The project manager satisfies himself that the budget allows for an acceptable profit level on the project and the departmental heads satisfy themselves that the budget is a feasible cost allowance for the completion of the works.

**Communicating the Budget**

It is essential to inform all personnel concerned with the implementation of the budget of the cost allowance within which they should execute their activities. The project manager should create a cooperative atmosphere through communication, discussion and consultation among his peers and subordinates in order to gain their highest possible commitment to the budget. This is an important determinant of realizing the objectives of the budget. While Bashir et al (1988) held that participative approach to budget development is generally more effective, especially in construction project management, Henke et al (1978) believe that there are times when authority must be asserted if managerial control is to be maintained. These views suggest a need for a balance to be struck between authority and participation, and the following guide-lines suggested by Henke et al (1978) should help in attaining such balance:

1. Always involve lower level managers in the establishment of their budgetary goals.
2. Be sure that budgetary goals are reasonably achievable but at the same time demand good effort.
3. Encourage two-way communications between upper level managers and those charged with the achievement of specific budgetary goals.
4. Provide frequent, timely reports showing managers how their achievements compare with budgetary plans. These reports should be prepared to reflect responsibility for only those costs under the control of the person receiving
the report. Furthermore, these reports should be prepared in a manner which can be understood by the recipient.

5. Emphasize self-control of cost by lower level managers rather than by reliance on policing actions.

6. Recognize good performance and work cooperatively with managers showing unfavorable budget variances.

Systems of Budgeting

Different approaches to budget preparation have been proffered in literature, especially in the area of management accountancy. An account is given below of two budgeting systems that appear to be applicable for construction projects, along with the pros and cons of each system so that we can later on assess the systems adopted in practice as revealed by investigation evidence. The systems to be reviewed employ the principle of responsibility accounting, and this makes them more relevant to construction business than other budgeting systems which are predicated to businesses with, more or less, a permanent or repetitive operational pattern. Construction budgeting, on the other hand, requires a system that is rather one-off or that can be moduled to suit the peculiarities of different projects.

1. Planning-Programming-Budgeting-System (PPBS)

When applied to construction projects this budgeting system proceeds by the following steps:

1. The overall objectives of the project are identified. These include all obligations that a contractor must discharge under the contract in connection with:

   - contract completion date
   - quality of work
   - quantity of work
   - attendance to subcontractors
   - patent rights.
   - individual operations
   - statutory regulations.
These objectives are then analysed to yield a list of functional activities that must be performed to complete the project.

2. The functional activities derived in step 1 are then arranged into a logical programme for the project. This entails careful consideration of the critical sequencing of all the activities and their possible overlaps and clashes.

3. The programme is then critically evaluated to ensure that it promotes the ultimate objectives of both the project and the contractors organization. Where this is not achieved, alternatives must be sought and similarly evaluated. Prudence requires that even if the first programme appears to be suitable, alternatives should still be investigated to see if there is a more suitable course of action.

4. The results or outputs expected or achievable from the selected programme are then determined. These outputs must be quantitative in terms of amount of work to be completed and a time scale for completing it.

5. The resource requirements in terms of labour hours, plant hours, quantities of materials, subcontractors, overheads, etc. necessary to achieve the required outputs are then estimated. The estimates are then expressed in monetary units (i.e. priced) for each major operational or functional activity. This step relies heavily on the availability of reliable data on construction costs and outputs for labour and plant.

6. The sums calculated above are then checked, adjudged and integrated into a project budget. This budget is then compared with the expected revenue from the contract to see if it allows for a profitable operation. It is then agreed by the project manager and other departmental heads (or members of the project management team) who then allow implementation to commence.
The above procedure, represented in figure 4.2, establishes the expense budget for the project. To prepare the revenue budget a similar procedure is adopted. In this case the selected programme is evaluated against the contract bills in order to determine the revenue to be received from each major operation or functional activity. The sums calculated are then compiled into a revenue budget or forecast for the project. The revenue and expenditure budgets are often recorded in the form of bar charts, S-curves or other diagrammatical representation that would enable the immediate visualization of the financial status of the project. A combination of the expense and revenue budgets yields the projected cash-flow pattern as well as an indication of the amount and timing of financing required for the project. The combination can also be used for periodic checks on status and profitability of the project. According to Musa et al (1988) budgets produced at the beginning are not final. They are bound to change as a result of subsequent variation orders that may be issued by the client and his consultants, as well as due to fluctuations, delays and other claim-generating situations agreed in the contract. This means the project management team must remain on the alert to identify such incidences and adjust the budget accordingly and promptly. Even when such incidences do not arise managers must continue to be on the look-out for unforeseen conditions that impair or improve the budget, and review it as necessary. The fact that deviations from budget have not occurred does not preclude the need for regular reviews because budgets are a means to and not the goals themselves.
IDENTIFY PROJECT OBJECTIVES

IDENTIFY FUNCTIONAL ACTIVITIES

EVALUATE PROGRAMME AGAINST PROJECT & COMPANY OBJECTIVES

DETERMINE ACHIEVABLE RESULTS FROM THE PROGRAMME

DETERMINE RESOURCE REQUIREMENTS OF THE PROGRAMME

COMPILE THE INPUTS & OUTPUTS THAT WILL YIELD THE BUDGET

REVIEW BUDGET AGAINST EXPECTED PROJECT REVENUE

budget guarantee project & co. objectives

AGREE THE BUDGET WITH PROJECT MANAGEMENT TEAM

IMPLEMENT

Figure 4.2: Steps of PPBS
Disadvantages of PPBS

The foregoing account of PPBS reveals the following apparent short-comings of the system:

1. The system emphasizes goals, (in terms of functional activities), to be accomplished without delineating how to do so.
2. Policy and programme decisions are made very early and can often be too early for well reasoned decisions to be taken.
3. It does not give enough room for the involvement of lower level personnel who may then find it difficult to implement some hasty decisions of their seniors.

In spite of these short-comings the PPBS remains particularly suited to budgeting of construction works because it directly relates the planning and programming functions with the cost assessment.

2. Zero-Base Budgeting

This system does not appear to be quite suitable for construction project budgeting because it is tedious and very analytical. The advent of computers, however, diminishes the significance of this view. Nevertheless the system is better suited to factory and government budgeting. It requires each unit of an organization to start its budget afresh each year by analysing and justifying proposed expenditure on all functional activities.

Proposed operations are grouped into decision packages which are then ranked in order of priority of decreasing benefit to the organization. Resources are then allocated to the packages according to the ranking. Monetary measures are applied to the allocated resources to yield the budget.

The system has the benefit of defining goals as well as means of achieving them. It provides lower level personnel with a monitoring tool and a means of periodic review of programmes. But the nature of construction operations hardly lends itself to
the annual open-and-close book-keeping routine required by the zero-base system.

Budgeting Philosophy

In order to fully comprehend and appreciate the contents of a construction budget and effectively employ it as a basis for monitoring and control, it is necessary to know the basic philosophy that informed the building of the budget. Mueller (1986) outlined two budgeting philosophies upon which each organization must, knowingly or otherwise, base its construction budget. They are market value and fair value budgeting.

*Market Value Budgeting*

This employs prices quoted by subcontractors, vendors and suppliers in the market place on their face values and uses them as the basis not only for estimating and tendering the project but also for budgeting the project when the bid and negotiations are successful. Due to the volatility of market values occasioned by free interplay of supply and demand forces, this budgeting philosophy would require superior knowledge of market place conditions.

A critical aspect of market value cost budgeting is the accurate anticipation of the time-frame in which the project purchasing will take place and subcontracts and purchase orders will be let. The anticipations must cover both seasonal or time of the year factors and factors relating to overall economic conditions because rising and declining markets present very important consequences for the cost budget. Figures 4.3 and 4.4 show the effects of market value purchasing when the market is on the decline and when it is on the rise respectively.
\[ \delta = P_1 - P_2 = \text{cost reduction from delayed purchasing} \]

\[ \delta = P_2 - P_1 = \text{cost increase from delayed purchasing} \]

Figure 4.3: Purchasing Cost over Time in Falling Market

Figure 4.4: Purchasing Cost over Time in Rising Market

**Fair Value Budgeting**

This relies on the contractor's experience in producing work of a specific kind at a specific point in time. Fair value is clearly less volatile than market value. This budgeting philosophy considers all major factors that affect the cost of a project without placing much emphasis on market fluctuations. Although changes in historical costs resulting from inflationary factors on wage rates, costs of materials and indirect costs such as pay-roll insurance, taxes and the like are accounted for, this budgeting
philosophy demands less knowledge of market conditions and trends. Another advantage of fair value budgeting is that it takes into account the cost effects, (both positive and negative), of technological changes.

A reasonable overhead allowance is added to the updated cost experience of the contractor to arrive at the budget of a new similar project. Additions and omissions to the base project will, of course, have to be taken care of as part of the updating process since no two construction projects can be identical in all respects. Mueller (1986) identified three assumptions which normally accompany the use of fair value as a basis for budgeting construction projects thus:

1. That the contractor's organization is well established in its market place.
2. That the contractor has established working relationships with subcontractors and principal vendors within that market place.
3. That subcontract and purchase negotiations are structured around fair value rather than market value. This implies that when the market is depressed or inflated fair value will be the basis for negotiations.

The last assumption is of critical importance and determines the viability of fair value budgeting concept because it signifies the existence of well developed working relationships that guarantee that subcontractors and vendors will neither be unduly penalized for depressions nor unduly enriched by rises in market value. Such a situation could have the effect of significantly modifying market fluctuations.

Thus, while market value budget is based on competitive and comparative pricing, to which the contractor only adds a suitable mark-up, the fair value budget is arrived at by the contractor independently establishing a fair value for the works, assessing the differences between this fair value and market value at that point in time and, then, separately assessing the fair value of the works from his judgements of the differences. The budget thus established is then modified to some degree to reflect market
conditions over which the contractor has no control. The result is a cost budget which is truly a reasonable statement of expectations with respect to the cost of the project. Mueller (1986) reported that, in practice, most well established contractors employ a mixture of fair value and market value budgeting. The primary budgeting systems discussed earlier are based on fair value concepts.

4.3 Measurement of Performance

We have thus far reviewed the concepts of estimating, planning, scheduling, budgeting and responsibility accounting as applied to construction projects and essential pre-requisites to effective cost and schedule control of construction projects on site. Application of the concepts reviewed so far would yield a project that is thoroughly planned, coded, scheduled and budgeted, ready for implementing by the contractor's site organization. In other words, all the performance models for sound project management would have been created and the project team is now faced with the logical step of commencing actual operations and measuring performance for the purpose of control. It was pointed out in chapter three that performance measurement consists of:

1. Recording or capturing raw performance data from ongoing operations.
2. Processing the recorded data to give useful management information.
3. Evaluating the processed information by comparing it with actual and planned performance.

The aim of performance measurement is to provide answers to questions such as:

1. What has happened?
2. Why has it happened?
3. What is to be done about it?
4. Who is responsible for taking action?
The main objective of performance measurement is to provide answers to questions such as:

1. What is to be measured?
2. How is it to be measured?
3. How is the measurement to be interpreted to provide a basis for corrective action?

In order to fully realize the defined aim and objectives of this research, it was essential to review some of the methods used at each of the identified steps of performance measurement, especially as they pertain to construction projects. The review should also reveal how the process of performance measurement answers the salient questions raised above. Before considering the process in any detail it is pertinent to remember that construction cost control invariably imply and encompasses expenditure control, schedule control and production control, and the various methods employed at each step of performance measurement recognize and take this fact into account. The result is that site control documents are (or should be) designed to capture, process and report data that is relevant for the control of all the various performance models. This concept is known as system integration and has been the subject of considerable research recently by notably Rasdorf et al (1991), Hendrickson et al (1989), Kim (1989), and Teicholz (1987).

4.3.1 Performance Data Capture

There are several methods of recording performance data especially in literature on production management and cost accounting in the manufacturing industries. There are, however, three methods that appear to be particularly suitable and have found some degree of application for construction projects. While one of the methods is computer-based, they all rely on project staff to record the actual performance data manually and transfer it to the processing stages of the cost control process. Whether a data capture system is manual or automated, there are certain criteria that it should meet if it is to provide a basis for cost control in a manner different from and more effective than the
much criticized contemporary cost accounting systems. Mueller (1986) identified these criteria thus:

1. The system must anticipate all data requirements of, and receive inputs from all project disciplines such as field production, project management, financial management and accounting, and overall company administration. This is achieved through design and use of appropriate forms.
2. The data capture process must be designed to match exactly the level of detail, item by item, contained in the performance models. This uniformity of details and activity within the data capture process should be extended to all work disciplines and ensure the collection of data that can be easily processed with the least amount of recasting.
3. The recording system should capture all the necessary or required data at a single most convenient time. This is known as Single Data Capture and imply the capture of more detailed information at a particular time. This aims to simplify the process and keep post data capture clerical effort to a minimum.
4. The data capture and subsequent analytical process should be designed in such a way that the data capture (source) documents commonly used, (such as labour time sheets), also become the source documents used in the analytical process. Again, the goal is to eliminate or reduce, where ever possible, the required recasting of raw data before it can be entered into the analytical process.

Card Recording System

Inspite of the wide variety of designs for cost monitoring forms in the construction industry, the common object remains to capture, in a systematic and progressive manner, all items of expenditure on site with regard, (but not limited), to:

1. Labour operational time and cost.
2. Materials consumption and wastage.
3. Equipment utilization, breakdown and idle time.
4. Overhead expenses.
5. Attendance costs on subcontractors.

The data collection must be progressive because of the need to ensure system integration and provide appropriate basis and inputs for subsequent steps of the monitoring process. For typical self-explanatory samples of the possible range of forms that can be used for manual capture, processing and reporting of time, production and cost data on medium to large construction projects reference can be made to Ng (1985), Adrian (1986), and Clough et al (1979). Although the forms have traditionally been used manually, their formats would allow computerisation at the processing, evaluation and reporting stages of their use.

**Implementation of the Card System**

Depending on variants of form design and site organization, the monitoring and control of projects via the forms may vary. The design of data capture forms assumes a project that has been properly planned, scheduled and budgeted via recognized cost codes, one or more of which fall within the supervisory domain of a given foreman. Thus, depending on the activities to be carried out within his trade that day, a foreman collects the relevant forms for labour, materials, plant and attendance before starting time each day and enters the relevant data through the day as the operations proceed. At the end of the day he signs and drops the completed forms at the site office where all the forms for that day will be processed. This means, if the returned forms are processed the following day, the results of all operations on the previous day could be visible, at least to the levels of site engineers or work superintendents. By extension, the results of all previous week's operations could be ready by the beginning of the subsequent week. As revealed in chapter 7 of this thesis and for reasons stated therein, this kind of timeliness is however rarely, if ever, achieved in practice.

It is important to note that at this level of the cost control process the data capture system is not concerned with company inventory control and procurement systems or policies but rather the control of resource utilization on the project. This is because as long as a particular resource is not consumed it does
not literally become an expense on the project, but a semi-liquid asset (or waste caused by inefficient project management). This is significantly different from the approach to control used in management accounting where expense is posted direct from invoices or payment vouchers. Thus, the card system used on construction projects leaves the control of procurements to headoffice management who must interpret a project's schedule as regards resource requirements and comply accordingly. In effect, this approach seeks to separate cost control of specific projects from the overall financial management scheme of the company.

**Advantages of the Card System**

1. It identifies precise sources of deviations.
2. It is simple to implement.
3. It is cheap since the implementation is done by routine project staff as part of their usual functions.
4. It is easily understood by all levels of project personnel.
5. It could ensure system integration, if properly applied.
6. It makes lower level staff to feel completely part of the cost monitoring system.
7. It has a relatively satisfactory information turn around time, if properly applied.
8. It requires only reasonable amount of clerical effort.

**Disadvantages of the Card System**

1. Leaves a lot of room for arithmetical and human errors when processing and evaluation are not computerised.
2. At the peak of operations the volume of forms requiring processing may necessitate increased clerical support if results are to be released on schedule, and the increased pressure on clerical staff increases the chance of errors.
3. Like all man-dependant systems, it depends on the integrity of foremen for its effectiveness.
4. Only limited amount of detail can be contained in manual based data capture systems.
5. Involves tedious and repetitive processing of captured data before it can be used in subsequent phases of the cost control process.

6. Storage of captured data is cumbersome, and retrieval is difficult and expensive.

Computer-generated Turnaround Document

Despite all attempts to regard the turnaround document as an automated means of monitoring and control for construction projects, see Mueller (1986), it still remains just another means of manual data capture even though the document is produced by computers. As implied by its name, the turnaround document is a communication tool of primary significance for conveying information between the office environment and the job site. Mueller (1986) observed that "all the information required by the field environment for production management and schedule control is communicated to the field in a specific and organized way. To expedite the flow of information from the field environment to the office on actual performance additional space is provided on the turnaround document (the form used to communicate expected performance data to the field) for the recording of actual performance and returning (or 'turning around') that information to the office environment".

With regard to implementation, the turnaround document is not much different from the card system. Each foreman picks up an exception printout of his expected activities for the day from the (site) computer room and returns the completed document at closing time for feeding into the computer. Strictly speaking, the turnaround document is simply a case of the card system linked to computerised database and with automated processing and evaluation.

Advantages of Turnaround Document

1. Larger volume of data can be handled more promptly than with card system.
2. Complies with requirements for system integration.
3. Cheaper than card system in the long run.
4. Greater flexibility afforded by a wide range of scheduling and budgeting softwares.
5. Minimizes arithmetical errors, though human errors would still be possible when recording and feeding the data into the computer.
6. Enables foremen and other line-staff to know the targets expected of them, though this may be too late to enable them evolve any positive strategy to ensure realization of the targets.

Disadvantages of Turnaround Document

1. It is not easily understood by all levels of project personnel.
2. Computer printouts of the turnaround document are cumbersome and less convenient than cards to be handled by foremen.
3. Larger quantity of detailed information required on the turnaround document could make the system confusing and retrogressive to speedy data capture.
4. Data such as start and finish times, activity durations and quantities of finished work which are the hall-mark of the document can not identify the cause of cost overrun on a given cost centre.
5. It depends on the integrity of foremen for its effectives.

Suitability of Turnaround Document Vs Card System

In order to compare the suitability of the card system and the turnaround document for data capture on construction projects, twenty postgraduate and research students with civil engineering background and who all claimed to have had relevant practical experience on construction sites were requested to study the two types of documents for thirty minutes each. The documents were then collected and the students requested to:

1. Identify the purpose of each document.
2. Identify which document would be more convenient to use for the identified purpose.
3. Identify which document they found easier to understand.
4. Make any other comment(s) concerning the documents.

The results of the experiment are shown in table 4.3 with the responses expressed as percentages.

<table>
<thead>
<tr>
<th>Designed cards</th>
<th>Turnaround document</th>
</tr>
</thead>
<tbody>
<tr>
<td>Purpose correctly identified</td>
<td>100%</td>
</tr>
<tr>
<td>Document judged convenient</td>
<td>95%</td>
</tr>
<tr>
<td>Easier document to understand</td>
<td>95%</td>
</tr>
<tr>
<td>Most general comment</td>
<td>Familiar, Simoler</td>
</tr>
<tr>
<td></td>
<td>Simpler</td>
</tr>
</tbody>
</table>

The results of this experiment indicate that the designed cards would be preferred by technical project personnel because they are easier to understand, more convenient to handle, simpler in outlook and more familiar.

**Graphical Methods**

These have limited applications to generally small projects with very simple schedules, repetitive projects and on management contracts where a main contractor schedules and monitors the activities of subcontractors. Each foreman gets a copy of the project schedule in bar charts or networks and shades the progress of his operations on a daily, weekly or monthly basis and reports regularly to the management. This method can, clearly, not be effective in monitoring actual costs even though it provides a good focus on project schedule. And it does not warrant any further review in this research beyond this recognition.

As revealed in **chapter 2**, other systems of performance data capture are currently being developed or at various stages of being tested. Since they have not yet been widely established in the industry, it was not considered necessary to attempt any assessment of them at this point beyond the review in **chapter 2**.
4.3.2 Data Processing

The processes and procedures reviewed so far would provide a source of adequate raw data to answer most of the questions that form the aim and objective of performance measurement. The questions of measuring and interpreting the measurements call for some computational and/or analytical routine to convert the captured raw data into measures that can be directly useful to project management and field supervision. Mueller (1986) stressed the need for performance measures to be presented in a simple, factual and concise way. To achieve this Beliveau (1984) and Clough et al (1979) suggested that data processing on construction sites be carried out in a standardized format, preferably similar to the data capture approach.

4.3.3 Performance Evaluations

The processed data has then got to be evaluated against planned performance models in order to reveal how far actual levels of performance comply with the planned levels. Before considering other more effective methods for performance monitoring, (see chapter 6) it is essential to review, here, the traditional methods that are currently in use, (see Harris et al 1991), so that we can appreciate why most current and earlier cost control systems have, according to Kharbamba et al (1987) and Abdullah et al (1988), not been adequately effective and "remained mere accounting systems". Kodikara (1990) identified "unsatisfactory" approach to "the very important task of checking the actual use of resources against estimated values", (that is performance evaluations), as a major cause of ineffective cost control and site management in contractors' organizations.

Profit and Loss Account

The most basic measure of performance used to be the profit and loss statement which presents the results of operation of an entire project or company over and at the end of a given period of time. From the point of view of construction management, Kharbamba et al (1987) and Abdullah (1988) among others, established that such data is almost always so far out of phase
with actual field construction and the ability to influence outcome that it is virtually useless for contemporary cost and schedule control. The following points underline the failures of profit measures as tools of effective cost monitoring and control:

1. Profit measures typically focus on current rather than long-term performance with the result that actions are always geared towards what happened rather than what will happen.
2. Due to multiplicity of business objectives, profit is not an adequate basis for comparing the relative performance of organizations or for monitoring the specific source of good or bad performance.
3. Profit measures do not relate performance to methods.
4. Profit measures are products of accounting rules which do not often record economic reality, (e.g. use of resources), but concentrate on historical values of resources.

**Job Costing**

Another historical measure of performance which is still widely used is job costing, (also known as standard costing), which attempts to provide information more closely related to actual performance than profit and loss statement. The basic data for job costing is posted from accounts payable and pay-roll. Mueller (1986) demonstrated that it is not possible to get job costing information as currently as required for construction project management using this system because pay-rolls usually involve a weekly cycle of processing and consequently of performance measurement information, while accounts payable usually involve monthly cycles.

**Performance Ratios**

These appear to provide a more pragmatic approach to the evaluation of performance data and involve a direct matching of data on an activity by activity basis, (or cost codes), to provide a basis for corrective decision-making. The formula for calculating performance ratios is:
Performance Ratio = \frac{Actual Performance}{Planned Performance} \\
\text{i.e. } PR = \frac{AP}{PP} \times 100\%

This simple calculation provides quick, accurate and valid information, beginning with the individual cost code and proceeding through any summary level for the project. It is obviously desirable from the above formula that PR should always be \( \leq 1 \) for the particular activity to be said to be within its budgeted cost, time, or production level. A PR of say 95\% imply that the activity has made a saving of 5\% on plan. It does not, however, mean that:

1. whenever PR > 1, something has gone wrong to warrant corrective action; or that
2. as long as PR \( \leq 1 \), there is nothing wrong with the project, and that conditions are all favourable.

For instance, in the first case it is possible that a different resource mix or operational method from those planned have been used and saving may only manifest itself at later stages of the project. And, in the second case, it is possible that saving is due to unacceptably low quality standards on the operations. Consequently, Gunning (1984) identified the need for a decision rule which will indicate when to act. Though performance ratios provide easy and quick means of detecting deviations, they fall short of providing a rational basis for determining whether or not the indicated deviation warrants any corrective effort or whether it is just a freak case of no significance to the financial well being of the project. This can only be realized through the use of scientific management techniques based on quantitative analysis, as will be shown in chapter 6.

Variance Analysis

Haber et al (1977), Levin (1987) and Wilson et al (1988) have shown the computation, classification and analysis of deviations as a starting point for corrective follow-up to be a vital feature of cost control. Like the ratio analysis discussed above, variance
analysis also requires a decision rule to be able to identify when corrective action would need to be taken to correct observed deviations from plans. For this, variance analysis employs predetermined performance ratios or absolute measures or values for the resource being controlled. The general formula for calculating variances is:

\[ V = (A-P)R \]

where: 
- \( V \) = variance of the resource being measured
- \( A \) = actual amount of resource used
- \( P \) = planned amount of resource to be used
- \( R \) = planned rate/price for the resource

This formula is applied to the performance records on weekly or daily basis to yield the following types of variances for each cost code or centre:

1. LRV = labour rate (price) variance
2. LEV = labour efficiency variance
3. MPV = materials price variance
4. MUV = materials utilization variance
5. MYV = materials yield variance
6. EEV = equipment efficiency variance
7. ERV = equipment rate variance
8. OHV = overhead variance
9. TCV = total cost variance

These are only some of the important variances that can be computed. A range of other variances can be computed from the recorded performance data. But it is not necessary to compute all these variances whenever a deviation is to be investigated as only the principal ones listed above need be analysed to evaluate the significance of the deviation. In the case of construction projects it may suffice to analyse the cost variance of labour, materials and plant, and variances in production quantities to decide on the significance of an observed deviation. The conventional way of evaluating the significance of variances is to observe the absolute size or the proportionate size of the
variance. For construction projects it is safer to combine both standards and investigate deviations whenever:

\[
[V] = X, \text{ or } \left( \frac{\text{Actual Performance}}{\text{Planned Performance}} \right) \times 100\% > Y
\]

where:

\[
[V] = [\text{Actual performance} - \text{Planned performance}]
\]

\[
X = \text{Absolute size decision constant, say £1000, 5m}^3, 10\text{hrs.}
\]

\[
Y = \text{Proportion decision constant, say 5%}
\]

This method has been criticized by Wilson et al (1988) among others, for not adequately dealing with the issues of significance of observed deviations, and balancing the costs and benefits of investigation. This criticism would, however, appear to hold only in contemporary applications of the method in management accounting since, in the case of construction projects, both matters can be (and indeed would have been) taken into consideration at the estimating and budgeting stages when the decision constants could be set. Harris et al (1990) also held that this method would seldom be directly applicable for construction projects because of the quite substantial departures from the manufacturing system that are necessary, unless the value of work done can be assessed in relation to the contract budget which, in turn, must reflect the amount the contractor can expect to be paid. This implies that the principle can be employed for construction cost control once the budgets are comprehensively coded and related to expected revenue.

Quantitative Analysis

Quantitative management techniques such as regression analysis, time-series forecasting and optimization models are applied in manufacturing and other industries successfully to monitor and control costs and performance, see Davis et al (1984). Available literature does not, however, indicate any significant attempt to employ these techniques in the construction industry, especially with regard to contractor's cost monitoring and control efforts.
Some of the closest attempts at applying quantitative techniques in the construction industry were due to Neale (1973), McCaffer (1975) and Trimble (1974). Jagboro (1991) has demonstrated how multiple regression could be employed to make preliminary estimates of costs at conceptual stages of projects. McCaffer et al (1983) have suggested the use of time-series analysis for forecasting building costs and tender prices. These researches, however, only explored the use of the techniques at very general levels without considering their possible use by contractors for actual cost monitoring and control of projects. Yet all the monitoring and evaluation methods reviewed so far can, at best, only identify sources of cost and performance deviations from plans. They neither explain the deviations or predict future performance, nor lead to rational and empirical 'estimates' of appropriate corrective decisions, which is what is required and advocated by most of the control systems reviewed earlier, (see chapter 3). A review of some quantitative models and methods that could be employed by contractors to effectively monitor and control costs of construction projects is presented in chapter 6 to provide a better basis for realizing the defined objectives of this research.

4.4 Corrective Decision-making

The requirements and approaches to the process of corrective action have been outlined in chapter 3. Irrespective of the type of control being used, (i.e. whether feedforward or feedback), Wilson et al (1988) have identified the following as the control options available to managements:

1. Changing the inputs to the system.
2. Changing the objective(s) of the system.
3. Amending the predictive model of the process to be controlled.
4. Changing the nature of the process itself.

When applied to construction project control these options can be translated thus:

1. Change the resource mixes of adverse activities.
2. Review/change the plan, schedule and budget of the project.

3. Review/change site organizational structure and/or project information system.

4. Review activities of vendors, subcontractors, consultants and client.

5. Re-evaluate local market for labour, materials, equipment, subcontractors e.t.c.

6. Employ alternative methods and or procedures for site operations and management.

7. Review contract conditions in relation to claim generating Clauses.

Mueller (1986) contends that, in the case of construction works, "no single process or procedure can provide the overall control cycle; it, rather, results from the effective use of a combination of techniques including schedule monitoring and updating, the weekly progress meeting, the project action check-list resulting from the weekly progress meeting, and continued cooperation and good communications from all of the team members for the project". This contention, perhaps, results from a recognition of the wide scope of control options for construction projects and the difficulty of considering these options within a good enough time to allow for effective control of on-going or projected deviations. One way out of this problem, as suggested by Carlisle (1982), is to use management by exception whereby exception reports pin-point the actual source of deviations for project management to concentrate corrective efforts. This would explain why the cost monitoring and control methods advocated in available literature and as presented so far in this chapter is geared towards providing the necessary exception reports for project managers.

Although management by exception has been criticized, see Koontz et al (1980), for emphasizing focus on negative aspects of performance with possible negative psychological impact on morale, a competent and experienced project management team can not fail to turn the concept to an advantage by propagating
recognition, responsibility and maximum participation as the ultimate goal of the approach.

While the earlier mentioned contention by Mueller (1986) with regard to cost monitoring and control of construction projects remains one of the clearest prescription for decision-making in technical literature it fails to define the techniques to be used and how they should be used in order to realize rational and timely performance results and corrective decisions which are essential to effective project management. Another important omission found in literature on cost monitoring and control of construction projects seem to be a failure to specify the manner in which the problem of incompatibility of formats between vital project management functions, (such as estimating, budgeting, data capture and performance evaluations), that influence the effectiveness of the overall project control system should be resolved. For instance, the format in which estimates are prepared is often different from those in which operational budgets are prepared and performance data captured and evaluated. Furthermore the formats and schedules of invoices could hardly suit the requirements of timely analysis of resource consumption on individual operations or cost codes.

In an attempt to address these omissions this research reviewed quantitative methods available in management science, (see chapter 6), with a view to applying the principles to cost control of construction projects. Furthermore the practical approach to cost monitoring and control by contractors was investigated, (see chapter 7), to determine the extent to which the omissions might have affected the practice as well as how the effectiveness of the practice could be improved using quantitative techniques.

4.5 Summary and Deductions

4.5.1 Summary

The review presented in this chapter has revealed the elements and activities that constitute the theoretical approach to cost monitoring and control of construction projects by contractors as proposed in available construction and related literature. The
approach defined by the review can be represented by the model shown in figure 4.5. The activities comprising each element of the model can be summarized as in figure 4.6.

Figure 4.5: Theoretical Model for Cost Monitoring & Control
Figure 4.6: Summary of Contractor's Cost Monitoring & Control Activities
The logical flow of the process in a typical construction project consists of various operational monitoring and control cycles which are presented in figure 4.7.

The essential features of the theoretical approach revealed in this chapter can be summarized in the following points:

1. The contractors functional organization provides the most primary and essential basis for effective monitoring and control of projects.
2. Existing literature and research was found to be heavily biased in favour of cost estimating and project planning aspects of construction projects.
3. Existing literature and research on construction cost control by contractors bears heavily on financial accounting principles of control which are not wholly suitable for construction projects at the site operational level.
4. Cost control by contractors, especially at site level, has not received adequate research attention despite a realization that true cost control in the construction industry starts at the contractor's office.
5. Comprehensive company and project cost information systems are some of the essential pre-requisites to establishing accurate and realistic project performance models and thus achieving effective cost monitoring and control.
6. Comprehensive and accurate cost estimating, planning and budgeting of projects is required for effective cost control by contractors; and PPBS is the most suitable budgeting system for construction projects.
7. Existing methods of performance measurement, (i.e. actual monitoring process), remain essentially manual and thus not fast enough to cope with the needs of real-time cost control.
8. Management by exception which, in turn, would be greatly enhanced by the application of responsibility accounting, would be necessary for effective cost monitoring because they attract attention directly to sources of problems.
9. Although effective corrective decisions need to be based on both performance feedbacks and predictions, descriptions of cost control in construction literature do not specify how this can be achieved. Decisions made solely on the basis of historical performance feedback result in control efforts being too late to be useful.

10. Quantitative models and methods for performance analysis and prediction which could be incorporated into the cost monitoring and control schemes of contractors have not received any significant consideration with regard to their application on construction projects.

11. Non-application of scientific quantitative techniques means that rational corrective decisions can not be made while future performance levels can not be predicted with any reasonable degree of reliability.

4.5.2 Deductions

The following deductions from the reviewed literature in this chapter should inform the design of a more effective alternative approach to cost monitoring and control by contractors:

1. An effective cost control system for construction projects would need to be divested of the current preponderance of accounting approaches and cycles, especially in the areas of performance evaluations and decision-making.

2. Formats for data capture and processing need not only be compatible with, but also tuned to serve the needs of subsequent cost control activities such as performance evaluations, forecasting and decision-making.

3. Performance evaluations need to be carried out within a framework that will not only reveal deviations but also explain the deviations so that rational predictions of future levels of performance could be made, and appropriate corrective measures determined. This would require the incorporation of quantitative models in cost monitoring and control schemes of construction projects right at the operational level.
Figure 4.7: Construction Monitoring and Control Network
CHAPTER FIVE

ORGANISATIONAL REQUIREMENTS FOR EFFECTIVE COST CONTROL OF CONSTRUCTION PROJECTS

5.1 Introduction
5.2 Concept of Organisational Structure
5.3 Criteria for Effective Organisational Structure
5.4 Effect of Site Organisation on Communication
5.5 Company and Site Organisational Structures
5.6 Summary
ORGANISATIONAL REQUIREMENTS FOR EFFECTIVE COST
CONTROL OF CONSTRUCTION PROJECTS

As long as mankind attempts to create order from chaos, to organize and
build, to defy entropy, dilemmas will exist -- R. I. McLaren (1983)

5.1 Introduction

In pursuance of one of the objectives of this research, and
following the realization in chapter 4 that organization plays a
significant role in cost control of projects, this chapter presents
some views and suggestions from literature on factors affecting,
as well as some of the essential considerations for effective site
organization to facilitate monitoring and control of costs on
construction sites. The essence of the chapter is to identify the
relationships and or the interdependence between organization
structure, site communication, and cost monitoring and control
efforts on a construction site. This should provide a basis for
viewing and analysing subsequent investigation evidence from
this research to precisely identify the contribution and role or
effects of organizational factors to the problems of cost overruns
on construction projects. Thus this chapter reviews the
following with regard to construction organizations:

1. The concept of organizational structure
2. Criteria for effective organizational structure
3. Relation of organizational structure to site communication
4. Types of company and site organizational structures

5.2 Concept of Organizational Structure

According to Dressel (1968), the management and organization
of a contracting business is the conscious and purposeful
cooperation of its separate members towards the achievement of
its objectives. Pascale et al (1982) have identified organizational
structure as one of the factors that impose constraints to the
performance of even the most accomplished managers. Gunning
shown how effective monitoring and control of costs, schedule
and physical progress of construction projects depend greatly on
the kinds of organizational structures of contractors at both company and site levels.

In addition to the works mentioned above others, including Torrinton et al (1989) and Child (1984), have identified the link between good organizational structure and effective control of construction projects or, indeed, any business concern. Such organizational theorists and management pundits have generally viewed organizations from the following viewpoint:

1. Division of duties, (job descriptions),
2. Lines of authority,
3. Staff relationships, and
4. Information or administrative committees or work groups

Dressel (1968) attributed the existence of some organization structures in practice which can be explained as a mixture of the different relationships to a general lack of clear understanding of the divisions. A more generally comprehended view in literature appears to be that organizational structure corresponds to the distribution of all the operational functions required to execute a project or business of the firm to its various departments or sections; which departments consist of one or more employees, with each given suitable authority and responsibility. Under this view, the basis of organizational structure is a departmentation plan in which the departments are related by the necessary lines of authority. According to Torrinton et al (1989) this view holds for line bureaucracy or matrix structures. Dressel (1968) defined the relationship between duties, authority and responsibility thus:

"Authority is the right to make arrangements which are necessary to fulfil the defined duties, for which the employee also carries the responsibility".

When the authority and the duties correspond to one another, and the responsibility agrees with duties to be undertaken, the organizational structure will become the foundation of a good commercial organization.
It was pointed out in chapter 3 that the attainment of broad company and specific project goals depend on the actions and interrelationships of specific persons - a fact which, among others, underlines the concept of responsibility accounting. The persons, together with the functional structures that govern the discharge of their individual and corporate responsibilities, (which results in the project goals), constitute the project organization. The foregoing concept of organizational structure shows the dilemma of the manager of a construction site who must bring together in a harmonious setting, persons of diverse professional disciplines, temperaments and personal objectives in order to achieve the objectives of the particular project and construction company at large.

It is perhaps a measure of the realization of the importance of organization structure to the success of construction and other businesses that pundits, administrators and researchers in the area of organization theories constantly seek better and better ways of doing things with the ultimate aim of realizing the hypothetical 'perfect' organization. However, Hood (1976) has identified the requirements for a perfect organization and shown that such organizational perfection is both "unapproachable and undesirable of being approached" if industry desires a crop of educated decision-makers operating within a dynamic society of progressive thought and actions. Whether or not Hood's findings were right does not alter the fact that integrating the goals of individuals with those of organizations is a dilemma demanding an astute combination of skills and experience from managers who are themselves essentially part of the organizational system.
5.3 Criteria for Effective Organizational Structure

Certain criteria were identified by Dressel (1968) among others as being the basis of sound organizational structure, and these are summarized as follows:

1. Functional requirements and practical considerations, rather than availability, abilities or wishes of staff, should decide the distribution of duties or functions to the various departments or groups on site, as well as determining the creation or abolishing of departments or groups.

2. Only suitable persons should be appointed to positions; suitability referring to agreement between the abilities of the employee and the requirements of the proposed duties for the position.

3. The duties allocated to each person or position must be no more than are capable of being fulfilled.

4. Persons in senior positions must be serviced with prompt and comprehensive communication, and should be familiar with the works of their subordinates in order to be able to control the positions under them.

5. Each position should have only one senior position over it, (i.e. unity of command principle should be adhered to).

6. Instructions may only be given (vertically) down the lines of authority. Information may, however, also travel (where necessary horizontally) through any positions of authority and direct to those who need it for use in their work.

7. Authority must correspond to duties and responsibilities and should be clearly defined.

8. The organization structure should be clearly defined in a written document or plan, (such as an organigramme), which indicates the positions occupied by individuals and their deputies and which is published to all the staff.

These criteria were criticized not for being wrong or unrealistic but for conveying a nightmarish picture of rigid formality and fascist regimentation of personnel, (see Leavitt et al 1973), as well as a tendency to inhibit individual initiative and innovation, (see Child 1984 and Torrington et al 1989). Since organizational
objectives and operational requirements vary, the above criteria may only be representative of the requirements for sound organizational systems. Among these criteria communication is of great importance to the smooth execution and effective control of a construction project on site because, no matter how well a project is staffed and organized, the personnel can not possibly discharge their duties without knowing what other persons or bodies concerned with the project are doing and how such related happenings are going to affect their own duties. This view has been supported by Gunning (1984), Forster (1989) and Greenbaum (1974) among others. Thus, though the other organizational criteria are important to the success of a project, the effect of communication on effective cost control of projects particularly deserves a closer examination.

5.4 Effect of Site Organization on Communication

According to Child (1981) systems for effective communication of information, integration of efforts, participation in decision-making process, performance appraisal and reward are essential components of any organization structure. Stallworthy et al (1987) identified interpersonal relationships and effective communication among what they called "the foundation blocks for good management". Communication within a construction site and between the site and a contractor's headoffice or other outside bodies is of two types, namely:

1. Organizational communication, and
2. Interpersonal communication.

Carlisle (1982) distinguished the two forms of communication thus:

"Interpersonal communication is face-to-face. It is person-to-person exchange of information that conveys meaning. Organizational communication is the deliberate establishment and use of a system to transmit information conveying meaning to large numbers of people both within and outside the organization".
The objectives of communication were identified in a study by Greenbaum (1974) as:

1. **Regulation**: which refers to seeking conformity of employee behaviour with organizational objectives.
2. **Innovation**: which refers to seeking to change aspects of organizational functioning in specific directions.
3. **Integration**: which refers to maintaining the morale of the workforce and developing a feeling of identity with the organization and its members.
4. **Information**: which refers to passing out the mainly factual information that people need in their everyday duties such as what is to be done and how it is to be done, customers' requests, quality standards, and so on.

