"COMPUTER AIDED SYSTEMS IN CIVIL ENGINEERING USING DRAINAGE AS THE PRIME DATA BASE"

VOLUME .1.

DAVID MATTHEW BRAMWELL

A THESIS SUBMITTED FOR DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF CIVIL ENGINEERING
THE UNIVERSITY OF ASTON IN BIRMINGHAM

OCTOBER, 1974

SUMMARY

Computer aided management systems have been available, through computer bureaus, for several years. However, successful introduction into many companies has failed because of the inflexibility of management systems or the inability of computer facilities to meet the needs of the organisation. This was recognised by the company management (Civil Engineering Division, Bryant Holdings Limited), but it felt that successful introduction could be achieved by studying the needs of the company and subsequently developing computer facilities to fulfil those needs.

This work may be divided into four broad sections. Firstly, the organisation is analysed and its objectives and the existing communication systems' shortcomings isolated. The analysis indicates that additional computer aided planning, estimating and value-cost control facilities would both increase the flexibility of the estimating and planning functions and make feedback of value-cost information to management possible. Secondly, the creation of a data base containing main drainage work study information and historical performance data to be used in the development of realistic computer aided planning and estimating techniques. Thirdly, three computer programmes are developed and implemented. Two of these use the work study data base to produce raw planning and estimating information (gang size, construction time, etc.) for main drainage, the third being a general programme for simulating a working project to determine the cost of resources used and the variations in

performance. Finally, the design, selection and subsequent introduction of commercially available "software" packages to create a value-cost monitoring system within the company as a whole.

ACKNOWLEDGEMENTS

The author would like to thank the following people for their help, advice and tuition during the past three years.

Mr. F. R. Bishop (Main Supervisor) Civil Engineering Department, University of Aston.

Mr. M. C. G. Smith (Industrial Supervisor, C. Bryant & Son Limited.

Dr. T. R. E. Chidley (Advisor - Computer Techniques) Civil Engineering Department, University of Aston.

Mr. V. H. Picken (Associate Supervisor - Work Study) Department of Industrial Administration, University of Aston.

Mr. B. J. Evans (Associate Supervisor - Systems Analysis) The Management Centre, University of Aston.

Professor M. Holmes, Head of Civil Engineering Department, University of Aston.

Dr. S. S. Chang, ex officio, I.H.D. Scheme, University of Aston.

Dr. D. J. van Rest, I.H.D. Scheme, University of Aston.

This research would not have been possible without financial support. The author would, therefore, like to thank C. Bryant and Son Limited and the Science Research Council for their help in this respect.

In preparation of this Thesis, the author would like to thank Mrs. Nanette Bramwell for typing the manuscript.

CONTENTS

Page

Page

Page

NOTATION

CHAPTER .4. COMPUTER GENERATION OF ESTIMATING INFORMATION

		UNIT
Ap	Apparent Earth Pressure	kn/m^2
B	Strut depth/width	mm
b	Bucket Width	mm
Bc	Theoretical Bucket Capacity	m^3
bc	Proportion of Theoretical Bucket Volume utilised	
C	Constant	
C_{Ti}	The standard cycle time required to excavate, slew and deposit the material excavated	mins
D	Depth	m
Di	Depth at increment 'I'	m
E_{Ti}	The below ground cycle time component	mins
H	Unloading Height	m
K_A	Coefficient of Active Earth Pressure	
L	Maximum Permissible Strut/Waler Spacing	
L_D	Required Vertical Strut/Waler spacing	m
N	Depth/Width Ratio	
ϕf	Obstruction Grading	
Qe	The quantity of material excavated by a single digging stroke	m^3
R	Horizontal Reach	m
r	Working Radius	m
Rs_i	Standard Rate of Excavation at Depth increment 'i'	m^3/min

		UNIT
s	Strata Grading	
U_T	The above ground cycle time component	mins
w	Width of Excavation	m
Zr	Required Section Modulus	cm^3
γ	Density	kg/m^3