Some recent studies carried out among managers, engineers and scientists have indicated that interpersonal communication is the most popular, effective and essential within any given organization. Mintzberg (1975) found that chief executives spent 78% of their time in verbal communication. Torrington et al (1989) reported a study of research engineers and scientists which showed that they spent an average of 61% of their time "interchanging facts, information, ideas, attitudes and opinions". Interpersonal communication on construction sites prevails at the lower levels of the site organization structure and tends to be more formal towards the top. According to Forster (1989) and McCaffer et al (1990) organizational communication within and outside the construction site is customarily done through designed forms which everyone finds easy to understand. These forms, according to Forster, are used to inform, notify, request, instruct, advise, collaborate and report.

In an investigation covering a wide range of construction sites, Cullen et al (1986) established that:

1. The type of organizational structure significantly affect the involvement of supervisory staff in short-term planning and control.
2. The type of organizational structure significantly affect and often determines the type and the effectiveness of site communication channels.

The Cullen investigation also classified organization structures into two types according to their effect on site communication. There are fluid structures that allow broader and generally more effective communication on site due to their largely informal and adhoc nature of channels. Secondly there are firm hierarchical structures that often inhibit the participation of supervisors in planning and decision making, thus rendering them "typically passive recipients of information and directives". This tended to encourage the formation of coalitions at various hierarchies, which would in turn militated against flexible interchange of information.

Another implication of the findings of the Cullen investigation for site communication was the revelation of a 'society syndrome' which caused different factions to compete for control and, in the process, distorted the communication channels and command structures defined by the 'family tree'. This turned lower tiers of personnel (usually foremen and supervisors) into "responsive to rather than participants in the flow of information and control". The investigation also established channels through which information was communicated and control implemented by analysing, from a variety of sites, three major factors affecting decision-making, namely:

1. **Information distribution**: This is the extent to which individuals in the organization were fully briefed on overall task requirements.
2. **Control use**: This is the extent to which individuals have access to the means through which tasks are organized.
3. **Control initiation**: This is the extent to which individuals have actually initiated mechanisms controlling tasks and activities.

Figure 5.1 shows the results of Cullen's analysis of the evidence from their investigations and it indicates that:
1. Communication, planning and control functions are largely monopolized by a coalition of experts and 'professionals' including planning engineers, project managers and field engineers.

2. Foremen and supervisors occupy a minor position in the system.

3. The construction manager occupies a substantially less powerful role than might be expected, since he tends to respond to rather than initiate channels of communication and control.

The immediate significance of the Cullen investigation to this research is to provide a basis for viewing and analysing the evidence and data obtained from returned questionnaires, (see chapter 7), leading to a better understanding of organizational structure and communication on job performance, monitoring and control efforts on site.
Figure 5.1: Analysis of Site Communication
source: Cullen et al (1986)

LEGEND

- Information distribution
- Level of access
- Extent of use

PERSONNEL GROUP

- Planners
- Superintendents
- Foremen
- Construction Manager
- Chief Engineer
- Field Engrs.
- Cost Engrs.
- Project Management Teams
- Materials Controller
- Client

SCORE
5.5 Company and Site Organizational Structures

An indication was given of the relationship between organization structure, communication, planning and control in the foregoing sections. It is thus far clear that an understanding of the nature of a contractor's organization structure at both company and site levels is essential for studying and assessing the contractor's efforts at cost monitoring and control of projects. It should thus aid the subsequent understanding and analysis of investigation evidence form this research to consider, albeit only definitively, the various types of organization structures used by contractors.

Among various classifications of organization structures found in literature three appeared particularly relevant to construction projects. The first classification due to Cullen et al (1986) has already been given in section 5.4 above. A second classification given by among others Forster (1989) groups organizations into:

1. **Shallow line structures**: Operated by small firms in which the owner monopolizes direct authority and control. The disadvantage of these is considerable loss of control when the structure gets wider, as shown in figure 5.2.

2. **Deep military line structures**: Operated by mainly medium to large companies in which responsibilities and authority are defined, structured, delegated and regulated through pre-determined command and communication channels. These have the advantage of allowing top managers time to concentrate on important matters while at the same time creating the motivation for subordinates to aspire to rise through the levels. This type of structure is shown in figure 5.3.
Figure 5.2: Shallow Line Structures
Source: Forster (1989)

Entrepreneur (Owner/boss)

- Secretary/bookkeeper
- Clerk/Wages
- Estimator/Quantities
- Driver/Labourer
- Carpenter/Joiner
- Bricklayer

Other trades

Span of Control
Figure 5.3: Deep Military Line Structures
Source: Forster (1989)
A more comprehensive classification of organization structures resulted from a research of construction companies and sites by Irwig (1984) who identified organization types as follows:

1. **Simple structure**: This is characterized by a centralized authority exerting direct supervision over a set of relatively undifferentiated activities.
2. **Professional bureaucracy**: This type is characterized by considerable delegation of authority along professional and trade lines, and relatively little direct supervision.
3. **Machine bureaucracy**: This is identifiable because of the division of work along strictly functional lines and the reliance placed on standardization of procedures for the coordination and control of activities.
4. **Divisionalised structure**: This type is characterized by a fragmentation of the organization into market-related segments which are relatively independent of each other and of central headquarters.
5. **Adhocracy**: This is characterized by delegation of authority along matrix lines, the existence of project groups, and the informality of coordination within these groups.

It is worthy of mention that construction literature considers contractors' organization structure at site level jointly with the company structure, with the former being a mere detail of the latter. There may, of course, be as many variations of the foregoing organization types as there are construction companies, with each adapting one type or the other to its own particular needs. Figures 5.4, 5.5 and 5.6 show typical company and site organization structures with the type of relationships at different levels of the organizations.

The figures reveal that site organizations are generally treated as just another (albeit bloated) department of an overall company structure. The immediate implication of this arrangement is that the company headoffice remains a kind of supreme command and control centre from which all decisions, instructions and policy must emanate. This could preclude flexibility and private initiative by the project staff actually on the field. Furthermore it
could slow down the process of decision-making when most, if not all, performance information must be judged at the 'centre' before corrective decisions are made. These problems tend to lend credence to having a policy of, at least, semi-autonomous project administrations with a high enough calibre of staffing to handle most matters promptly on site. There is, however, the need for more concerted research into various aspects of construction site organization and administration, and how they relate to successful project delivery, in order to arrive at a more pragmatic and optimum approach.
Figure 5.4: Head Office Level Structure
Source: Forster (1989)
Figure 5.5: Site Level Structure (medium projects)

- Project manager
  - Safety officer
  - Security officer
  - Struct. engineer
- Trainee site mgr
  - Storeman/checker
  - Timekeeper and Wages clerk
  - Production control/bonus surveyor
- General foreman
  - Trades foremen and gangers level
- General foreman
  - Trades foremen and gangers level
- Tradesmen/Labourers/Apprentices and other operatives' level
Figure 5.6: Typical Constr. Site Orgtn. (large projs)
(source: Stallworthy et al (1987))

- Project team
- Site manager
  - Field engineer
  - Civil engineer
  - Construction superintendent
  - Safety officer
  - Industrial relations officer
    - Area superintendent
    - Area superintendent
    - Office manager
      - Clerks
      - Secretaries
      - Janitors
    - Other subcontractors
      - Insulation
      - Painting
    - Serv. s/contractors
      - Scaffolding
      - Radiography
    - Planning
      - Subcontractors
      - Administration
      - Cost control
      - Quantity
      - Surveyors
    - Trades
      - Supervisors
      - Piping
      - Welding
      - Mechanical
      - Rigging
      - Instruments
      - Electrical
      - Refractory
    - Direct labour
    - Trade foremen
5.6 Summary:

The review of literature presented in this chapter has revealed:

1. That there is theoretical realization of the dependence of cost monitoring and control efforts for construction, or indeed any business, on a well designed organization structure.
2. That organization structure is akin to distribution of authority and responsibilities of a given concern among its personnel, who are accountable for the manner in which they discharge these responsibilities and authority. This implies that sound organization structure underpins the successful application of responsibility accounting principles discussed in chapter 3.
3. That the type of organizational structure defines formal as well as adhoc communication channels and affects the effectiveness of communication within the organization.
4. That effective and timely communication of information within and outside a construction site is essential to successful cost monitoring and control efforts on the site.
5. That fluid, (as opposed to firm hierarchical), organization structures with flexible channels of communication enhances broader interpersonal communication, which in turn is more effective towards monitoring and control efforts on construction site.
6. That site organization structures have not received much attention of their own in literature because they are generally considered to be mere details of contractors' overall organizational structures.
7. That more autonomy is needed for project administrators on site to enable them to promptly and realistically solve problems.
8. That further research needs to be directed specifically to the subject area of site organization and administration to enhance effective cost control of construction projects.
CHAPTER SIX

QUANTITATIVE MODELS AND METHODS FOR MONITORING AND CONTROL

6.1 Introduction
6.2 Scientific Management Techniques
6.3 Regression and Correlation Models
6.4 Time-series Methods
6.5 Optimization Models
6.6 Computer Application and Packages
6.7 Summary
QUANTITATIVE MODELS AND METHODS FOR COST MONITORING AND CONTROL

It is to managers who grow with the needs and resources of their time that we must continue to look for the new ideas and their implementation to meet the challenges of the future --- President J. F. Kennedy (1963)

6.1 Introduction

In pursuance of one of the objectives of this research, namely to determine the applicability of scientific management techniques in cost monitoring and control of construction projects by contractors, and further to the earlier identification of the need for cost control efforts to be forward-looking as typified by the concepts of feedforward control, (see chapter 3), this chapter reviews the theoretical concepts and principles of problem formulation and solving using statistical and quantitative methods developed by management science. The review is, however, limited to the principles and applications of the various models and statistical tests without going into their derivations and theories. Where necessary, conditions that limit the applicability of certain models and tests as well as their interpretations are discussed.

The aim of the chapter is to provide a basis for proposing another approach to cost monitoring and control of construction projects by contractors via the use of scientific management techniques which, as pointed out in chapter 4, are being used successfully by manufacturing and other industries. The search for another approach stemmed from the realization that not only is current construction literature largely not cognisant of the applicability of these management techniques to cost monitoring and control on site, but that none of the available research works reviewed made adequate attempts to explore the possible use of the techniques by construction contractors, (see chapters 2, 3 and 4). In the light of the theoretical approach to cost control of construction projects reviewed in chapter 4 and the various theories of management control presented in chapter 3, the review in this chapter is limited to those models and methods which appeared to be capable of suitably advancing the course of
cost monitoring and control efforts on construction sites. Thus, starting with a brief background to the development and use of management science, modelling and computer technology in industry, the chapter reviews the principles and applications of:

1. Regression and correlation models.
2. Forecasting methods based on statistical time-series, e.g.:
   - moving averages,
   - exponential smoothing,
   - series decomposition methods,
   - autocorrelation methods,
   - multivariate methods.
3. Quantitative optimisation models such as:
   - linear programming,
   - integer programming, and
   - goal programming.
4. Computer applications and packages for the quantitative models.

6.2 Scientific Management Techniques

6.2.1 Concept of Management Science

Management science and the on-going strides in computer and information technology have brought about strong and positive changes to management practice. These changes are evident from the boom in global economic activity that has taken place especially since the end of the second world war. Davis et al (1984) defined management science as:

"the application of scientific procedures, techniques and tools to operating problems to develop and help evaluate solutions. ------ Management science includes all rational approaches to management decision making that are based on the application of scientific methodology".

The basic philosophy of management science is that most (if not all) managerial functions are essentially problem solving and that the decision-making process that leads to solutions of those management problems consists of:
1. Identifying and analysing problems that can be quantified.
2. Identifying and understanding the relationships among interacting factors.
3. Isolating factors over which the decision-maker has control.

Thus, management science purposes to provide procedures and processes that enhance a manager's ability to solve problems.

As mentioned in section 6.1, this research focussed mainly on some of the tools of implementing management science- namely quantitative methods employing modelling and statistical tests-to formulate and solve management problems. The techniques reviewed are also known as operational research, a term that is often used, albeit in a narrower sense, to refer to management science.

6.2.2 Types of Models

From the concept of modelling given by Davis et al (1984), a model can be defined as a representation, physical or otherwise, of some real object, system or situation, that has most of the characteristics of what it represents and can thus be used to study and make predictions about the represented object or situation. To the extent that models are means of solving problems, modelling can be viewed as the formulation of the problem and determining the characteristics of the model to represent the problem.

There are several classifications of models depending on their nature, formulation, construction or uses. Davis et al (1984) gave some of such classifications which can be summarised thus:

1. Mental models that involve mental visualization of different perspectives of a problem and evaluating each alternative.
2. Iconic or scale models that involve constructing a physical representation of a problem to evaluate possible solutions.
3. Mathematical models that employ mathematical symbols and or relationships to represent various components of a problem and then the analysis of the model to solve the
problem. These are generally faster, cheaper and more popular with managers.

4. Descriptive models that represent relationships between components of a problem such that system behaviour can be predicted, but they do not indicate the appropriate course of action for the decision-maker.

5. Normative or optimisation models that prescribe optimum or appropriate courses of action for the decision-maker's desired objectives. This is in addition to their descriptive characteristics. They represent the bulk of models used in management science and are characterized by three basic elements, namely:
   - decision variables or system parameters,
   - constraints or component relationships, and
   - one or more objective functions.

6. Deterministic models in which the functional relationships (i.e. model parameters) are known with certainty. Thus the contribution of each parameter is definite and known.

7. Stochastic models in which the contribution of some or all of the model parameters are not known with certainty but a degree of probability is assignable.

8. Linear models in which there is direct proportionality between the dependent and independent variables.

9. Nonlinear models in which some or all of the functional relationships within the model are governed by curvilinear or non-proportional equations.

10. Static models in which the functional relationships do not change for a given period of time during the solution process, implying that an optimal decision or course of action is not affected by decisions prior or subsequent to current period under consideration.

11. Dynamic models in which the optimal or best course of action is determined through a consideration of actions taken over multiple time periods. In other words the functional relationships in such models vary with time though outcomes may still be related.
6.2.3 Statistical tests

These provide a means of assessing the reliability and or the limitations of results obtained through the use of quantitative or models to solve problems. The results of statistical tests also enable appropriate interpretations to be made of the results of model applications, and thus guide the decision-making process. Areas of caution while using statistical tests are highlighted along with the relevant tests associated with models reviewed in this chapter.

6.3 Regression and Correlation Models

6.3.1 The Need for Regression Analysis

It was shown in chapter 4 that the computation and analysis of performance variances can lead to a decision to investigate deviations in performance and or cost. Wilson et al (1988) identified inability to make reliable estimates of the outcomes of future events as a major inhibition to control via feedforward systems. The inability was attributed to limited understanding of "causal relationships" both within the sub-systems of productive enterprises, and between the enterprises and their operating environment. Mueller (1986) showed that projections of cost, completion time, and quantities may be done using various performance ratios, but the illustration was rather too simplistic to be of real value. It did not, for instance, recognize and take into account the realities of site activities and the complex, and often dynamic, interrelationships between various construction resources during site operations; all of which are not captured by projections that are based on individual performance ratios.

The foregoing defines the need for some means of predicting the outcomes of future events while taking into account, (and using), the interrelationships between the variables within the productive enterprise. This would then lead to decisions that can influence future events towards desired goals. Regression methods employ mathematical models that use sample data from a given situation to compute an estimate of the proposed relationships, and then evaluate the fitness of the estimates.
using statistics such as $t$, $F$, and $R^2$ so that such estimates are used to predict future outcomes or make decisions to control future outcomes. According to Madsen et al. (1986), regression analysis entails the use of information about one or more variables to make predictions about another, and that this makes regression "a most useful tool in forecasting, predicting or estimating future values of certain variable quantities". Fellows (1987) suggested that forecasting accuracy may be considerably improved by using regression methods and stochastic time-series models because such models "produced more accurate forecasts over a longer forecasting period" Thus, regression methods would appear to be capable of advancing the course of effective feedforward cost monitoring and control of construction projects, and should merit further consideration.

6.3.2 Principles of Regression

The starting point in any regression analysis is the assumption that a basic relationship exists between the predictor, (or independent), variable(s) and the response, (or dependent), variable, and that this relationship can be represented in some functional form.

\[ Y = f(X_1, X_2, X_3, X_4, \ldots, X_m); \quad (6.1) \]

where:
- $Y$ is the response variable,
- $X$ is the predictor variable, and
- $m$ is the number of $X$ variables affecting $Y$.

When $Y$ is affected by (or is related to) only one predictor variable and the relationship between the two variables is linear, the regression is termed simple and its model is written as:

\[ y = a + bx \quad (6.2) \]

where:
- $a$ and $b$ are parameters of a straight line, and
- $y$ is the estimated value of $Y$ corresponding to the value $x$ of the predictor variable $X$.

Thus, once the values of $a$ and $b$ are estimated from sample data of corresponding values of $X$ and $Y$, the parameters can be used in equation 6.2 to predict $Y$ values for any given values of $X$. One
method of determining values of \( a \) and \( b \) is to plot the sample data, as in figure 6.1, and read off the values graphically. An easier and more accurate approach to obtain the values of \( a \) and \( b \) that can be used consistently within the regression range and giving 'best' values of \( y \) is provided by the method of least squares. The full theory of this method has been discussed by Madsen et al (1986) among others. Using this method the values of \( a \) and \( b \) can be computed as follows:

\[
b = \frac{\sum_{XY} - \sum_X \cdot \sum_Y}{\left( \frac{\sum_X^2}{n} \right)} \tag{6.3}
\]

and
\[
a = \bar{Y} - b \bar{X} \tag{6.4}
\]

where: \( n \) is the number of observations or data points,

\[
\bar{Y} = \frac{\sum Y}{n}, \quad \bar{X} = \frac{\sum X}{n}, \quad \text{and} \quad \bar{XY} = \frac{\sum XY}{n}.
\]

### 6.3.3 Multiple Regression

When there are more than one predictor variables affecting the outcome of the response variable, the principle of simple regression can be extended to forecast values of \( Y \) for different sets of values of \( X \) using the following:

\[
y = a + b_1 x_1 + b_2 x_2 + \ldots + b_m x_m. \tag{6.5}
\]

where: \( a, b_1, b_2, \ldots, b_m \) are parameters to be computed using equations 6.3 and 6.4.

### 6.3.4 Non-linear Polynomial Regression

Both simple and multiple regression models given above are predicated on a linear relationship between response and predictor variables. Lack of linearity, however, does not by itself preclude the use of the method of least squares to compute parameters that enable predicting future values of \( Y \), provided the appropriate function defined by the sample data is identified.
Once again this functional identification can be done via a plot of the sample data or from theoretical knowledge of the data source. The general form of non-linear models is:

\[ y = a + b_1 x + b_2 x^2 + b_3 x^3 + \ldots + b_h x^h \]  \hspace{1cm} (6.6)

where: \( h \) is the degree of the polynomial.

As it is seldom possible in practice to find regression curves that are exactly linear, Madsen et al (1986) have shown that within a given range of \( X \) values most regression curves can be approximated to linear functions. Furthermore, when necessary, non-linear functions can be transformed into linear ones by variable substitution or using logarithms, as illustrated by Makridakis et al (1983).

### 6.3.5 Precision and Significance in Regression

The models for simple and multiple regression defined thus far specify the most appropriate linear relationship to yield a forecast of \( Y \) values, while equations 6.3 and 6.4 enable the regression coefficients to be determined statistically from sample data. These do not, however, by themselves enable a manager to make confident decisions without addressing the questions of the significance of the regression equation itself and the computed coefficients. Wheelwright et al (1984) identified the questions to be addressed by the manager as:

1. Is the regression coefficient, \( b \), significantly different from zero or did it just occur by chance?
2. What level of confidence can be placed in the regression coefficient \( b \); i.e. how precise is the estimate of \( b \)? For what range of values around \( b \) can the manager be confident that the true value of \( b \) is within that range?
3. How confident can the manager be when making a forecast, \( y \), that the actual value of \( Y \) will lie within a narrow range surrounding that forecast value; i.e. what is the precision of \( y \)?

Another statistical way of asking the first question is: if we suppose that the true value of \( b \) is zero, what is the likelihood
that we could have our specific value of \( b \), or a larger value? The statistic needed to determine the significance of a regression coefficient is the standard error, \( (SE) \), of that coefficient, given by:

\[
SE_b = \sqrt{\frac{\sum (y_i - \bar{y})^2}{(n-2)} \sqrt{\sum (x_i - \bar{x})^2}}
\]

(6.7)

The next step in testing the significance of the regression coefficient is to divide the coefficient by its standard error, \( (SE_b) \), to give the number of standard errors, \( N \), the coefficient is from zero. The value of \( N \) is then compared with the appropriate entry in a table of t-values to find the likelihood of computing a regression coefficient in error by \( N \) standard errors or more. Wheelwright et al (1984) have provided guidelines for determining (approximately) when the computed regression coefficient is significantly different from zero; (see table 6.1).

<table>
<thead>
<tr>
<th>Number of Observations</th>
<th>Number of standard errors required for significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 to 15</td>
<td>( \geq 3 )</td>
</tr>
<tr>
<td>&gt;15</td>
<td>( \geq 2 )</td>
</tr>
</tbody>
</table>

The theory of the method for establishing confidence intervals to answer question 2, above, involves too much mathematical complications. It surfaces to state that the theory yields a test of significance which determines the required confidence interval and level for the regression coefficient relative to the number of observations, \( n \), in the sample data that was used to compute the coefficient. A 95% confidence interval would be the range within which the manager is 95% certain that the true value of the regression coefficient will be found. Wheelwright et al (1986) have provided guidelines, (see table 6.2), for approximating the confidence interval:
Table 6.2: Testing Confidence Intervals for Regression Coefficients

<table>
<thead>
<tr>
<th>Confidence level</th>
<th>Number of observations</th>
<th>Interval around the regression coefficient that provides that level of confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>95%</td>
<td>≥5</td>
<td>±3.2 standard errors</td>
</tr>
<tr>
<td></td>
<td>≥15</td>
<td>±2.2 standard errors</td>
</tr>
<tr>
<td></td>
<td>≥30</td>
<td>±2.0 standard errors</td>
</tr>
<tr>
<td>98%</td>
<td>≥5</td>
<td>±4.5 standard errors</td>
</tr>
<tr>
<td></td>
<td>≥15</td>
<td>±2.7 standard errors</td>
</tr>
<tr>
<td></td>
<td>≥30</td>
<td>±2.5 standard errors</td>
</tr>
</tbody>
</table>

The third question, on the reliability of an individual forecast, \( y \), using the regression model being close to the true value of \( Y \), can be answered by means of a confidence interval around \( y \). The basis for establishing the confidence interval for a specific forecast value is the standard error of forecast, \( SE_f \), calculated thus:

\[
SE_f = \left( \sqrt{\frac{\sum (y_i - \hat{y}_i)^2}{n-2}} \right) \left( \sqrt{1 + \frac{1}{n} + \frac{(X_f - \bar{X})^2}{\sum (X_i - \bar{X})^2}} \right)
\] (6.8)

The confidence interval for the estimate of \( Y \) is given by:

\[
y - 2(SE_f) \quad \text{to} \quad y + 2(SE_f)
\]

Thus, assuming the pattern of the forecast data remains unchanged during the forecasting phase, the manager would be 95% certain that actual values of the dependent variable will lie within ±2 standard errors from the forecast value. This is because equation 6.8 is standard deviation of the regression line multiplied by an adjustment that accounts for sample size and the distance of the predictor variables from their mean value.

A more important concern of the manager when using multiple regression is the overall significance of the regression equation. This can be tested by means of the F-statistic which can be computed with either of the following formulae:
\[
F = \frac{\sum(y_i - \bar{Y})^2}{\frac{k-1}{n-k}}
\]
\[
(6.9)
\]

or

\[
F = \frac{\frac{R^2}{k-1}}{\frac{1 - R^2}{n-k}}
\]
\[
(6.10)
\]

where: \( k \) is the number of coefficients, and \( R^2 \) is called coefficient of determination (see equation 6.12).

For this test Wheelwright et al. (1984) provided approximate decision rules, (see table 6.3), concerning significance at the 95% confidence level:

<table>
<thead>
<tr>
<th>Confidence level</th>
<th>Number of Observations</th>
<th>Value of F-statistic that proves significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>95%</td>
<td>6 to 10</td>
<td>( F &gt; 6 )</td>
</tr>
<tr>
<td>&gt;10</td>
<td></td>
<td>( F \geq 5 )</td>
</tr>
</tbody>
</table>

### 6.3.6 Unexplained Variation in Regression

The equations \( y = a + bx \) and \( y = a + b_1x_1 + b_2x_2 + \ldots + b_mx_m \) for simple and multiple regressions respectively are abstract models that represent some aspects of reality. Real situations, however, are such that more (or indeed an infinite number of) variables than shown in these models determine the outcomes of \( y \). And it is not practicable to construct a model that captures 100%, all aspects of the reality. To account for the fact that a regression model does not capture some parts of the real process, a disturbance or residual term, \( u \) is included in the models. Thus:
\[ Y = a + bx + u, \] for simple regression, and
\[ Y = a + b_1x_1 + b_2x_2 + \ldots + b_mx_m + u, \] for multiple regression;

where: \( Y \) is the true value of the dependent variable, and \( u \) is the error due to variables other than the predictors included in the model.

This implies that the more predictors used, the less the error in \( y \). Wheelwright et al (1984) and Madsen et al (1986) cautioned against the temptation to use many predictor variables because they add to both cost and complexity of the analysis. The principle of parsimony requires that we introduce the smallest number of variables and at the same time achieve as small as possible a range of values for \( u \). Wheelwright et al (1984) identified limitations of \( u \) which must be met before it becomes safe to use the regression models defrayed of the error term, (i.e. as in equations 6.2 and 6.5), thus:

1. The mean value of \( u \) must be equal to zero.
2. The residuals must be random (i.e. independent of one another); this eliminates possible autocorrelation.
3. The residuals must be normally distributed to smoothen the consequences of the large number of factors that influence \( Y \) but that are not included in the regression equation.
4. The variance of the residuals must be constant within the entire range of observations.

Madsen et al (1986) defined residuals as follows:

"If \( y_1, y_2, \ldots, y_n \) are the observed values of a response variable and \( \bar{Y}_1, \bar{Y}_2, \ldots, \bar{Y}_n \) are the fitted values corresponding to the (predictor) values \( x_1, x_2, \ldots, x_n \), respectively, the differences
\[ (y_i - \bar{Y}_i) \text{ for } i = 1, 2, \ldots, n \]
are said to be the residuals".
6.3.7 Autocorrelation

This is a problem that arises when residuals are not random (i.e. when they follow some kind of systematic pattern). Once it is established that the residuals are not independent, (usually via a plot of the residual values), the Durbin-Watson statistic, D, can be used to test for the presence of autocorrelation. The theory of this test provided by Madsen et al (1986) defines the test statistic as:

\[ D = \frac{\sum_{t=2}^{n} (u_t - u_{t-1})^2}{\sum_{t=1}^{n} u_t^2} \]  \tag{6.11}

where: n is the number of observations and u is the residual value at time t.

Due to the difficulty of obtaining the exact distribution of the D-statistic, Durbin and Watson found bounds that can be used as critical values. Wheelwright et al (1984) established that when the computed value of D is between 1.5 and 2.5 then there is no autocorrelation and the model can be safely used for forecasting, subject to its passing other tests of significance. Thus the decision rule for the D-W test is:

If 1.5 < D < 2.5, then accept the regression equation.

6.3.8 Coefficients of Correlation and Determination

Intrinsic to the principles of general regression outlined so far is the assumption of dependence relationship between two variables. In this case values of predictor variables are taken to be those determined experimentally, as opposed to those occurring randomly. In situations where variables are merely related but without the value of one variable necessarily depending on or being caused by the value of the other(s), or where the variables are both (or all) random it is necessary to investigate the relationships further before using the corresponding regression model for forecasting. The coefficient of correlation, R, is a measure of such a relationship and
indicates the strength of linear relationship between two variables. The formula for computing $R$ is:

$$R = \sqrt{\frac{\sum(y_i - \bar{Y})^2}{\sum(Y_i - \bar{Y})^2}} = \sqrt{\frac{\text{Explained Variation}}{\text{Total Variation}}} \quad (6.12)$$

Thus, in order that the regression line be able to explain variations in actual values of $Y$, we require the square of the coefficient of correlation, $R^2$, known as the coefficient of determination. The meaning of the above formula is illustrated in figure 6.1 which shows that $R^2$ gives the proportion of the variation from the mean that is explained by the regression line.

The raw values of $R$ and $R^2$ are not by themselves adequate to accord acceptability to the overall relationship specified by the regression line. A test of significance that compares the explained variance, (not variation this time), to the unexplained variance is required, and this test is provided by the $F$-statistic as defined in equations 6.9 and 6.10. The computed value of $F$ is compared with the appropriate entry in a table of $F$ values to determine the significance for a given confidence level. Wheelwright et al (1984) provided the following guide-lines for determining confidence relative to the sample size:

<table>
<thead>
<tr>
<th>Confidence level</th>
<th>Number of observations</th>
<th>Value of $F$-statistic required for confidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>95%</td>
<td>6 to 10</td>
<td>$F \geq 6$</td>
</tr>
<tr>
<td></td>
<td>10 to 45</td>
<td>$F \geq 5$</td>
</tr>
<tr>
<td></td>
<td>&gt; 45</td>
<td>$F \geq 4$</td>
</tr>
<tr>
<td>99%</td>
<td>6 to 10</td>
<td>$F \geq 14$</td>
</tr>
<tr>
<td></td>
<td>10 to 45</td>
<td>$F \geq 10$</td>
</tr>
<tr>
<td></td>
<td>&gt; 45</td>
<td>$F \geq 7.2$</td>
</tr>
</tbody>
</table>
In multiple regression it is useful and usual to compute the individual coefficients of correlation for each of the pairs of variables so that the manager can see how each of the pairs are related. Most computer packages automatically compute these coefficients and present them as a matrix of simple correlations, such as in the following table:
6.3.9 Assumptions and Limitations of Regression

The following are some of the important considerations required when using regression analysis:

1. Regression is applicable only when a relation is known or can be reasonably assumed to exist between the variables to be modeled.

2. It is preferable, though not essential, for the relationship between the variables to be linear. Certain transformations may be used to correct problems of non-linearity and unequal variances.

3. It is desirable to know the true form of the regression curve from theoretical considerations, else it has to be determined otherwise because the interpretations of the regression parameters $a$ and $b_1$ depend on the equation of the regression curve being fit.

4. Raw values of $a$, $b_1$, and $R^2$ are not sufficient to enable a model to be reliably used for forecasting; they have to pass certain tests of significance.

5. All predictor variables, $X_i$, whose corresponding regression coefficients, $b_i$, are significantly different from zero should be included in the regression model in order to reduce the residual error.

6. It is necessary to make periodic reviews of the basic relationships between the regression variables to ensure that they have not changed. The model has to be adjusted accordingly whenever the relationships are found to have changed.
6.3.10 Advantages of Regression

1. Regression analysis can be used with explanatory or causal predictors as well as with time variables, (see section 6.4). This enables predictions to be made in a wider range of situations.

2. Regression analysis uses straightforward and fairly simple statistical models to discover and measure relationships, and thus requires little knowledge of statistics to apply.

3. The volume of data and amount of computation required in regression analysis is moderate when compared to those required by other statistical models. Thus it is relatively cheaper to apply.

4. Multiple regression analysis enables a number of different relationships to be hypothesized and tested easily with the help of computers.

6.3.11 How to Apply Regression in Practice

The foregoing discussion of regression and correlation analysis has revealed certain logical steps to be followed in putting the principles to practice. Wheelwright et al (1984) has identified those steps and the following is an abridged version:

1. **Problem formulation**: This entails identifying what is to be explained or predicted, the decision-making situation and the variable or variables to be forecast. This step results in a number of predictor variables and the response variable being defined.

2. **Choices of economic and other relevant indicators**: This entails identifying factors that can possibly affect the regression and deciding on those that can suitably be included in the equation. This step relies on historical data for the company and or industry, e.g. economic series, production series, as well as information related to future periods.

3. **Initial test run of multiple regression**: This entails the use of all the data on response and predictor variables to test a handful of plausible regression equations in order to observe the results that can be obtained. A useful output of
this test run is the simple correlation matrix to be used in step 4.

4. **Studying the matrix of correlations:** This is for selecting the variables to be included in the regression equation to enhance better forecasts. The key is to pick predictor variables whose simple correlations are not so close to +1 or -1 as to create a problem of multicollinearity, (though high R values do not necessarily lead to multicollinearity), and that add to the explanatory ability of the regression equation. The output of this step is a number of alternative regression equations that seem to be promising and can be tested further.

5. **Deciding among individual regressions:** This entails estimating the coefficients of the alternative equations from step 4, testing the significance for each of the equations as well as their regression coefficients and standard errors of forecast to determine the equation whose predictor variables have a more significant influence on their response variable. The selected equation is then improved by increasing its $R^2$ value through introduction of additional predictor variables in a stepwise manner, checking each time to be sure that the tests of significance are still met.

6. **Checking the validity of regression assumptions:** This entails the use of the Durbin-Watson test to assess the nature of residuals for the selected equation(s) to see if they satisfy the properties outlined earlier in this section. Any equation that fails the D-W test is not to be trusted as a basis for forecasting no matter how large its value of $R^2$.

7. **Preparing a forecast:** This entails using the selected regression equation, (i.e. one with a sufficiently high value of $R^2$ and which meets the assumptions inherent in regression and the tests of significance), to make the forecasts.

8. **Using the regression equation to increase understanding:** This entails interpreting the forecasts and the regression coefficients to explain the situation and enable a better understanding of it.
6.3.12 Use of Regression Analysis on Construction Projects

The foregoing sequence for applying regression in practice can be translated into the following practical steps that can be employed for any system, including construction projects, to which regression is to be applied:-

1. Analysing the project objectives (e.g. total budget, total duration e.t.c.), and performance models to determine the different sets of response and predictor variables related to each of the objectives.
2. Defining the relationships between different variables and identifying those that need to be explained or predicted.
3. Deciding on the regression model to use from theoretical knowledge and experience or via a preliminary plot of relevant data from past and or ongoing operations.
4. Using the prescribed tests to validate the selected model.
5. Using the validated model to make the required forecasts.

The concepts of regression and correlation presented earlier, if applied to a construction project through the above steps, would reveal the quantitative trends and relationships between utilization levels for labour, materials, plant, subcontracting, e.t.c. and operational costs, durations, and outputs. Once such trends and relationships are computed at the beginning of the project for the major operations, they can be used to predict the manner in which overall budget, schedule and physical progress of the project will be affected by either current decisions, resource mixes, or operational methods. Thus regression and correlation models could be used on construction projects to administer overall programme and budget, and pre-determine the future course of physical progress and costs.

Despite the applicability of regression analysis to cross-sectional and time-related data alike, the forecast $y$ of the response variable $Y$ made via the method represents not only the value of $Y$ based on the system trends present in the analysed data, but the state and or stage of the system process at which the data was obtained. This feature of regression analysis is particularly significant when the method is to be applied to data from
construction projects whose system process, unlike manufacturing operations, neither have a uniform state nor repetitive cycles. Thus the cross-sectional trends of the data at different stages of a construction operation or project may vary, and this factor will need to be taken into account when applying regression analysis to construction projects. There are two possible ways of doing this; namely:

1. Establishing, from historical data, different sets of regressors (and consequently regression equations) for the stages (or control points) of construction operations or projects so that the appropriate set may be employed to make straight-forward forecasts using equations 6.5 or 6.6 as the case may be.

2. Applying a progress factor $k$ derived from the construction budget or schedule, (depending on whether cost or time is the subject of control), to the regression equation as shown below, and as done in chapter 9, to make a forecast. The progress factor $k$ is simply the proportion (say 80% = 0.80 in terms of either cost or duration) of the operation or project that has been completed up to the stage at which the forecast is to be made. Thus:

$$y = \frac{a + b_1x_1 + b_2x_2 + \ldots + b_mx_m}{k}$$

While the above approaches may overcome the possible lack of repetitive cycles in construction data and smoothen the lack of uniformity in the system process (by changing the value of $k$ with work progress), the veracity of, especially, the second approach can only be established through intensive empirical trials which, for reasons revealed in chapter 9, are beyond the scope of this research. Ideas for developing that phase of investigation have however been identified and suggested in chapters 9 and 10 respectively.

An illustration of the application of regression analysis to data from construction projects and how the results could be used to enhance effective construction cost management are given in
chapter 8 as part of a proposed quantitative approach to cost monitoring and control of construction projects on sites.

6.4 Time-series Methods

It was pointed out in section 6.3 that regression can be used to predict future values of a response variable from both cross-sectional data as well as time-related data, (known as time-series). A time-series is a series of observations of a variable taken over time. In situations where short-term forecasts of a variable are required, it is usual to simply 'smooth' (or average) the variable's time-series to obtain the forecast. Smoothing techniques are used everyday, often unconsciously, to aid decision making. The basic notion inherent in time-series smoothing is that there is some underlying pattern in the historical values of the variables to be forecast, as well as a component of random variations. The techniques separate the random variations from the underlying pattern by smoothing the historical values, and then basing a forecast on the smoothed value. Smoothing, thus, amounts to systematic elimination of extreme values found in the historical values.

6.4.1 Composition of a Time-series

In order for random variations to be eliminated from a time-series to enable its pattern to be projected into the future, it is necessary to separate the pattern into its various components by a process known as decomposition. Madsen et al (1986) have identified the components of a time-series as:

1. **Trend**: This is the component that gives the long-term downward or upward movement in the series.
2. **Seasonal variations**: These are the variations that regularly repeat themselves with a periodic pattern that makes a complete circle within the period of the series.
3. **Cyclical fluctuations**: These are the long-term upward and downward movements around the general trend levels.
4. **Random variations**: These are variations that occur in an unpredictable fashion. It is the variation not accounted for by trend, seasonal, or cyclical factors.
Mathematically, a time-series can be expressed as:

\[
\text{Data} = \text{pattern} + \text{random error} = f(\text{trend, cycle, seasonality}) + \text{error}.
\]

Denoting these components by T, C, S, and E respectively we can see that a time-series may contain one, two or all of T, C and S, whereas all time-series will contain some measure of E. Decomposition methods employ the relationship between these components, and the value, \( Y_t \), of a time-series variable at time \( t \) to identify sub-patterns and then use a combination of forecasts for those sub-patterns in predicting future values of the time-series.

The most common relationships between components of a time-series are additive and multiplicative models. Thus:

\[
Y_t = T + C + S + E \quad \text{or} \quad Y_t = T \cdot C \cdot S \cdot E
\]

Since additive models lend themselves to regression analysis it is usual to convert multiplicative models to additive ones using logarithms. Several methods of decomposing time-series have been developed, and some were treated in detail by McHaughlin et al (1962, 1968) and Wheelwright et al (1984) among others.

6.4.2 Moving Averages

This is one of the techniques of smoothing a time-series to eliminate randomness and, at the same time, to provide a value of the forecast of the time-series for the period following that covered by the average. A given number, \( k \), of consecutive values of the variable, \( Y_t \), are averaged to provide the forecast. Thus as successive values of \( Y_t \) are brought into the calculation the average changes (i.e. moves) progressively. For example; if \( f(X_i, \text{for } i = 1, 2, 3, \ldots, n) \) represents a time-series for \( X \), then a k-point moving average is found by taking the mean of \( k \) consecutive values \( X_i, X_{i+1}, X_{i+2}, \ldots, X_{i+k-1} \) for \( i = 1, 2, \ldots, n-k+1 \). Thus if \( Y_{t+1} \) denotes the forecast value of the time-series at time \( t+1 \) then, according to the method of moving averages:
Thus equation 5.14 can be written as:

\[ Y_{t+1} = \frac{X_t + X_{t-1} + X_{t-2} + \ldots + X_{t-k+1}}{k} \]

Conversely:

\[ Y_t = \frac{X_{t-1} + X_{t-2} + \ldots + X_{t-k}}{k} \]  

This means that each new forecast, \( Y_{t+1} \), using moving averages is simply an adjustment of the preceding moving average forecast, \( Y_t \), and also that as \( k \) becomes larger the adjustment between consecutive forecasts decreases (i.e. smoothing effect increases).

6.4.3 Exponential Smoothing

This method corrects two drawbacks of the method of moving averages, namely:

1. The necessity in moving averages to store all previous \( k \) values of the variable to enable a forecast.
2. The allocation of equal weighting, (i.e. \( 1/k \)), in moving averages to all \( k \) values of the variable irrespective of their position in time.

Since it is reasonable to assume that the more recent values of a variable contain more relevant information on the variable, it is desirable to have a weighting scheme that accords more importance to these recent values. Exponential smoothing fulfils this desire and rectifies the other drawback by replacing the observed value, \( X_{t-k} \), of the time-series variable corresponding to period \( t-k \) from equation 6.16 with an approximate value, a reasonable estimate of which would be the forecast value of the
period preceding that being currently forecast. Thus equation 6.16 becomes:

\[ Y_{t+1} = \frac{X_t}{k} + \frac{Y_t}{k} + Y_t = \frac{X_t}{k} + (1 - \frac{1}{k})Y_t = \alpha X_t + (1-\alpha)Y_t \]

where: \( \alpha = \frac{1}{k} \) \hspace{1cm} (6.17)

Thus with only the most recent observation and forecast of the variable we can predict the next value of the variable. Also substituting the value of \( Y_t \) from equation 6.17 gives:

\[ Y_{t+1} = \alpha X_t + (1-\alpha)[\alpha X_{t-1} + (1-\alpha)Y_{t-1}] \]

\[ = \alpha X_t + \alpha(1-\alpha)X_{t-1} + (1-\alpha)^2Y_{t-1} \]

which with progressive substitution leads to the general equation for exponential smoothing thus:

\[ Y_{t+1} = \alpha X_t + \alpha(1-\alpha)X_{t-1} + \alpha(1-\alpha)^2X_{t-2} + \alpha(1-\alpha)^3X_{t-3} + \hspace{1cm} (6.18) \]

Equation 6.18 guarantees an exponential decay of the weightings assigned from the most recent to the most distant values of the variables.

It is obviously important to select a suitable value for \( \alpha \) to ensure good smoothing. Bowerman et al (1979) gave several methods for choosing \( \alpha \) and suggested that a value of between 0.10 and 0.30 often works well.

6.4.4 Autocorrelation Methods

These are an improvement on exponential and decomposition methods because they enable forecasting to be done directly without having to separate the subpatterns of the time-series. The methods rely on the autocorrelation, (which is a measure of mutual dependence), between successive values of the time-series to identify its basic pattern and determine an appropriate model that fits the series. As there are many types of autocorrelation models, and their derivative theories are complex, it surfaces to define here three classes of these models.
which, according to Wheelwright et al (1984), "for all practical purposes, describe any type or pattern of time-series data".

The first class of these models is called autoregressive models, (AR), given as:

\[ Y_t = \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \Phi_3 Y_{t-3} + \ldots + \Phi_p Y_{t-p} + e_t \quad (6.19) \]

where: \( Y_t \) is the response variable; \( Y_{t-1}, Y_{t-2}, \ldots, Y_{t-p} \) are predictor values of the same variable, \( Y_t \), but of previous periods \( t-1, t-2, \ldots, t-p \); \( e_t \) is the error or residual term due to randomness; and \( \Phi_1, \Phi_2, \ldots, \Phi_p \) are the regression parameters.

Equation 6.19 is called autoregressive because it is similar to equation 6.5 except that in 6.19 the predictors are 'lagged' values of the same response variable. Once the parameters \( \Phi_1, \Phi_2, \ldots, \Phi_p \) and number of terms to be included, \( p \), are estimated, equation 6.19 can be used to forecast the value of \( Y \) at time \( t \).

The second class of autocorrelation models is called moving average models, (MA), which predict \( Y_t \) based on previous values of the error term; \( e_1, e_{t-1}, e_{t-2}, \ldots, e_{t-q} \); and are given by:

\[ Y_t = e_t - \Theta_1 e_{t-1} - \Theta_2 e_{t-2} - \ldots - \Theta_q e_{t-q} \quad (6.20) \]

Here the regression parameters are \( \Theta_1, \Theta_2, \ldots, \Theta_q \).

The third class is a mixture of AR and MA, and is called ARMA or mixed models, given by:

\[ Y_t = \Phi_1 Y_{t-1} + \Phi_2 Y_{t-2} + \ldots + \Phi_p Y_{t-p} + e_t - \Theta_1 e_{t-1} - \Theta_2 e_{t-2} - \ldots - \Theta_q e_{t-q} \quad (6.21) \]

Thus ARMA models combine past values of both the predictors and error terms as their basis for predicting \( Y_t \).

It is obvious that AR, MA, and ARMA models require the use of computers to be realistically applicable. This might explain why prior to the '70s these models remained mainly as theoretical knowledge. For instance, AR models were proposed by Yule (1926, 1927), MA models were proposed by Slutsky (1937), and
ARMA models were proposed by Wold (1954). The development of computers has since led to formulating various approaches to applying these models, with the most popular being:

1. The Box-Jenkins Approach due to Box et al (1976)
2. Parzen's Methodology due to Parzen (1982)
5. Lewandowski's Forsys due to Lewandowski (1979)

6.4.5 Multivariate Methods

While time-series models include only one variable, multivariate models attempt to capture and measure the effect of external independent factors on the response variable. Multivariate ARMA models, (known as MARMA models), combine characteristics of multiple regression with those of univariate models described above, and are therefore more powerful means of forecasting. But they are more difficult and costly to develop. The general form of these models is:

\[
Y_t = \delta_1 Y_{t-1} - \delta_2 Y_{t-2} - \delta_3 Y_{t-3} - \ldots - \delta_r Y_{t-r} \\
+ \omega_0 X_{t-b} - \omega_1 X_{t-b-1} - \omega_2 X_{t-b-2} - \ldots - \omega_s X_{t-b-s} \\
+ \lambda_0 Z_{t-c} - \lambda_1 Z_{t-c-1} - \lambda_2 Z_{t-c-2} - \ldots - \lambda_v Z_{t-c-v} \\
+ \xi_0 W_{t-d} - \xi_1 W_{t-d-1} - \xi_2 W_{t-d-2} - \ldots - \xi_u W_{t-d-u} \\
+ e_t
\]

(6.22)

where: \(\delta, \omega, \lambda, \) and \(\xi\) are parameters; \(X, Y, Z, W\) are predictors; and \(t-b, t-c, t-d, t-r, \) e.t.c. are time periods.

6.4.6 Use of Time-series Methods on Construction Projects

The essential steps of time-series methods of forecasting have thus far been identified as:

1. Defining the response and the predictor variables of the system or operation under consideration.
2. Obtaining an initial series of the variable(s) of the system and coding the data suitably for use in the forecasting model.

3. Selecting a suitable forecasting model depending on the nature of observed data, level of accuracy required in the forecast, volume of forecasts to be made and whether or not computers will be used.

4. Making short-term forecasts of the response variable based on the observed data.

These steps would appear to be applicable on construction projects since virtually all construction operations are time-related. Indeed any construction operation can be regarded as a process of employing some specific mix of the following resources (or variables) to produce a specific amount or part of the finished project:

1. Materials (consumables and otherwise).
2. Man-hours (skilled, semi-skilled, and unskilled).
3. Plant time.
4. Overheads.

Thus by making production quantities the response variables while other resources are made the predictor variables in construction operations, periodic forecasts of production levels achievable can conveniently be made using time-series models. The most obvious application of such forecasts is in verifying short-term operational plans to find out whether or not planned outputs would be achievable based on existing trends from on-going operations.

Significantly, by making operational costs the response variable while translating costs of resources consumed into predictor variables, the time-series models could be used to monitor and control costs of on-going operations against their budgetary allocations. Conversely, by making elapsed operational time the response variable to be predicted vis-a-vis production quantities, the short-term programme of on-going operations could be monitored and controlled by predicting expected completion time of the operations at current rates of production.
The application of some quantitative models as part of an overall cost monitoring and control model for construction projects is proposed in chapter 8. It is worth emphasizing that the models reviewed thus far simply forecast future operational status based on current trends. They neither explain the relationships between the variables, (as in regression models), nor identify the appropriate course of action to achieve a desired status in future; for which we have to turn to optimization models. Moving average and exponential models also have other limitations to their applicability on construction projects because such models envisage a more or less uniform rate of resource utilization which is not necessarily the case on construction operations. Furthermore construction operations hardly ever repeat themselves with cyclic periods which means that generated data may not be a perfect time-series.

Autoregressive models could have overcome this problem due to their use of regression parameters that measure relations even within and between cross-sectional data but for their univariate nature whereas construction operations are multivariate. Thus the only possible option for using T-S models on construction projects remain the MARMA models which combine multivariate parameters with the capabilities of regression to make forecasts. But the peculiarities (or nature) of construction cost data mentioned earlier make even this option appear unrealistic.

Another limitation to the use of time-series methods remain the need to confine forecasts to short-term intervals. This is not suitable for construction projects because long-term data from construction operations, for a variety of reasons, loses the serial characteristics that would make it suitable for T-S forecasting. On long-term forecasting multiple regression would always be safer to use than T-S. Nevertheless MARMA models could have possible use for forecasting on many civil engineering operations such pipe works and road construction where the operational sequences and the consequently resource mixes tend to be repetitive within the same project.
6.5 Optimization Models

The models described in sections 6.3 and 6.4 are explanatory in nature since they employ the relationships between components of a problem to explain the behaviour of the represented system and enable such behaviour to be predicted. As earlier pointed out, such models do not identify the appropriate or optimum course of action to realize specified objectives from an operation of the system. The models that provide definite basis to decision makers as well as explain system behaviour are known as optimization or decision models. Examples of these models include linear programming, (LP), integer programming, (IP), dynamic programming, (DP), goal programming, (GP), queuing models, assignment models, and transportation models. Though most of these models could find useful application with the manager of a construction project, LP, IP and GP models appear particularly suitable to advance the course of cost monitoring and control tasks, especially as part of a feedforward control system.

6.5.1 Linear Programming

This is a powerful quantitative technique of problem solving that focuses on an objective of the system, and determines optimum mixes of the system components within the defined constraints of the system to optimize the system objective. Davis et al (1984) identified the characteristics or assumptions of LP models as:

1. Single identifiable objective such as maximizing profit or minimizing costs.
2. Constraints on levels of system variables.
3. Proportionality between the objective, the constraints and decision variables. This is a linearity pre-condition similar to that mentioned with regard to regression analysis.
4. Divisibility of the system variables, (i.e. fractional allocation of the variables is possible).
5. Additivity of the contributions of the individual variables to the system objective.
7. Certainty of all parameters; i.e. values such as contributions of variables, availability of resources, relationships between levels of production and resource utilization are known.

The absence of any of the above characteristics does not always preclude the use of LP. It only means that the true situation differs from the model being used and that the results will have to be interpreted accordingly. Davis et al (1984) ruled that "if LP gives useful information about the problem, the decision-maker can still utilize the model".

The application of LP techniques require two main steps:

1. Problem formulation which, in turn, comprises:-
   - problem verification;
   - problem description;
   - mathematical formulation (or modelling).
2. Solution process which comprises:-
   - either graphical plotting; or
   - tabulation and computer coding.

Problem verification entails an assessment of the real system to determine, according to Davis et al (1984), if:

1. An objective function for the problem can be stated in terms of decision variables, i.e. $x_1, x_2, x_3, \ldots, x_n$.
2. The variables of the problem are interrelated in the generation of the 'total output'; i.e. if a quantity of one variable may be foregone to produce or use more of another variable.
3. Constraints related to the availability or use of resources, satisfaction of requirements, or meeting of demands are linear in form.
4. The values of the variables in the solution can be fractional but always greater than or equal to zero.

Meeting these conditions means the problem has the LP characteristics and is, thus, amenable to solution.
Problem description entails, in this order:

1. Identifying the overall objective of the problem, such as maximizing profits, minimizing costs, minimizing resource requirements, or maximizing resource utilization.
2. Stating the identified objective 'verbally', indicating how it is related to the decision variables which the decision-maker can control.
3. Identifying each constraint and stating it 'verbally'.

The mathematical modelling step entails transforming the verbal descriptions of the problem (from the previous step) into the proper mathematical structure conforming to the general form of the LP model which is as follows:

**MAXIMIZE:** \( Z = c_1x_1 + c_2x_2 + c_3x_3 + \ldots + c_nx_n \)

**SUBJECT TO:**

\[
\begin{align*}
a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + \ldots + a_{1n}x_n & \leq b_1 \\
a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + \ldots + a_{2n}x_n & \leq b_2 \\
a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + \ldots + a_{3n}x_n & \leq b_3 \\
\vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\
a_{m1}x_1 + a_{m2}x_2 + a_{m3}x_3 + \ldots + a_{mn}x_n & \leq b_m \\
x_1, x_2, x_3, \ldots, x_n & \geq 0
\end{align*}
\]

where: \( x_i \) are the decision variables;
\( a_{ij} \) (\( i = 1 \) to \( n \), \( j = 1 \) to \( m \)) are the physical rate of substitution, (i.e. usage), coefficients for the resources, (i.e. the variables);
\( c_1, c_2, \ldots, c_n \) are contribution coefficients; and
\( b_1, b_2, \ldots, b_m \) are resource constraints.
Davis et al (1984) proffered the following procedure for the mathematical modelling step:

1. Identify and or define all the decision variables (the $x_j$'s) associated with the problem, including in the definition the units of measure associated with each variable.
2. Identify the contribution coefficients (the $c_j$'s) associated with each variable, including in the definition the associated unit of measure.
3. Formulate the objective function and check for consistency of units of measure.
4. Identify the physical rate of substitution coefficients (the $a_{ij}$'s), including in the definition the associated units of measure for the respective coefficients.
5. Identify the available resources or requirements (the $b_i$'s), including in the definition the units of measure associated with the resources.
6. Formulate constraints related to each respective resource or requirement and check each constraint for consistency of units of measure.
7. Define the non-negativity condition associated with the decision variables.

Once the LP model of the problem is constructed the equations can be plotted and optimal solutions read off the graph (if the problem is simple with only a few decision variables). Alternatively, the problem can be tabulated and solved via the simplex algorithm developed by Danzig (1947); (see Davis et al (1984) and Cooke (1985) for details of the algorithm). More conveniently, the model is coded and entered into a computer to automatically generate the optimum solution in a matter of minutes as opposed to manual use of the algorithm which can take a qualified staff several days to solve a medium-sized problem!
6.5.2 Integer Programming

The assumption of divisibility of decision variables in LP means that fractional (allocation of) resources and fractional solutions are possible even though this is contrary to many real situations. Integer programming is a variant of LP that solves this riddle by changing the last equation in the LP model to read:

\[ x_1, x_2, x_3, \ldots, x_n \geq 0 \text{ and integer;} \]

thus allowing the decision variables to assume only discrete integer values. This variation removes IP models from the realm of simplex solution process which always guarantees an overall optimal solution irrespective of the values taken by the decision variables. Thus the solution of IP models is left to such methods as the 'branch and bound', [see Cooke (1985) for details], which is so cumbersome that it makes computer application more costly and limited to problems with much fewer variables, (in the order of one tenth), than LP models. Nevertheless their conformity to reality makes IP models very often desirable or even necessary.

6.5.3 Goal Programming

This technique was first identified by Charnes et al (1961), refined and extended by Ijiri (1965), and developed and applied by Lee (1972) and Ignizio (1976). It is a variant of LP that seeks to solve decision-making issues in multiple goal problems. Whereas LP can solve problems with only one objective, many real systems consist of several goals which may conflict or, at the least, have differing dimensions. For such problems GP provides solutions that not only satisfy the multiple objectives, but also fulfils whatever priorities and or weightings the decision-maker may wish to assign the various objectives. The formulation and solution processes for LP and GP are similar except that in the latter the objective function always seeks to minimize deviations from the specified objectives, resulting in the goals being expressed as constraints while the objective function contains only the deviational variables to be minimized. The general form of the GP model for a problem with m goals, p structural
constraints, n decision variables and k priority levels is given below:

\[
\text{MINIMIZE: } Z = \sum_{k=1}^{K} \sum_{i=1}^{m} \left( w_{i,k}^+ d_i^+ + w_{i,k}^- d_i^- \right)
\]

\[
\text{SUBJECT TO: } \sum_{j=1}^{n} a_{ij} x_j + d_i^- - d_i^+ = b_i ; i = 1, 2, \ldots, m
\]

\[
\sum_{j=1}^{n} a_{ij} x_j \quad (\leq, \geq) \quad b_i ; i = m+1, m+2, \ldots, m+p
\]

\[x_j, d_i^+, d_i^- \geq 0 ; i = 1, 2, \ldots, m; j = 1, 2, \ldots, n\]

where:

\[P_k = \text{priority coefficient for the } k^{\text{th}} \text{ priority},\]

\[w_{i,k}^+ = \text{the relative weight of the } d_i^+ \text{ variable in the } k^{\text{th}} \text{ priority level},\]

\[d_i^+ = \text{the overachievement variable for the } i^{\text{th}} \text{ goal; }\]

\[\text{i.e. the amount by which the goal has been overachieved.}\]

\[d_i^- = \text{the underachievement variable for the } i^{\text{th}} \text{ goal; }\]

\[\text{i.e. the amount by which the goal has not been fully achieved.}\]

The following points clarify the differences between LP and GP:

1. Whereas LP models solve problems with only one objective, GP models solve problems with multiple objectives.
2. Whereas LP provides an optimum solution to the problem, GP provides a solution that satisfies all the objectives. This means that where LP may provide no solutions due to infeasibility caused by some constraints, GP will still provide a solution and, at the same time, highlight decision options such as how much of one goal to forego to meet another goal.
3. Whereas LP either maximizes or minimizes a specific goal, GP always minimizes deviations from specified levels of the various goals. This allows GP to handle multiple goals irrespective of their dimensions or units of measure.

4. GP allows the ranking of goals as well as weighting of goals within the same priority rank.

5. Whereas LP models use the objectives as coefficients in the objective function, GP converts the goals to constraints and replace them in the objective function with deviational variables.

6. Both GP and LP can be solved with simplex algorithm as well as the graphical technique but the algorithm used for solving GP problems is an 'extended' version of simplex.

7. In addition to identifying decision options the presence of deviational variables and goal constraints in GP models places limits on the extent to which specific goals are satisfied. For instance, omitting $d_i$ places a lower bound on the $i^{th}$ goal while omitting $d_i^*$ imposes an upper bound on the goal.

It is worth commenting here that though critical path methods, (CPM), and programme evaluation & review techniques, (PERT), are famous decision models, especially within the construction industry, they are more of planning and scheduling techniques that result in network presentations of plans and schedules for projects. Their significance in cost monitoring and control lies in affording convenient presentation of performance models.

### 6.5.4 Use of Optimization Models on Construction Projects

While discussing the applicability of regression and time-series models to monitor and control cost, schedule and physical progress of construction operations it was pointed out that such models could not identify the appropriate course of action to correct incidences of poor performances. Since optimization models are essentially decision-making tools they would appear to be a necessary compliment of any management monitoring and control system that is based on quantitative techniques.
By virtue of their conformity to the requirements of regression and time-series methods, construction projects would also meet the requirements for problem formulation and solution via optimization models. The proposal in chapter 8 of this thesis shows how typical construction problems can be formulated for solution by means of optimization models. As was the case with regression and time-series models the following principal objectives can be defined for optimization problems:

1. Minimizing deviations from project budget.
2. Minimizing deviations from project schedule.
3. Minimizing resource requirements.

Thus once construction problems are formulated, as shown in chapter 8, optimization models can be employed to determine how best to achieve the defined objectives within the identified constraints of the various resources. Since the nature of construction business, as opposed to other business concerns, is such that the amount and or level of profit is pre-envisaged at the estimating and tendering stages, the chief aim of the contractor at operational stages is to realize the profit margin built into the tender estimates or, failing that, to minimize deviations from the course of action that was planned to lead to the realization of that profit margin. This means the most suitable optimization models for use on construction projects would be GP. Other reasons for the preference of GP to other optimization models on construction projects are:

1. GP makes it possible to optimize multiobjective problems.
2. The fact that GP always produces feasible solutions that satisfy all objectives as opposed to the hypothetical optimizations that are obtained through other models.
3. In addition to satisfying all objectives GP solutions also highlight other decision options.
6.6 Computer Applications and Packages

As mentioned earlier the applications of most of the models and methods reviewed thus far are so difficult and mathematically complex as to be impracticable without the use of computers. Luckily a lot of the statistical packages and other management software contain programmes for implementing these models through batching or interactive processing. Notable among these are SPSS, MPSX-370, SIMPLEX, GENSTAT, MINITAB e.t.c. . Furthermore many computer centres have developed their own in-house systems.

Other factors also assist the application of quantitative models to monitor and control construction projects. Firstly, most of the essential implementation software are now available in packages that can be used on microcomputers. So even small to medium companies that may not be able to afford Mainframe computers can easily implement the packages. Secondly the use of modern versions of the software requires only moderate knowledge of microcomputer operation since the software are mainly menu- or command-driven. Thirdly the development of spreadsheet and database management programmes that allow for storage, retrieval and interchange of data between files, in addition to automatic computations of specified formulae and functions, further enhances the applicability of the quantitative models.

6.7 Summary

The chapter has reviewed the principles of various management models and methods that can find possible application in the construction industry to aid the contractor's effort in cost monitoring and control on site. Methods of formulating and solving problems using these techniques have also been outlined along with essential assumptions, considerations, and limitations to their applications.

The criteria and requirements of the reviewed models were assessed against the requirements and criteria for effective cost monitoring and control of construction projects. The assessment revealed that the quantitative models could be applied to the
monitoring and control of the construction projects to improve the effectiveness of the process and overcome some of the shortcomings identified with the theoretical approach described in chapters 3 and 4 of this thesis. The quantitative management techniques identified as applicable to construction projects are as follows:

1. Forecasting methods that were based on statistical time-series. These were found to be useful for mainly short-term forecasts of future outcomes of operations. The essential features of three types of time-series methods were identified and related to the requirements of short-term forecasting of the objectives of construction operations; namely timely completion within planned budget and available resource constraints. The comparison indicated that time-series forecasting methods could be usefully applied to construction projects in verifying short-range operational plans, schedules and budgets by predicting the achievability of such plans and budgets based on current trends from on-going operations.

2. Explanatory models such as regression and correlation models that can be used to identify system trends and relationships between various components of the system to enable the future behaviour of the system to be predicted. It was shown that problems of cost, schedule and progress monitoring on construction projects could be formulated within the characteristic framework of regression and correlation modelling in order to reveal quantitatively the trends and relationships between utilization levels of construction resources and operational costs, durations and outputs. This indicated that regression and correlation models can be used on construction projects to administer the overall programme and budget, and pre-determine the future course of physical progress and costs by predicting the manner in which budgets, schedules and physical progress of projects will be affected by current decisions, resource mixes or operational methods.
3. Optimization models such as LP, IP, and GP which are used to determine the best course of action to achieve specified goals. Reviewed characteristics of optimization models indicated that they could be applied to decision-making situations on construction projects to define the optimum quantitative mix of various resources that would minimize deviations from required levels of expenditure, durations, outputs and resource utilization. These models would thus appear to be crucial for feedforward control of costs on construction sites due to the anticipatory manner in which they employ system trends and relationships to define the optimum course of future activities within the system in order to achieve desired objectives.
CHAPTER SEVEN

SURVEY OF CONTRACTORS' COST MONITORING AND CONTROL TASKS ON CONSTRUCTION SITES

7.1 Introduction
7.2 Data Collection
7.3 Presentation and Analysis of Responses
7.4 The Practical Approach to Cost Monitoring and Control
7.5 Summary
SURVEY OF CONTRACTORS' COST MONITORING AND CONTROL TASKS ON CONSTRUCTION SITES

And he that seeketh shall findth --- Mathew (7:8 New Testament Bible)

7.1 Introduction

In pursuance of the aim and objectives of this research and in accordance with the methodology defined in chapter one, a survey of contractors' cost monitoring and control tasks on construction sites was carried out. The aim of the investigation presented in this chapter was to establish the approaches to cost monitoring and control tasks as practiced by construction contractors on sites, and also to assess the effectiveness of such practical approaches by rating the degree of satisfaction or otherwise expressed by the contractors with the results of their practices. The survey was also intended to identify the aspects and or features of the practical approaches to cost monitoring and control that needed to be improved in order to enhance the effectiveness of the whole process. The findings from the survey provided essential and useful basis for the design of an improved alternative to cost control of construction projects, (see chapters 8 and 9).

The survey was carried out in two phases. The first phase comprised administering a suitably designed questionnaire, (see Appendix I), on selected contractors in U.K.. The questionnaire was completed and returned by the contractors. A preliminary analysis of the questionnaire responses raised further more specific questions which were then administered on the original respondents via telephone and face-to-face interviews. The scope of questions covered in the follow-up interviews is shown in Appendix II. This approach was considered to be a suitable means of obtaining information from construction firms, whose personnel may be too busy to complete a very detailed and thus lengthy questionnaire, while at the same time affording an opportunity to get clarification and or further explanation of the information gathered in the first phase
7.2 Data Collection

7.2.1 Design of Questionnaire

The underlying objectives of the questionnaire were to ensure a wide coverage of issues relevant to the research and to present the enquiries in the simplest possible format in order to limit the length of the questionnaire and to ease understanding and response by busy project personnel and executives. These objectives were realized through systematic grouping and or tabulation of either related issues or enquiries that may have similar formats of responses. A covering letter was attached to the questionnaires explaining the aim and objectives of the research and assuring respondents of the confidentiality with which supplied information would be treated. Respondents were required to identify themselves on the questionnaires only if they wished to either receive a copy of the research findings or participate in the subsequent phases of the research.

The forty-eight questions listed in the questionnaire can be classified into the following sets of information:

1. The respondent companies and their operations.
2. Companies' experiences with cost overruns on projects.
3. Types and assessment of performance models.
4. Practice of performance measurement on sites.
5. Approach(es) to corrective decision making.
6. Organizational and responsibility structures on sites.
7. Use of computers for monitoring and control of projects.

7.2.2 Research Population: The Top 100

As pointed out in chapter 1 the research was centred on the construction industry in the United Kingdom. The companies selected for the research were those identified as The Top 100 in 1990 by The Contractors' File, published along with the New Civil Engineer on an annual basis. The File, which was claimed to be based on a detailed questionnaire survey and to provide "the most comprehensive and up-to-date reference document on the British construction industry", identified these companies as the
most important in terms of their financial turnover, share of the industry's business, profit and profitability, and business territorial spread both locally and inter-continentally. These and other reasons such as long experience, established business practices, specializations and expertise developed through competition, and availability of comparatively more resources for innovation made The Top 100 a more suitable target for any research seeking to apply scientific management techniques in construction project management.

7.2.3 Questionnaire Administration and Response

The issues raised in the literature review presented in previous chapters clearly identified project personnel who are principally site-based, as the appropriate target for the research enquiries. Consequently the questionnaire was administered to this cadre of personnel represented by or through project managers of the selected companies. The questionnaires were administered by post in the first instance with clarifications and further detailed enquiries carried out subsequently through telephone and face-to-face interviews.

Twenty-five companies responded fully to the questionnaire survey, two companies returned the uncompleted questionnaires without any explanation while one company sent a letter expressing interest in the findings but declining to participate on the grounds of company policy. The twenty-five completed questionnaires, (representing 25% response level), were analysed in the following sections in accordance with the content classification given in section 7.2.1. This response was considered adequate for the purpose of the statistical analysis to be carried out, and appreciable when compared to responses to other recent researches of similar approach among construction contractors. In this and indeed most other instances the level of response is not necessarily a measure of the relevance of either the problem under investigation or concern of the respondents with the problem. The evidence given in section 7.3.2 clearly proves the importance and relevance of the research problem to the contractors and industry at large. Possible explanation for
the failure of some companies to participate in the survey include:

1. Lack of time to complete the questionnaire.
2. Lack of enthusiasm due to company's current financial or operational status.
3. Lack of knowledge on issues raised in the questionnaire.
4. Lack of confidence that information would be held in confidence.
5. Retrogressive company policy.
6. Inexplicable apathy.

7.3 Presentation and Analysis of Responses

For ease of comparison and deductions the responses were either tabulated and or expressed as percentages. Bar charts were also used, where necessary, to reveal the pattern of the responses as well as enhance the analysis which was mainly statistical and descriptive.

Twenty-four percent of the companies that participated in the survey, merely wanted to receive findings and recommendations of the research, while 48% of them additionally agreed to grant follow-up interviews and participate in subsequent phases of the research. Impressions gathered during the oral phase of the survey confirmed the objectivity of the responses on the returned questionnaires.

7.3.1 Respondent Personnel and Company Operations

Forty-eight percent of the companies that participated in the survey have been in business for between 10 to 25 years, 40% for over 25 years and 12% for between 5 to 10 years. That is to say 88% of the respondents have been in business for over 10 years while none of them has spent less than 5 years in business. This shows that majority of the companies were well established and would have acquired the requisite experience to participate in the survey. Furthermore 84% of the companies specialized in either building or civil engineering works, while 36% undertake projects combining aspects of both. Forty percent of the
companies also undertook process engineering projects, while 24% also ventured into maintenance works. Only 20% of the companies handled jobs of less than £500,000, with 84% of them going for projects of £1 million to £10 million. Forty-four percent of the firms claimed to be capable of handling projects of over £10 million. These show that not only did the companies represent business in all sectors of the construction industry, but that they mainly handled medium to large projects that call for elaborate and specialized application of construction and cost management principles.

On the tenure of respondent staff in the various companies, 84% have been in the services of their companies for at least 5 years, with 20% having served for over 10 years. Only 16% have spent less than 5 years on their jobs. Furthermore the staff were variously trained as civil engineers, project managers, quantity surveyors, builders, architects and planners. Their designations were, variously, project managers, contract managers, project engineers, project quantity surveyors, planning managers and group technical executives. This shows that the respondents were adequately trained, experienced and positioned to provide credible answers to the research enquiries. Furthermore they would be capable of comprehending and implementing any proposals arising out of the investigations.

7.3.2 Experience with Cost Overruns on Projects

Incidence of cost overruns

The experience of the construction industry with the problem of cost overrun on projects and its assessment of the causes as well as remedial factors was considered necessary for a proper evaluation of the theoretical model for and issues relating to cost monitoring and control presented in previous chapters, and for proposing another approach to effective cost monitoring and control on sites. Accordingly the respondents were questioned about the frequency of cost overruns at various levels of project cost structure, and their ratings of some possible factors related to cost overruns, (see questions 2.1, 2.2, 2.3, 4, and 20 of Appendix I). Table 7.1 gives the response of the contractors
expressed as percentages. It is shown on the table that 44% of the contractors *always* suffered cost overruns on individual cost codes, while 16% of them suffered similar overruns 75% of the time, (or generally). That is to say 60% of the companies suffered cost overruns on individual cost codes in at least 75% of all cases. Furthermore a similar proportion (60%) experienced overruns on overall project budgets in 75% of their projects.

Table 7.1: Frequency of Cost Monitoring and Control Issues

<table>
<thead>
<tr>
<th>ISSUES</th>
<th>RESPONSES</th>
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<td><img src="image" alt="Table content" /></td>
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</table>

During the follow-up interview some of the companies lamented that "while clients are on the whole getting excellent value for money, contractors have little chance of profit unless their clients initiate sufficient variations as to increase the value of the contracts by 15% to 20%".

When required to judge the frequency with which cost overruns on cost codes directly resulted into overruns on overall project budget, 72% of the companies said overruns at the two levels were directly related in at least 75% of all cases, with 24% believing that there was *always* a direct relationship between cost overruns at the two levels. Perhaps the most significant
revelation from table 7.1 was that none of the companies claimed either not to have suffered overruns at both cost code and overall project levels in at least 25% of their projects, or that overruns of costs at the two levels were unrelated.

During the follow-up interview there was general agreement between the contractors that, in terms of the effect of the issues raised in table 7.1 on the physical and financial success of a project, occurrences rated as 'generally' produced similar effects to those rated 'always', and those rated 'occasionally' and 'never' also produced similar effects. This implies that for any of the issues in table 7.1 occurring generally was as good, (or bad), as occurring always, and occurring occasionally was as good, (or bad), as never occurring. Thus table 7.1 can be transformed into table 7.2 to reveal a clearer pattern of the responses.

Table 7.2: Frequency of Cost Monitoring and Control Issues (Revised)

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<thead>
<tr>
<th>ISSUES</th>
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<tbody>
<tr>
<td></td>
<td>Always</td>
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<tr>
<td>2.1 Cost overruns on cost codes</td>
<td>60</td>
</tr>
<tr>
<td>2.2 Cost overruns on overall project</td>
<td>60</td>
</tr>
<tr>
<td>2.3 Cost &amp; schedule overruns related?</td>
<td>72</td>
</tr>
<tr>
<td>2.4 Foremen knew of targets in advance</td>
<td>12</td>
</tr>
<tr>
<td>2.5 Models &amp; record formats coordinated?</td>
<td>40</td>
</tr>
<tr>
<td>2.6 Decision-making based on feedback?</td>
<td>72</td>
</tr>
<tr>
<td>2.7 Decision-making based on predictions?</td>
<td>28</td>
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</tbody>
</table>

The table shows that in at least 50% of their projects, 80% of contractors overspent their construction budgets. This should certainly amount to a poor success rate in any undertaking let alone construction projects that involve relatively big one-off expenditures on most operations; a characteristic that requires contractors to always get things right the first time. It is also evident from the responses that if contractors could effectively monitor and control expenditures on each operation or cost centre, there is only an 8% chance of ever overspending on overall project budgets. Thus if the alternative approach to be proposed in chapter eight provides a means of preventing
overruns on individual cost codes its implementation should reduce profit erosion in 92% of projects handled by contractors.

**Causes of Cost Overruns**

In order to find out the industry's assessment of the causes of cost/schedule overruns, the companies were requested to rank various categories of the causes in terms of both their frequency of occurrence and significance towards cost/schedule overrun. Table 7.3 shows the ranking assigned by the companies to the causes in order of their frequency of occurrence, with the ranks having been adjusted for tied ranks.

To test the degree to which the contractors agreed in the rankings, the Kendall's coefficient of concordance, W, was calculated. [for the theory of this test see Siegel, (1956)]. as follows:

\[
W = \frac{S}{\frac{1}{12} K^2 (N^3 - N) - K \sum T}
\]

where: \( S = \sum (R_j - \frac{R_j}{N})^2 \) i.e. sum of squares of the observed deviations from the mean of \( R_j \).  

\( K \) = number of sets of rankings, i.e. number of respondent companies;  
\( N \) = number of entities ranked;  
\( T \) = correction factor for tied observations

\[ T = \frac{\sum (t^3 - t)}{12} \]

t = number of observations in a group tied for a given rank.
<table>
<thead>
<tr>
<th>Factors</th>
<th>Design</th>
<th>Technical</th>
<th>Managerial</th>
<th>Consultants</th>
<th>Suppliers</th>
<th>Clients</th>
<th>Contingency</th>
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\[ \begin{array}{cccccc}
T_i & 1 & 0.5 & 1 & 2 & 2.5 & 5.5 \\
\sum T_i & 13 & 16 & 21 & 22 & 23 & 24
\end{array} \]
From table 7.3, $S = 5951.87$, $K = 25$, $N = 7$ and $\sum T = 29.5$. When these are substituted in equation 7.1 we find that $W = 0.3551$. The significance of $W$ can be tested by measuring the probability of occurrence of any value as large as the observed value of $W$ using the $\chi^2$ statistic. Since the number of judges (respondents) exceeds 20, the 'small samples' test suggested by Siegel (1956) cannot be used. Consequently the 'large samples' test in which the expression $K(N-1)W$ is approximately distributed as $\chi^2$ with degree of freedom, $(df) = N-1$, is adopted. Thus table 7.3 leads to: $\chi^2 = 25(7-1)0.3551 = 53.27$.

From statistical tables by Siegel (1956) this value of $\chi^2$ has the probability of occurrence under the null hypothesis that the $K$ rankings are unrelated of $P < 0.001$. This enables us to reject the null hypothesis at the 1% level of significance and to conclude that there was considerable agreement in the ranking among the contractors surveyed and that the degree of agreement among them was higher than would occur by chance.

Following Siegel's suggestion, the true ranking, $R$, of the causes is given by the "order of various sums of ranks", $R_j$, and is shown on table 7.3. It reveals that design factors were the most frequent causes of cost and schedule overrun on construction sites, with technological and managerial factors coming second and third respectively. Contingencies and outside agents were ranked as the least frequent causes of cost/schedule overrun.

The ranks assigned to the importance of the causes of cost and schedule overruns, after adjustment for tied ranks are given in table 7.4 from which it is seen that $S = 5597.43$, $K=25$, $N = 7$ and $\sum T = 23.5$. Substituting these values in equation 7.1 gives $W = 0.3310$. Again as the data represents a large sample the significance of $W$ can be tested by the $\chi^2$ distribution. In this case $\chi^2 = 49.65$. From the statistical tables this value of $\chi^2$ has probability of occurrence under the null hypothesis that the $K$ rankings are unrelated of $P < 0.001$. This enables us to reject the null hypothesis at the 1% level of significance and to conclude that there was considerable agreement in the ranking among the companies, and that the degree of agreement was higher than
would occur by chance. Thus the true ranking of the causes was derived as shown on table 7.4 and revealed that design factors, actions of clients, and technical factors, in this order were the three most significant causes of cost/schedule overruns to the contractors.

Other Causes (identified by the respondents)

The contractors were also requested to identify and rank any other causes of cost and schedule overrun that were not listed on the questionnaire. One respondent each identified weather and competitive tendering, while two respondents mentioned subcontractors' inability to perform as the 'other' causes. Since weather can be classed as contingency, competitive tendering as managerial factor and subcontractors' inability as either or all of technical, managerial or outside agents, (see items b, c, and g of tables 7.3 and 7.4), these other causes were not included in the responses analysed in the tables.

Other factors that contractors blame for cost/schedule overruns were also revealed during the follow-up interviews as follows:

1. The structure of the industry.
2. The "aggressively competitive first-past-the-post tendering system".
3. The forms of contract.

These factors were claimed to contribute to cost overruns by escalating contractors' expenses.
Table 7.4: Significance Ranking for Causes of Cost and Schedule Overruns

| Factor       | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | [M=99.7] |
|--------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|--------|
| Design       | 3.5| 3.5| 1  | 1.5| 1.5| 1.5| 1.5| 1.5| 7  | 2  | 1  | 1  | 1  | 1  | 3  | 4  | 2.5| 3.5| 1.5| 3.5| 1  | 2.5| 4  | 68.5 | 156.49 |
| Technical    | 3.5| 5  | 3  | 3.5| 3.5| 3.5| 3.5| 5.5| 1.5| 1  | 7  | 5  | 2  | 5  | 2  | 5  | 2  | 2.5| 4  | 3.5| 4  | 3.5| 2  | 4  | 4  | 88.5 | 125.44 |
| Managerial   | 5  | 3.5| 3  | 5  | 5  | 5  | 5  | 5.5| 3.5| 5  | 2  | 6  | 1  | 3  | 4  | 4  | 5.5| 5.5| 5  | 4  | 5  | 5  | 5  | 5  | 111  | 139.24 |
| Consultants  | 6  | 6  | 5  | 1.5| 1.5| 1.5| 1.5| 5.5| 5  | 3  | 4  | 2  | 4.5| 7  | 2  | 2  | 5.5| 5.5| 6  | 4  | 6  | 3  | 6.5| 6  | 102  | 7.84  |
| Suppliers    | 7  | 7  | 6  | 6  | 6  | 6.5| 4  | 5.5| 4  | 4.5| 3  | 5  | 6  | 7  | 7  | 7  | 7  | 7  | 6  | 7  | 6.5| 7  | 146  | 2143.69|
| Clients      | 1  | 1  | 3  | 3.5| 3.5| 3.5| 3.5| 5.5| 3.5| 2  | 3  | 3  | 6  | 4  | 3  | 1  | 1  | 1  | 1  | 6  | 1  | 4  | 1  | 1  | 68   | 1004.89|
| Contingency  | 2  | 2  | 7  | 7  | 7  | 7  | 7  | 7  | 2.5| 7  | 6  | 5.5| 7  | 7  | 7  | 6  | 7  | 6  | 2.5| 2.5| 2  | 1.5| 2  | 7  | 2.5| 2.5| 122  | 519.84 |
| Ti           | 0.5| 0.5| 2  | 1  | 1  | 1  | 1  | 1  | 5.5| 1  | 0  | 2.5| 0  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 0.5| 2.5| 0.5| 0  | 1  | 0.5 | 698  | 5597.43 |

\[ \sum T_i = 23.5 \]
Factors Affecting Cost Monitoring and Control on Site

In the literature review presented in foregoing chapters several factors were identified as being capable of positively influencing the course of effective monitoring and control of construction projects on site. The contractors were requested to rank these factors in order of their importance in positively aiding effective cost monitoring and control on site. The responses are given in table 7.5 with the ranks having been adjusted for tied ranks. It is shown on the table that $S = 50770.25$, $K = 25$, $N = 13$ and $\Sigma T = 174.5$. Substituting these values in equation 7.1 we find that $W = 0.4641$. The significance of this value of $W$ was tested through the $\chi^2$ test and it was found that $\chi^2 = 139.23$, and $df = 12$. This value of $\chi^2$ was found to have probability of occurrence under the null hypothesis that the $K$ rankings are unrelated of $P < 0.001$.