CHAPTER.5. PRE-CONTRACT APPRAISAL BY SIMULATION

Ap	Actual Productive man-hours	hrs
b	Basic Rate	p/hr
bpi	Unit Bonus for Plant type 'i'	£
Cij	Number of operatives type 'i' present in the gang required for activity 'j'	
c	Cost of Living Allowance	£/week
C'	Intercept Point	hrs
c^1	Adjustments	
c^{11}	Operative Class Increase	%
Cpj	Total plant cost for single weekly period for activity 'j'	£
cpi	Unit cost of plant type 'i'	£
Cmj	Total material cost for single weekly period for activity 'j'	£
cm_i	Unit cost of material type 'i'	£
fw	Performance forced waiting time	hrs
f	Fall Back Bonus	p/hr
fb	Total Fall Back Bonus	£
g	Guaranteed Bonus	p/hr
gb	Total Guaranteed Bonus	£

		UNIT
h	Public Holidays with Pay (H.W.P.) allowance	£/week
L	Labour cost for a given period	
M	Large Positive Integer	
m	Slope	
n	Minimum Practical Gang Size	
na	Actual Gang Size	
n′	National Insurance Allowance	£/week
N_{pij}	Number of plant type 'i' in activity 'j'	
ø	Operative Performance Index	
øfw	Overloaded Forced Waiting Time	hrs
pu	Productive Unmeasured Time	hrs
p	Plus Rate	p/hr
p′	Annual Holidays with Pay (P.H.W.P.) allowance	£/week
pb	Total Productive Bonus	£
Q	Total Activity Quantity	
q	Quantity produced in a single period	
Qm	Quantity left after 'm' periods	
r	Random Fraction	
R_o	Positive Integer	
Su	Standard man-hours per unit quantity	hrs/unit
S	Site Performance Index	
s	Subsistence Allowance	£/week
T	Construction Duration	
t_i	Time period increment 'i'	
Tfw	Total forced waiting time	hrs

		UNIT
t	Travelling Allowance	£/week
t^1	Tool money allowance	£/week
Tc	Total Labour Cost	£
Tmi	Transport cost of material type 'i'	£
ufw	Underloaded Forced Waiting Time	hrs
w	Worked Overtime	hrs
w^1	Wet time addition	%
x	Dependent Variate	
Xij	Quantity of material type 'i' in activity 'j'	
z	Working day duration per man	hrs
z^1	Actual Attendance	hrs
α	Zero production coefficient	

CHAPTER 1

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1 The Parent Company

The parent Company (Bryant Holdings Limited) is based in Birmingham. It is made up of several smaller companies and divisions, each of which deal with a different aspect of construction - geotechnical investigation, structural design, industrial development, private and local authority house construction, multi-storey construction and civil engineering. With the exception of the Civil Engineering Division, most divisions operate within a 50 mile radius of Birmingham. The company turnover is presently in excess of £35 million, of which approximately £5 million is attributable to pure civil engineering work.

1.2 The Civil Engineering Division

The Civil Engineering Division was formed in the middle 1960's. Its task is to undertake 'pure' civil engineering work which involves the construction of main drainage, sewage schemes, road, bridge and railway projects.

During the early life of the Division, a large proportion of the work undertaken was concentrated within the Birmingham conurbation. However, over the past few years, projects up to 120 miles away have been successfully completed.

At any one time there are approximately 7 civil engineering projects underway ranging from small bridges of about £30,000 value, to major road works' schemes of value in excess of £3 million.

1.3 The Research Problem - The Management's View

Civil engineering has always been a highly competitive, high risk industry. During recent years projects have increased in physical size and constructional complexity, consequently, the financial involvement of both clients and contractors has increased proportionally.

The Management of the Civil Engineering Division (in particular Mr. M. C. G. Smith) foresaw that as the turnover was becoming dominated by a few large, multi-million pound schemes, the high risk element would become crucial in the appraisal of contracts. Hence, to cope with this developing situation, Estimators and Planners would require more detailed and more accurate information. Also, line management would require flexible yet explicit value-cost information more rapidly. In short, management would require more CONTROL.