This enables us to reject the null hypothesis at the 1% level of significance and to conclude that there was considerable agreement in the ranking among the companies and that the degree of agreement was higher than would occur by chance. Consequently the true ranking of the factors was derived, as shown in table 7.5, and revealed that the factors considered by the companies to be most significant in enhancing effective cost monitoring and control on site were, in the following order:

1. Knowledge and experience of site management.
2. Methods of site communication.
4. Coordination of subcontractors.
5. Organizational structure on the site.

While participatory approach to goal setting, as advocated by Henke et al (1978) and Koontz et al (1984), among others, was fairly highly rated, the use of computers was rated among three least significant factors that enhance effective cost monitoring and control. This is not surprising considering the evidence in table 7.22 showing that only 32% of the contractors considered the contributions of computers in cost monitoring and control as positive.
Table 7.5: Significance Ranking of Factors that Enhance Effective Cost Monitoring and Control

| Factors          | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |   | \[M=174.5\] |
|------------------|----|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|\[M=174.5\]|
| Experience       | 1.5| 1 | 1.5| 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 1 | 3 | 9.5 | 1 | 1 | 2.5 | 1.5 | 3 | 6 | 1.5 | 1 | 1.5 | 1.5 | | R_i  | (R_i-M)^2 | R  |
| Joint plang      | 11 | 4 | 6.5 | 4.5 | 6.5 | 3.5 | 3.5 | 2 | 6.5 | 3 | 7 | 4 | 5 | 9 | 9.5 | 4 | 7 | 6 | 6.5 | 8.5 | 7 | 9 | 2 | 8.5 | 7 | 151 | 552.25 | 7 |
| Site orgn        | 3.5 | 5 | 6.5 | 9 | 6.5 | 7.5 | 7.5 | 4 | 6.5 | 5 | 1 | 3 | 3 | 8 | 9.5 | 3 | 6 | 4.5 | 4.5 | 6 | 10* | 6.5 | 7 | 6.5 | 7 | 147 | 756.25 | 5 |
| Co. policies     | 11 | 9 | 12 | 9 | 3 | 10.5 | 10* | 5 | 12 | 11 | 6 | 8 | 11 | 11 | 1 | 9 | 8 | 9.5 | 6.5 | 8.4 | 9 | 8 | 8.5 | 9.5 | 210* | 1296 | 10 |
| Skilled staff    | 7 | 7 | 3.9 | 10* | 3.5 | 3.5 | 3.5 | 7 | 3 | 6 | 3 | 5 | 3.1 | 2 | 2 | 3 | 7.5 | 8.5 | 6 | 11.5 | 6 | 10.5 | 4 | 133* | 1681 | 3 |
| Incentives       | 11 | 8 | 6.5 | 4.5 | 3 | 7.5 | 7.5 | 9 | 6.5 | 11 | 11 | 1 | 12* | 2 | 9.5 | 8 | 10* | 7.5 | 11* | 12 | 5 | 11.5 | 12 | 10.5 | 11 | 210 | 1260.25 | 9 |
| Communicatn      | 5 | 6 | 3 | 1.5 | 6.5 | 3.5 | 3.5 | 6 | 3 | 7 | 4 | 10 | 3 | 4 | 9.5 | 5 | 2 | 1 | 1.5 | 1 | 10.5 | 1.5 | 11 | 1.5 | 1.5 | 108* | 4356 | 2 |
| Computers        | 11 | 11 | 12 | 4.5 | 3 | 10.5 | 10* | 10 | 12 | 11 | 10 | 9 | 10 | 12 | 5 | 12 | 10* | 12 | 11* | 6 | 10.5 | 4 | 9 | 4 | 4 | 225 | 2550.25 | 11 |
| Proj environ.    | 8 | 13 | 12 | 12.5 | 10* | 12.5 | 12* | 12 | 12 | 11 | 13 | 13 | 12* | 10 | 9.5 | 11 | 10* | 9.5 | 8.5 | 10* | 3 | 4 | 10 | 6.5 | 9.5 | 258 | 6972.25 | 12 |
| S/con coodrn     | 3.5 | 2 | 9.5 | 9 | 13 | 7.5 | 7.5 | 8 | 9.5 | 4 | 5 | 6 | 6 | 6 | 3 | 6 | 4 | 2.5 | 3 | 3 | 9 | 4 | 3 | 4 | 4 | 142 | 1056.25 | 4 |
| Resce. coodrn    | 5 | 3 | 6.5 | 9 | 10* | 7.5 | 7.5 | 3 | 6.5 | 8 | 7 | 7.5 | 5 | 4 | 7 | 9 | 4.5 | 4.5 | 3 | 2 | 6.5 | 4 | 4 | 7 | 149* | 625 | 6 |
| Client/consult   | 6 | 10 | 3 | 4.5 | 6.5 | 3.5 | 3.5 | 12 | 3 | 2 | 9 | 11 | 7.5 | 7 | 9.5 | 10 | 5 | 12 | 11* | 10* | 8 | 9 | 5 | 12 | 12 | 193 | 342.25 | 8 |
| Mkt. research    | 11 | 12 | 9.5 | 12* | 10* | 12.5 | 12* | 12 | 9.5 | 11 | 12 | 12 | 9 | 13 | 9.5 | 13 | 10* | 12 | 11* | 13 | 10.5 | 13 | 13 | 13 | 13 | 291 | 13572.25 | 13 |
| \( T_i \)        | 11 | 0 | 9.5 | 16 | 12 | 11 | 11 | 2 | 9.5 | 10 | 0 | 0 | 3 | 0 | 42 | 0 | 5 | 4 | 4 | 5 | 5.5 | 0 | 4 | 5 | 2260 | 50770.25 | 13 |

\[ \Sigma T_i = 174.5 \]
A more important reason for the low rating of the role of computers by the contractors would appear to be the fact that only 12% of them, (see table 7.18), claimed to apply scientific management techniques, (which essentially depend on the use of computers), for cost monitoring and control. The relatively high rating for subcontractor coordination, on the other hand, reflects the ever increasing role of subcontracting as a means of project delivery, (as in management contracting). The high rating for site organizational structure and communication methods agrees with their importance to successful project management as revealed in chapters 4 & 5.

Perhaps the most significant and interesting revelation from table 7.5 was the near unanimous verdict that knowledge and experience of project management is the most important determinant of effective cost monitoring and control on site. This judgement was reinforced by the evidences of tables 7.18 and 7.19 which emphasize the degree of reliance of contractors on previous experience to forecast future courses of action and make corrective decisions. Interviews with the respondents, however, revealed that the 'knowledge' aspect was not being seriously, (if at all), drawn from in forecasting and decision-making, with the result that forecasts remained mere 'foreguesses' while the corrective decisions were reduced to 'corrective trials'. This assertion is underpinned by the review presented in chapter 6 - which showed that effective forecasting and decision-making can best be achieved through the use of scientific quantitative models - and the evidence in tables 7.18 and 7.19 to the effect that practically none of the contractors employed these scientific techniques for their activities.

The evidence in table 7.5 and deductions made therefrom agree largely with views expressed in reviewed literature. It also raised an inexplicable paradox that although contractors were generally aware of the factors that would ensure effective monitoring and control of costs, investigation evidence, (as in tables 7.2, 7.10, 7.12, and 7.18), indicate that these factors were largely not employed in financial management of projects. As a result, cost/schedule overruns have remained a feature of construction
projects, as seen in table 7.2. For instance, despite the high rating accorded organizational structure and communication methods evidence contained in table 7.20 shows that the bulk of contractors, (92%), employed simple command structures on project sites even though these would clearly be unsuitable for the scale of projects that are handled by the Top 100 class of contractors. Furthermore, progressive communication channels can hardly be maintained when simple command structures are used on large scale projects because highly qualified project personnel could get bogged down with trivialities, group disputes, or excessive exchanges with company headoffices.

This situation could impede initiative and full application of an employee's knowledge. For instance, while table 7.19 indicates that most contractors were not aware of the scientific methods for forecasting, the follow-up interviews with some respondents revealed that most of them have learnt these techniques as part of their training but have not considered using them because their companies neither introduced them nor encouraged such "adventures". This assertion of the respondents also agrees with the data in table 7.18. Most of the respondents believed that the success levels in tables 7.1 and 7.2 would be favourably different if a more "forward-looking" scientific approach were adopted for cost monitoring and control on sites.

7.3.3 Performance Models

The theoretical cost monitoring and control approach reviewed in chapters 3 & 4 has identified the significance and types of performance models that need to be established prior to the start of site operations on a construction project. The issues raised in the review made it pertinent to find out the current approach with regard to performance models, including the contractors' assessment of the contribution of the models to effective cost monitoring and control on sites. Questions 2.4, 2.5, 3.5, 3.6, 5, 7, 8, and 9 of Appendix I addressed the salient matters on the role of performance models in cost control.

The contractors were asked to identify the models that were normally established before commencing site operations. Table
7.6 gives the responses and shows that most of the contractors named construction schedule, construction budget and schedule of expected revenue as the most important pre-requisites to work commencement.

Table 7.6: Guiding Performance Models for Cost Control

<table>
<thead>
<tr>
<th>Performance Model</th>
<th>Response In %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction Schedule</td>
<td>92</td>
</tr>
<tr>
<td>Construction Budget</td>
<td>92</td>
</tr>
<tr>
<td>Cost Curves</td>
<td>20</td>
</tr>
<tr>
<td>Schedule of Expected Revenue</td>
<td>80</td>
</tr>
<tr>
<td>Production Curves</td>
<td>12</td>
</tr>
<tr>
<td>Schedule of Values Curves</td>
<td>16</td>
</tr>
<tr>
<td>Cash Requirement Curves</td>
<td>24</td>
</tr>
</tbody>
</table>

The contractors were asked to rank the performance models in order of their importance as cost control tools in general. The responses are given in table 7.7 with the ranks having been adjusted for tied ranks. It is shown on the table that \( S = 10640.37, K = 25, N = 7 \) and \( \Sigma T = 74.5 \). From equation 7.1 these values lead to \( W = 0.6804 \). When this value of \( W \) was tested as earlier described, it was found that \( \chi^2 = 102.06, \text{ df} = 6, \text{ and } P < 0.001 \). This enables us to reject the null hypothesis at the 1% level of significance and to conclude that there was considerable agreement in the ranking among the contractors, and that the degree of agreement was higher than would occur by chance.

Following Siegel’s suggestion the true ranking has been derived, as shown on table 7.7, and showed that construction schedule, construction budget, cost curves and schedule of expected revenue, in that order, were the most significant models for cost monitoring and control. This ranking generally agrees with the notion of significance of the models as presented in the theoretical approach reviewed in chapters 3 & 4. It was revealed during the interviews (by 80% of the interviewees) that the prominence of construction schedule over budget resulted from the fact that schedule overruns almost invariably resulted in cost overruns.
Table 7.7: Significance Ranking of Performance Models for Cost Monitoring and Control

| MODELS | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|--------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Programme | 1.5 | 1.5 | 1 | 1.5 | 1.5 | 1.5 | 1 | 1 | 1 | 4 | 6 | 2 | 1 | 2 | 1 | 2 | 1.5 | 1.5 | 1.5 | 2.5 | 1.5 | 1 | 1.5 | 1.5 |
| Budget | 1.5 | 1.5 | 2.5 | 1.5 | 1.5 | 1.5 | 1.5 | 5 | 1 | 2 | 1 | 1.5 | 1.5 | 1.5 | 4 | 1.5 | 2 | 1.5 | 1.5 |
| Cost curves | 3.5 | 5 | 2.5 | 5 | 4.5 | 3 | 2 | 3 | 5.5 | 2 | 3.5 | 3.5 | 3 | 2.5 | 3 | 5.5 | 3 | 3.5 |
| Sched. of rev. | 3.5 | 5 | 4.5 | 5 | 3.5 | 3.5 | 3 | 6 | 4.5 | 3 | 5 | 4 | 5.5 | 3 | 5.5 | 3.5 | 4.5 | 5 | 5.5 | 4.5 | 5 | 3.5 |
| Prodn. curves | 5 | 5 | 4.5 | 5 | 5.5 | 5.5 | 5 | 5 | 4.5 | 6.5 | 7 | 2 | 3 | 7 | 5.5 | 6 | 5 | 5.5 | 5.5 | 4.5 | 1 | 4.5 | 5.5 | 4.5 | 5 |
| Sched. of val. | 6.5 | 5 | 6 | 5 | 5.5 | 5.5 | 5 | 5 | 3 | 6 | 6.5 | 2 | 6 | 5.5 | 3 | 5.5 | 3 | 5 | 5.5 | 5.5 | 6 | 6.5 | 5.5 | 6.5 | 6 |
| Cash reqs. | 6.5 | 5 | 7 | 5 | 7 | 7 | 7 | 7 | 7 | 5 | 6 | 6 | 5.5 | 6 | 5.5 | 6 | 6 | 7 | 7 | 7 | 6.5 | 6.5 | 5.5 | 6.5 | 7 |
| $T_i$ | 1.5 | 0.5 | 1 | 10.5 | 1.5 | 1.5 | 1.5 | 0 | 1 | 0.5 | 2 | 2 | 5 | 0 | 5 | 2 | 10 | 1.5 | 1.5 | 1 | 1 | 1.5 | 10 | 1.5 | 1 |

$\Sigma T_i = 74.5$

<table>
<thead>
<tr>
<th>[M=99.6]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_j$</td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td>43.5</td>
</tr>
<tr>
<td>48</td>
</tr>
<tr>
<td>90.5</td>
</tr>
<tr>
<td>108</td>
</tr>
<tr>
<td>118</td>
</tr>
<tr>
<td>132</td>
</tr>
<tr>
<td>156</td>
</tr>
<tr>
<td>697</td>
</tr>
</tbody>
</table>
Budgeting

When asked to identify the most suitable budgeting approach for use on construction projects, 68% of the contractors named PPBS, while 28% preferred a combination of PPBS and zero-base budgeting, (see table 7.8 where the responses are expressed as percentages).

Table 7.8 shows that none of the companies considered zero-base budgeting approach to be (alone) suitable for construction projects. One company identified its budgeting approach as 'independent site-based' but was found, during the follow-up interview, to actually be adopting some modification of PPBS. The response shown in table 7.8 generally agrees with the views reported in chapter 4.

The main philosophy governing the formulation of construction budgets, (see table 7.9), was found to be a combination of the companies' experience of fair values of goods and services, and current market values of such goods and services. Only 8% of the companies relied solely on their past experience to formulate project budgets. Again this shows that in matters of selecting and formulating appropriate performance models, contractors' practices generally appeared to be in agreement the standards expected in reviewed literature.

Table 7.8: Favoured Budgeting Systems

<table>
<thead>
<tr>
<th>Budgeting System</th>
<th>Response in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>PPBS</td>
<td>68</td>
</tr>
<tr>
<td>Zero-base Budgeting</td>
<td>0</td>
</tr>
<tr>
<td>Combined PPBS and Zero-base</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 7.9: Favoured Basis of Project Estimating

<table>
<thead>
<tr>
<th>Basis</th>
<th>Response in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Market Values</td>
<td>24</td>
</tr>
<tr>
<td>Experienced-based Fair Values</td>
<td>8</td>
</tr>
<tr>
<td>Combined Market and Fair Values</td>
<td>68</td>
</tr>
</tbody>
</table>
It was pointed out in *chapter 4* that formats in which certain monitoring and control activities on site are carried out could significantly affect the success and effectiveness of the activities. Accordingly the contractors were requested to identify the formats in which they carried out estimating, budgeting, performance recording and reporting, and storage of cost and performance data. Their responses, expressed as percentages, are shown on table 7.10. It reveals that work sections, functional elements and ganging are not popular formats for these cost monitoring activities. The most popular formats were found to be subcontract packages, company cost codes, operational packages, resource-based coding and trades. It is also evident from the table that none of the companies stuck to one particular format for its projects as each of the popular formats had a high percentage of respondents employing it for the various activities.

<table>
<thead>
<tr>
<th>FORMATS</th>
<th>ACTIVITIES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimating</td>
</tr>
<tr>
<td>Trades</td>
<td>52</td>
</tr>
<tr>
<td>Operations</td>
<td>56</td>
</tr>
<tr>
<td>Work sections</td>
<td>4</td>
</tr>
<tr>
<td>Functional elements</td>
<td>8</td>
</tr>
<tr>
<td>Gang activities</td>
<td>4</td>
</tr>
<tr>
<td>Subcontract packages</td>
<td>80</td>
</tr>
<tr>
<td>Company's cost codes</td>
<td>44</td>
</tr>
<tr>
<td>Individual resources</td>
<td>72</td>
</tr>
</tbody>
</table>

It was revealed during the follow-up interviews that the format adopted for any given project varied according to such factors as nature of project, type of contract, amount of pre-construction information available, preferences of project team, e.t.c.. While varying formats for cost monitoring activities might have some other advantages towards managing specific projects, it could hinder easy and quick utilization of information and experiences.
from other projects, managed under different formats, to make corrective decisions on an on-going project.

Perhaps the most significant evidence from table 7.10 was the lack of uniformity in the response levels for any of the formats through the various activities. This means that, though there might be considerable coordination of formats between various cost monitoring activities, the coordination was not maintained through all the activities, (as confirmed by the evidence of item 2.5 in tables 7.1 and 7.2). The obvious significance of this lack of coordination is to elongate ITT as a result of processing and re-processing of information whenever it is passed from one activity to another. For instance, it was revealed during the interviews that although there was a good degree of format coordination, the form in which raw cost data, such as invoices and time-sheets for labour and equipment, was posted to their respective centres for processing, utilization and storage was not suitable for timely cost control. The reason was found to be that the form of such information was always intended for accounting purposes and cycles which were in most cases different from the requirements for timely monitoring and control.

Roles of Personnel

Other issues that were advocated in literature to be significant to effective cost monitoring and control of construction projects were participatory approach to preparation of performance models, and advance knowledge by line-staff of their expected cost, schedule and production targets. Thus, the contractors were requested to identify from a range of possible designations, those project personnel that partake in preparing construction programmes and budgets. They were also required to name the designation of other personnel that contributed to programming and budgeting but which were not listed on the questionnaire. The responses are given in table 7.11, (items 3.5 and 3.6). It shows that in most companies programming was done by project managers with input from the headoffices, while only 44% of companies involved the site engineer. Also project budgeting was found to be mainly done by project managers, with 56% of
the companies allowing the participation of project quantity surveyors who were never consulted at the programming stage.

An important revelation from table 7.11 was that none of the companies claimed to involve foremen in preparing programmes and budgets. It was found during the interviews that in most firms the designations 'project manager' and 'site manager' were interchangeable. The 'other' designations, (planners, estimators, & building engineers), were either based at head offices or under the supervision of site engineers. Thus table 7.11 was revised to table 7.12 to give a clearer picture of the responses.

Table 7.11: Role of Personnel in Cost Monitoring & Control

<table>
<thead>
<tr>
<th>Responsibilities</th>
<th>Project</th>
<th>Site</th>
<th>Site</th>
<th>Site</th>
<th>Head</th>
<th>Lines</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mangr.</td>
<td>Mangr.</td>
<td>Engr.</td>
<td>Q.Sr.</td>
<td>Office</td>
<td>Foremen</td>
<td></td>
</tr>
<tr>
<td>3.1 Performance recording</td>
<td>16</td>
<td>28</td>
<td>60</td>
<td>32</td>
<td>0</td>
<td>60</td>
<td>8</td>
</tr>
<tr>
<td>3.2 Processing recorded data</td>
<td>28</td>
<td>12</td>
<td>52</td>
<td>60</td>
<td>16</td>
<td>0</td>
<td>8</td>
</tr>
<tr>
<td>3.3 Performance evaluation</td>
<td>52</td>
<td>8</td>
<td>32</td>
<td>52</td>
<td>52</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>3.4 Making corrective decsion.</td>
<td>80</td>
<td>20</td>
<td>4</td>
<td>8</td>
<td>72</td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>3.5 Construction scheduling</td>
<td>76</td>
<td>8</td>
<td>44</td>
<td>0</td>
<td>64</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>3.6 Construction budgeting</td>
<td>68</td>
<td>8</td>
<td>8</td>
<td>56</td>
<td>12</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>3.7 Expenditure on cost code</td>
<td>80</td>
<td>12</td>
<td>8</td>
<td>4</td>
<td>56</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>3.8 Prof. &amp; cost control</td>
<td>76</td>
<td>28</td>
<td>56</td>
<td>64</td>
<td>4</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>3.9 New methods/investments</td>
<td>64</td>
<td>4</td>
<td>0</td>
<td>4</td>
<td>76</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 7.12: Role of Personnel in Cost Monitoring and Control (revised)

<table>
<thead>
<tr>
<th>Responsibilities</th>
<th>Project</th>
<th>Site</th>
<th>Site</th>
<th>Site</th>
<th>Head</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mangr.</td>
<td>Engr.</td>
<td>Q.Sr.</td>
<td>Office</td>
<td>Foremen</td>
<td></td>
</tr>
<tr>
<td>3.1 Performance recording</td>
<td>44</td>
<td>64</td>
<td>36</td>
<td>0</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>3.2 Processing recorded data</td>
<td>40</td>
<td>56</td>
<td>64</td>
<td>16</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3.3 Performance evaluation</td>
<td>60</td>
<td>36</td>
<td>52</td>
<td>52</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3.4 Making corrective decsion.</td>
<td>100</td>
<td>8</td>
<td>8</td>
<td>72</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3.5 Construction scheduling</td>
<td>84</td>
<td>44</td>
<td>0</td>
<td>88</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3.6 Construction budgeting</td>
<td>76</td>
<td>8</td>
<td>56</td>
<td>28</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3.7 Expenditure on cost code</td>
<td>100</td>
<td>28</td>
<td>28</td>
<td>20</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>3.8 Prof. and cost control</td>
<td>96</td>
<td>24</td>
<td>24</td>
<td>16</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>3.9 New methods/investments</td>
<td>68</td>
<td>0</td>
<td>4</td>
<td>80</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
The evidence of tables 7.11 and 7.12 indicate that contractors did not appear to appreciate the need to widely involve project personnel in setting goals even though these persons were to be directly responsible for realizing the goals. Furthermore it was revealed, (see item 2.4 in tables 7.11 and 7.12), that only 4% to 12% of companies cared to *always* let foremen have advance knowledge of their expected targets, while 68% *never* provided such advance knowledge at all. In the light of these revelations it seems little wonder that such dismal record of success in cost control was achieved by the contractors, as reported in section 7.3.2 above. Since these lapses are a human-cum-management problem it can only be hoped that, (through improved training of personnel), contractors will realize the need for participation in goal setting and declassifying of performance targets.

### 7.3.4 Performance Measurement

The components of cost monitoring on construction sites were identified in reviewed literature as the capture, processing and evaluation of performance information. It was also pointed out that the time taken to complete these tasks for any given construction operation plays a major role in determining whether or not the cost of that operation, and by extension the whole project, will be effectively controlled. Consequently the survey sought to know the current practice of performance measurement so that it could be analysed to find areas that need improvement. Questions 3.1, 3.2, 3.3, 10, 11, 12, 13, and 14 of Appendix I have addressed the salient aspects of performance measurement on construction sites.

#### Data Capture

The contractors were requested to indicate the method(s) they employed to record actual performance on site by ticking among the three methods discussed in *chapter 4* and or naming any other method used but which was not included in the three. The response, expressed as percentages, is shown in table 7.13 and indicates that 92% of the companies used designed forms to record performance data. Only 16% of the companies used
computer turn-around documents. Thus designed forms/cards were overwhelmingly more popular.

Table 7.13: Performance Recording Methods

<table>
<thead>
<tr>
<th>Recording Method</th>
<th>Response in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designed forms</td>
<td>92</td>
</tr>
<tr>
<td>Graphical Methods</td>
<td>36</td>
</tr>
<tr>
<td>Computer Turn-around forms</td>
<td>16</td>
</tr>
</tbody>
</table>

The contractors were then required to rank various possible reasons/advantages for preferring the method they ticked in table 7.13. The responses are shown in table 7.14 with the ranks having been adjusted for tied ranks. It is shown in the table that $S = 32687.06$, $K = 25$, $N = 11$ and $\sum T = 322$. From equation 7.1 these values lead to $W = 0.5385$. When this value of $W$ was tested as earlier described, it was found that $\chi^2 = 134.63$, $df = 10$, and $P < 0.001$. This enables us to reject the null hypothesis at the 1% level of significance and to conclude that there was considerable agreement in the ranking among the companies and that the degree of agreement was higher than would occur by chance.

Following Siegel's suggestion the true ranking has been derived, as shown in table 7.14, and revealed that the most important reasons for the popularity of designed forms or cards with the contractors were ease of understanding, simplicity, precision in identifying sources of deviations, cheapness, and ease of clerical processing, in that order. Incidentally the ability to handle large amount of data, lower possibility of errors and system integration which were some of the key advantages of computer turn-around documents, were regarded as the least important considerations by the contractors. The evidence in table 7.14 will be significant in informing the factors to consider when recommending the data capture system to use with the approach to cost monitoring and control proposed by this research.

During the interviews most companies insisted that their apathy toward the computer turn-around form was not reactionary, but mainly due to the same reasons and disadvantages mentioned in
Chapter 4. Another reason was the inadequate involvement of computers in planning and scheduling, which would result in additional time and effort being required to manually transform prepared plans and programmes on the computer in order to enable the generation of the necessary turnaround document. Yet most contractors admitted that in any case the cards were more familiar and convenient because "they've been with us since".

196
Table 7.14: Significance Ranking of Criteria for choosing Data Capture Methods

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<tr>
<th>Criteria</th>
<th>1</th>
<th>2</th>
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</table>

Ri = (Ri - M)^2 / M
Roles of Personnel

Contrary to the approach advocated in literature - namely that foremen who are directly in charge at the operational level should be principally responsible for data capture - it was found, (see item 3.1 on tables 7.11 and 7.12), that in practice site engineers tend to be involved in data capture more than the foremen. In 44% of the companies even project managers were not left out of the recording task. The involvement of quantity surveyors, (in 36% of companies), was mainly attributed to their role in measuring works in place, dayworks and the like.

This scenario can not be the most suitable for cost control of construction projects. While it is completely unnecessary for the project managers to be involved in line activities, the role of site engineers in such activities would, at best, be expected to be limited to random checks on the line staff to improve propriety and ensure adherence to desired procedures. Indeed the picture painted by tables 7.11 and 7.12 is that key project personnel and, to a large extent, the headoffices of the companies do not seem to have specific roles as they meddled in almost every task. This situation could result in tasks being done unsatisfactorily, and could be partly responsible for the dismal record revealed in tables 7.1 and 7.2.

Data Processing

Data processing was found to be carried out mainly by site engineers and quantity surveyors, with 44% of the companies involving project managers. Only 16% of companies allowed headoffices to meddle in this task. Although the involvement of project managers and headoffices in data processing may not be commendable for earlier stated reasons, the predominance of site engineers and quantity surveyors on this task is hard to fault.

Performance Evaluation

Despite the identified shortcomings of profit and loss accounts and direct comparison methods of performance evaluation, they were found to be the most favoured methods among the
contractors surveyed, (see table 7.15). Only 4% and 8% of the
companies cared to compute and analyse performance ratios and
performance variances respectively as a means of detecting
deviations between plans and performances. It was revealed
during the interviews, and as evident from the high degree of
involvement of headoffices (see item 3.3 of tables 7.11 and 7.12),
that this situation resulted from an excessive involvement of
accounting departments in performance evaluation. This would
explain the predominant use of accounting-based methods for
the performance evaluation. Another reason was found to be, as
mentioned earlier, the lack of format compatibility between the
processed information and the plans or standards with which it
was to be compared. Some of the consequences of this situation
were found to be that the results of such evaluations were mostly
too late to lead to timely corrective decisions and actions on the
affected operations, and that such results often failed to indicate
precisely which construction operation needed to be 'corrected'
to conform to plans.

Table 7.15: Methods of Detecting Deviations

<table>
<thead>
<tr>
<th>Detection Method</th>
<th>Response in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct comparison</td>
<td>92</td>
</tr>
<tr>
<td>Analysis of performance ratios</td>
<td>4</td>
</tr>
<tr>
<td>Analysis of performance variances</td>
<td>8</td>
</tr>
<tr>
<td>Profit and loss analysis</td>
<td>88</td>
</tr>
</tbody>
</table>

The contractors were asked to rank various basis for detecting
deviations between standards and achieved performance. Table
7.16 gives the response with the ranks having been adjusted for
tied ranks. It is shown in the table that $S = 6874.37$, $K = 25$, $N = 7$ and $\sum T = 29.5$. From equation 7.1 these values lead to $W = 0.4102$. When this value of $W$ was tested as earlier described, it was found that $\chi^2 = 61.53$, $df = 6$ and $P < 0.001$. This enables us
to reject the null hypothesis at the 1% level of significance, and
to conclude that there was considerable agreement in the
ranking among the companies, and that the degree of agreement
was higher than would occur by chance.
Table 7.16: Significance Ranking of Various Basis for Detecting Deviations between Schedule/Budget and Performances

| Basis            | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  | 15  | 16  | 17  | 18  | 19  | 20  | 21  | 22  | 23  | 24  | 25  | Rj  | (Rj·M)² | R  |
|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Co. cost syst.  | 7   | 5   | 7   | 2   | 7   | 7   | 6   | 6.5 | 1   | 4   | 2   | 6.5 | 5   | 1   | 7   | 5   | 7   | 7   | 6   | 7   | 6   | 4   | 6   | 6   | 6   | 135 | 1149.21 | 6  |
| Proj. cost syst | 6   | 1   | 6   | 4.5 | 6   | 6   | 6   | 6.5 | 4   | 6   | 1   | 6.5 | 3   | 5   | 1   | 4   | 5.5 | 6   | 5   | 5   | 5   | 3   | 5   | 6   | 129 | 778.41  | 5  |
| Tender est.     | 4   | 4   | 4   | 4.5 | 3   | 4   | 4   | 1   | 3   | 5   | 2   | 6   | 3   | 2   | 5   | 2   | 3   | 3.5 | 3.5 | 3.5 | 3.5 | 5   | 3.5 | 3.5 | 89  | 149.41  | 3  |
| Priced BOQs     | 4   | 6   | 3   | 2   | 4   | 3   | 3   | 6   | 4   | 2.5 | 3   | 7   | 4   | 4   | 5   | 3   | 2   | 3.5 | 3.5 | 3.5 | 3.5 | 3.5 | 6   | 3.5 | 3.5 | 96  | 26.01   | 4  |
| Constr prog     | 1.5 | 2   | 1.5 | 2   | 1.5 | 1.5 | 1.5 | 2   | 1.5 | 2.5 | 5   | 3   | 2   | 1   | 5   | 4   | 1   | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 2   | 1.5 | 1.5 | 51  | 2510.01 | 1  |
| Proj. budget    | 1.5 | 3   | 1.5 | 6.5 | 1.5 | 1.5 | 1.5 | 3   | 1.5 | 6   | 7   | 4   | 1   | 6   | 2   | 5   | 6.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1   | 1.5 | 1.5 | 70.5 | 936.36  | 2  |
| Cost/rev curve  | 4   | 7   | 5   | 6.5 | 5   | 5   | 5   | 4   | 5   | 7   | 1   | 5   | 5   | 7   | 5   | 6   | 6.5 | 5.5 | 5   | 7   | 6   | 7   | 7   | 6   | 137 | 1324.96 | 7  |
| Tj              | 2.5 | 0   | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 2   | 1   | 0.5 | 0   | 0   | 0.5 | 0   | 10  | 0   | 0.5 | 1.5 | 1   | 1   | 1   | 1   | 0   | 1   | 1   | 708 | 6874.37 |    |

\[ \sum T_j = 29.5 \]
Following Siegel's suggestion the 'true' ranking was derived, as shown in table 7.16, and revealed that contract programme, project budget, tender estimate and priced bills of quantities, in that order were judged as the most important basis for detecting deviations between standards and performance on construction projects. This ranking appear to be in general agreement with reviewed literature in chapter 4.

Information Turn-around Time (ITT)

To assess the efficiency of the cost monitoring cycle occasioned by the prevailing approach(es) to performance measurement, the contractors were requested to indicate the range of time it took site management to receive feedback from line-staff after operational instructions were issued. The response, expressed as percentages, is given in table 7.17 and shows that only 28% of the companies had an ITT of \( \leq 7 \) days, while 21% of them never received feedback earlier than 21 days. Meanwhile 80% of contractors interviewed were of the opinion that an ITT \( \leq 3 \) days would be more desirable for most kinds of construction operations if expenditure on the operations was to be effectively controlled.

Table 7.17: Information Turnaround Time (ITT)

<table>
<thead>
<tr>
<th>Range of ITT</th>
<th>Response in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not more than 2 days</td>
<td>8</td>
</tr>
<tr>
<td>3 to 7 days</td>
<td>20</td>
</tr>
<tr>
<td>8 to 14 days</td>
<td>24</td>
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<td>15 to 21 days</td>
<td>36</td>
</tr>
<tr>
<td>More than 21 days</td>
<td>12</td>
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</tbody>
</table>

Comparison of tables 7.2 and 7.17 shows a considerable degree of correlation between the percentage of firms that claimed never to have experienced cost overruns and those who claimed to have an ITT \( \leq 7 \) days. Furthermore most of the project staff interviewed believed that they could be able to alter the course of operations to a more financially favourable direction if they
could get results of performance evaluations in "good enough" time while the operation was actually proceeding.

7.3.5 Decision Making

All the control models discussed in chapter 3 have advocated rational approaches to corrective decision-making once it is discovered that plans are being deviated from; which discovery would have been made from the performance evaluation reports. Most importantly, the models stressed that control can only be effective when future courses of action could be predicted and altered while the affected operations are still going on. In order to find out the current approach to making corrective decisions, the companies were requested to indicate their usual basis for making and implementing such decisions. The response, shown in table 7.18 expressed as percentages, revealed that virtually all the contractors relied on experience and personal intuition and judgement to make corrective decisions. Twelve percent of the contractors even admitted to employing trial and error.

Table 7.18: Basis for Corrective Decisions

<table>
<thead>
<tr>
<th>Basis</th>
<th>Response in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Past experience</td>
<td>92</td>
</tr>
<tr>
<td>Trial and error</td>
<td>12</td>
</tr>
<tr>
<td>Personal intuition and judgement</td>
<td>72</td>
</tr>
<tr>
<td>Use of scientific models</td>
<td>12</td>
</tr>
</tbody>
</table>

Twelve percent of the contractors claimed to employ scientific management techniques to arrive at corrective decisions but the claims were later found to be inaccurate because the methods used by the claimants; namely CPM, Computer-aided Project Management System and HORNET Project Control; are not decision-making tools as defined by the context in chapter 6. While CPM is principally a scheduling technique, the others are, at best, budgetary control systems in a strictly accounting sense because they are not anticipatory. The evidence of table 7.18 means the conclusion by Mu'azu (1982) that "intuition and guess-work are the hallmark of the construction industry" is still
valid ten years after it was made! It is, thus, little wonder that when requested to rank various forecasting methods in order of suitability for cost/schedule control, 100% of the companies identified personal judgement as the most suitable method. The response of the companies, given in table 7.19, indicated either a lack of awareness by the contractors of other, (quantitative-based), forecasting methods, or the contractors have not applied such methods and so could not (objectively) rank them. The follow-up interview confirmed that none of the interviewees had used the methods on construction projects, and of 30% who claimed to "know" the methods none ever considered applying them for reasons such as:

1. Lack of a precedent in the company.
2. Lack of coordinated software.
3. Lack of time to develop the methods.

In the light of this revelation it was considered unnecessary to carry the analysis of the evidence in table 7.19 further than what is shown in the table.

Another insight into the process of corrective decision-making is obtained from tables 7.1 and 7.2, (items 2.6 and 2.7), which show that only 28% of the contractors attempted feedforward control, though only based on the personal intuition of project managers. While as much as 60% of the contractors had never attempted feedforward control, 72% of them always relied on feedback data to make corrective decisions. In the light of the theories discussed in chapter 3 this situation could clearly not be conducive for effective cost control. Comparison of items 2.1, 2.2, and 2.7 on table 7.2 reveals a suggestive match between the percentage of contractors that always suffered cost overruns and the percentage of those that never used predictions of future performance as basis for corrective decisions.
Table 7.19: Suitability Ranking of Forecasting Methods for Cost/Schedule Control on Construction Projects

| Methods          | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 |
|------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| Judgement        | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 25.5 | 3806.89 | 1 |
| Time-series      | 4 | 1.5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 2 | 4 | 3 | 4 | 4 | 4 | 4 | 2 | 2 | 4 | 4 | 2 | 4 | 86.5 | 0.49 | 2 |
| Regression       | 4 | 4.5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4.5 | 4 | 2 | 4 | 4 | 4 | 4 | 3 | 3 | 4 | 3 | 4 | 4.5 | 4 | 94.5 | 53.29 | 3 |
| Econometrics     | 4 | 4.5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4.5 | 4 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 5 | 4 | 4.5 | 4 | 105 | 334.89 | 5 |
| Other models     | 4 | 4.5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4.5 | 4 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 5 | 4 | 4.5 | 4 | 105 | 334.89 | 5 |
| Trend Extrapt    | 4 | 4.5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4.5 | 4 | 5 | 4 | 4 | 4 | 4 | 5 | 5 | 4 | 5 | 4 | 4.5 | 4 | 105 | 334.89 | 5 |
| $T_i$            | 10 | 5.5 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 2 | 10 | 10 | 10 | 10 | 2 | 2 | 10 | 2 | 10 | 5 | 10 | 523 | 4865.34 |

$\sum T_i = 203.5$
During the follow-up interview most contractors said though the idea of feedforward control was most appealing they could not pursue it because performance information was always too late to allow useful predictions on the affected operations. Most often the operations were completed before the feedback got to the project management team who made corrective decisions.

With regard to responsibility for making corrective decisions, (see item 3.4 in tables 7.11 and 7.12), it was found that project managers always made such decisions, with 72% of companies allowing inputs from headoffice departments. While this accords with theoretical views given in chapters 3 & 4, the practical non-involvement of key project personnel such as engineers, quantity surveyors and lines foremen can not be regarded as favourable to making realistic decisions. Furthermore the great reliance of control decisions on inputs from headoffices, which are essentially outside the immediate project environment, renders the control systems into open-loops, (see chapter 3), which were shown to be unsuitable for control of construction costs because of the possibility of delayed corrective decisions, in addition to the possibility of the decisions being unrealistic. This situation would appear to make a strong case for more autonomy to project management teams on sites than was found to currently obtain.

7.3.6 Organizational and Responsibility Structures

In view of the identified significance of organizational types and responsibility structures to effective cost monitoring and control on construction sites, the contractors were requested to identify their most common form of site organizations and the personnel accountable for various financial matters concerned with their projects. Table 7.20 gives the response in respect of favoured organizational types, and indicates that despite the fact that the respondents represented large construction companies in U.K., 92% of them employed simple command types of organizational structures on sites. Very few of them claimed to employ other organizational types on site. Considering the experience of this category of contractors, the scale of projects they handle and the
earlier mentioned pros and cons of simple command structures it would seem that the poor record of success in project cost management reported in section 7.3.2 was not unjustified. Although most interviewees subsequently claimed to know the benefits of other organizational types, many could only suggest that "other considerations of company policies" might have inhibited the introduction of these structures.

Table 7.20: Prevailing Organizational Types

<table>
<thead>
<tr>
<th>Organizational Structure</th>
<th>Response in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple command structure</td>
<td>92</td>
</tr>
<tr>
<td>Machine bureaucracy</td>
<td>0</td>
</tr>
<tr>
<td>Professional bureaucracy</td>
<td>12</td>
</tr>
<tr>
<td>Adhocracy</td>
<td>8</td>
</tr>
<tr>
<td>Divisionalised (matrix) form</td>
<td>12</td>
</tr>
</tbody>
</table>

The contractors were also requested to rank the organizational types according to their suitability for project monitoring and cost control. The responses are given in table 7.21 with the ranks having been adjusted for tied ranks. It is shown on the table that $S = 2074.80$, $K = 25$, $N = 5$ and $\Sigma T = 34$. From equation 7.1 these values lead to $W = 0.3842$. A significance test of $W$ carried out as earlier described gave $\chi^2 = 38.42$, $df = 4$, and $P < 0.001$. This enables us to reject the null hypothesis at the 1% level of significance and to conclude that there was considerable agreement in the ranking among the contractors and that the degree of agreement was higher than would occur by chance.

When the true ranking was derived, as shown on table 7.21, it was found that the contractors almost unanimously judged simple command structures as the most suitable for effective project monitoring and cost control. Despite the results of the significance test this ranking cannot be accorded much (if any) credibility not only because of its contradiction with existing knowledge, (see chapter 5), but also due to the earlier revelation that most of the contractors have always used only the simple command structure. Thus, although there is near unanimous
agreement in the ranking, it is not unbiased since most of the respondents have not had the benefit of experiencing the other forms of organization on their projects.