Introduction of computer facilities into the company had previously been attempted, with partial success, viz: successful introduction of a computerised wage payroll system, failure to introduce computerised cost control. The experience gained indicated that computer facilities are 'data hungry', they require a rigid information transfer system and attempt to change the existing manual systems too quickly. Therefore, with the objective (more control) in mind and armed with practical experience, the management decided to set up a research project. Firstly, to investigate the existing management system and determine where computer facilities would be of use. Secondly, recognising that a large amount of data would be necessary, if all fields of civil engineering were investigated, to limit the data collection to main drainage, chosen because of the Company's lack of detailed information on the subject.

1.4 The Brief:

To investigate the Division, indicate where computer facilities would help management, and show practically the feasibility of such facilities.

Where possible, the data used should be common to all aspects of civil engineering construction but where impractical, main drainage should form the prime data base.

1.5 The Interdisciplinary Higher Degrees (IHD) Scheme

It was collectively decided by Mr. M. C. G. Smith and representatives of the University of Aston, that the research should be carried out under the IHD scheme available at the University. A paper by Chang (55) in 1973 describes the intentions of the scheme and the method of training.

> "THE INTENTION OF THE IHD SCHEME
>
> The aim of the Scheme is to broaden by interdisciplinary research training, new or recent graduates from any discipline and to prepare them for technical, commercial and administrative careers in industry and other organisations. The broadening is interpreted not in the narrow sense of breaking into a neighbouring field such as extending mechanical engineering into civil engineering, but

is meant to cover a wider spectrum of industrial functions such as combining technical expertise with commercial or social considerations as is required in practical problem-solving in a real situation.

The Joint Science Research Coucil and Social Science Research Council Committee has taken the view that research in breadth is as challenging and demanding as specialist research, is in no way superficial or shallow, requires able people to pursue its aims and is a proper activity for a university to undertake.

METHOD OF TRAINING

At Aston, each graduate (student) investigates a problem of direct concern to his sponsoring firm or organisation and spends up to two-thirds of his time working in that firm. The rest of the time is spent at the University under supervision and taking selected courses in multiple disciplines and other forms of training as required by the project. Movement between the University and the firm depends entirely on the needs of the project and coursework and no fixed period or frequency is specified for visits. The student is supervised by a team comprising a Main Supervisor, whose expertise covers the major discipline involved in the research project, one or more Associate Supervisors to cover other disciplines, an Industrial Supervisor from the sponsoring enterprise and an IHD Tutor to co-ordinate the team.

It is therefore an interdisciplinary postgraduate research training by the 'sandwich' principle which has proved so successful at undergraduate level in many technological universities."

1.6 Research Strategy and Presentation

The research approach may be divided into four parts:-

(i) The study of the organisation (Civil Engineering Division) to determine where the existing systems fail to cope with the demands made on them by management and subsequently proposing computer facilities to remedy the failings.

(ii) The collection of the data necessary for successful use of the computer facilities.

(iii) The development and use of three computer programmes to assist Estimators and Planners.

(iv) The selection and introduction of bureau computer facilities for value-cost monitoring and control.

This Thesis is presented in two volumes, the first containing the main text and the second containing appendices of explanation and demonstration.

The first volume contains seven chapters, of which chapters one and seven are the Introduction and Conclusion respectively. Chapters two to six are synoptically summarised below, to expand the brief and help in the development and understanding of the problem.

Chapter two details the analysis of the organisation. Initially the existing communication structure and the objectives of the organisation are established. Their incompatibility is then discussed by dividing the communication structure into three management functions - Pre-Contract Appraisal, Post-Contract Production and Post-Contract Financial Monitoring. An idealised system is subsequently prepared from which it is established that in order to achieve the functional objectives, two 'feedback' cycles are necessary. Firstly, the feedback of work measurement and performance information to assist pre-contract appraisal. Secondly, the feedback of financial information to be used by the management of both post-contract production and financial monitoring. Introduction of work measurement feedback is discussed, the introduction of financial feedback being omitted as it is subsequently dealt with in chapter six.