The follow-up interviews revealed that communication on sites was mainly carried out via designed forms, memos, meetings, telex, telephone, e.t.c.. Communication channels were, however, found to be adhoc, unclear and generally ineffective especially at interpersonal levels. Most of the interviewees believed that this situation was due to the "rather fluid" and generally vague nature of responsibility structure on site. Organizational communication channels, however, appeared to be more clearly defined and generally effective.

Responsibility Accounting

On the question of financial responsibilities such as expenditure on cost codes and overall cost control, it was found that project managers were almost entirely accountable in most companies, while in 28% of the companies engineers and quantity surveyors shared in the responsibility, (see items 3.7, 3.8, & 3.9 in tables 7.11 & 7.12). In 20% of the companies headoffices participated in discharging this responsibility even at the risk of pausing a cumbersome obstruction to smooth project management on site. In 80% of the companies headoffices reserved the responsibility for investments and or decisions on new methods or processes of working, with 68% of the companies requiring project managers to participate in such decisions. This picture differs considerably with the views of advocates of responsibility accounting reported in chapter 3. According to such views it would be more helpful to the course of effective cost monitoring and control if more accountability for expenditure on cost codes and overall cost control was assigned to staff down the line.
Table 7.21: Suitability Ranking of Organisational Types for Cost Monitoring and Control

| Structures | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | [M=76.8] |
|------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|---|
| Simple comd. | 1 | 1 | 1 | 1.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1.5 | 1 | 2 | 5 | 2 | 1 | 1 | 1 | Rj | (Rj-M)^2 | R |
| Machn b’cracy | 4 | 4 | 3.5 | 3.5 | 2.5 | 3.5 | 3.5 | 3 | 2 | 3.5 | 4 | 4 | 4 | 3 | 3.5 | 4.5 | 3.5 | 4 | 3.5 | 4.5 | 3.5 | 4 | 2.5 | 89 | 148.84 | 4 |
| Prof. b’cracy | 2.5 | 4 | 2 | 3.5 | 4 | 2 | 2 | 2 | 3.5 | 3.5 | 3 | 4 | 2 | 2 | 3.5 | 4.5 | 3.5 | 3 | 3.5 | 3 | 2 | 1 | 3.5 | 2.5 | 4 | 74 | 7.84 | 2 |
| Adhocracy | 2.5 | 2 | 3.5 | 5 | 2.5 | 3.5 | 3.5 | 5 | 3.5 | 3.5 | 5 | 4 | 4 | 4.5 | 3.5 | 2 | 3.5 | 1.5 | 2 | 1 | 1 | 3 | 3.5 | 2.5 | 2.5 | 78 | 1.44 | 3 |
| Matrix divns. | 5 | 4 | 5 | 1.5 | 5 | 5 | 5 | 4 | 5 | 3.5 | 2 | 2 | 4 | 4.5 | 3.5 | 3 | 3.5 | 5 | 5 | 5 | 3.5 | 4.5 | 3.5 | 5 | 5 | 102 | 635.04 | 5 |
| T_i | 0.5 | 2 | 0.5 | 1 | 0.5 | 0.5 | 0.5 | 0 | 0.5 | 5 | 0 | 2 | 2 | 0.5 | 5 | 0.5 | 5 | 0.5 | 0 | 0.5 | 0.5 | 5 | 0.5 | 0.5 | 384 | 2074.80 |

\[ \sum T_i = 34 \]
7.3.7 Use of Computers

The contractors were asked to assess the impact of the use of computers on their efforts at cost monitoring and control on sites. The response, given in table 7.22, showed that only 32% of the companies believed that computers have made positive contributions to their efforts at cost monitoring and control. A comparison of tables 7.13 and 7.22 reveals that while all the contractors claimed to use computers in their works, only 16% of them used computer-based turn-around document for data capture. Subsequent oral interviews revealed that the computers were mainly used in estimating and accounting departments of the companies.

All the companies who rated the impact of computers as positive identified speedy processing of information, accuracy and neatness as the positive impacts made by the computers. Some respondents claimed lack of sufficient flexibility of their systems as reasons for their negative verdicts, with others having no view because their systems were relatively newly installed.

Table 7.22: Impact of Computers

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Response in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative contribution</td>
<td>16</td>
</tr>
<tr>
<td>Positive contribution</td>
<td>32</td>
</tr>
<tr>
<td>No change</td>
<td>28</td>
</tr>
<tr>
<td>No view</td>
<td>12</td>
</tr>
</tbody>
</table>

The low rating for the impact of computers in cost monitoring and control can be explained by their more general use for estimating and accounting tasks, and the fact (as revealed earlier that virtually none of the contractors employed the scientific management techniques (which are essentially computer-based) for cost monitoring and control on sites.
7.4 The Practical Approach to Cost Monitoring and Control

7.4.1 Overview of the Practical Approach

The findings reported and analysed so far have revealed the practical approach to monitoring and control of construction projects. The essential features and structure of the practical approach are shown in figure 7.1 from which the following components of the model can be identified:

1. Basis for cost monitoring and control, comprising:
   - contractor's functional organization,
   - company's cost system, and
   - project organization.

2. Standards for cost monitoring and control, comprising:
   - tender estimates,
   - priced (contract) bills of quantities,
   - construction schedule,
   - construction budget, and
   - schedule of expected revenue.

3. Performance measurement, comprising:
   - recording actual performance,
   - processing recorded performance, and
   - evaluation of performance data against standards.

4. Making corrective decisions based on a combination of experience, personal intuition and judgement, or trial and error.

The most important aspects of the practical approach to cost monitoring and control revealed in this chapter are that it not only confirms the existence of the problems identified in the review of existing researches on cost control but also identifies and explains the causes of the problems, thus answering the first question posed for this research as a result of the review (see chapter 2). Other aspects of the practical approach along with some consequences of the various aspects of the approach can be deduced from the investigation evidences and analysis presented so far and are summarized in the following deductions.
Figure 7.1: Practical Cost Monitoring & Control Model
7.4.2 Deductions

In the light of existing literature reviewed in foregoing chapters of this thesis, the results and analysis of investigations presented in this chapter lead to the following deductions:

1. That while there may be substantial agreement between contractors' current efforts at cost monitoring and control on sites and the approach advocated in literature the diversion between the two is sufficient to account for the dismal record of success in construction cost management as found in the survey.

2. That a major set-back in the current cost monitoring and control system is its being confused with, and thus being operated as, a budgetary control system in an accounting sense. This resulted in cost overruns being discovered mainly when it was too late to correct them.

3. The degree of consistency and coordination in the formats of performance models could not allow easy, quick and effective exchange of performance information between activities or personnel groups. The consequence was the elongation of ITT as a result of repetitive processing of information at different stages.

4. The degree of involvement of lower to middle level project staff in preparing performance models and the making of corrective decisions was too little to enable the staff make effective contributions towards effective cost monitoring and control because it does not infuse enough feeling of responsibility and accountability.

5. The degree of involvement of staff at headoffices and senior project staff in purely line to middle level functions such as recording and processing performance information on site negatively affected the effectiveness of monitoring and control efforts by elongating the ITT.

6. The preponderance of manual methods for the capture and processing of performance data, despite the enthusiastic rating by the contractors, contributed greatly to the failure of cost monitoring and control efforts by elongating the ITT and limiting amount of detail that can be conveniently
contained in the process documents. Reduced accuracy and suitability for effective communication at all levels are other disadvantages of manual data capture methods that could impede effective cost monitoring and control.

7. The methods used to detect deviations could not possibly pin-point the source of cost overruns and, in any case, never in the desired time to enable necessary changes to be made while the affected operations were in progress.

8. Quantitative models and methods for performance analysis and prediction which could be incorporated into contractors' cost monitoring and control schemes have not received any significant consideration with regard to their applicability on construction projects.

9. Without employing quantitative forecasting and decision-making techniques it was not practicable (if at all possible) to achieve the rational decisions that could be certain to effect correction on erring construction operations. Thus the rationality of corrective decisions arrived at could not be guarantied while future performance levels could not be predicted with any reasonable degree of reliability.

10. The simple command organizational structures employed on sites may not allow effective communication and, thus effective cost monitoring and control, on the scale of projects reported to be handled by the contractors.

11. There was inadequate sharing of responsibilities through the various levels of project personnel to spur the feeling of accountability that was needed for effective cost control.

12. Use of computers in cost monitoring and control was poorly rated because the contractors relied on experience and guess-work instead of using scientific methods that essentially depended on computers.
7.5 Summary

This chapter has described:

1. The research carried out using both written questionnaires and oral interviews with key project personnel concerned with realization of construction projects in contractors' organizations.

2. The manner in which the investigation evidence was analysed both statistically, (for ranked responses), and descriptively with, in both cases, appropriate comparisons being made between results of the analysis and information from literature review as reported in foregoing chapters of the thesis.

3. The results of the investigations and analysis, and how such results would bear on the successful monitoring and control of costs on construction projects.

The results and analysis of investigations presented in section 7.3 have revealed not only the causes and extent of the problem of cost and schedule overruns experienced by contractors on sites, but also the approach of construction companies to monitoring and control of projects. The current practical approach to the various activities that constitute project monitoring and control functions were identified and a summary of the approach was presented in section 7.3. More significantly, the contractors' own assessment of the causes of the problem of, as well as the various factors that affect effective monitoring and control efforts on projects were obtained and have informed the search for an improved alternative approach to the functions.

In addition to the components of the practical approach to cost monitoring and control, (as shown in figure 7.1), the following aspects of the approach were also identified:

1. Site organizational structures are predominantly of simple command types. As a result of this delineations of authority and responsibilities are mostly blurred and often chaotic while channels and methods of communication at the interpersonal level are ad hoc, unclear and generally
ineffective. Accountability and responsibilities are largely concentrated in the hands of senior members of the project management teams and company headoffices.

2. Project personnel responsible for implementing required performance models do not usually have a say in the formulation of the models and, in most cases, do not have prior knowledge of the targets expected of them.

3. Roles of project personnel with regard to key monitoring and control activities are often varied and mixed up as a consequence of the unsuitable organizational structures employed on construction sites.

4. Practice of performance measurement is predominantly based on accounting methods and cycles which results in elongation of information turnaround time and makes control action generally late and ineffective.

5. Corrective decision-making is generally based on feedback information, while decisions are 'calculated' based on the experience and personal judgement, (or guess-work), of project managers.

The investigation evidence analysed in the chapter revealed not only the nature of the practical approach to cost monitoring and control but also the deficiencies of the approach which rendered it generally unsatisfactory and ineffective. The reasons for such deficiencies were also identified with a view to formulating a more effective approach and making recommendations towards an improved practice. While the above aspects of the practical approach significantly contributed to its ineffectiveness, the most important deficiencies were found to be attributable to:

1. Inefficient flow of information due to generally unsuitable organizational structures.
2. Poor coordination of the formats for data acquisition and processing.
3. Excessive meddling and centralized control by company headoffices in purely line and staff functions that should have been more suitably handled on site.
4. Use of unsuitable methods of performance evaluation for detecting deviations between plans and achievements.
5. Use of irrational approaches to making corrective decisions as opposed to scientific methods that are capable of relating decisions to current trends and project goals.

6. Failure to make effective use of computers for the capture, processing and evaluation of performance data.

The results of the investigation coupled with the theoretical approaches reviewed in previous chapters of the thesis have clearly established the need for an improved approach to cost monitoring and control of construction projects by contractors to increase the effectiveness of the process.
CHAPTER EIGHT

A QUANTITATIVE APPROACH TO COST MONITORING AND CONTROL OF CONSTRUCTION PROJECTS

8.1 Introduction
8.2 Criteria for Effective Monitoring and Control
8.3 Proposed Approach to Cost Monitoring and Control
8.4 Analysis of the Proposed Approach
8.5 Summary
A QUANTITATIVE APPROACH TO CONTRACTORS' COST MONITORING AND CONTROL OF CONSTRUCTION PROJECTS

8.1 Introduction

Thus far this research has considered and or identified three approaches to cost monitoring and control of construction projects by contractors, as follows:

1. The theoretical approach as reviewed in chapters 3 & 4.
2. The quantitative approach as reviewed in chapter 6.
3. The practical approach as revealed in chapter 7.

This chapter presents a collation of deduced criteria from the three approaches which are then evaluated to isolate the essential features of an effective cost monitoring and control approach that would eliminate the shortcomings that had earlier been identified with the individual approaches. The cost monitoring and control process as carried out on construction sites is then formulated as a problem whose solution process is proposed by employing the criteria of some of the models and approaches presented earlier in this thesis.

The proposed approach or model, (comprising the formulated cost monitoring and control problem along with the solution process), is then evaluated in terms of its component activities and procedure against theoretical and investigation evidence contained in the previous chapters.

8.2 Criteria for Effective Cost Monitoring and Control

Various approaches and or systems for monitoring and control were identified in the previous chapters of this thesis. Literature review and subsequent investigation evidence from a survey of construction contractors revealed three distinct approaches to cost monitoring and control of construction projects, namely:

1. The theoretical approach which represents the current thinking on cost monitoring and control by construction contractors as contained in construction and related literature and reviewed in chapters 3 and 4.
2. The quantitative approach as advocated by management science and widely applied in manufacturing and other industries, as reviewed in chapter 6.

3. The practical approach as revealed by the evidence from investigations of actual monitoring and control activities carried out by top U.K. construction companies on sites, as reported in chapter 7.

The approaches were defined against a background of reviewed:

1. Theories and systems of cost monitoring and control from management science.
2. Organizational requirements for effective monitoring and control of construction projects.
3. Causes of cost/schedule overruns on construction projects within contractors' organizations.
4. Findings from previous researches into various aspects of cost monitoring and control by construction contractors.

While none of the defined approaches appeared to adequately meet all the requirements for effective monitoring and control functions, each was found to have some vital criteria or aspects that could compliment in proposing an alternative approach that would be designed to eliminate the identified deficiencies of the defined approaches and to ensure more effectiveness in cost monitoring and control of construction projects.

8.2.1 Criteria from Theoretical Approach

The cost monitoring and control approach that was described in chapter 4 was geared, largely, towards effecting the various theories and requirements defined in chapter 3. The essential criteria for effective control outlined in the various theories and systems described in those chapters are, thus, similar and can be summarized as follows:

1. Establishment of comprehensive control standards for all characteristics of the process which are to be controlled, and expressing them in such a manner and format that
would allow easy comparison with subsequent measures of actual performance.

2. Establishment of a comprehensive system of performance measurement in such a manner and format that:
- can be easily understood and applied by all levels of project personnel;
- yields performance measures that can be readily compared with the standards with as little recasting of information as possible;
- enables future levels of performance to be predicted from the measures of current levels of performance.
- generates performance exception reports identifying areas of 'loss' of performance and the exact causes of such loss.

3. Establishing a decision-making module which can evaluate current and predicted levels of performance against the project goals and determines how to correct undesirable performance either in advance, (e.g. feedforward controls), or in future operations, (e.g. feedback controls).

4. Organizational structures on construction sites need to be systematically designed to reflect the type or work content of the project, as well as the responsibilities to be assigned to persons within the project organization. Design of communication channels and responsibility packages need to take into account both objectives and characteristics of the project.

Some of the implications of the above criteria from theoretical approach include:

1. The need for projects to be modeled in such a way that performance goals in respect of the various characteristics to be controlled (e.g. cost, time, quality and output) are separated into discrete units or stages (known as control points) with each assigned a unique code or address that could be used to trace all happenings related to the goal up to its final realization.

2. The need for project personnel to be organized such that each individual is assigned specific and well defined roles
and boundaries for relating with other persons on the project, especially those whose roles directly affect the discharge of his own roles.

3. The need for each performance goal to be assigned to specific persons within the project organization who should be responsible for its realization as well as accountable for all activities related to realizing the goal.

4. The need for the performance measurement system, in addition to assessing what has happened (from feedback data), to explain why it has happened in order to be able to predict what will happen if corrections are not effected. This would require the information cycle that feeds the measurement system to be concurrent with, (and never lagging behind), both the construction process and the evaluation stages of the measurement process, and in any event the cycle in respect of each performance goal needs to run one or more full courses before the component activities of the goal are completed.

Deficiencies of The Theoretical Approach

From the review of available construction literature concerning monitoring and control activities of projects by contractors, the following criticisms of the theoretical approach described would appear to be realistic:

1. The methods advocated for the capture of performance information, (i.e. designed forms, charts and turnaround documents), do not appear to adequately anticipate the requirements of subsequent monitoring and control stages like data processing and performance evaluation. Little, if any, recognition has been made of the need for designing the recording documents to be in tune and or compatible with the requirements for prompt and timely use of the captured data to detect performance deviations and design appropriate corrective actions. The prescribed recording methods are mainly geared towards serving accounting cycles operated by finance departments of construction companies despite the inability of such cycles to always
meet the monitoring and control schedule required for
collection operations. This would appear to explain the
preponderant use (based on the preponderance in the
literature) of accounting-based methods such as profit and
loss accounting and job costing as the means of detecting
deviations between plans and performance. The reliance of
project managers on experience, intuition and personal
judgement, (or guess-work), to make corrective decisions
when performance is not satisfactory, instead of recourse
to more scientifically rational methods could also be due to
the deficiency of the recording and evaluation methods in
operation.

2. Despite the recognition in literature of the need for
monitoring and control systems to be forward-looking and
capable of predicting future happenings and performance
levels on a project, the literature falls short of prescribing
the requirements for and approaches to such predictions.
For instance, neither the suitable data cast for forecasting
nor the forecasting methods appropriate for construction
projects appear to have been clearly identified or defined.
The possibility of employing quantitative management
techniques for performance analysis and predictions on
construction projects does not appear to have received any
significant consideration. Consequently future performance
levels could not be predicted with any reasonable degree
of reliability based on the theoretical approach, and the
rationality of corrective decisions (arrived at via guess-
work) could not be guarantied.

8.2.2 Criteria from Practical Approach

The practical approach to cost monitoring and control revealed
in chapter 7 is considerably similar to the procedure advocated
in literature. Consequently, the implications, deficiencies and the
criteria of the practical approach are similar to those identified
with the theoretical approach. In addition to these the practical
approach has other aspects, as indicated in section 7.4, which
further impede its effectiveness in cost monitoring and control of construction projects, and these aspects include:

1. Use of unsuitable organizational structures which not only make effective communication and control difficult but which also generally failed to relate to responsibility and accountability modules of the projects.
2. Lack of adequate involvement of lower to middle levels of project staff in performance modelling.
3. As a consequence of 1 above, line and intermediate project personnel are not made accountable for performance at their levels of activities.
4. Unsuitable approach to performance evaluation as a result of the excessive reliance on purely accounting methods and cycles for data capture, processing and evaluation. This led to inability to pin-point the causes of performance deviations, and to explain and predict respectively current and future levels of performance.
5. Failure to base corrective decisions on rational projections of future performance levels. This resulted from failure to employ quantitative techniques to carry out thorough post-mortems of data on current performance.

8.2.3 Criteria from Quantitative Models

The application of quantitative management principles for the cost monitoring and control of any given system, including construction projects, was shown to require:

1. Defining the objectives of the system (i.e. project) such as total and operational budgets and schedules.
2. Identifying the system variables and determining how they relate to one another and to the objectives of the system.
3. Formulating the system process as a quantitative problem consisting of identified system variables and the defined objectives of the system.
4. Designing required structure of data to be gathered from the system operations in order to fit a solution process of the formulated problem.
5. Designing a solution process to generate explanatory and predictive reports concerning current and future states of the system operations as well as to prescribe appropriate courses of action that would ensure achieving the defined objectives of the system.

8.3 Proposed Approach for Cost Monitoring and Control

The essence of the alternative cost monitoring and control approach proposed in this section is to combine the identified elements or criteria for good practice in monitoring and control as defined in construction and management literature as well as the gathered investigation evidence to provide a more effective procedure divested of the identified deficiencies of the various approaches discussed earlier. While the cost control activities of contractors can be said to commence pre-tender when the first estimates of a project's costs are made, the critical monitoring and control activities that could make or mar the success of the contractor are carried out post-contract and, specifically, during construction operations. Accordingly the proposal made by this research concentrates on designing a procedure for executing monitoring and control activities at the level of site operational stages of the project. The proposal assumes a project for which comprehensive performance models were prepared according to the principles described in chapters 3 and 4.

Starting with a definition of the cost monitoring and control problem on construction projects, the proposed approach formulates a model of such a problem in the form of a logically coordinated procedure that can be realized using some of the quantitative management models discussed in chapter 6. The solution process for the formulated model is then prescribed along with an outline of how to implement the proposals on a typical construction project.
8.3.1 Problem Definition

The cost monitoring and control problem of construction companies can be stated as:

Procuring, organizing and or assembling all the necessary resources required for, and executing all the necessary operations in such a manner as to realize the completion of a project of a specified quality within a specified period and at a cost that would guarantee a planned profit margin to be made by the company.

This definition immediately reveals the essential objectives of a construction project as:

1. Meeting a required schedule; i.e. Time.
2. Meeting a required budget; i.e. Cost and Profit.
3. Meeting a required output of finished work; i.e. Production.
4. Meeting a required quality standard; i.e. Quality Control.

Some of the implications of the above problem include:

1. Establishing suitable standards or performance models to guide the execution of the project.
2. Designing a suitable performance measurement and control system to guide the implementation of the performance models, and this in turn requires:
   - a comprehensive system of performance data capture;
   - a prompt data processing system compatible with the structure and cycles of the data capture system; and
   - a performance prediction and optimization system that would employ the processed performance data to direct subsequent activities on the project towards desired objectives.

As a contribution towards solving the defined problem in a more effective and scientifically rational manner the proposed model addresses the second implication of the problem (No. 2 above) with a view to ensure the realization of the first three objectives defined above. The fourth objective is a matter for quality control.
engineers whose activities on site concern the interpreting and administering of project specifications.

8.3.2 Problem Formulation

Verification

From the outline of possible applications of quantitative models on construction projects given in chapter 6 it is clear that the first step in a quantitative formulation of the cost monitoring and control problem is to identify the variables that influence the realization of the system objectives. These variables, in the case of construction projects, were identified in figure 4.1. Table 8.1 shows the variables (or resources) that influence each of the three defined objectives addressed by the proposed approach.

Table 8.1: Verification of Construction Objectives against Resource Variables

<table>
<thead>
<tr>
<th>Resources (Variables)</th>
<th>SYSTEM OBJECTIVES</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Operational Costs</td>
</tr>
<tr>
<td>Labour cost</td>
<td>Yes</td>
</tr>
<tr>
<td>Labour output rates</td>
<td>Yes</td>
</tr>
<tr>
<td>Materials costs</td>
<td>Yes</td>
</tr>
<tr>
<td>Materials wastage</td>
<td>Yes</td>
</tr>
<tr>
<td>Mats. procurement &amp; storage</td>
<td>Yes</td>
</tr>
<tr>
<td>Plant &amp; Equipment costs</td>
<td>Yes</td>
</tr>
<tr>
<td>Plant &amp; Equipment schedule</td>
<td>Yes</td>
</tr>
<tr>
<td>Plant &amp; Equipment mix</td>
<td>Yes</td>
</tr>
<tr>
<td>Preliminaries</td>
<td>Yes</td>
</tr>
<tr>
<td>Subcontract schedule</td>
<td>Yes</td>
</tr>
<tr>
<td>Subcontract attendance</td>
<td>Yes</td>
</tr>
<tr>
<td>Overheads</td>
<td>Yes</td>
</tr>
</tbody>
</table>

From the literature review presented in chapter 4 and table 8.1, it is evident that:

1. The objectives of a construction project can be stated in terms of a set of constituent resources.
2. The resources are interrelated to one another in meeting the various objectives; for instance using more efficient mechanical plant could change the amount of the labour costs of operations, reduce durations and increase outputs.

3. Total operational quantity, duration and cost could occasion limits to the amounts of individual resources that could be employed on the operations (i.e. set system constraints).

4. Fractional values are possible in the calculation of resource consumptions on individual operations.

The above verification implies that:

1. Initial data from on-going operations or historical data from similar ones, could be used to forecast future outcomes on the operations by employing multiple regression or time-series models.

2. Regression and correlation models could be employed to explain performance trends either from initial data on on-going operations, or historical data from similar ones. This would allow progressive administering of overall budget and construction programme.

3. Linear programming and goal programming models could be employed to determine the appropriate course of action to adopt in order to alter projected trends of an on-going operation towards the desired objectives.

**Problem Description**

While profit maximization is a universal objective for all business concerns, including construction, the principal objective of a contractor on individual projects, as pointed out in chapter 6, is to realize the profit margin built into the tender estimates for the project or, failing that, to minimize any deviations from the course(s) of action that was planned to lead to the realization of such profit levels. This means the contractor's main concern is to minimize deviations from the project's cost budget and the construction schedule which in turn imply:

1. Minimizing costs by minimizing resource requirements.
These imply:

1. Avoiding or minimizing materials wastage.
2. Avoiding or minimizing labour and plant idle time through proper selection and or matching of plant and establishing the optimum mix between mechanical plant and labour.
3. Ensuring that expected, (i.e. planned), outputs of labour, plant and materials are realized.
4. Ensuring that specified quality standards are realized so as to avoid costly reworks and delays.
5. Careful regulation of preliminary costs and other ancillary expenses.

The budgetary allocation for each operation or cost code defines the 'expected' constraint on the use of constituent resources on that code. Similarly the construction schedule specifies the time constraint for each operation.

The problem that has been defined and described thus far can be summarized in the following question:

How should contractors gather and process information on an on-going construction project to reveal both the physical progress and financial status of the project and direct future courses of operations to ensure realization of planned goals?

As pointed out earlier, (chapters 3, 4, & 7), this question can only be effectively answered when comprehensive performance models of the project have been prepared in such a manner that generated project data can be promptly compared against such models. It is not necessary to restate here the principles of the preparation of project performance models because that has been adequately treated in chapter 4.
8.3.3 Solution Process

Process Specification

The main resource constituents of construction projects which are the subject for monitoring and control were categorized in chapter 4 under the following cost heads:

1. Labour
2. Materials
3. Plant and equipment
4. Subcontractors
5. Project overheads
6. Preliminaries

Under the different approaches identified and or reviewed by this research the data needed to control expenditure on these cost heads is obtained from different sources, (see table 8.2), and processed into periodic cost sheets (or reports) that are transmitted to company headoffices for evaluation and necessary decision-making. This usually meant a two-tier data capture in the sense that while site foremen and engineers continuously record time and resource consumptions on site, the headoffices accumulate their own files of invoices, subcontracts and pay-rolls all of which have to be meticulously but tediously reconciled with the site records and then compared with the project's budgetary allocations. Such a practice was identified by James et al (1989) as one of the causes of failure to effectively control costs. The effect of this approach was to delay the process of corrective decision by compounding the cost control system with a mass of unsuitable data that, more often than not, was not essential to the requirements of real time cost control on site.

Under the new approach being proposed the first or primary tier of the traditional approach to data capture is recognized as the one that is essential to real time cost monitoring and control of the project because it captures the quantity of resources that have actually been consumed by the project and this, as pointed out in chapters 3 & 4, is the crux of cost control. Consequently the use of invoices, delivery tickets and the like which were...
found to be detrimental to the requirements for timely monitoring and control is avoided by employing the SMS system (described in chapter 2) to capture the actual resources that are consumed by a given project. For reasons discussed in chapter 4, the card system of performance data capture is still advocated in the proposed approach despite some of its stated disadvantages. The approach would, however, require fewer types of cards than is currently in use while at the same time relating the coding of information gathered on the cards directly to that of the project performance models and other data to be held in a database serving as a computerized library for the project.

Table 8.2: Sources of Data Generation for Cost Monitoring and Control

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Labour</th>
<th>Mats</th>
<th>Plant</th>
<th>S/cont</th>
<th>O/heads</th>
<th>Prelims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pay-roll</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Priced B. of Q.</td>
<td>--</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>--</td>
<td>Yes</td>
</tr>
<tr>
<td>Outputs rates</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Cost codes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Qty. of wk. done</td>
<td>--</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Field knowledge</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Purchase orders</td>
<td>--</td>
<td>Yes</td>
<td>--</td>
<td>Yes</td>
<td>--</td>
<td>Yes</td>
</tr>
<tr>
<td>Delivery tickets</td>
<td>--</td>
<td>Yes</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>S/contract order</td>
<td>--</td>
<td>--</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Hire order</td>
<td>--</td>
<td>--</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Hire rates</td>
<td>--</td>
<td>--</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Off hire tickets</td>
<td>--</td>
<td>--</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Basic costs</td>
<td>--</td>
<td>--</td>
<td>Yes</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Consumables</td>
<td>--</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>--</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Thus manual handling of captured data, (by recasting it through different processing stages, e.g. from daily records to weekly summaries, costing and cost reconciliations), is minimized in the proposed approach through the use of the SMS system and other processing software in the project library. Furthermore, since all data processing and performance evaluation is to be carried out directly in the automated library, most of the other disadvantages of the card system will not apply to the approach.
The data capture software accumulates and sorts the data according to operational or cost codes and generates data in a format suitable for use by the quantitative models to make performance evaluations, forecasts and to compute corrective decisions in the event of deviations from plans. The quantitative models and the prescribed transformation processes required to be performed on the data are stored in the project library along with the project's performance models and decision rules established at the estimating and planning stages. The outputs of the transformations carried out in the library would be cost summaries, performance exception reports, and prescribed adjustments to resource utilization levels on operational codes found to have deviated from set targets.

**Mathematical Formulation and Implementation**

Figures 8.1 and 8.2 illustrate the proposed approach as well as an implementation flowchart showing its various components and how they would be employed in cost monitoring and control. For reasons given in chapter 6, the most suitable quantitative models for use in implementing the proposed approach are:

2. Multiple regression models along with associated tests and evaluation models.

Due to the limitations of MARMA models that were identified in section 6.4.6 and the fact that their forecasting potentials are equally realizable from multiple regression models with greater accuracy, the proposed approach to cost monitoring and control will employ mainly multiple regression to forecast future cost and operational status as well as isolate and explain sources of deviations from expected performance levels. In the event of unfavorable costs and performance levels being projected based on current trends, the approach will employ goal programming to compute optimum adjustments to be made with regard to utilization of individual resources in on-going operations in order to realize planned objectives.
The first step in implementing the approach is to select/define the objective, (i.e. dependent variable), that is to be monitored and controlled. In the illustration below cost (C) or expenditure on a given code is the objective function. Since expenditure on any construction operation is a function of the costs of materials (M), (direct) labour (L), plant and equipment (E), subcontracts (S), overheads (H), and preliminary expenses (P), the problem can be formulated thus:

\[ C = f(L, M, E, H, S, P), \]

or

\[ C_a = L_a + M_a + E_a + H_a + S_a + P_a + \alpha, \]

and
\[ C_f = \frac{b_1 L_a + b_2 M_a + b_3 E_a + b_4 H_a + b_5 S_a + b_6 P_a + a}{k} \]  

(8.1)

where:  
- \( C_a \) = Actual expenditure to date on a given cost code.
- \( \alpha \) = An optional constant determined from historical data on similar operations and represents establishment or set up costs. Where such costs are included in \( P \) then \( \alpha = 0 \).
- \( C_f \) = Projected cost of a given operation or cost code.
- \( a, b_1, b_2, \ldots, b_6 \) = Regression parameters for a given operation or project computed from historical data.

The second step of the approach is to compute the values of \( \alpha, a, b_1, b_2, \ldots, b_6 \) from available records of the contractor. The computed values are then tested for suitability and significance (as prescribed in chapter 6) as regression parameters that can be employed to make valid predictions on operations or cost codes that are similar to the data source of the parameters. After passing the relevant tests the parameters are entered into the library of the new project that is going to be monitored and controlled. Such a library would have already received such entries as project budget (\( B \)), schedules (durations of individual operations or cost codes, \( D \)), cost schedules, revenue schedules, values of \( k \) and any other decision rules or formulae required to process the data to be collected on the project. Table 8.3 shows a typical 'page' from such a project library stored in Quattro. The table is compiled as follows:

1. The cost (or operational) codes, transformation formulae and the values of \( B, k, \alpha, a, b_1, b_2, \ldots, b_6 \) will be entered at the planning and modelling stage of the project.
2. The values of \( L, M, E, H, S, \) and \( P \) will be entered on a periodic basis from the source or data capture documents completed by foremen and site engineers in charge of various operations and processed by Site Manager.
3. The values of \( C_a, C_f, |C_a - C_e|, |C_f - B| \), and other decision nodes will be automatically computed in the library by the built-in transformation formulae.
4. Prescribed reports are then sorted by the library software (Quattro) and printed on request along with any required 'flagged' values not satisfying the built-in decision nodes.
Table 8.3: Typical Page from Project Library

<table>
<thead>
<tr>
<th>Cost Codes</th>
<th>B</th>
<th>k</th>
<th>I_a</th>
<th>M_a</th>
<th>E_a</th>
<th>H_a</th>
<th>S_a</th>
<th>P_a</th>
<th>C_e</th>
<th>C_a</th>
<th>C_f</th>
<th>α</th>
<th>a</th>
<th>b_1</th>
<th>b_2</th>
<th>b_3</th>
<th>b_4</th>
<th>b_5</th>
<th>b_6</th>
<th>C_a+C_e</th>
<th>C_f*B</th>
</tr>
</thead>
</table>

\[ C_a = I_a + M_a + E_a + H_a + S_a + P_a \]
\[ C_e = \text{Supplied from project's cost schedule} \]
\[ C_f = a + b_1L + b_2M + b_3E + b_4H + b_5S + b_6P \]
Thus far the approach has employed multiple regression twice. First to determine suitable parameters for forecasting costs and performance levels and, secondly as part of the transformations carried out in the project library to make the forecasts and evaluate such forecasts against built-in targets. The reports generated at this stage of the process would reveal the operations or cost codes that are incurring overspending and indicate the particular resource(s) that contributed to the overspending. The next stage of the process is to compute an optimum decision that would, if implemented, satisfy the various goals of the operation and bring costs and performance towards desired levels.

In order to compute the required optimum adjustments the approach employs GP to minimize deviations from desired levels of resource utilization that was envisaged at the estimating and modelling stages of the project. (The reasons for selecting GP instead of LP and IP models in the case of construction projects have already been discussed in chapter 6). This phase of the approach utilizes the actual cumulative expenditure to date for each of the constituent resources of a given cost code in order to compute what the optimum levels of expenditure should have been based on the established regressors of the cost code. Another requirement of this phase of the approach is a GP file or subroutine that could be called upon to utilize the records or entries of the exception codes under investigation to compute optimum resource utilization levels.

The mathematical formulation for this phase of the approach is represented by the GP equation given below. In effect, what the GP equation does is to apply the established regressors of a given operation or cost code, (along with whatever priorities and rankings a project manager may wish to realize with regard to resource utilization), within the constraints of the accrued expenditure on its constituent resources to compute optimum amounts that should have been spent in order to remain within project goals.
Minimize: \( Z = p_1^+ + p_2^+ + \cdots + p_6^+ + p_1^- + p_2^- + \cdots + p_6^- \)

Subject to:
\[
b_1l + b_2m + b_3e + b_4h + b_5s + b_6p + p_1^+ + \cdots + p_6^+ - p_1^- - \cdots - p_6^- = C_a - a
\]
\[
b_1l + p_1^- - p_1^+ = L_a
\]
\[
b_2m + p_2^- - p_2^+ = M_a
\]
\[
b_3e + p_3^- - p_3^+ = E_a
\]
\[
b_4h + p_4^- - p_4^+ = H_a
\]
\[
b_5s + p_5^- - p_5^+ = S_a
\]
\[
b_6p + p_6^- - p_6^+ = P_a
\]

where: \( p_1^-, p_2^-, \ldots, p_6^- \) = Underachievement variables for set goals of L, M, E, H, S, P respectively.
\( p_1^+, p_2^+, \ldots, p_6^+ \) = Overachievement variables for set goals of L, M, E, H, S, P respectively.

\( L_a, M_a, E_a, H_a, S_a, P_a \) = The actual cumulative costs of labour, materials, plant and equipment, overheads, subcontracts and preliminaries respectively incurred on the code under investigation.
\( l, m, e, h, s, p \) = The optimum values of expenditure (to be computed) for labour, materials, plant and equipment, overheads, subcontracts and preliminaries respectively for the code, i.e. the required solutions.

The differences between the actual and the computed levels of expenditure would indicate the component of the code which contributed to the overspending that led to the unfavorable forecast value \( C_f \). The differences computed from this application of the model are as follows:

- \( L_a - l \) = for labour costs
- \( M_a - m \) = for materials costs
- \( E_a - e \) = for plant and equipment costs
- $H_a - h$ = for overhead costs
- $S_a - s$ = for subcontracts
- $P_a - p$ = for preliminary costs

The magnitude and sign of these differences should inform a project manager on the aspect(s) of an on-going operation that need to be adjusted and the 'direction' in which the adjustments should be made. This provides the project manager with a more rational and scientific basis for taking corrective actions than the experience-based trial-and-error approach currently employed, as revealed in chapter 7.

Another application of the GP equation for project monitoring and control could be made at the estimating and modelling stages of the project.

Minimize: $Z = p_1^- + p_2^- + \ldots + p_6^- + p_1^+ + p_2^+ + \ldots + p_6^+$

Subject to:

$b_1l + b_2m + b_3e + b_4h + b_5s + b_6p + \ldots + p_6^- - p_1^+ - \ldots - p_6^+ = B - a$

where: $p_1^-, p_2^-, \ldots, p_6^-$ = Underachievement variables for set goals of $L, M, E, H, S, P$ respectively.

$p_1^+, p_2^+, \ldots, p_6^+$ = Overachievement variables for set goals of $L, M, E, H, S, P$ respectively.

$L, M, E, H, S, P$ = The budgeted costs of labour, materials, plant and equipment, overheads, subcontracts and preliminaries respectively.

$l, m, e, h, s, p$ = The optimum values of expenditure (to be computed) for labour, materials,
plant and equipment, overheads, subcontracts and preliminaries respectively for each code, i.e. the required solutions.

\[ B = \text{The total budgetary allocation of the code that is being modeled.} \]

thus by replacing the values of \( C_a, L_a, M_a, E_a, H_a, S_a, \text{ and } P_a \) with \( B, L, M, E, H, S \text{ and } P \) respectively, as shown above, the equation could be used to 'estimate' the optimum levels of expenditure to be allowed on constituent resources of each cost code in order to realize the defined project objectives. It needs to be noted that the 'estimated' values are arrived at using budget targets as constraints and the trends or experiences of previous similar operations (via the regression parameters) as regulators or determinants.

The significance of these 'estimates' vis-a-vis budgetary targets in guiding the process of cost monitoring and control lie in the relative advantages of the former over the latter, and these include:

1. While budgetary targets are derived primarily from the measured work content of an operation or cost code, (see chapter 4), without regard to actual field experience, the 'estimated' values consider both field experience and work content of the operation. Even where fair value principles formed the basis for setting of budgetary targets, the only experiences reflected in the targets would be those of the market place.

2. Budgetary targets define the expected levels of expenditure required to realize the physical work contents of individual operations or cost codes, without regard to the economical balance or mix of the cost targets in relation to field experience and technological demands. The 'estimated' values, on the other hand, define optimum feasible costs taking into account the field and technological experience both of which are reflected in the regressors in addition to all other considerations contained in the budgetary targets which are used as constraints to make the estimates.
3. While setting budgetary targets does not (through any known convenient approach) allow a project manager to rank his priorities and specify the order in which resource utilization targets should be met for a given operation, the 'estimating' of optimum values using GP could take into account any such requirements of company policy.

A converse application of the GP equation to cost monitoring and control is to employ the revised values of resource requirements of a given operation or cost code occasioned by change orders or variations in planned methods of work to compute future optimum levels of expenditure on the constituent resources of the operation. This requires the replacement of $B$, $L$, $M$, $E$, $H$, $S$, and $P$ with $B_n$, $L_n$, $M_n$, $E_n$, $H_n$, $S_n$, and $P_n$ respectively; where the latter are the new or revised values of the former.

The following points need to be made concerning the foregoing formulation and application of GP to construction projects:

1. The problem could have more easily been formulated as a LP model with the objective function $Z$ containing the resource variables as coefficients. But this is not suitable because in such a case only the total budgetary allocation of each code would be optimized. Furthermore it is possible for such a formulation to prescribe unfeasible or unrealistic solutions like zero costs for materials in, say reinforced concrete code.

2. The above model can be expanded as necessary by the project manager to reflect other experiences or policies of the company on resource mixes for specific operations or codes. Also the manager can assign priorities to and rank the objectives (i.e. $L$, $M$, $E$, $H$, $S$, $P$ and $B$) in the order in which he would like them to be realized. This would result in the general form of the GP model given in section 6.3.5.
8.4 Analysis of the Proposed Approach

In order to appreciate the significance of the proposals made in the previous section vis-a-vis the requirements for effective cost monitoring and control of construction projects it is necessary to evaluate the proposed approach in terms of characteristics, implementation, requirements and limitations against those of the theoretical and practical approaches reviewed in foregoing chapters of the thesis. This should not only highlight the similarities and differences between the proposed approach and the other approaches but also reveal the extent to which the proposed approach could overcome the various shortcomings identified with the other approaches.

8.4.1 Characteristics of the Proposed Approach

The component activities of the control process as represented in the proposed approach is not different from that discussed in chapters 3 and 4 in that the proposed approach comprises the same process components namely project modelling (or setting standards), performance measurement (made up of data capture, data processing and performance evaluation), and corrective decision-making. A significant difference between the proposed approach and the other approaches reviewed earlier is that the former places greater emphasis on making complete, accurate and comprehensive project models prior to job commencement. The proposed approach also extends the traditional scope of project modelling beyond estimating, planning and budgeting to include the establishment of parameters and criteria that will guide the subsequent use of captured data for performance evaluation, forecasting and decision making. Furthermore, by automating the processing and evaluation of performance data, (inside the project library), the proposed approach has made it possible to integrate these functions in one step and eliminate the need for data recasting (with all its attendant delays and consequential errors). The processing routine of the proposed approach can also, in the same breath, employ the processed data to forecast future levels of performance and consequently compute suitable adjustments to on-going operations. Perhaps
the clearest advantage of the proposed approach over the others is that it actually prescribes and demonstrates how controls can be made both concurrent with the operation or process being controlled, and forward-looking by practically anticipating in a scientific and rational manner the likely future effect of current failures and how best to avoid or minimize such effect.

When viewed in terms of the classifications of management controls reviewed in chapter 3, the proposed approach evidently contain the essential features for effective controls that were identified in the review. For instance, while it does not have the features and disadvantages of open-loop controls which were identified as unsuitable for construction projects, the new approach meets the recommendations of such pundits as Wilson et al (1988), Lynch et al (1983) and Summers (1974), among others, by combining the features of feedback and feedforward controls in a complimentary manner. It employs feedback data from operations of past projects to establish control parameters and decision criteria, and feedback data from similar on-going operations to compliment the former in making performance predictions and corrective decisions.

By making system objectives not only a part of but also the centre around which the measurement and predictive aspects of the control process revolve, the new approach represents a practical actualization of Tocher's cybernetic approach to control which was shown in figure 3.6. This is moreso because the proposed approach employs a rational and reliable prediction model that would overcome the reservations of Otley (1980) with regard to the reliability of predictive models, (as revealed in chapter 3), and justifies the author's earlier assertion that Tocher's model could be applicable to construction projects if predictive models were based on parameters and decision rules emanating from reliable historical evidence. When considered in the light of Hofstede's contingency classification of controls as illustrated in figure 3.7 the proposed approach represents a case of expert control, which was indicated to be the surest level of control that can be hoped to be achieved for non-repetitive systems or operations like construction projects.
With regard to the relation of the proposed approach to the defined principles of responsibility accounting it only needs be pointed out that the former depends entirely for its success and effectiveness on comprehensive application of the latter. The approach even extends the use of responsibility accounting beyond tying accountability to authority, to the realm of corrective decision-making.

The clearest implication of the proposed approach to project organizational structures on site is placing accountability for project resources with the persons directly responsible for utilizing them. This should in turn necessitate the increased participation of line and staff levels of project personnel in modelling and decision-making, and less negative interferences from company headoffices in matters that site management could and should handle. This should reduce some of the shortcomings identified with the practical approach as revealed in chapter 7. Integrated data acquisition and processing in the project library should also overcome problems associated with lack of format coordination and inefficient flow of information between and among project staff and company headoffices. Furthermore the problems of "untimely", [see Abdullah (1988) and Kharbanda et al (1987)], and "unsatisfactory", [see Kodikara (1990)], approach to performance evaluation which were found to hinder effective cost control should be minimized because the proposed approach constantly and automatically carries out such evaluations within the project library and flags out codes that fail to satisfy the built-in decision rules.

Another important achievement of the proposed approach lies in demonstrating how to actually make corrective decisions in a rational way as opposed to the purely subjective suggestions and contentions in construction literature, as revealed in chapters 3 and 4, and the trial and error approach currently employed by contractors as revealed in chapter 7. Furthermore, corrective decisions arrived at through the proposed approach are those required to rectify on-going deviations since they are derived using data from the on-going affected operations, while at the same time enriching the contractors repository of practical
experience with reliable data. The forward-looking nature of the proposed approach, (ensured by the continuous performance predictions and optimization), also makes the decision-making process virtually continuous.

Other questions which would be of interest to contractors in implementing the proposed cost monitoring and control approach relate to its effect on cashflow problems in the case of operations whose tender figures were 'loaded', and on variations. Because the approach is essentially designed to ensure that planned operational costs, (as opposed to revenues), are not exceeded it is unaffected by contractors' price loading of items that would enhance early cashflow positions of projects. For instance, when two operations A and B estimated to cost £5000 and £10000 respectively are tendered for at £10000 and £5000 respectively, (because A would be done and paid for earlier than B), are 50% complete, then regardless of their valuation figures (which would show £5000 and £2500 for A and B respectively) the approach would rightly indicate cost overruns if $C_a$ values significantly exceeded £2500 and £5000 respectively.

In the event of variations the approach would require project engineers to promptly assess the impact of the required changes on the amounts of resources for the affected cost codes, and substitute old with new values of resource allocations in the project library. These assessments can be done in the 'omit and add' manner that is traditionally employed to value variations. The only difference required by the approach is imposing the discipline to assess all variation orders as soon as they are issued instead of the traditional practice of (at best) waiting for the next valuation or, more often, the end of the project.
8.4.2 Requirements & Implementation of the Proposed Approach

In addition to the traditional requirements (or criteria) for effective cost monitoring and control such as comprehensive project models and organization (as defined in previous chapters of this thesis) the new approach requires:

1. A coordinated package of management software loaded into a (site) computer. The various programmes contained in the package would be accessed as and when required in the form of subroutines of an overall system, (see figures 8.1 and 8.2).

2. A comprehensively coded project library, which is akin to project cost systems described in chapter 4, comprising such models as a construction budget, a cost schedule, a construction schedule and a schedule of expected revenue, all of which are compiled according to the same coding system.

3. A standardized system of data capture based on the same coding system as that used for the models stored in the project library. This proposal requires data capture to be carried out using only one set of data capture or primary source documents comprising:
   - labour daily time card
   - plant/equipment daily time card
   - materials daily utilization card
   - subcontracts diary
   - dayworks diary

4. An appropriate set of reports to be printed at required instances.

5. An appropriate computing facility (preferably site-based).

Figure 8.2 shows a flowchart for implementing the proposed approach. As pointed out earlier, the data captured on the primary source documents is entered into the computer which sorts and accumulates the information according to cost codes. If desired, accumulated cost code totals can be printed at intervals and compared with original project estimates to see how they match. The system also compares cost and time totals
of the various activity codes with budget and schedule models from the project library and issues exception reports on any code(s) that show significant deviations from the models.

Further investigation of the problem codes may then be pursued by a multiple regression formula contained as a 'record' in the project library which automatically utilizes either the whole or any section of the accumulated data on those codes to make forecasts of final expenditure (and or durations) on the codes based on existing trends contained in the accumulated data. If the cost forecasts are found to be significantly outside acceptable limits when compared to the project's cost objectives, (which comparison may again be carried out within the project library), then exception reports that will clearly isolate the source(s) of overspending, (or large underspending), and guide engineers and foremen in regulating on-going operations will be generated. Consequently a G-P module or subroutine, (for optimization), could be called to employ the accumulated data and models of the problem code(s) to compute optimum adjustments that need to be made to on-going operations in order to realize the planned goals.

The system being proposed can also render other accounting services if required by expanding the data in the project library. For instance including the names, badge numbers and hourly wages of project staff could enable the system to produce weekly pay-roll, as well as labour summaries and distributions.
8.5 Summary

The essential characteristics and criteria for monitoring and control of construction projects as revealed in the various cost control systems reviewed in earlier chapters of this thesis were collated in this chapter. The implications of these criteria for effective cost control was assessed vis-a-vis the nature of construction projects and the characteristics of the reviewed cost control systems. This led to the identification of certain deficiencies of the reviewed systems and a clear need for a more effective cost monitoring and control approach for construction projects. The identified deficiencies of traditional approaches to cost control, coupled with the investigation evidence presented in chapter 7, indicated a specific need for a forward-looking approach which could employ scientific principles to generate suitable and timely information and utilize same to make rational corrective decisions in the event of unsatisfactory performance being recorded on a project. Accordingly a quantitative approach to cost monitoring and control of construction projects was proposed.

The proposal defined the cost monitoring and control problem on construction projects in terms of project objectives to be accomplished, the requirements for and or constraints to accomplishing the objectives, and the available sources of data required to effectively solve the problem. The proposal also specified and mathematically formulated a solution process that is based on regression and optimization models and explained how the process would acquire and utilize information from on-going construction operations to evaluate the financial status of the operations and recommend rational adjustments to those operations found to be exceeding their planned costs.

The advantages and achievements of the proposed approach vis-a-vis the requirements for effective cost monitoring and control of construction projects were established by evaluating the characteristics, requirements, implementation and limitations of the proposed approach against those of the theoretical and practical approaches reviewed in earlier chapters of the thesis.
The evaluation revealed that, while the proposed approach share similar components, such as project modelling, performance measurement and corrective decision-making with the reviewed approaches, it also applies the essential features for effective controls required by management science in a way that does not obtain with the other approaches. The proposed approach specifically:

1. Demands accurate and comprehensive project models that must include parameters and criteria for subsequent evaluation of captured performance data, forecasting and decision-making.
2. Prescribes a simple procedure for automated processing and evaluation of performance data, forecasting future level of performance based on that data, and computing the adjustments needed to on-going operations based on actual data from those operations instead of the often subjective judgements of project managers.
3. Combines features of feedback and feedforward controls in a complimentary manner to establish control parameters and decision criteria, on the one hand, and to make performance predictions and corrective decisions on the other.
4. Extends the application of responsibility accounting in construction projects beyond cost modelling and relating accountability to authority, to the realm of corrective decision-making.
5. Seeks to minimize the problem of untimely and inefficient flow of performance data on construction projects through coordinated utilization of the data inside an automated project library without the need for recasting and transfer of the data from one department to another.

The proposed cost monitoring and control approach along with the prescribed implementation procedure was then tested (see chapter 9) in order to assess its effectiveness in practice.
CHAPTER NINE

TEST IMPLEMENTATION OF THE PROPOSED APPROACH TO COST MONITORING AND CONTROL

9.1 Introduction
9.2 Procedure for the Test Implementation
9.3 Analysis of Cost Data from Residential Housing Projects
9.4 Analysis of Cost Data from Public Building Projects
9.5 Analysis of Cost Data from Civil Engineering Projects
9.6 Trial Run of the Proposed Approach
9.7 Limitations of the Established Regression Equations
9.8 Summary
9.1 Introduction

In order to assess the proposals made in chapter 8 for improving the effectiveness of cost monitoring and control of construction projects and to provide a basis for obtaining useful recommendations from this research, it was necessary to test the proposal in real-life situations and evaluate the results of the test against available knowledge, as reviewed in earlier chapters of this thesis. Accordingly, this chapter presents the procedures carried out to test the proposed cost monitoring and control model, the results obtained from the test and an analysis of the results.

The process of collecting and processing test data is described along with the implementation of the various quantitative models and statistical tests reviewed in chapters 6 & 8. A trial-run of the new approach is also illustrated with data obtained from ongoing construction projects. The results obtained were analysed to identify any limitations to the application and or success of the new approach.

Due to the confidentiality requirements of the companies that supplied the test data, which in some cases had to be examined in the offices of the companies, the names of the projects from which the data was extracted is not identified in the thesis. Furthermore sensitive data such as wages, outputs and rates which were used to compile the cost profiles of the projects analysed in this chapter could not be revealed. However the cost data extracted from the various source documents of the companies and which was used to build up the cost profiles analysed in this chapter are presented in appendices at the end of the thesis.

Although the proposals made in chapter 8 could be used for monitoring and control of project schedules as well as costs, the tests reported in this chapter were limited to project costs only. The same procedure, however, would be applicable on schedule
control which was not included here mainly because the objectives of the research were centered on cost control.

9.2 Procedure for the Test Implementation

9.2.1 Summary of Activities Carried out

Testing the proposed cost monitoring and control approach was carried out via the following steps:

1. Collection of historical cost data from past construction projects. (section 9.2.2)
2. Processing the data by organizing and classifying it in the form that is suitable for utilization in the quantitative procedures as in appendices III, IV and V. (section 9.2.3)
3. Compiling and plotting the cost profiles represented by the processed data to identify the nature of regression models likely to fit the data.
4. Trial generation of regression parameters and statistics for all the categories of projects selected for testing
5. Testing the generated parameters statistically to evaluate their fitness for use in regression.
6. Collecting cost data from on-going construction projects.
7. Using the cost data from the on-going projects and the generated parameters to predict costs of the projects and compute adjustments needed to avoid deviations.

Steps 3, 4 and 5 were carried out using mainly Microsoft-PC software such as Statworks and Newcricket. The outputs were then presented in tables for easier analysis and comparison with reviewed literature and proposals made earlier in the thesis.

9.2.2 Data Collection

The data employed to test the proposed cost monitoring and control approach was obtained from two construction companies whose operational bases are in the British Midlands. One of the companies is involved in mainly building construction for residential and public users and executes projects of scope up to £5,000,000 in value. The other company executes mainly civil engineering projects comprising pipe-laying and related works within the same scope in value as the first company.
The data collected from each of the companies covered several past projects based on the following criteria:

1. The projects were executed within a maximum of five years of each other in order to reduce the effect of time differentials on cost and technological trends in the operations of the projects.
2. The projects were reasonably similar in their design, specifications and size.
3. The projects were tendered for and executed under fairly similar market environments. For this reason, choice of projects was limited to projects situated in England.

The method of acquiring the data used for the tests in this chapter varied between the two source companies. The building construction company which supplied the data on residential and public buildings, (analysed in sections 9.3 and 9.4), required that relevant project documents be examined in its headoffice and the selected data extracted with the assistance of the company's staff. This made for prompt clarification of any queries arising during the examination of the projects documents. The company that supplied the data on civil engineering projects, (analysed in section 9.5), on the other hand, supplied the cost data on a personal computer along with the company's own software, (SMS - described in chapter 2), that was used for the capture and part-processing of the data on sites. This allowed easier selection of projects and speedier extraction of the data.

The cost data analysed in this chapter was extracted from the following source documents:

1. Projects schedules
2. Budgets estimates
3. Completed labour time-sheets
4. Project cost reports
5. Completed plant time-sheets
6. Plant hire rates
7. Site records of overhead expenses
8. Materials invoices and delivery tickets
9. Work output records
In addition to obtaining the above documents the data collection also involved talking to some of the site staff who had experience on the selected projects in order to get clarifications on the recorded information as well as glean some further insight into the circumstances under which the information was generated. This personal contact was often needed to also verify that the project whose data was being examined met the criteria listed earlier in this section.

An important problem that was encountered during the data collection occasioned a limit to the level of detail to which the subsequent analyses presented in this chapter could be carried out. The proposals made in chapter 8 required cost data to be classified, preferably, on the basis of operational, trade, or work section cost codes. But it was found during the data collection that contractors often considered blocks, housing units or even whole projects as accounting units in their budgeting and cost accounting for projects. Consequently, it was found impractical to reduce the available cost data to smaller accounting cost codes. Thus whole projects or individual units of them were used as cost codes. To obtain the kind of cost data envisaged by the proposals, it was found that the data capture arrangement would have to be specially made with companies that may agree to test the proposals. This was not practicable for this research due to the vast quantity of data required and the time (several years will be required to collect data on 20 projects) and the number of people that would need to be involved. Nevertheless, neither the essence of the proposals nor the outcomes of the tests and analysis would be affected by this problem. Hence it was not considered necessary to alter the proposal to tune with the format of the available data.
9.2.3 Data Processing

This was perhaps the most labourious and time-consuming experience of this phase of the research. It involved having to organize and classify a mass of data recorded on a myriad of forms. The data was not recorded and stored in a manner that would enable its easy utilisation for subsequent monitoring and control activities. For the selected projects the process involved:

1. Identifying and or establishing the suitable cost breakdown structures or cost codes for the projects, where possible.
2. Selecting projects for which the items of expenditure could most easily be traced from the site documents. Whole projects were considered as accounting unit or cost code because the companies system of cost recording did not allow an easy break-down of the data into operational cost codes.
3. Tracing and assigning each item of expenditure in respect of labour, plant, materials, subcontractors and overheads to one cost code or another and to a time period of the project schedule.
4. Summing up the costs of each of the component resources of the selected projects or accounting unit; (as shown in appendices III, IV & V).
5. Compiling the cost profiles of each project or accounting unit across all the selected projects (as shown in tables 9.1, 9.9 and 9.18) ready to be used in the quantitative models.

The cost data was classified into three categories as follows:

1. Cost data from purely residential housing projects (RHP), which is presented in Appendix III and from which table 9.1 was compiled.
2. Cost data from public/educational building projects (PBP), which is presented in Appendix IV and from which table 9.9 was compiled.
3. Cost data from civil engineering projects (CEP) involving mainly pipe-laying operations, which is presented in Appendix V and from which table 9.18 was compiled.
This classification was done to enable the analysis to identify the applicability of the proposed approach to different project categories. It must, however, be immediately acknowledged that the applicability or otherwise of the models on these categories of projects may not necessarily be symptomatic through all project categories for reasons stated in the discussion following the results of the analysis. Furthermore, even for the project categories analysed herein, the results obtained may not amount to conclusive proof that either the defined quantitative models or the identified statistical trends will be applicable within each construction company. The significance of the results from these analyses would lie mainly in establishing the existence of, and actually identifying the typical relationships or trends in construction cost data that can be employed as a basis for timely, rational and effective cost control of projects by contractors.
9.3 Analysis of Cost Data from Residential Housing Projects

9.3.1 Cost Profile of Residential Housing Projects

Appendix III shows the cost data compiled from 20 RHPs that were selected for this analysis. The RHP cost profile, (shown in table 9.1), was derived from this data by extracting for each of the projects, the totals of labour, materials, plant, subcontracts and preliminary costs along with the projects' actual total cost. It should be pointed out that the figures in the 'response' column (i.e. total costs) in table 9.1 are not the sums of the individual costs in the 'predictors' columns because the former represents the company headoffice's final record of all expenditure on the projects from procurement to the end of the maintenance period, while the latter represent the sites' records of actual resource consumption on the projects.

Table 9.1: Cost Profile of Residential Housing Projects (RHP)

<table>
<thead>
<tr>
<th>Project</th>
<th>Labour</th>
<th>Materials</th>
<th>Plant</th>
<th>S/contracts</th>
<th>Prelims</th>
<th>RESPONSE</th>
<th>Total Cost</th>
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<td>44793</td>
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<td>37698</td>
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<td>186011</td>
<td>65028</td>
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<td>84110</td>
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<td>39681</td>
<td>92000</td>
<td>34567</td>
<td></td>
<td>485200</td>
</tr>
</tbody>
</table>

256
9.3.2 Investigating underlying Trends within the Cost Data

As pointed out in chapter 6, the first step in analysing any set of data via regression is to identify, from theoretical considerations and actual examination of the data, the kinds (or shapes) of models it represents. The RHP cost data was thus similarly treated.

Theoretical Model

From theory it was shown (see chapters 4 and 6) that the cost to a contractor of any construction operation or project is made up of the costs of labour, materials, plant & equipment, overheads, subcontracts and preliminary expenses, among others. Thus actual costs of projects are sums of these individual costs. This means that increasing or decreasing any of the component costs would correspondingly affect the total cost of a project. This implies that the relationship between total and component costs of a project would be additive and linear. This proved to be the case for the RHP cost data when the total costs were plotted against the component costs (as shown in figures 9.1 to 9.5).

It is worth noting here that this does not necessarily mean that the relationships (if any) among the component costs are also linear. This would be best determined via actual plots of the data, but is not essential for the purposes of this analysis. Thus the expected model from this analysis would be of the form given in equation 8.1; namely:

\[ C_f = a + b_1 L_a + b_2 M_a + b_3 E_a + b_4 H_a + b_5 S_a + b_6 P_a \]

Since the companies that supplied the cost data used in the analysis distributed the overhead elements of their expenditure as either labour or preliminaries, the \( b_4 H_a \) term is subsequently dropped from the model.
Figure 9.1: Effect of Labour costs on Total cost of RHP

Figure 9.2: Effect of Materials costs on Total cost of RHP

Figure 9.3: Effect of Plant costs on Total cost of RHP
Examining Residual Plots

The residual values for the RHP cost data were obtained by actually regressing its cost profile using Statworks. This automatically computed and printed the residuals as an additional column for the data being analysed. Table 9.2 shows the residuals obtained from the cost profile in table 9.1. The residuals were then plotted against their corresponding total costs as well as the individual component costs. Figures 9.6 to 9.11 show the scatter plots obtained. An examination of these plots reveals that the points are fairly evenly scattered on both sides of the zero residual value. This implies that the distribution of the residuals is normal and that the proposed regression model can be safely used without having to introduce an error term to account for cost factors that were not explicitly represented in the model.
### Table 9.2: Residual Values from RHP Cost Data

<table>
<thead>
<tr>
<th>Project</th>
<th>Total Cost</th>
<th>Residual value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>140982</td>
<td>-1426.3</td>
</tr>
<tr>
<td>2</td>
<td>166899</td>
<td>-2061.0</td>
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</tr>
<tr>
<td>4</td>
<td>225900</td>
<td>-1311.5</td>
</tr>
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<td>254344</td>
<td>245.4</td>
</tr>
<tr>
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<td>-359.0</td>
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<tr>
<td>20</td>
<td>485200</td>
<td>4217.2</td>
</tr>
</tbody>
</table>

**Figure 9.6: Scatter Plot of Labour cost Residuals for RHP**
Figure 9.7: Scatter Plot of Materials cost Residuals for RHP

Figure 9.8 Scatter Plot of Plant cost Residuals for RHP

Figure 9.9: Scatter Plot of Subcontract cost Residuals for RHP
The distribution of the plots also indicate an underlying linear trend in the cost profile analysed. In order to confirm the nature of the underlying trends the cost profile was regressed exponentially to second and third degrees using Statworks. The results obtained are shown in table 9.3. The coefficients of the quadratic and cubic terms were found to be so small that the software rounded them up to zero, while all the first degree coefficients are non-zero. This indicates that polynomial trends are not significantly present within the RHP cost data.

Furthermore the t-values and their corresponding significance tests contained in table 9.3 show that none of the variables yielded a polynomial coefficient that is acceptable at the 95% confidence level. This allows us to conclude that exponential
relationships are not present while linear relationships exist in the data. This provides justification for continuing the analysis of the cost profile using linear multiple regression and based on the model proposed earlier in this section.

### Table 9.3: Statistics for Polynomial Regression of RHP Cost Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>1st Degree</th>
<th>2nd Degree</th>
<th>3rd Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t</td>
<td>Prob&gt;t</td>
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</tr>
<tr>
<td>Labour</td>
<td></td>
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<tr>
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<tr>
<td>Prelims.</td>
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<td>-1.3</td>
</tr>
</tbody>
</table>

#### 9.3.3 Generation of Regression Parameters and Statistics

The multiple regression function of Statworks was then applied to the cost profile in table 9.1. This generated the following sets of statistics among others:

1. The regression coefficients $b_1, b_2, b_3, b_4$ and $b_5$ for each of the cost components represented in the proposed model.
2. The constant term (a) of the model.
3. The corresponding $t$-statistic for testing the significance of each of the regression coefficients.
4. The standard errors of estimate for each of the regression coefficients.
5. The $F$-statistic and degrees of freedom for testing the significance of the overall regression equation.
6. The coefficients of correlation and determination for the overall regression equation.
7. The standard error of estimate for the overall regression equation.
8. The Durbin-Watson statistic for testing the presence of autocorrelation among the regression variables.
9. The overall correlation matrix for the regression variables.

Tables 9.4 and 9.5 show the above sets of statistics generated for the RHP cost data.
### Table 9.4: Regression Parameters and Statistics for RHP Cost Data

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefs.</th>
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<th>F</th>
<th>Prob&gt;F</th>
<th>R</th>
<th>R²</th>
<th>D</th>
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<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Preliminaries</td>
<td>1.3</td>
<td>5.7</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total cost</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>30088</td>
<td>0.00</td>
<td>0.99</td>
<td>0.98</td>
<td>2.0</td>
</tr>
</tbody>
</table>

### Table 9.5: Correlation Matrix of Regression Variables for RHP Cost Data

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total cost</th>
<th>Labour</th>
<th>Materials</th>
<th>Plant</th>
<th>S/contracts</th>
<th>Prelims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost</td>
<td>1.000</td>
<td>0.986</td>
<td>0.984</td>
<td>0.979</td>
<td>0.829</td>
<td>0.980</td>
</tr>
<tr>
<td>Labour</td>
<td>0.986</td>
<td>1.000</td>
<td>0.976</td>
<td>0.989</td>
<td>0.755</td>
<td>0.985</td>
</tr>
<tr>
<td>Materials</td>
<td>0.984</td>
<td>0.976</td>
<td>1.000</td>
<td>0.963</td>
<td>0.733</td>
<td>0.975</td>
</tr>
<tr>
<td>Plant</td>
<td>0.979</td>
<td>0.989</td>
<td>0.963</td>
<td>1.000</td>
<td>0.765</td>
<td>0.977</td>
</tr>
<tr>
<td>S/contracts</td>
<td>0.829</td>
<td>0.755</td>
<td>0.733</td>
<td>0.765</td>
<td>1.000</td>
<td>0.744</td>
</tr>
<tr>
<td>Prelims</td>
<td>0.980</td>
<td>0.985</td>
<td>0.975</td>
<td>0.977</td>
<td>0.744</td>
<td>1.000</td>
</tr>
</tbody>
</table>

#### 9.3.4 Inferences from the Statistical Tests of the Regressions

The regression parameters and other statistics generated for the cost profile were then analysed in the light of the tests and conditions prescribed in literature (see chapter 6) in order to define the actual regression equation appropriate for the data and determine whether or not such equation passes the tests required to make it suitable for use in practical forecasting and cost control.

**Examining the Regression Coefficients**

The regression coefficients and their respective t-values are shown in columns 2 and 3 of table 9.4. Column 4 of the table shows that each of these coefficients are acceptable at the 95% level of confidence because their values have exceeded the $t \geq 2$ specified in table 6.1. This means that there is a less than 5% chance of our getting these values from the regression if their
true values were zero. Thus all the coefficients have passed the prescribed test of significance.

**Examining the Coefficients of Correlation and Determination**

The value of R (0.99) for the regression equation indicates a very strong degree (99%) of correlation between the response and predictor variables in the equation. The value of R² (0.98) for the regression suggests that 98% of the variations in the total cost of housing units is accounted for by the predictor variables used in the regression. The reliability of these values with regard to the regression model is established by the value of the F-statistic (30088) which is well beyond the limit of F ≥ 5, (specified in table 6.4), required for 95% level of confidence. Indeed column 7 of table 9.4 (Prob>F) shows that the values of R and R² are reliable at a confidence level in excess of 99%. Thus both R and R² have passed the prescribed tests of significance.

**Examining the Durbin-Watson Statistic**

Since the value of the D-W statistic (2.0) for the regression falls within the range (1.5<D<2.5) recommended by Wheelwright et al (1984), it can be concluded that the multicollinearity (if any) between the regression variables does not significantly affect the reliability of the regression equation. Thus the model has passed the the D-W test.

**Examining the Matrix of Simple Correlations**

The values contained in the matrix of simple correlations shows the strengths of relationships between the regression variables. The values in table 9.5 range from 0.733 to 0.989 which indicate very strong relationships between the variables. This is very significant to the outcome of this analysis because it suggests that the regression equation proposed earlier can be further simplified by dropping off some of the predictor variables without significantly affecting its reliability. In other words fewer variables than those contained in the equation may adequately serve the purpose of the model with virtually the same degree of accuracy. The reason for this can be seen from the R values in the first row of the matrix. Four of these values, (namely 0.986 for labour, 0.984 for materials, 0.979 for plant and 0.980 for
preliminaries), lie within a range of only $\pm 0.7\%$ of each other. This means that any one of these variables could adequately represent the others in the regression model.

In order to decide which of the related variables to include in a revised version of the regression model, the author sought the advice of professional statisticians from the Business School of LUT. In addition to agreeing with the foregoing deductions regarding the matrix values, the general advice obtained was that stepwise regression should be applied to the data in order to obtain a simpler version of the regression equation. Although the theory of this approach to multiple regression was not discussed in chapter 6, (the theory has been covered by Madsen et al (1986), the need was stressed for including in regression models only as many variables as would be necessary to minimize the range of residuals without unnecessarily adding to the cost and complexity of the models (see sections 6.3.6 and 6.3.11).

**Variables Selection via Stepwise Regression**

Stepwise regression accomplishes such variable selection by a step-by-step introduction of the variables into a regression model via a combination of forward and backward elimination steps. The procedure begins by finding the first variable (if any) to be included in the model. Then, after any variable is added to the model, a backward elimination step is performed to see if any of the variables already in the model should be deleted. What the elimination step does in effect is to remove any of the variables already in the model which effects the least significant change to the values of the model's $R$ and $R^2$. This has the effect of automatically re-assessing the degree of multicollinearity in the model towards a more favourable level.

Accordingly the data in table 9.1 was regressed step-wise using the SPSS-X package and the results obtained are summarized in tables 9.6 and 9.7.
Table 9.6: Stepwise Regression of RHP Cost Data

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>Decision</th>
<th>( R^2 )</th>
<th>SS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Labour</td>
<td>added</td>
<td>0.972</td>
<td>1.088E12</td>
<td>1.719E9</td>
</tr>
<tr>
<td>2</td>
<td>S/conts.</td>
<td>added</td>
<td>0.989</td>
<td>1.107E12</td>
<td>7.220E8</td>
</tr>
<tr>
<td>3</td>
<td>Materials</td>
<td>added</td>
<td>0.999</td>
<td>1.118E12</td>
<td>6.900E7</td>
</tr>
<tr>
<td>4</td>
<td>Prelims.</td>
<td>added</td>
<td>0.999</td>
<td>1.118E12</td>
<td>5.501E7</td>
</tr>
<tr>
<td>5</td>
<td>Plant</td>
<td>out</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

Table 9.7: Coefficients from Stepwise Regression of RHP Cost Data

<table>
<thead>
<tr>
<th>Step</th>
<th>Labour</th>
<th>Materials</th>
<th>S/conts.</th>
<th>Prelims</th>
<th>Constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.67</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>£8538</td>
</tr>
<tr>
<td>2</td>
<td>3.96</td>
<td>--</td>
<td>1.01</td>
<td>--</td>
<td>-£6634</td>
</tr>
<tr>
<td>3</td>
<td>1.91</td>
<td>0.96</td>
<td>1.03</td>
<td>--</td>
<td>-£1964</td>
</tr>
<tr>
<td>4</td>
<td>1.58</td>
<td>0.90</td>
<td>1.03</td>
<td>1.42</td>
<td>-£1923</td>
</tr>
</tbody>
</table>

The above tables show that by adding subcontracts costs to a model containing labour costs as the only predictor the \( R^2 \) value increases by 1.7%, \((0.989 - 0.972)\), whereas the introduction of further variables, (namely materials and preliminary costs), does not produce any further noticeable increase in the value of \( R^2 \). Furthermore the tables reveal that plant costs are not relevant to the effectiveness of the regression model and was thus dropped off. Since there was no noticeable increase in the value of \( R^2 \) after the second step of the analysis we may conclude that labour and subcontract costs are adequate predictors of the total costs of housing units and hence define the revised regression equation as:

\[
C = 3.96L + 1.01S - 6634
\]  

(9.1)

An important question that arises from this model would be the criteria for accepting or rejecting the additional variables into the equation. How, for instance, can we be certain that 1.7% increase in the value of \( R^2 \) caused by introducing subcontract costs in the regression is significant enough to warrant including the variable into the equation? The answer to this lies in the outcome of yet another F-test derived from the sum and mean
square values of the successive steps of the stepwise regression. The formula for the test is:

\[ F = \frac{SS_{j+1} - SS_j}{MS_{j+1}} \]

where: \( j \) = the number of regression step of last variable added.

\( SS_j \) = sum of squares of the regression at step \( j \).

\( SS_{j+1} \) = sum of squares of the regression at step \( j+1 \).

\( MS_{j+1} \) = mean square of residuals at step \( j+1 \) of the regression.

The computed F-value is then compared with the entry in the F-table corresponding to the degrees of freedom of the regression step. If the computed F-value is greater than the corresponding value in the table, then the variable introduced at step \( j+1 \) of the regression is significant and, therefore, admitted into the equation. Applying this test for subcontract costs using the values in table 9.6, we get:

\[ F_{(1,17)} = \frac{1.107 \times 10^{12} - 1.088 \times 10^{12}}{7.22 \times 10^8} = 26.32 \]

and from F-table we get \( F_{(1,17)} = 4.45 \)

When similar tests were applied to materials and preliminary costs the results obtained were as follows:

<table>
<thead>
<tr>
<th></th>
<th>Computed F</th>
<th>Table F</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcontract costs</td>
<td>26.32</td>
<td>4.45</td>
<td>accepted</td>
</tr>
<tr>
<td>Materials costs</td>
<td>0.00</td>
<td>3.68</td>
<td>rejected</td>
</tr>
<tr>
<td>Preliminary costs</td>
<td>0.00</td>
<td>3.41</td>
<td>rejected</td>
</tr>
</tbody>
</table>

The foregoing analysis confirms the significance of subcontracts costs as a predictor variable for total costs of housing units. Since materials and preliminary costs are both within the possible control of the contractor and are reasonably linked to the amount of labour employed on a construction project, and are thus capable of being represented by labour costs, whereas
subcontract costs are the one variable upon which the contractor could not have much control, this outcome is reasonable and acceptable.

Another important question that needs to be addressed before the revised equation can be recommended for acceptance concerns the reliability of the constant term (-£6634). That is to say, how can we be certain that the total cost of every housing unit computed using the equation is in excess of its value by £6634? An examination of table 9.7 reveals that the constant term substantially changed from £8538 in step 1 to -£6634 in step 2 of the regression. This indicates that the constant changes and may well be zero. To ascertain the nature of the constant we test the hypothesis that the constant is not zero against the null hypothesis that the constant is zero.

i.e. test \[ H_0: \text{constant} = 0 \text{ Vs } H_1: \text{constant} \neq 0 \]

The test is provided by the t-values of the constants and their corresponding significance tests as generated at steps 1 and 2 of the regression. The results obtained were as follows:

<table>
<thead>
<tr>
<th>Step</th>
<th>Constant</th>
<th>t</th>
<th>Prob&gt;t</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>£8538</td>
<td>0.522</td>
<td>0.608</td>
<td>accept the hypothesis</td>
</tr>
<tr>
<td>2</td>
<td>-£6634</td>
<td>-0.602</td>
<td>0.555</td>
<td>accept the hypothesis</td>
</tr>
</tbody>
</table>

These results allow us to reject the hypothesis in both steps and accept the null hypothesis that the true value of the constant term in each case was zero. Consequently, to obtain the true regression model, the data in table 9.1 was regressed with the only predictors being labour and subcontract costs but with the constant term as zero. The results obtained were as follows:

Table 9.8: Revised Regression Parameters and Statistics for RHP Cost Data

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefs.</th>
<th>t</th>
<th>Prob&gt;t</th>
<th>F</th>
<th>Prob&gt;F</th>
<th>R</th>
<th>R²</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>3.9</td>
<td>22.3</td>
<td>0.00</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Subcontracts</td>
<td>1.0</td>
<td>5.1</td>
<td>0.00</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td></td>
</tr>
<tr>
<td>Total cost</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>745.5</td>
<td>0.00</td>
<td>0.99</td>
<td>0.98</td>
<td>2.2</td>
</tr>
</tbody>
</table>
These results establish the true regression equation for the residential housing cost data to be:

\[ C = 3.9L + S \]  \hspace{1cm} (9.2)

It is worth pointing out here that this equation is simpler and thus easier to implement than the first model proposed earlier in this section, and is also as efficient because it achieves the same \( R^2 \) value (98%) as the first model.

The Regression Equation and its Meaning

The significance of the above regression model for the RHP cost data, in theory at least, is that once the costs of labour and subcontracts for a given housing unit (under construction) are known, its final cost can be predicted using the equation. Furthermore, such a prediction would have at least 95% chance of being correct. In practice, however, the equation may not be used without knowing whether or not it is applicable at every stage of the construction projects to which it refers. And the answer to this would lie in the profile of the cost data contained in Appendix III.

Determining the limits of applicability of equation 9.2 would entail comprehensive investigations into the profiles and cost distributions of the actual cost data collected from a much larger number of projects than is contained in Appendix III. Such investigations would only be practicable with the participation of a construction company in order to obtain more data that would be appropriate for the kind of analyses required, (and this could not be properly accommodated into the schedule of this kind of research). While the use of the progress factor \( k \) as proposed in chapter 6 provides one way round this problem, it does not remove the need to fully investigate the distributions of trends within construction cost data. The essence of the investigations would be to define the intervals and corresponding models for estimating the control parameters (cost and duration) of construction projects. If, for instance, the collected data reveals a normal (or near normal) distribution then the derived regression model could be used to predict project costs at time \( t = t_0 \pm SD \), where \( t_0 \) is the average duration of the project being controlled and SD is the standard deviation of the distribution of
costs over time represented by the cost data. The theory of this estimation was provided by Madsen et al (1986) and Walpole (1974) among others. Thus one of the limitations to the use of the equation, when whole projects (as opposed to individual construction operations) are used as accounting units, would be the stage of the project at which it is applicable. Whether or not this limitation would apply when specific construction operations are considered as the accounting units can only be ascertained by collecting and analysing actual data as specified in chapter 8, and which could not be accomplished by this research for the reasons given earlier in section 9.2.2. This kind of ascertainment, together with a thorough investigation of the stages within the durations of construction projects at which various estimates with regression models could be made, could form the basis of further research into the subject covered in this thesis.
9.4 Analysis of Cost Data from Public Building Projects

9.4.1 Cost Profile of Public Building Projects

Appendix IV shows the cost data compiled from 16 public building projects selected for this analysis. The cost profile for these projects, (shown in table 9.9), was extracted from the appendix in the same way as was described for the residential housing cost profile. The relationship between the values in the 'predictor' and 'response' columns of table 9.9 is also similar to that described for table 9.1.

Table 9.9: Cost Profile of Public Building Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Labour</th>
<th>Materials</th>
<th>Plant</th>
<th>S/contracts</th>
<th>Prelims</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>80016</td>
<td>210639</td>
<td>40557</td>
<td>620256</td>
<td>64079</td>
<td>1037580</td>
</tr>
<tr>
<td>2</td>
<td>110355</td>
<td>283519</td>
<td>60742</td>
<td>832341</td>
<td>83106</td>
<td>1383491</td>
</tr>
<tr>
<td>3</td>
<td>140694</td>
<td>350399</td>
<td>71928</td>
<td>1040427</td>
<td>110132</td>
<td>1731561</td>
</tr>
<tr>
<td>4</td>
<td>161363</td>
<td>381839</td>
<td>80521</td>
<td>1144470</td>
<td>121146</td>
<td>1902335</td>
</tr>
<tr>
<td>5</td>
<td>176033</td>
<td>421278</td>
<td>90114</td>
<td>1240513</td>
<td>130159</td>
<td>2076975</td>
</tr>
<tr>
<td>6</td>
<td>205372</td>
<td>490158</td>
<td>105300</td>
<td>1451598</td>
<td>154185</td>
<td>2423970</td>
</tr>
<tr>
<td>7</td>
<td>230711</td>
<td>567038</td>
<td>121485</td>
<td>1660683</td>
<td>170212</td>
<td>2764563</td>
</tr>
<tr>
<td>8</td>
<td>58677</td>
<td>141759</td>
<td>30371</td>
<td>416170</td>
<td>44053</td>
<td>697020</td>
</tr>
<tr>
<td>9</td>
<td>73347</td>
<td>170199</td>
<td>30964</td>
<td>520213</td>
<td>50066</td>
<td>865605</td>
</tr>
<tr>
<td>10</td>
<td>181901</td>
<td>439454</td>
<td>94151</td>
<td>1201130</td>
<td>131564</td>
<td>2145824</td>
</tr>
<tr>
<td>11</td>
<td>126157</td>
<td>309783</td>
<td>60298</td>
<td>894767</td>
<td>94714</td>
<td>1491727</td>
</tr>
<tr>
<td>12</td>
<td>93884</td>
<td>220815</td>
<td>48594</td>
<td>665873</td>
<td>70484</td>
<td>1108406</td>
</tr>
<tr>
<td>13</td>
<td>200306</td>
<td>503246</td>
<td>95818</td>
<td>1470406</td>
<td>150388</td>
<td>2459456</td>
</tr>
<tr>
<td>14</td>
<td>241446</td>
<td>590390</td>
<td>118560</td>
<td>1747917</td>
<td>179028</td>
<td>2904339</td>
</tr>
<tr>
<td>15</td>
<td>290389</td>
<td>701798</td>
<td>148857</td>
<td>2080854</td>
<td>218265</td>
<td>3456356</td>
</tr>
<tr>
<td>16</td>
<td>320595</td>
<td>791853</td>
<td>171080</td>
<td>2330557</td>
<td>220697</td>
<td>3877681</td>
</tr>
</tbody>
</table>

9.4.2 Investigating underlying Trends within the Cost Data

Theoretical Model

The underlying trends within the PBP cost data were investigated in the same way as for the RHP cost data. For the same reasons as were given in section 9.3 the linear multiple regression model (shown in equation 8.1) was (initially) adopted for the data. The presence of such relationship in the data was
further supported by the linear graphs, (figures 9.12 to 9.16), obtained when the response values were plotted against the predictor values. Thus the model initially proposed for the data was:

\[ C_f = a + b_1 L_a + b_2 M_a + b_3 E_a + b_4 S_a + b_5 P_a \]  

(9.3)
Figure 9.14: Effect of Plant costs on Total cost of PBP

\[ y = 92188 + 22.530x \quad R^2 = 0.992 \]

Figure 9.15: Effect of Subcontract costs on Total cost of PBP

\[ y = 13889 + 1.6619x \quad R^2 = 0.998 \]

Figure 9.16: Effect of Preliminary costs on Total cost of PBP

\[ y = -51573 + 16.640x \quad R^2 = 0.991 \]
Examining Residual Plots

The residual values from the PBP cost data were obtained, as earlier described, and plotted against the corresponding total costs and the individual component costs. Table 9.10 gives the computed residuals while figures 9.17 to 9.22 show the various residual plots obtained. An examination of the plots reveals a fairly even distribution of the plots on either side of the zero residual value. This implies that the distribution of the residuals is normal and that the proposed regression model can be safely used without having to introduce an error term to account for the cost factors that were not explicitly represented in the model.

Table 9.10: Residual Values from PBP Cost Data

<table>
<thead>
<tr>
<th>Project</th>
<th>Total Cost</th>
<th>Residual Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1037580</td>
<td>7797.3</td>
</tr>
<tr>
<td>2</td>
<td>1383491</td>
<td>-1268.9</td>
</tr>
<tr>
<td>3</td>
<td>1731561</td>
<td>8850.4</td>
</tr>
<tr>
<td>4</td>
<td>1902335</td>
<td>5384.7</td>
</tr>
<tr>
<td>5</td>
<td>2076975</td>
<td>-3312.9</td>
</tr>
<tr>
<td>6</td>
<td>2423970</td>
<td>2293.1</td>
</tr>
<tr>
<td>7</td>
<td>2764563</td>
<td>-14068.5</td>
</tr>
<tr>
<td>8</td>
<td>697020</td>
<td>-9883.2</td>
</tr>
<tr>
<td>9</td>
<td>865605</td>
<td>4782.2</td>
</tr>
<tr>
<td>10</td>
<td>2145824</td>
<td>6326.4</td>
</tr>
<tr>
<td>11</td>
<td>1491727</td>
<td>-15220</td>
</tr>
<tr>
<td>12</td>
<td>1108406</td>
<td>4315.8</td>
</tr>
<tr>
<td>13</td>
<td>2459456</td>
<td>-1402.4</td>
</tr>
<tr>
<td>14</td>
<td>2904339</td>
<td>629.3</td>
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<td>15</td>
<td>3456356</td>
<td>1625.5</td>
</tr>
<tr>
<td>16</td>
<td>3877681</td>
<td>3151.3</td>
</tr>
</tbody>
</table>
Figure 9.17: Scatter Plot of Labour cost Residuals for PBP

Figure 9.18: Scatter Plot of Materials cost Residuals for PBP

Figure 9.19: Scatter Plot of Plant cost Residuals for PBP
Figure 9.20: Scatter Plot of Subcontract cost Residuals for PBP

Figure 9.21: Scatter Plot of Preliminaries cost Residuals for PBP

Figure 9.22: Scatter Plot of Total cost Residuals for PBP
As was the case in section 9.3, the distribution of the plots also indicate an underlying linear trend in the cost profile analysed. Consequently, the analysis of the cost profile was carried out as described in section 9.3. The results obtained, shown in table 9.11, are similar to those in table 9.3. Therefore the interpretation of the results in table 9.11 is the same as was given for table 9.3. This enables us to rule out any significant presence of exponential relationships in the PBP cost data and to accept the existence of linear relationships. Thus continuing the analysis of the PBP cost profile using the linear multiple regression model proposed earlier in this section is justified.

Table 9.11: Statistics for Polynomial Regression of PBP Cost Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>1st Degree</th>
<th></th>
<th></th>
<th>2nd Degree</th>
<th></th>
<th></th>
<th></th>
<th>3rd Degree</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t</td>
<td>Prob&gt;t</td>
<td></td>
<td>t</td>
<td>Prob&gt;t</td>
<td></td>
<td>t</td>
<td>Prob&gt;t</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td>89.8</td>
<td>0.00</td>
<td></td>
<td>0.8</td>
<td>0.44</td>
<td></td>
<td>0.7</td>
<td>0.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>246.1</td>
<td>0.00</td>
<td></td>
<td>0.2</td>
<td>0.84</td>
<td></td>
<td>-0.0</td>
<td>0.98</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>40.7</td>
<td>0.00</td>
<td></td>
<td>-0.8</td>
<td>0.47</td>
<td></td>
<td>-0.8</td>
<td>0.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S/contracts</td>
<td>94.7</td>
<td>0.00</td>
<td></td>
<td>-1.1</td>
<td>0.30</td>
<td></td>
<td>0.4</td>
<td>0.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prelims.</td>
<td>40.3</td>
<td>0.00</td>
<td></td>
<td>1.9</td>
<td>0.08</td>
<td></td>
<td>0.5</td>
<td>0.64</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

9.4.3 Generation of Regression Parameters and Statistics

The multiple regression function of Statworks was then applied to the cost profile in table 9.9. This generated the same set of statistics as was earlier described. Tables 9.12, 9.13 and 9.14 show the statistics generated for the PBP cost data.

Table 9.12: Regression Parameters and Statistics for PBP Cost Data

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefs.</th>
<th>t</th>
<th>Prob&gt;t</th>
<th>F</th>
<th>Prob&gt;F</th>
<th>R</th>
<th>R²</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>12907.7</td>
<td>2.1</td>
<td>0.54</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Labour</td>
<td>2.3</td>
<td>3.0</td>
<td>0.01</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Materials</td>
<td>3.2</td>
<td>9.2</td>
<td>0.00</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plant</td>
<td>-0.4</td>
<td>-0.6</td>
<td>0.59</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Subcontracts</td>
<td>0.3</td>
<td>3.1</td>
<td>0.01</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Preliminaries</td>
<td>0.0</td>
<td>0.0</td>
<td>0.97</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total cost</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>31829</td>
<td>0.00</td>
<td>0.99</td>
<td>0.98</td>
<td>2.3</td>
</tr>
</tbody>
</table>

278
2.4
7.7
-0.8
2.5
0.5
0.03
0.00
0.42
0.02
0.61
0.03
0.00
0.42
0.02
0.61
0.22038
0.00
0.99
0.98
2.2

9.4.4 Inferences from the Statistical Tests of the Regressions

The regression parameters and statistics from the PBP cost data were also examined in the light of the various tests and conditions prescribed in chapter 6 to determine the actual regression equation and its suitability for use in practical forecasting and cost control.

Examining the Regression Coefficients

The regression coefficients and their respective t-values are shown in columns 2 and 3 of tables 9.12 and 9.13. Column 4 of table 9.12 shows that only labour costs, materials costs and subcontracts costs passed the t-test at 95% level of significance, while plant costs, preliminaries and the constant term were not admissible into the model at the same level of significance. Consequently the regression was repeated without the constant term and the results (given in table 9.13) showed that plant and preliminary costs could still not be included into the model at
the 95% level of significance. Thus at this stage of the analysis three of the variables have passed the t-test of significance and appear to be suitable for use in the model.

**Examining the Coefficients of Correlation and Determination**

The interpretations of the R (0.99), \( R^2 \) (0.98) and F (31829) statistics are the same as was given in section 9.3. Thus both R and \( R^2 \) have passed the prescribed tests of significance.

**Examining the Durbin-Watson Statistic**

The interpretation of the D-W statistic (2.3) is the same as was given in section 9.3. Thus the model has passed the D-W test.

**Examining the Matrix of Simple Correlations**

The values contained in the matrix of simple correlations shows the strengths of relationships between the regression variables. The values in table 9.14, which range from 0.994 to 1.000, indicate very strong relationships between the variables. For the reasons given in section 9.3, these values suggest the need to prune down the number of the variables to be included in the model. This selection of variables was carried out via stepwise regression.

**Variable Selection via Stepwise Regression**

The data in table 9.9 was regressed step-wise using the SPSS-X package. The results obtained are given in tables 9.15 and 9.16.

**Table 9.15: Stepwise Regression of PBP Cost Data**

<table>
<thead>
<tr>
<th>Step</th>
<th>Variable</th>
<th>Decision</th>
<th>( R^2 )</th>
<th>SS</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Materials</td>
<td>added</td>
<td>0.999</td>
<td>1.288E13</td>
<td>1.288E13</td>
</tr>
<tr>
<td>2</td>
<td>Labour</td>
<td>added</td>
<td>0.999</td>
<td>1.288E13</td>
<td>6.442E12</td>
</tr>
<tr>
<td>3</td>
<td>S/conts.</td>
<td>added</td>
<td>0.999</td>
<td>1.288E13</td>
<td>4.295E12</td>
</tr>
<tr>
<td>4</td>
<td>Prelims.</td>
<td>out</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>5</td>
<td>Plant</td>
<td>out</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>
Tables 9.15 and 9.16 suggest the revised regression model for the PBP cost data to be:

\[
C = 2.17L + 3.15M + 0.29S + £13880
\]  
(9.4)

The tables, however, reveal that introducing additional variables beyond step 1 of the regression does not produce any noticeable increase in the values of the model's R². When the significance of the contributions made to the value of R² by adding variables to the regression model was tested using the F-formula given in section 9.3, the following results were obtained:

<table>
<thead>
<tr>
<th>Computed F</th>
<th>Table F</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>0.00</td>
<td>4.60</td>
</tr>
<tr>
<td>Subcontract costs</td>
<td>0.00</td>
<td>3.98</td>
</tr>
</tbody>
</table>

These results establish materials costs as the only significant predictor of total costs for the PBP category of projects for the company that supplied the data. The corresponding regression model would thus be:

\[
C = 4.88M + £16260
\]  
(9.5)

As in section 9.3 the significance of the constant term (£16260) was determined by employing its corresponding t-values and Prob>t at step 1 of the regression to test the hypothesis that the constant was not zero against the null hypothesis that the constant was zero.

i.e. test \( H_0: \text{constant} = 0 \) Vs \( H_1: \text{constant} \neq 0 \)
The result obtained was as follows:

<table>
<thead>
<tr>
<th>Step</th>
<th>Constant</th>
<th>t</th>
<th>Prob&gt;t</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16260</td>
<td>1.823</td>
<td>0.090</td>
<td>reject the hypothesis</td>
</tr>
</tbody>
</table>

This allows us to accept the null hypothesis and to conclude that the true value of the constant was zero. Consequently, to obtain the true regression model, the data in table 9.9 was regressed with materials costs as the only predictor but with the constant term as zero. The results obtained are as follows:

Table 9.17: Revised Regression Parameters and Statistics for PBP Cost Data

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefs.</th>
<th>t</th>
<th>Prob&gt;t</th>
<th>F</th>
<th>Prob&gt;F</th>
<th>R</th>
<th>R²</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>4.90</td>
<td>545.1</td>
<td>0.00</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Total cost</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>48958</td>
<td>0.00</td>
<td>0.99</td>
<td>0.98</td>
<td>2.4</td>
</tr>
</tbody>
</table>

These results establish the true regression equation for the PBP cost data to be:

\[ C = 4.90M \quad (9.6) \]

This is a much simpler model to both contemplate and apply. The contrast between this equation and that derived for the residential housing projects appear to suggest that expenditure on materials in public building projects is more significant than the other cost variables as determinant of total costs. As such the equation means that once a company ascertains the cost of materials that have been consumed it should be able to predict the cost of the project at that stage. It should, however, be pointed out that the limitations identified for the RHP equation in section 9.3 also apply to the above equation.
9.5 Analysis of Cost Data from Civil Engineering Projects

9.5.1 Cost profile of Civil Engineering Projects

Appendix V shows the cost data from 13 civil engineering projects selected for analysis. The cost profile for these projects, (shown in table 9.18), was extracted from the appendix in the same way as was described for the residential housing cost profile. The relationship between the values in the 'predictor' and 'response' columns of table 9.18 is also similar to that described for table 9.1. In this case the contractor claimed that preliminary costs were recorded with either labour, materials or plant, while subcontracting was not usually employed on small scale projects like those profiled in table 9.18. Due to the company's recent change over from traditional methods of data capture to the use of SMS it could not supply cost data on bigger projects which could suitably be processed for use in these tests.

Table 9.18: Cost Profile of Civil Engineering Projects

<table>
<thead>
<tr>
<th>Project</th>
<th>Labour</th>
<th>Materials</th>
<th>Plant</th>
<th>S/contracts</th>
<th>Prelims</th>
<th>RESPONSE Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>13060</td>
<td>51434</td>
<td>171532</td>
<td>--</td>
<td>--</td>
<td>256037</td>
</tr>
<tr>
<td>2</td>
<td>20761</td>
<td>92453</td>
<td>271494</td>
<td>--</td>
<td>--</td>
<td>486700</td>
</tr>
<tr>
<td>3</td>
<td>25513</td>
<td>110944</td>
<td>322793</td>
<td>--</td>
<td>--</td>
<td>475250</td>
</tr>
<tr>
<td>4</td>
<td>30152</td>
<td>151586</td>
<td>436330</td>
<td>--</td>
<td>--</td>
<td>624069</td>
</tr>
<tr>
<td>5</td>
<td>33626</td>
<td>150850</td>
<td>452662</td>
<td>--</td>
<td>--</td>
<td>656000</td>
</tr>
<tr>
<td>6</td>
<td>30306</td>
<td>162058</td>
<td>499447</td>
<td>--</td>
<td>--</td>
<td>708810</td>
</tr>
<tr>
<td>7</td>
<td>32723</td>
<td>180897</td>
<td>548897</td>
<td>--</td>
<td>--</td>
<td>775525</td>
</tr>
<tr>
<td>8</td>
<td>43955</td>
<td>210605</td>
<td>636072</td>
<td>--</td>
<td>--</td>
<td>908634</td>
</tr>
<tr>
<td>9</td>
<td>46903</td>
<td>231134</td>
<td>676736</td>
<td>--</td>
<td>--</td>
<td>967774</td>
</tr>
<tr>
<td>10</td>
<td>25126</td>
<td>120821</td>
<td>360608</td>
<td>--</td>
<td>--</td>
<td>525559</td>
</tr>
<tr>
<td>11</td>
<td>47985</td>
<td>241323</td>
<td>720339</td>
<td>--</td>
<td>--</td>
<td>1037647</td>
</tr>
<tr>
<td>12</td>
<td>18612</td>
<td>76934</td>
<td>227922</td>
<td>--</td>
<td>--</td>
<td>327469</td>
</tr>
<tr>
<td>13</td>
<td>44270</td>
<td>192445</td>
<td>585743</td>
<td>--</td>
<td>--</td>
<td>836458</td>
</tr>
</tbody>
</table>
9.5.2 Investigating underlying Trends within the Cost Data

Theoretical Model

The underlying trends within the CEP cost data were investigated in the same way as for the RHP cost data. For the same reasons as were given in section 9.3 the linear multiple regression model was (initially) adopted for the data. The presence of such relationship in the data was further supported by the linear graphs, (figures 9.23 to 9.25), obtained when the response values were plotted against the predictor values. Thus the model initially proposed for the data was:

\[ C_f = a + b_1L_a + b_2M_a + b_3E_a \]  \hspace{1cm} (9.7)

Figure 9.23: Effect of Labour costs on Total cost of CEP

Figure 9.24: Effect of Materials costs on Total cost of CEP
Examining Residual Plots

The residual values from the CEP cost data were obtained, as earlier described, and plotted against the corresponding total costs as well as the individual component costs. Table 9.19 gives the computed residuals for the CEP cost data.

Table 9.19: Residual Values from CEP Cost Data

<table>
<thead>
<tr>
<th>Project</th>
<th>Total Cost £</th>
<th>Residual Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>256037.60</td>
<td>-8207.0</td>
</tr>
<tr>
<td>2</td>
<td>486700.65</td>
<td>72664.0</td>
</tr>
<tr>
<td>3</td>
<td>475250.00</td>
<td>-12546.2</td>
</tr>
<tr>
<td>4</td>
<td>624069.01</td>
<td>-20077.6</td>
</tr>
<tr>
<td>5</td>
<td>656000.00</td>
<td>-3458.7</td>
</tr>
<tr>
<td>6</td>
<td>708810.90</td>
<td>-693.6</td>
</tr>
<tr>
<td>7</td>
<td>775525.27</td>
<td>-4287.6</td>
</tr>
<tr>
<td>8</td>
<td>908634.11</td>
<td>2684.3</td>
</tr>
<tr>
<td>9</td>
<td>967774.30</td>
<td>-4896.5</td>
</tr>
<tr>
<td>10</td>
<td>525559.25</td>
<td>-6486.3</td>
</tr>
<tr>
<td>11</td>
<td>1037647.68</td>
<td>14148.3</td>
</tr>
<tr>
<td>12</td>
<td>327469.13</td>
<td>-26281.2</td>
</tr>
<tr>
<td>13</td>
<td>836458.59</td>
<td>-2561.9</td>
</tr>
</tbody>
</table>

Figures 9.26 to 9.29 show the various residual plots obtained from the residuals in table 9.19. An examination of the plots reveals an uneven distribution of the plots on either side of the
zero residual line. For instance, the plot of total cost Vs residuals shows that 10 out of the 13 points fall below the zero residual line. This implies that the mean value of the residuals is not zero. Thus the proposed regression model can not be safely used without introducing error term(s) to account for cost factors that were not explicitly represented in the model.

Figure 9.26: Scatter Plot of Labour cost Residuals for CEP

Figure 9.27: Scatter Plot of Materials cost Residuals for CEP
Due to the apparent defect in the cost profile in table 9.18, the linear trend suggested by theoretical considerations and the linear graphs of individual predictors in figures 9.23 to 9.25 cannot be conclusively established. As was the case with the other cost profiles analysed earlier, the presence of other exponential relationships within the CEP cost data was investigated by regressing the data exponentially to second and third degrees using Statworks. The results obtained are shown in table 9.20. The coefficients of the quadratic and cubic terms were found to be so small that the software rounded them up to zero, while all the first degree coefficients were non-zero. This indicates that polynomial trends are not significantly present within the CEP cost data. The t-values and their corresponding significance tests contained in table 9.20 show that none of the variables
yielded a polynomial coefficient that is acceptable at the 95% confidence level. This allows us to conclude that exponential relationships are not present in the data.

Table 9.20: Statistics for Polynomial Regression of CEP Cost Data

<table>
<thead>
<tr>
<th>Variable</th>
<th>1st Degree</th>
<th>2nd Degree</th>
<th>3rd Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t</td>
<td>Prob&gt;t</td>
<td>t</td>
</tr>
<tr>
<td>Labour</td>
<td>14.3</td>
<td>0.00</td>
<td>-0.7</td>
</tr>
<tr>
<td>Materials</td>
<td>31.4</td>
<td>0.00</td>
<td>0.4</td>
</tr>
<tr>
<td>Plant</td>
<td>32</td>
<td>0.00</td>
<td>0.3</td>
</tr>
</tbody>
</table>

The first degree t-values and their corresponding significance tests in table 9.20 also suggest the existence of linear relations between the predictor and response variables in the CEP cost data. Despite this, the evidence of figures 9.26 to 9.29 statistically precludes any realistic analysis of the data based on the multiple regression model in equation 9.7. For instance, when the multiple regression analysis was attempted on the data, the results obtained, (see tables 9.21 & 9.22), supported discontinuing the analysis. As shown in the tables, the overall model passed the F-test of significance but failed the Durbin-Watson test for autocorrelation. Furthermore, none of the regression coefficients passed the t-test of significance. This provided justification for discontinuing the analysis of the CEP cost profile using linear multiple regression and based on equation 9.7.

Table 9.21: Regression Parameters and Statistics for CEP Cost Data

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefs.</th>
<th>t</th>
<th>Prob&gt;t</th>
<th>F</th>
<th>Prob&gt;F</th>
<th>R</th>
<th>R²</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>1.1</td>
<td>0.3</td>
<td>0.75</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Materials</td>
<td>1.6</td>
<td>0.7</td>
<td>0.53</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Plant</td>
<td>0.8</td>
<td>1.0</td>
<td>0.33</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Total cost</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>302</td>
<td>0.00</td>
<td>0.99</td>
<td>0.98</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Table 9.22: Correlation Matrix of Regression Variables for CEP Cost Data

<table>
<thead>
<tr>
<th>Variables</th>
<th>Total cost</th>
<th>Labour</th>
<th>Materials</th>
<th>Plant</th>
<th>S/contracts</th>
<th>Prelims</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost</td>
<td>1.000</td>
<td>0.974</td>
<td>0.994</td>
<td>0.995</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Labour</td>
<td>0.974</td>
<td>1.000</td>
<td>0.978</td>
<td>0.975</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Materials</td>
<td>0.994</td>
<td>0.978</td>
<td>1.000</td>
<td>0.998</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Plant</td>
<td>0.995</td>
<td>0.975</td>
<td>0.998</td>
<td>1.000</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>S/contracts</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>1.000</td>
<td>--</td>
</tr>
<tr>
<td>Prelims</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

The evidence contained in figures 9.26 to 9.29 and tables 9.20 to 9.22 reveal that the cost data in table 9.18 does not support the proposed regression model. The distribution of residuals indicate that there were either significant predictors that were not included in the data, or the values of those predictors in the data were incorrectly represented, (i.e. the data over- or under-represents the true contribution of the predictors towards the value of the response variable). Consequently, the linear relationships indicated by the data could not be conclusively established.

An examination of the cost data for Project No.2 in Appendix V reveals that there is a difference of more than £100,000 between the total actual cost recorded by headoffice and the component costs recorded on site. This discrepancy was confirmed by the source company who attributed it to subcontracts awarded by the headoffice. As this was an unusual practice by the company (as pointed out in section 9.5.1) the project staff on site had no record of the subcontracts. While these factors do not allow us to conclude that the proposed approach was applicable to the CEP cost data, the defects identified with the data also preclude the conclusion that the proposed model was not applicable with the data. But the results of the analysis clearly established the need for comprehensive recording, classification and exchange of cost data in order to enable effective use of quantitative methods for cost monitoring and control.
9.6 Trial Run of the Proposed Approach

9.6.1 Procedure

A trial run of the proposed cost monitoring and control approach was carried out. The trial run also amounted to a test implementation of the second phase of the proposals made in chapter 8. The following steps were carried out in order to test the feasibility of GP on the results of the foregoing analysis:

1. Collecting cost data from on-going construction projects, (given in tables 9.23 and 9.24). This was done in the same way as was described earlier in this chapter and from the same source company.

2. Entering the data into a project 'library' created on Quattro, (as shown in table 9.25), which then applies equation 9.2 and other built-in transformations to compute \(C_f\) and other decision nodes for the on-going project. Table 9.26 shows a typical report generated by the 'library'.

3. Computing optimum adjustments to be done on current expenditure levels on the project for it to stay within its budget. This step was done using goal programming.

9.6.2 Test Data

The cost data shown in tables 9.23 and 9.24 was obtained from two on-going construction projects that were being executed by the same company which supplied the data given in Appendices III and IV. The criteria used for choosing these test projects were the same as those described in section 9.2.2. Thus the test projects were selected because they had similar characteristics as those which were the source of the regression parameters established in sections 9.3 and 9.4. Table 9.23 shows the cost profile of a residential housing project \((T_1)\) with similar characteristics to those profiled in Appendix III, while table 9.24 shows the cost profile of a public building project \(T_2\) (for educational use) with similar characteristics to those profiled in Appendix IV. Project \(T_1\) was a block of duplex houses being constructed in Quorn, while project \(T_2\) was a block of students hostel at LUT. The tables give the costs of the various resources used up on the projects during the first seven months of their schedules. The cumulative values \((C_e)\) of their expected cost
schedules based on the company's budget are also shown along with the corresponding progress factors (k).

Table 9.23: Cost Data of T1 (Budget = £328034)

<table>
<thead>
<tr>
<th>Month</th>
<th>Labour</th>
<th>Materials</th>
<th>Plant</th>
<th>S/conts.</th>
<th>Prelims.</th>
<th>Ce</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>205.98</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>5111.26</td>
<td>4920.0</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>275.30</td>
<td>232.15</td>
<td>0.00</td>
<td>1010.67</td>
<td>2534.10</td>
<td>3750.0</td>
<td>0.03</td>
</tr>
<tr>
<td>3</td>
<td>705.58</td>
<td>639.03</td>
<td>0.00</td>
<td>2100.01</td>
<td>606.76</td>
<td>3750.0</td>
<td>0.04</td>
</tr>
<tr>
<td>4</td>
<td>1020.60</td>
<td>4236.63</td>
<td>5538.02</td>
<td>0.00</td>
<td>2454.48</td>
<td>12280.0</td>
<td>0.07</td>
</tr>
<tr>
<td>5</td>
<td>8937.04</td>
<td>20838.60</td>
<td>4371.28</td>
<td>1428.23</td>
<td>607.42</td>
<td>33500.0</td>
<td>0.18</td>
</tr>
<tr>
<td>6</td>
<td>12239.92</td>
<td>16157.78</td>
<td>1660.82</td>
<td>3356.20</td>
<td>624.18</td>
<td>31520.0</td>
<td>0.27</td>
</tr>
<tr>
<td>7</td>
<td>12771.90</td>
<td>32963.83</td>
<td>3455.96</td>
<td>25604.89</td>
<td>561.87</td>
<td>69780.0</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Total 36156.3 75068.02 15026.08 33500.0 12500.0 159500.0

Table 9.24: Cost Data of T2 (Budget = £1900500)

<table>
<thead>
<tr>
<th>Month</th>
<th>Labour</th>
<th>Materials</th>
<th>Plant</th>
<th>S/conts.</th>
<th>Prelims.</th>
<th>Ce</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>97.91</td>
<td>2196.68</td>
<td>238.56</td>
<td>15463.12</td>
<td>10606.38</td>
<td>27500.0</td>
<td>0.01</td>
</tr>
<tr>
<td>2</td>
<td>520.90</td>
<td>1467.55</td>
<td>584.61</td>
<td>55077.46</td>
<td>340.01</td>
<td>55700.0</td>
<td>0.04</td>
</tr>
<tr>
<td>3</td>
<td>1017.88</td>
<td>9695.18</td>
<td>9965.76</td>
<td>53332.64</td>
<td>10221.53</td>
<td>80900.0</td>
<td>0.09</td>
</tr>
<tr>
<td>4</td>
<td>12792.54</td>
<td>53138.02</td>
<td>14234.17</td>
<td>182705.67</td>
<td>28456.35</td>
<td>279820.0</td>
<td>0.23</td>
</tr>
<tr>
<td>5</td>
<td>23205.51</td>
<td>67766.07</td>
<td>13149.13</td>
<td>272695.15</td>
<td>1553.10</td>
<td>363420.0</td>
<td>0.42</td>
</tr>
<tr>
<td>6</td>
<td>27720.00</td>
<td>39466.41</td>
<td>6565.47</td>
<td>40776.18</td>
<td>12323.30</td>
<td>121800.0</td>
<td>0.49</td>
</tr>
<tr>
<td>7</td>
<td>35881.39</td>
<td>63395.50</td>
<td>10862.30</td>
<td>104957.98</td>
<td>470.83</td>
<td>211160.0</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Total 101236.1 237125.4 55600.0 725008.2 68207.5 1140300.0

9.6.3 Results

Tables 9.23 and 9.24 were manually compiled from very extensive site records of the contractor because the company does not employ any computerized data capture systems. The totals, expected cost to date Ce and the progress factor k were entered into a library in Quattro, which already contained the corresponding regression parameters (established in sections 9.3 and 9.4) and the budgets B of the projects. Table 9.25 shows the entries made in the library and the current and future cost overruns on the projects computed by the library.

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Table 9.25: Library Entries for Cost Data of Test Projects T1 and T2

<table>
<thead>
<tr>
<th>Proj</th>
<th>I&lt;sub&gt;a&lt;/sub&gt;</th>
<th>M&lt;sub&gt;a&lt;/sub&gt;</th>
<th>E&lt;sub&gt;a&lt;/sub&gt;</th>
<th>S&lt;sub&gt;a&lt;/sub&gt;</th>
<th>P&lt;sub&gt;a&lt;/sub&gt;</th>
<th>b&lt;sub&gt;1&lt;/sub&gt;</th>
<th>b&lt;sub&gt;2&lt;/sub&gt;</th>
<th>b&lt;sub&gt;5&lt;/sub&gt;</th>
<th>B</th>
<th>C&lt;sub&gt;a&lt;/sub&gt;</th>
<th>k</th>
<th>C&lt;sub&gt;e&lt;/sub&gt;</th>
<th>C&lt;sub&gt;f&lt;/sub&gt;</th>
<th>C&lt;sub&gt;a&lt;/sub&gt; - C&lt;sub&gt;e&lt;/sub&gt;</th>
<th>C&lt;sub&gt;f&lt;/sub&gt; - B</th>
<th>d&lt;sub&gt;1&lt;/sub&gt;</th>
<th>d&lt;sub&gt;2&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>T&lt;sub&gt;1&lt;/sub&gt;</td>
<td>36156</td>
<td>75068</td>
<td>15026</td>
<td>33500</td>
<td>12500</td>
<td>3.9</td>
<td>0.0</td>
<td>1.0</td>
<td>328034</td>
<td>172250</td>
<td>0.5</td>
<td>159500</td>
<td>349017</td>
<td>12750</td>
<td>20983</td>
<td>8.0</td>
<td>6.4</td>
</tr>
<tr>
<td>T&lt;sub&gt;2&lt;/sub&gt;</td>
<td>101236</td>
<td>237125</td>
<td>55600</td>
<td>725008</td>
<td>68207</td>
<td>0.0</td>
<td>4.9</td>
<td>0.0</td>
<td>1900500</td>
<td>1187176</td>
<td>0.6</td>
<td>1140300</td>
<td>1936521</td>
<td>46876</td>
<td>36020</td>
<td>4.1</td>
<td>1.9</td>
</tr>
</tbody>
</table>

C<sub>a</sub> - C<sub>e</sub> = Cost overrun to date (negative values indicate cost savings)
C<sub>f</sub> - B = Forecast of total cost overrun (or savings) at the end of the project.

\[
d_1 = \frac{C_a - C_e}{C_e} \times 100 = \text{Decision nodes for cost overrun to date.}
\]

\[
d_2 = \frac{C_f - B}{B} \times 100 = \text{Decision node for predicted cost overrun.}
\]

T<sub>1</sub> = Test project No. 1 (residential)
T<sub>2</sub> = Test project No. 2 (educational)
In order to obtain the results given in tables 9.25 and 9.26, the totals from tables 9.23 and 9.24 were entered into the Quattro library along with the values of $b_1$, $b_2$ and $b_5$ (as established in sections 9.3 and 9.4). The values of $B$ and $C_e$ were obtained from the projects' budgets, schedules and contract bills, while the values of $C_f$ were computed by the library for projects $T_1$ and $T_2$ using the following formulae derived from equations 9.2 and 9.6.

\[ C_f = \frac{3.9L + S}{k} \text{ for } T_1, \text{ and} \]

\[ C_f = \frac{4.9M}{k} \text{ for } T_2. \]

The formulae were 'built into' the project library and would only change if subsequent reviews of the established regression models cause equations 9.2 and 9.6 to alter.

To enable a project manager to see whether or not there are cost overruns, the project library computes the current cost overrun, $(C_a - C_e)$ and projected cost overrun or savings, $(C_f - B)$. The library also computes decision nodes $d_1$ and $d_2$ for current and projected final cost overruns respectively. These decision nodes represent the percentages of current and projected cost overruns vis-a-vis the planned costs to date $C_e$ and total project budget $B$. The formulae for computing $d_1$ and $d_2$, given below, are also 'built into' the project library:

\[ d_1 = \frac{C_a - C_e}{C_e} \times 100 \]

\[ d_2 = \frac{C_f - B}{B} \times 100 \]

Consequently, the library prints on demand a cost report showing, for each project or cost code, the budgeted cost, final cost forecast, current cost overruns, projected final cost overruns and the corresponding values of the decision nodes. Thus a glance at the decision nodes and the absolute values of the current and predicted cost overruns will 'tell' the manager the current status of a given project or cost code. Table 9.26
shows such a cost report generated for projects T₁ and T₂ with the projected final costs of the projects alongside their budgets. Absolute values of current and projected total cost overruns are also shown along with the percentages they represent of planned current and final costs respectively of the projects. The results show that project T₁ was currently recording an 8.0% overrun with a projected final 'loss' of 6.4%, while project T₂ had recorded a 4.1% overrun to date with a projected final 'loss' of 1.9%. Depending on the tolerance limits (both in absolute and percentage terms) allowed for the projects at estimating and budgeting stages of the projects, a project manager can immediately decide whether or not there is need to effect adjustments to on-going operations.

Table 9.26: Cost Report generated by Project Library

<table>
<thead>
<tr>
<th>Proj.</th>
<th>Budget (B)</th>
<th>Final Cost Forecast (Cf)</th>
<th>Current Cost Overrun</th>
<th>Predicted total cost overrun</th>
<th>d₁</th>
<th>d₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁</td>
<td>£370000.00</td>
<td>£349017.00</td>
<td>£12750.00</td>
<td>£20983.00</td>
<td>8.0</td>
<td>6.4</td>
</tr>
<tr>
<td>T₂</td>
<td>£1900500.00</td>
<td>£1936521.00</td>
<td>£46876.00</td>
<td>£36020.00</td>
<td>4.1</td>
<td>1.9</td>
</tr>
</tbody>
</table>

To fully illustrate the implementation of the proposed approach, the results in tables 9.25 and 9.26 were optimized by fitting them to a goal programming model. In this case the source company allowed tolerance limits of ± 5% for its projects. Consequently operations on project T₁ need to be investigated to get the optimum adjustments needed. The model optimized for this purpose is as follows:

Minimize:

\[ Z = p_1^- + p_5^- + p_1^+ + p_5^+ + 10A_1 + 10A_2 + 10A_3 \]

Subject to:

\[ 3.9L + S + p_1^- + p_5^- - p_1^+ - p_5^+ + 1A_1 + 0A_2 + 0A_3 = £172250 \]
\[ L + 0 + p_1^- + 0 - p_1^+ + 0 + 0A_1 + 1A_2 + 0A_3 = £36156 \]
\[ 0 + S + 0 + p_5^- - p_5^+ + 0 - p_5^+ + 0A_1 + 0A_2 + 1A_3 = £33500 \]
\[ L, S > 0 ; \ p_1^-, p_5^- \geq 0 \ and \]
\[ A_1, A_2, A_3 \ are \ slack \ variables \]
This is a single objective GP model in which the objective is to minimize deviations (both under- and over-spending) from the cost target. If the project manager's desire was to minimize cost overruns only, without regard to under-spending, then the objective function $Z$ would not contain the underachievement variables. The slack variables were introduced to remove the inequalities used in the original models, (see chapter 6), and to provide an initial basic solution for the iterations. The factors of 10 applied to the slack variables are arbitrary and were designed to avoid working purely with decimals in the optimality row ($C_j - Z_j$); they do not affect the results.

To solve the above model using GP, the coefficients are compiled in a simplex tableau as shown in table 9.27. This tableau would then be solved using any statistical software containing the GP simplex routine. In this case the GP routine in QAM software, available on the software menu of the Civil Engineering Department of Loughborough University of Technology, was used. The iterations carried out and the results obtained are shown in tables 9.28, 9.29 and 9.30.

<table>
<thead>
<tr>
<th>$C_j$</th>
<th>RHS</th>
<th>0</th>
<th>0</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>10</th>
<th>10</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basis</td>
<td>L</td>
<td>L</td>
<td>S</td>
<td>$p_1^-$</td>
<td>$p_5^-$</td>
<td>$p_1^+$</td>
<td>$p_5^+$</td>
<td>$A_1$</td>
<td>$A_2$</td>
<td>$A_3$</td>
</tr>
<tr>
<td>10 $A_1$</td>
<td>172250</td>
<td>3.9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10 $A_2$</td>
<td>36156</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>10 $A_3$</td>
<td>33500</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$Z_j$</th>
<th>2419060</th>
<th>49</th>
<th>20</th>
<th>20</th>
<th>20</th>
<th>-20</th>
<th>-20</th>
<th>10</th>
<th>10</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_j - Z_j$</td>
<td>-49</td>
<td>-20</td>
<td>-19</td>
<td>-19</td>
<td>19</td>
<td>19</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
Table 9.28: Tableau II of GP Analysis of Trial Cost Data

<table>
<thead>
<tr>
<th>( C_j )</th>
<th>RHS</th>
<th>0</th>
<th>0</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>10</th>
<th>10</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_B ) Basis (solution)</td>
<td>( L )</td>
<td>( S )</td>
<td>( p_1^- )</td>
<td>( p_5^- )</td>
<td>( p_1^+ )</td>
<td>( p_5^+ )</td>
<td>( A_1 )</td>
<td>( A_2 )</td>
<td>( A_3 )</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>L</td>
<td>44166.67</td>
<td>1</td>
<td>0.26</td>
<td>0.26</td>
<td>0.26</td>
<td>-0.26</td>
<td>-0.26</td>
<td>0.26</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>( A_2 )</td>
<td>-8010.67</td>
<td>0</td>
<td>-0.26</td>
<td>0.74</td>
<td>-0.26</td>
<td>-0.74</td>
<td>0.26</td>
<td>-0.26</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>( A_3 )</td>
<td>33500</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

\[ Z_j \] 254893.3 | 0 | 7.4 | 7.4 | 7.4 | -7.4 | -7.4 | -2.6 | 10 | 10 |

| \( C_l-Z_1 \) | 0 | -7.4 | -6.4 | -6.4 | 8.4 | 8.4 | 12.6 | 0 | 0 |

Table 9.29: Tableau III of GP Analysis of Trial Cost Data

<table>
<thead>
<tr>
<th>( C_j )</th>
<th>RHS</th>
<th>0</th>
<th>0</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>10</th>
<th>10</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_B ) Basis (solution)</td>
<td>( L )</td>
<td>( S )</td>
<td>( p_1^- )</td>
<td>( p_5^- )</td>
<td>( p_1^+ )</td>
<td>( p_5^+ )</td>
<td>( A_1 )</td>
<td>( A_2 )</td>
<td>( A_3 )</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>L</td>
<td>36156</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>-1</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>S</td>
<td>30810.27</td>
<td>0</td>
<td>1</td>
<td>-2.85</td>
<td>1</td>
<td>2.85</td>
<td>-1</td>
<td>1</td>
<td>-3.85</td>
</tr>
<tr>
<td>10</td>
<td>( A_3 )</td>
<td>2689.73</td>
<td>0</td>
<td>0</td>
<td>2.85</td>
<td>0</td>
<td>-2.85</td>
<td>0</td>
<td>-1</td>
<td>3.85</td>
</tr>
</tbody>
</table>

\[ Z_j \] 26897.3 | 0 | 28.5 | 0 | -28.5 | 0 | -10 | 38.5 | 10 |

| \( C_l-Z_1 \) | 0 | 0 | -27.5 | 1 | 27.5 | 1 | 20 | -28.5 | 0 |

Table 9.30: Tableau IV of GP Analysis of Trial Cost Data

<table>
<thead>
<tr>
<th>( C_j )</th>
<th>RHS</th>
<th>0</th>
<th>0</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>1</th>
<th>10</th>
<th>10</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_B ) Basis (solution)</td>
<td>( L )</td>
<td>( S )</td>
<td>( p_1^- )</td>
<td>( p_5^- )</td>
<td>( p_1^+ )</td>
<td>( p_5^+ )</td>
<td>( A_1 )</td>
<td>( A_2 )</td>
<td>( A_3 )</td>
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</tr>
<tr>
<td>0</td>
<td>L</td>
<td>35857.37</td>
<td>1</td>
<td>0</td>
<td>0.26</td>
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</tr>
<tr>
<td>0</td>
<td>S</td>
<td>33500</td>
<td>0</td>
<td>1</td>
<td>0</td>
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<td>-1</td>
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<tr>
<td>10</td>
<td>( A_2 )</td>
<td>698.63</td>
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<td>0</td>
<td>0.74</td>
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<td>-0.74</td>
<td>0</td>
<td>-0.26</td>
<td>1</td>
</tr>
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</table>

\[ Z_j \] 6986.3 | 0 | 28.5 | 0 | -28.5 | 0 | -10 | 28.5 | 10 |

| \( C_l-Z_1 \) | 0 | 0 | 27.5 | 1 | 27.5 | 1 | 20 | -28.5 | 0 |

The optimum results of the optimization (given in table 9.30) revealed that:

1. The observed cost overrun on project \( T_1 \) was not caused by increased subcontract costs because the optimum value of \( S \) (£33500) is the same as its constraint value in the model.

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2. The optimum labour cost (£35857.37) is less than its constraint value in the model, which indicates that the observed cost overrun was partly due to over-spending on labour. The value of the objective function $Z_j$ (£6986.30) at the optimum stage of the iteration, which is the same as the slack factor 10A2, gives a measure of the extent to which the project has deviated from its planned costs as a result of the over-spending on labour.

3. The $C_j - Z_j$ values for all the non-basic variables are greater than zero. This means bringing any of them into the basis would cause further deviation from the cost targets. Thus, at this stage of the project, the table represents the optimal solution for the model. Furthermore, since none of the non-basic variables has a zero value of $C_j - Z_j$, this is the only optimal solution for the model. For the theory behind these deductions see Davis et al (1984).

The results of the analysis, thus, tell a project manager the precise source of cost overruns, the 'direction' in which to make adjustments, and the likely effects of any further under- or over-achievement of cost targets. The analysis also proves beyond doubt that the models and the approach proposed in chapter 8 are applicable to cost monitoring and control of construction projects.

9.7 Limitations of the Derived Regression Equations

The equations that were derived in sections 9.2.4 and 9.2.5 for the categories of construction projects used for testing the proposed approach can be used to make cost predictions on similar on-going projects. As with all forecasts the cost predictions are based on certain assumptions and or considerations which define limits within which the predictions are reliable and or applicable. Likewise the equations derived in this chapter and the results of their applications are subject to the following limitations:

1. While the models and methods developed in this thesis could be applied to monitor and control the costs and schedules of any construction project, the specific equations (9.2 and 9.6) derived in this chapter are only
applicable to the companies that supplied the test data. And even in those companies, the application would be limited to projects with similar characteristics to those used as basis for deriving the equations.

2. As pointed out in chapter 6, the reliability of regression models needs to be constantly verified by periodically updating the models with information from more and more recent projects. The up-dating process must include all the significance tests demonstrated in this chapter. Should the model fail any of the tests in the light of the newer cost data, it has to be discarded and new models developed and tested.

3. Since the regression models only represented average conditions it is necessary for companies using such models to be constantly on the look-out for any unusual operational conditions (technical, economical etc) on the project while applying the models and in interpreting the results.

4. Although most commonly available PC software packages contain the relevant programmes for implementing the proposed approach, it would be easier, faster and more convenient if there was a single integrated software to implement this approach. The development of such an integrated package would provide another facet for future research into the approach.

Despite these limitations, the results of the analysis presented in this chapter have proved that quantitative methods are applicable to cost monitoring and control of construction projects. The analysis has revealed that trends and relationships exist in construction cost data which can be employed to monitor and control costs of on-going operations or projects while they are in progress. It was proved that multiple regression models could be fitted to the cost data to effect such monitoring and control of costs. This is a significant improvement on the traditional approaches to cost control which, (as earlier revealed in the thesis), fail to provide suitable information in time to enable control decisions to be made.

The analysis in this chapter conclusively proves that GP techniques can be used to calculate the adjustments needed on the use of resource constituents of construction projects or
operations in order to control their costs. By extension, as illustrated in chapter 8, the technique can also be used at the estimating stages of construction projects once suitable parameters are established for the project operations. The analysis also establishes a rational and scientific procedure for making corrective decisions which are based on observed cost trends from the affected operations or projects. This also is another great improvement on the trial and error approach that is currently prevalent in the construction industry (as revealed in chapter 7).

Although the trial run of the approach presented in this chapter covered only three categories of projects, the results obtained clearly prove the hypothesis proffered in chapter 1. And since the thesis of the hypothesis is that quantitative methods are applicable to cost monitoring and control of construction projects, the results obtained have proved the thesis. Furthermore, the trial run demonstrates in very great detail the procedure to implement the approach proposed by the thesis. Thus the identified benefits of the approach can be realized in practice on other project categories, and by other companies, following the prescribed procedure, tests and the recommendations (see chapter 10) resulting from this research.

9.8 Summary

This chapter has described the procedure for implementing the proposals made in earlier chapters of this thesis. Cost data for residential, public and civil engineering projects was collected and analysed along the lines prescribed in the proposals. The results obtained revealed that:

1. A measurable relationship or trend exists between total costs of construction projects (and by extension individual operations) and the costs of their constituent resources.
2. The relationship referred to above is linear and additive.
3. Multiple regression analysis is suitable for measuring the identified trend or relationship, and for forecasting future values of the total costs based on the measures of the trends.
4. There are very strong cost correlations between the various cost components of construction operations, and between the costs of the components and the total cost.

5. The correlations referred to above meant that while total costs of construction operations and projects are made up of the costs of several components, (namely labour, materials, plant, subcontracts and preliminaries), only the costs of one or two key components are required for forecasting the total costs.

6. Goal programming can be applied to the trend measures obtained through multiple regression analysis of the cost data to calculate the optimum levels of expenditure for the key cost components to ensure compliance with project budget.

7. Commonly available software for microcomputers, (such as Statworks, Quattro, New Cricket, SPSS-X and Genstat), could be used to implement the proposals, carry out the required statistical tests and generate needed exception and or other cost reports. Nevertheless it would be desirable to have a single software that contains all the relevant programmes from the packages. This would ease the implementation of the approach and increase its effectiveness.

The results of the test implementation were also discussed against the background of identified problems and criteria for effective cost monitoring and control of construction projects given in earlier chapters of this thesis. It was found that the proposals made by this research (confirmed by the test results) go further than previous research in solving the problems identified in the thesis, and thus realizing the research aim defined in chapter 1.

The data analysis carried out also led to the derivation of specific regression equations for the different categories of projects used for the tests. The limitations of the derived equations, and thus the results obtained through their application, were highlighted in order to facilitate the interpretation of results obtained when the proposed approach is used in practice.
CHAPTER TEN

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

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CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

The solution is in the constant search for one--- Ludlum (1989)

10.1 Introduction

The aim of this research was to determine a more effective approach to cost monitoring and control of construction projects by contractors. The objectives were to investigate and assess the adequacy or otherwise of current theory and practices as a basis for effective cost control of projects.

This chapter presents a summary of the salient aspects and or issues covered by this research. It highlights the achievements of and the conclusions that resulted from the research. The limitations of the research findings are also stated along with specific recommendations both for utilizing the findings and for further investigations that would need to be carried out on various aspects of the subject matter in order to enhance the practical realization of the aim of the research and to develop on its objectives.

10.2 Conclusions

The research reported in this thesis has reviewed the findings of existing researches, as well as construction and management science literature related to cost monitoring and control functions. It has also investigated the practical approach to the functions, and evaluated the current practices against both the existing research findings and theoretical concepts.

The review of existing researches identified the (existence of a) problem for this research and clearly defined the scope of the problem. The review of construction literature revealed the theoretical basis for the problem while management science literature provided a scientific basis for solving the problem. The investigations into the current cost monitoring and control practices established the nature, the causes and the extent of the problem. An analysis of the investigation evidence indicated
what needed to be done to overcome the problem and that scientific management techniques could be used in that regard.

The information obtained from these four phases led the author to propose and test a quantitative approach for cost monitoring and control of construction projects. The achievements of the various phases of the research are briefly given in the following subsections.

**10.2.1 Identifying the Problems of Cost Monitoring and Control**

Research works relating to different aspects of cost control of construction projects were reviewed in this thesis. The review revealed the different kinds of problems that hinder effective cost monitoring and control of projects as:

**Inadequate Performance Models:**

This referred to the failure of construction programmes, schedules and budgets, which form the basis for cost monitoring and control, to provide adequate and or suitable frameworks for subsequent monitoring, evaluation and forecasting of cost and performance data. Consequently, these models failed to provide the needed framework for generating accurate and timely cost and performance data needed to make corrective decisions.

**Inefficient Cost Information Systems:**

This referred to ineffectiveness of the systems for the capture, processing and transmitting of cost and performance data on construction projects to generate cost data of an appropriate format, detail and timeliness that would enable on-going operations to be controlled. The problem was attributed to lack of integration between cost and schedule control functions, and the use of purely accounting approaches to cost control.

**Unsuitable Approaches to Performance Measurement:**

This referred to the inability of the systems for processing and evaluating cost and performance data to clearly isolate and or explain the causes and or sources of observed cost overruns in
good enough time to correct the affected operations or projects while they were still in progress. The systems were also found to be incapable of predicting future costs to enable advance corrective measures to be taken.

Lack of Rational Decision-making Procedures:

As a consequence of the above three problems, the cost control systems were found to be incapable of leading to rational and forward-looking corrective decisions to be made.

In view of the problems identified in existing research, this study set out to "specifically ascertain the nature and causes of the above problems, and to seek a more effective approach for acquiring and processing cost data from on-going construction operations in such a way that performance (and costs) could be predicted and corrective measures taken while the operations were still in progress".

10.2.2 Identifying the Theoretical Basis of the Problems

Construction and management science literature were reviewed to provide a basis for assessing the identified problems and formulating possible solutions. The review revealed the nature and characteristics of different approaches to control both as a management function and as applied to construction projects. It was found that:

1. The theoretical approaches to cost monitoring and control available in construction literature are largely derived from (and so resemble) financial and management accounting which are not wholly suitable for construction projects at the site operational level.

2. The prediction of future levels of performance and courses of action on on-going operations or projects based on on-going trends was essential to making corrective decisions and to achieving effective cost control. Yet construction literature does not prescribe how this essential function is to be carried out on construction projects.
3. The application of quantitative methods in cost monitoring and control of construction projects by contractors has not been adequately considered by existing research and construction literature.

4. The open-loop approaches to cost control (where by the decision-making process and responsibility are removed from the production system and environment) would not be suitable for construction projects.

5. While none of the other approaches to control would alone be adequate for construction cost control they each had features or aspects that could contribute towards effective cost control of construction projects.

6. Responsibility accounting could be used to aid effective cost control of construction projects by making different hierarchies of management structures on the projects accountable for costs at different responsibility centres of the projects.

7. Realistic construction budgets could best be realized by applying a combination of market value and fair value of the expected work content of the operations through the planning-programming-budgeting-system (PPBS).

8. Manual methods of performance measurement were error-prone, slow and generally inadequate for the needs of real-time cost control of on-going construction works.

9. To achieve effective cost control of construction it is necessary to coordinate the formats in which cost and performance data was captured, processed, evaluated and transmitted through the cost control process.

10. To achieve effective cost control of construction projects it is necessary for the performance evaluation process to reveal and explain deviations so that rational predictions of future levels of performance could be made, and appropriate corrective measures determined in advance.

The foregoing revelations from existing researches and literature led this study to postulate the hypothesis that "if cost and performance data on construction projects could be quantitatively modeled, then such models would provide rational measures of the costs, (i.e. resource requirements and utilization
levels or rates), for the projects, which would in turn provide a basis for making rational corrective decisions”.

10.2.3 Identifying the Effects of Organization on Cost Control

The research also reviewed the role of organizational structures employed by construction companies in the cost control of their projects. The review identified the organizational requirements for effective cost control and the organizational aspects that affect the cost control process. It was found that:

1. Contractors' functional organizations were the primary and a very essential basis for cost control. The organizations generate and maintain the company and project cost information systems that form the source of information for project modelling as well as cost monitoring and control activities.

2. Effective and timely communication of information within and outside construction sites is essential for effective cost control, and organization structures determine both the channels and the effectiveness of communication.

3. Organization structures that afford flexible channels of communication would facilitate effective cost control on construction site because such structures enhance broader interpersonal communication.

4. Granting responsibility for decision-making to project staff on site would greatly enhance the effectiveness of cost control efforts for construction projects.

10.2.4 Identifying a Scientific Basis for Effective Cost Control

The research reviewed management science literature in order to identify possible quantitative models that could be used for cost monitoring and control of construction projects, and to overcome the problems identified earlier. The review revealed that:

1. The characteristics of certain quantitative models (i.e. multiple regression, time-series, LP, IP and GP) make them applicable to cost monitoring and control activities
on construction projects. Furthermore the characteristics of those models appeared to satisfy the criteria and requirements for effective cost control of construction projects identified in literature and as summarized in sections 10.2.2 and 10.2.3.

2. Regression and correlation models could be used to identify and measure, (and thus to explain), trends within construction cost data, and to use such trends as basis for forecasting and decision-making on similar operations or projects. This would be useful for effective monitoring of overall programmes and budgets of construction projects.

3. Time-series forecasting methods could be used on a short-term basis to verify short-range plans, schedules and budgets by predicting the achievability of such plans and budgets based on current trends from on-going operations.

4. Goal programming models could be used in cost control of construction projects to make corrective decisions by defining the optimum mix of construction resources that would minimize deviations from specified levels of expenditure or durations. The models would also allow feedforward control of costs due to the anticipatory manner in which they employ cost trends to define the optimum course of future operations in order to achieve the specified objectives.

10.2.5 Assessment of the Cost Control Problems in Practice

The research investigated the practical approaches to cost monitoring and control tasks among major U.K. contractors in order to assess the causes, nature and extent of the identified problems in practice. The following are some of the significant findings from an analysis of the evidence from the investigations:

1. The cost control systems operated by contractors in practice do not reveal cost and schedule overruns in time for them to be corrected while the affected operations are still in progress. This was found to be mainly caused by:
   - Elongation of ITT due to lack of format coordination between different monitoring and control activities or
phases, and excessive involvement of company headoffices in line functions on site.

- Use of manual methods for the capture and processing of cost and performance data which resulted in inadequate data of unsuitable format, detail and accuracy. This also impeded effective exchange of cost and performance data between different project personnel.

2. Profit and loss accounts and direct comparison methods were predominantly used for performance evaluation and this often resulted in failure to pin-point the sources of cost overruns. Quantitative techniques for cost monitoring, forecasting and decision-making were not found to be in use.

3. Lower to middle levels of project staff were not adequately involved in preparing the cost and performance models they were expected to implement on site. They were also not vested with the responsibility for costs at their levels of organizational responsibility.

4. The use of computers in construction cost management was mainly limited to estimating and accounting functions carried out by the finance departments of the contractors. No significant evidence was found of their use in real-time cost control of on-going operations.

5. The roles of project personnel on site with regard to cost monitoring and control activities were not clearly defined with the result that interpersonal communication was generally chaotic and ineffective. Yet communication was ranked as the second most significant determinant of effective cost control.

The above deficiencies of the practical approach to cost monitoring and control were found to have some very profound consequences on the ability of the contractors to effectively control the costs of their projects. For instance, the incidence of cost overruns was found to be universal among the contractors, as the following findings reveal:
1. 44% of contractors *always* suffered cost overruns on all their projects, while 16% *always* suffered cost overruns in 3 out of every 4 projects they executed.

2. 60% of contractors overspent their budgets in 3 out of every 4 projects they executed, while up to 80% of them overspent their budgets in 1 out of every 2 projects.

3. All the contractors (i.e. 100%) suffered cost overruns in at least 1 out of every 4 projects they executed.

4. All the contractors found that cost overruns on individual operations resulted in overruns on overall budgets in 92% of all cases. Thus effective cost control of operations would leave only an 8% chance of overspending project budgets.

The significance of the findings from the investigations lie not only in establishing the continued existence of the problems identified in *chapter 2* but also in revealing the wide gap that exists between current cost control practice and what is prescribed in literature, (see *chapters 3, 4 and 5*). And while this is partly responsible for the serious incidences of cost overruns revealed above, the most significant cause was found to be the failure to employ a scientific approach to the overall cost monitoring and control process.

**10.2.6 Proposing an Effective Approach to Cost Control**

The theoretical and practical approaches to cost control presented in this thesis have revealed the need for a forward-looking approach that could apply scientific techniques to achieve greater effectiveness. Consequently, the research collated and employed the criteria and requirements for effective cost control prescribed in reviewed construction and management literature to propose a quantitative approach to the function designed to overcome the short-comings identified with the theoretical and practical approaches. The proposal:

1. Identified a cheap, easy and effective method of capturing cost and performance data in a way that would enable timely processing and evaluation of the information for corrective decision-making.
2. Defined an integrated, easier and cheaper way to process and evaluate cost and performance data, and to make performance forecasts and corrective decisions in a computerized project library. This would eliminate the delays caused by using manual methods and at the same time overcome the problems caused by lack of format coordination between different cost monitoring and control activities.

3. Formulated the cost monitoring and control process on construction projects as a quantitative problem comprising clear and measurable objectives that are dependant upon a clear and measurable set of constituent resources. The relationships between the constituent resources and project objectives (e.g. total cost and duration) were defined as a basis for a solution process.

4. Specified and mathematically formulated a solution process for implementing the proposed quantitative models. Total operational or project costs were fitted as functions of the costs of labour, materials, plant, subcontracts and preliminaries, (needed to accomplish the operations or projects), in regression and goal programming models as a way to effectively control costs of construction projects.

5. Clearly defined an implementation model (or procedure) based on commonly available PC softwares - Quattro and Genstat - and explained how they could be used to achieve effective cost control.

6. Also identified how the proposed models could be used at estimating and budgeting stages of construction projects to make more rational estimates of budgetary targets than currently obtained using traditional methods.

7. Guarantees that cost and performance forecasts as well as corrective decisions are not only based on actual information from the affected operations or projects but are also based on scientific and rational principles rather than on subjective judgements.

8. Makes effective use of responsibility accounting principles through all cost monitoring and control stages of projects including the decision-making phase. This would enable
staff at all levels of project organizations to know the effectiveness or otherwise of their efforts and how to make improvements.

9. Combines the good features of feedforward and feedback controls and applies the essential features for effective controls required by management science in a way that does not obtain in current practice and was not prescribed in construction management literature.

10.2.7 Assessing the Feasibility of the Proposed Approach

The proposed approach to cost monitoring and control was tested with historical and current cost data from three categories of construction projects. The tests established that:

1. The proposals made in chapter 8 were statistically feasible and applicable for cost control of construction projects.
2. The problems identified in this chapter could be substantially overcome by the proposed approach.
3. Multiple regression equations that passed statistical tests of significance could be derived from the cost data of construction projects and used to monitor the costs of such projects.
4. The cost correlations between the various cost components (or resources) of construction operations or projects, and between the costs of the components and the total costs of the operations or projects were so strong that, for different categories of projects, only one or two key resource needed to be identified and used by the approach to forecast and control total costs.
5. While the PC software proposed in the approach were adequate for implementing the approach, the development of a single coordinated package comprising the needed programmes of the different software was desirable and would enhance the effectiveness of the approach.
6. The approach could achieve up to 90% reduction in ITT. This enabled performance feedback to be received and corrective decisions made in time to correct the affected operations.
10.3 Recommendations

The thesis developed as a result of this research led to the following recommendations:

10.3.1 To Implement the Proposed Cost Control Approach

To achieve effective implementation of the cost monitoring and control approach proposed in this thesis companies need to:

1. Establish a structured approach to project modelling, data capture and processing, and the exchange of information within construction sites and between the sites and headoffice. This would require coordinating the formats in which information is captured, processed and stored at each of the monitoring and control stages of projects. The use of computerized methods (instead of the current manual methods) of data capture provides the needed structure and coordination in these functions, and in this regard the SMS which has proved to be a useful starter is recommended.

2. Establish a comprehensive system of reporting, storage and retrieval of cost and performance data to make it available as and when required for establishing and or up-dating regression parameters of the different project categories undertaken by the companies, and for project modelling, performance evaluation and decision-making.

3. Establish organizational and responsibility structures on sites that allow for effective exchange of information, accountability at individual responsibility centres and making corrective decisions within the project’s immediate environment and by people directly involved in its execution.

4. Separate the cost control of projects at site level from the financial control systems operated at headoffices in order to be able to detect cost and schedule overruns in good enough time to correct them while the affected projects are still in progress.
10.3.2 Further Research

1. There are so many quantitative models and methods in management science which may well be applicable in cost monitoring and control activities on construction sites that it would be impracticable to adequately evaluate the applicability of all of them in this research. Thus further research into the applicability of other quantitative techniques to construction projects is recommended. Possible models that appear to offer positive prospects include assignment, transportation, queuing, simulation and dynamic programming. Other types or approaches to the statistical analysis of cost and performance data should also be investigated in order to detect other types of curves or trends that could be used for cost monitoring and control. Exponential, geometric, reciprocal and hyperbolic are some of the trends that may be investigated.

2. Since effective cost control significantly depends on the timing of feedback data and corrective decisions, a knowledge of the appropriate or optimum time intervals, stages or periods for issuing performance reports, and making performance predictions and corrective decisions would appear to be vital to project control. Thus investigations are recommended into the relationships between various construction activities, and between their costs and schedules and how these relate to the optimum timing for reporting performance on the activities.

3. Since the proposed cost monitoring and control approach is based on the principle of employing past experience on construction projects to predict and control costs, the approach appears to be developable into an expert system. Such a system will accommodate the knowledge and experiences on previous projects concerning their costs, regression parameters and cost/schedule predictions. The system will simulate a dialogue between an expert and a project manager in which a PC is the expert that 'tells' the user (project manager) the various decision options on a given operation or project based on the data stored in it.
4. As pointed out in chapter 9, the implementation of the proposed cost monitoring and control approach would be faster, more convenient and more effective if the various computer programs needed for the implementation were available in a single software package. Thus research leading to the development of such a coordinated package is recommended.

5. Due to the greater emphasis of construction literature and existing research works to the organizational structures of construction companies vis-a-vis organizational structures on construction sites, the effectiveness of the latter in cost monitoring and control of projects is inadequate. Thus more research needs to be directed at finding more suitable organizational and responsibility structures and more effective communication methods and channels for use on construction sites.

6. Although the SMS (recommended in section 10.3.1) appeared to be an effective and convenient means of data capture and reporting on construction sites, it does not contain all the features needed to guarantee timely and effective cost reporting that meets the requirements for effective cost control. More research is, thus, recommended to extend the system's capabilities to include forecasting costs and performance levels and optimizing recorded performance levels against performance models to provide a basis for decision-making.

7. More investigations are needed into the profiles and cost distributions of construction cost data in order to establish the suitable ranges within which the regression equations derived from data of similar operations or projects are applicable. This (as shown in chapter 9) will define the intervals in terms of cost, schedule or physical progress of projects, and the corresponding models for estimating the control parameters (cost and duration) of the projects and for applying the derived equations for forecasting and optimization.

The achievements outlined so far in this chapter indicate that this research has achieved its stated aim and objectives, and also
identified areas in which further research can be carried out to
further the achievements of the research. The research also
provides a cogent motivation to transform cost and performance
data, which often lies dormant, into measurable trend profiles
that could be used to predict future cost and performance levels,
and to make rational and timely corrective decisions.
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<table>
<thead>
<tr>
<th>APPENDICES</th>
</tr>
</thead>
<tbody>
<tr>
<td>I Questionnaire for Survey of Contractors' Cost Monitoring and Control Tasks on Site</td>
</tr>
<tr>
<td>II Scope of Follow-up Interviews with Respondents</td>
</tr>
<tr>
<td>III Cost Data from Residential Housing Projects</td>
</tr>
<tr>
<td>IV Cost Data from Public Building Projects</td>
</tr>
<tr>
<td>V Cost Data from Civil Engineering Projects</td>
</tr>
</tbody>
</table>

Dear sir,

Like most companies, you may be aware of the problem of cost overruns on construction projects and their attendant consequences to individual companies as well as the industry at large. Like most companies, you might be uncertain as to the true causes of the problem and how best to go about solving it.

I am currently undertaking a survey of construction companies in U.K. to determine the true causes and extent of the problem with a view to formulating a possible solution of (as much as possible) general applicability within the industry. Your assistance in this research will be invaluable.

Please complete the attached questionnaire which seeks information on various aspects of cost monitoring and control of construction projects by contractors. Then, using the envelope provided, return the questionnaire directly to me. The data you supply will be treated with the strictest confidentiality. No data on individual companies will be disclosed either within the Department of Civil Engineering or outside the University.

This research is probably the most comprehensive investigation yet undertaken with respect to the problems of cost monitoring and control on construction sites. Should you require a copy of the research findings please indicate your name and address in answer to question 1.9 on the questionnaire and I will be pleased to send you one.

Thanking you in anticipation of your cooperation.

Yours sincerely,

Mr. A. Abubakar.
QUESTIONNAIRE FOR SURVEY OF CONTRACTORS' COST MONITORING AND CONTROL TASKS ON SITE

Please tick the appropriate response where applicable

1. General information on your company.

1.1 What type of work does your company undertake?
   a. Purely civil engineering works
   b. Purely building works
   c. Process engineering and construction
   d. Combined building and civil engineering works
   e. Maintenance works

1.2 What is the range of value of projects that you tender for?
   a. Less than £500,000
   b. £500,001 to £1,000,000
   c. £1,000,001 to £10,000,000
   d. Over £10,000,000

1.3 For how long has the company been in business?
   a. Less than 5 years
   b. 5 to 10 years
   c. 10 to 25 years
   d. Over 25 years
1.4 For how long have you been employed by the company?
   a. Less than 5 years
   b. 5 to 10 years
   c. Over 10 years

1.5 What is the nature of your basic training?

1.6 What is your usual designation on project sites?

1.7 Do you want to receive a copy of the research findings?
   Yes  No

1.8 Would you be able to grant a follow-up interview?
   Yes  No  Undecided

1.9 If your answer to either of questions 1.7 or 1.8 is 'yes' please indicate the name and address of your company below.

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2. General issues on cost monitoring and control on site. (Use table Q2 below to answer questions 2.1 to 2.7 by ticking the appropriate response correspondingly).

2.1 How often do you experience overruns on costs from individual cost codes or centres?
2.2 How often do you experience overruns on cost of overall project?
2.3 How often are overruns on costs and schedules directly related?
2.4 How often do lines foremen have advance knowledge of the periodic cost and/or schedule targets of their tasks?
2.5 How often is coordination of formats achieved between project plan, budget and performance records?
2.6 How often are corrective decisions for cost and schedule deviations based on performance feedback?
2.7 How often are corrective decisions for cost and schedule deviations based on performance predictions of time cost and production quantities?

<table>
<thead>
<tr>
<th></th>
<th>Always</th>
<th>Most of the time or generally</th>
<th>Half of the time or usually</th>
<th>Rarely i.e. occasionally</th>
<th>Never</th>
</tr>
</thead>
<tbody>
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<td>2.7</td>
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</tbody>
</table>
3. Roles of personnel in cost monitoring and control on site. (Use table Q3 to answer questions 3.1 to 3.9 by ticking the appropriate response correspondingly).

3.1 Who is/are responsible for actually recording performance information during site operations?
3.2 Who are responsible for processing recorded information on performance?
3.3 Who is/are responsible for the evaluation of the processed performance information?
3.4 Who is/are responsible for deciding on corrective actions in the event of cost and/or schedule deviations?
3.5 Who is/are responsible for preparing actual construction programme?
3.6 Who is/are responsible for preparing construction budget?
3.7 Who is/are responsible or accountable for expenditure on individual cost codes?
3.8 Who is/are responsible or accountable for profit and cost control on individual cost codes?
3.9 Who is/are responsible or accountable for investment and/or decisions on new methods/processes of working?

Table Q3: Roles of Project Personnel:

<table>
<thead>
<tr>
<th></th>
<th>Project mangr.</th>
<th>Site mangr.</th>
<th>Site engnr.</th>
<th>Site Q.Sr.</th>
<th>Head office</th>
<th>Lines foremen</th>
<th>Others (specify)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
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<td>3.4</td>
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<td>3.9</td>
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</tbody>
</table>
4. Rank the following factors in order of their:

4.1 - Frequency as causes of cost/schedule overruns.
4.2 - Significance as causes of cost/schedule overruns.

(E.g. 1 for most frequent or most significant, 2 for the next & so on. Note that the same rank may be assigned to more than one factor. Use columns 4.1 & 4.2 below for frequency and significance rankings respectively).

<table>
<thead>
<tr>
<th>Factors</th>
<th>4.1</th>
<th>4.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a - design factors</td>
<td></td>
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<tr>
<td>b - technical factors</td>
<td></td>
<td></td>
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<tr>
<td>c - managerial factors</td>
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<tr>
<td>d - actions of consultants</td>
<td></td>
<td></td>
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<tr>
<td>e - actions of suppliers</td>
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<tr>
<td>f - actions of clients</td>
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</tr>
<tr>
<td>g - contingencies &amp; outside agents</td>
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<tr>
<td>h - others (please specify)</td>
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</tr>
</tbody>
</table>

5. Which of the following performance models does your company normally establish before commencing any site operations, (indicate by ticking in column 5.1 below); and rank the models in order of importance to the site manager as tools of monitoring and controlling costs of construction projects generally, (put the ranks in column 5.2).

<table>
<thead>
<tr>
<th>Models</th>
<th>5.1</th>
<th>5.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>a - construction schedule</td>
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<tr>
<td>b - construction budget</td>
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<tr>
<td>c - cost curves</td>
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</tbody>
</table>
6. By means of a tick in column 6.1 indicate the type of structure that best describes your form of site organization; and rank the types of structure in order of their suitability for project monitoring and cost control, (put the ranks in column 6.2).

<table>
<thead>
<tr>
<th>Type of Structure</th>
<th>6.1 (tick)</th>
<th>6.2 (ranks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a - simple command structure</td>
<td></td>
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<tr>
<td>b - machine bureaucracy</td>
<td></td>
<td></td>
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<tr>
<td>c - professional bureaucracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d - adhocracy</td>
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<td></td>
</tr>
<tr>
<td>e - divisionalised (matrix) form</td>
<td></td>
<td></td>
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<tr>
<td>f - other (please specify)</td>
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</tbody>
</table>

7. Which of the following budgeting systems do you find (from your experience) to be most suitable for use on construction sites?

<p>| | | |</p>
<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>a - planning-programming-budgeting-system (PPBS)</td>
<td></td>
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<tr>
<td>b - zero-budgeting (i.e. fresh budgets for each accounting period)</td>
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<tr>
<td>c - a combination of PPBS &amp; zero-base</td>
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<tr>
<td>d - other (please specify)</td>
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</tbody>
</table>
8. Which of the following forms the basis of project estimating and budgeting in your company?

a - market value of goods and service

b - experience-based fair value of goods and services

c - a combination of a & b above

d - other (please specify)

9. By means of a tick in columns 9.1 to 9.4 corresponding to the following activities in cost monitoring, identify the format(s) for carrying out each of the activities in your company.

9.1 Construction project estimating
9.2 Construction project budgeting
9.3 Performance and or cost recording & reporting
9.4 Storage of company and project cost/performance data

<table>
<thead>
<tr>
<th>Format</th>
<th>9.1</th>
<th>9.2</th>
<th>9.3</th>
<th>9.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>a - trades</td>
<td></td>
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<tr>
<td>b - operations</td>
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<tr>
<td>c - work sections</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>d - functional elements</td>
<td></td>
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<td></td>
</tr>
<tr>
<td>e - gang activities</td>
<td></td>
<td></td>
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<tr>
<td>f - subcontract packages</td>
<td></td>
<td></td>
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<tr>
<td>g - company-designed cost codes</td>
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<tr>
<td>h - individual resources (e.g. labor)</td>
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<tr>
<td>j - other (please specify)</td>
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10. What is the average Information Turnaround Time (ITT) on your site? (ITT is defined as time taken between issue of information by site management and receipt of performance feedback from the line level by site management).

a - Not more than 2 days
b - 3 to 7 days
c - 8 to 14 days
d - 15 to 21 days
e - More than 21 days

11. Which of the following methods do you employ to record actual performance on site?

a - standard designed forms
b - computer-generated turnaround document
c - other (please specify)

12. Rank the following factors in order of their importance as reasons for using the method ticked in question (11).

<table>
<thead>
<tr>
<th>Factors</th>
<th>Ranks</th>
</tr>
</thead>
<tbody>
<tr>
<td>a - simplicity</td>
<td></td>
</tr>
<tr>
<td>b - ease of understanding</td>
<td></td>
</tr>
<tr>
<td>c - cheap to operate</td>
<td></td>
</tr>
<tr>
<td>d - precision in identifying sources of deviations</td>
<td></td>
</tr>
<tr>
<td>e - Foster good morale and human relations</td>
<td></td>
</tr>
<tr>
<td>f - shorter information turnaround time (ITT)</td>
<td></td>
</tr>
<tr>
<td>g - minimum clerical effort in processing</td>
<td></td>
</tr>
<tr>
<td>h - allows larger volume of data to be handled</td>
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</tr>
</tbody>
</table>
13. Which of the following methods is used to detect deviations between plans/schedules/budgets and performance?

a - Direct comparison of performance with plans e.t.c.
b - Computation and analysis of performance ratios
c - Computation and analysis of performance variance
d - Profit and loss accounts
e - Other (please specify)

14. Rank the following models in order of their importance as basis for detecting deviations between schedule/budget and performance.

<table>
<thead>
<tr>
<th>Models</th>
<th>Ranks</th>
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<tbody>
<tr>
<td>a - company cost system</td>
<td></td>
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<tr>
<td>b - project cost system</td>
<td></td>
</tr>
<tr>
<td>c - tender estimate</td>
<td></td>
</tr>
<tr>
<td>d - priced bills of quantities</td>
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</tr>
<tr>
<td>e - contract programme</td>
<td></td>
</tr>
<tr>
<td>f - project budget</td>
<td></td>
</tr>
<tr>
<td>g - cost Vs revenue curves</td>
<td></td>
</tr>
<tr>
<td>h - other (please specify)</td>
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</table>
15. Rank the following forecasting methods in order of their suitability for cost/schedule control on construction sites.

<table>
<thead>
<tr>
<th>Methods</th>
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<tbody>
<tr>
<td>a - experience-based personal judgement</td>
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</tr>
<tr>
<td>b - statistical time-series</td>
<td></td>
</tr>
<tr>
<td>c - regression models</td>
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</tr>
<tr>
<td>d - econometric models</td>
<td></td>
</tr>
<tr>
<td>e - statistical multivariate models</td>
<td></td>
</tr>
<tr>
<td>f - technological trend extrapolation</td>
<td></td>
</tr>
<tr>
<td>g - other (please specify)</td>
<td></td>
</tr>
</tbody>
</table>

16. Corrective decisions are usually arrived and implemented as a result of (your):

| a - Experience derived from routine |       |
| b - Trial and error                |       |
| c - Personal intuition and judgement|       |
| d - Application of scientific management methods |       |
| e - Other (please specify)         |       |

17. If your answer to question (16) was (d) please give the name of the method(s).

18. If your company uses computers for site cost monitoring and control, how do you judge their contributions so far?

| a - Negative interference |       |
| b - Positive interference |       |
| c - No change             |       |
d - No view or undecided

e - Other (please specify)

19. Briefly state the reason for the judgement (if any) given in question (18) above.

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20. Rank the following factors in order of their importance to the site manager in positively influencing cost monitoring and control on construction sites.

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<tr>
<td>b - participatory approach to short-term planning</td>
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<tr>
<td>c - organizational structure on the site</td>
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</tr>
<tr>
<td>d - company policies and corporate strategy</td>
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</tr>
<tr>
<td>e - skills of operatives and supervisors</td>
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<tr>
<td>f - motivation and incentive schemes</td>
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</tr>
<tr>
<td>g - methods of site communication</td>
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<tr>
<td>h - use of computers</td>
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</tr>
<tr>
<td>j - projects environment outside contractor's control</td>
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</tr>
<tr>
<td>k - co-ordination of subcontractors</td>
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<tr>
<td>l - co-ordination of resource procurement</td>
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</tr>
<tr>
<td>m - attitude/actions of client and or consultants</td>
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<tr>
<td>n - market research and monitoring</td>
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<tr>
<td>p - other (please specify)</td>
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</table>

344
Attention: Project/Site Manager, 10th April, 1991

Dear sir,

RESULTS FROM SURVEY OF SOME U.K. CONTRACTORS ON COST MONITORING AND CONTROL ON CONSTRUCTION SITES

As you are aware, a survey of contractors' cost monitoring and control tasks among U.K.'s 1990 Top 100 construction companies, (of which you are one), was carried out last September. We believe the survey findings and conclusions drawn from them would be of interest to contractors in highlighting areas of existing approaches to cost monitoring and control that need to be improved so as to ensure more profitable business. Accordingly, I am hereby pleased to send you a copy of the results of the survey.

As pointed out during the survey and in the attached document, the ultimate aim of the research is to find an alternative and more effective approach to cost monitoring and control on construction sites. The survey findings revealed some shortcomings in the current approach to project monitoring and control by contractors and a need for a more effective system of construction cost management. In addition, the findings have raised further and more specific questions that need to be answered to allow a better understanding and assessment of the nature and extent of the identified short-comings with a view to avoiding them in any new system that may be proposed by this research.

The specific nature of the additional enquiries that have arisen from the survey findings have made us to consider oral interviews, either face-to-face or by telephone, as the best approach to this phase of the research. We would be grateful if you can grant us an interview to enable us get your views and suggestions on some aspects of the survey results as well as our ideas for an alternative approach to cost monitoring and control by contractors. Should you accept this request, kindly let me know the most convenient time for you to grant the interview. If you prefer the interview to be conducted by phone, please let me know when to call and whom to speak to.

Yours sincerely,

Mr. A. Abubakar.
SCOPE OF FOLLOW-UP INTERVIEWS WITH RESPONDENTS

Preamble

The purpose of this interview is to clarify and obtain further explanation on the information you supplied in the written questionnaire you answered earlier on the subject of cost monitoring and control activities on construction sites.

Experience with Cost Overruns on Projects

1. What are the effects of the issues raised in table Q2 of the questionnaire on physical and financial success of projects?

2. What other aspects of construction projects in particular or business practice in general could cause an overrun on planned budget from a contractors viewpoint?

Factors Affecting Cost Monitoring and Control on Site

3. Why do companies (as revealed in the survey results) not employ statistical or quantitative techniques to forecast future performance and costs of operations?

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4. Why are construction schedules regarded as more significant than other performance models as basis for cost monitoring and control?

5. What factors determine your company's choice of formats in which particular projects are budgeted, scheduled and monitored?

6. Why are the formats referred to above not kept the same from estimating right through the budgeting, scheduling and monitoring stages of the projects?

7. What are the effects of the lack of format coordination between the various cost monitoring and control activities on the effectiveness of the process?

Organization and Responsibility Structure

8. Why are project personnel, (such as foremen), who are responsible for line functions on site not involved in scheduling and budgeting?
9. Why are project personnel responsible for line functions not generally given advance knowledge of their expected production and cost targets?

10. Why are lower to middle levels of project personnel not made accountable for expenditure and performance at the levels of individual cost codes?

11. What means of communication are employed on site and between the site and other external points?

12. How effective do you judge these communication channels?

Performance Measurement and Evaluation

13. Why do companies seem to be reluctant to use computer-generated turnaround document for data capture?
14. Why is performance evaluation not carried out via ratio and variance analysis instead of profit and loss accounts which are usually late in identifying deviations?

15. What range of ITT do you think would conveniently allow project management to alter the course of unfavorable performance while operations are actually proceeding?

16. Have you ever considered using forecasting and optimization models to calculate corrective decisions?

17. What are the reasons for the response to question 16 above?

18. If you employed the models referred to in 16, what are their effects on the effectiveness of your cost control efforts?
19. In your view, are computers being applied to cost monitoring and control tasks as they are used in estimating and accounting in contractors' organizations?

20. If the answer to question 19 is no, what do you think are the reasons for the situation?
# APPENDIX III

## COST DATA FROM RESIDENTIAL HOUSING PROJECTS

### Project No. 1  Actual Cost = £140982

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353
### Project No. 3  Actual cost = £209689

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**Actual Cost = £254344**

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## APPENDIX IV

### COST DATA FROM PUBLIC BUILDING PROJECTS

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376
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## APPENDIX V

### COST DATA FROM CIVIL ENGINEERING PROJECTS

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