The work measurement and performance level data base is presented in chapter three. As explained earlier, the amount of data required to investigate all aspects of civil engineering construction is vast. Consequently, the field of main drainage is used as the prime data base.

Chapter three introduces the different elements of main drainage construction. It goes on to discuss the difficulties found when applying established work study techniques to construction activities. The Time Study approach used to obtain the work measurement data, together with the relaxation and contingency allowance applied to the data are then presented. A catalogue of the main drainage work measurement data and a user manual for planning and estimating is given in Volume two (Appendix 1 and Appendix 5).

Basically, there are two components to the work measurement information used for estimating and planning. Firstly the 'standardised component' which describes the work rate of "Mr. Mean". Subsequently, this must be adjusted by applying the 'performance component', which contains such production variables as operative and site performance levels, absenteeism and gang overloading etc. The 'performance component' (performance data) is discussed and presented in the latter part of Chapter three.

Chapter four presents two computer programmes which store the work measurement information (Standardised Component) discussed in Chapter three. The first programme analyses the pipeline component of main drainage, the second analyses the manhole component. The subprogrammes and subroutines of each programme are presented separately with the relevant theory and flow diagrams. Several practical examples are discussed at the end of the chapter in an attempt to show the flexibility of the programmes.

A simulation programme is developed and presented in chapter five. The programme uses the information produced by the pipeline and manhole programmes together with the performance data (performance component) discussed in Chapter three. The simulation is designed specifically for the organisation and is capable of showing the effects of differing levels of performance on contract duration and cost. Several examples are presented aimed at illustrating how changes in operative and site performances and absenteeism affect contract duration. Subsequently, the construction of a river bridge is analysed to show the practical applications of the simulation programme.

Chapter six discusses the development of a computer aided value-cost monitoring system. Existing value, labour, material and plant cost monitoring procedures are discussed and their shortcomings established. Because of the large number of Computer Bureau programmes available for value-cost monitoring, new programmes are not developed. However, an overall computer system is designed (based on Bureau facilities) and its introduction discussed. During the research period, a Computer Bureau was appointed by the company to introduce the value-cost monitoring system developed in this chapter.

1.7 Historical Review

Because of the interdisciplinary nature of this research, the historical review is presented in three sections, each of which attempt to group associated disciplines, although there are no clear boundaries between them.

1.7.1 Systems Thinking and Analysis

Before introducing systems thinking and analysis, several relevant ideas expounded by prominant researchers will be introduced in an attempt to put the organisation and its characteristics in perspective.

The immediate post war years saw a more rationalised and critical development of the ideas governing organisations. In 1948, Wiener(1) summarised work on organisation published between 1930 and 1940. He expounded that information transfer and control are essential processes in a functioning organisation and that the elements of such organisations operate together to reach or maintain an external goal.

During the 1950's, Churchman(2) and Ackof(3) postulated that the surrounding environment exerts a profound effect on the interlinkage between the subsystems within such an organisation. This was verified by several researchers[4]. In 1958, March and Simon[5] showed that organisations which operate in fast changing conditions (such as those in the construction industry) exhibit a high degree of interlinkage between subsystems. This was also noted by Burns and Stalker[6] in 1961. Thompson[7] in 1967, postulated that the greater the interdependency between subsystems within an organisation, the more co-ordination and control there must be. Subsequently, in 1970, Woodward[8,9] qualified this by showing that high degrees of subsystem interlinkage, whether created by external or internal forces, is a result of uncertainty.

Once working within the organisation, the development of a rational approach requires "Systems Thinking", Etzioni[10], 1964. The researcher's aim must be to increase the effectiveness of the organisation as a whole, not just part of it, Ansoff[11], 1968, thus systems thinking is non-reductionary[4] - it is not possible to take the properties of a subsystem and apply them to a higher one. Systems have boundaries, Benien[12], 1968, within which the objective is to reach a common goal, Jenkins[13], 1969.

Many of the researchers mentioned discuss organisations in general terms and their ideas seem somewhat disjointed. However, once actually investigating an organisation, their ideas invoke an understanding of the environment in which the research is taking place.

Systems Analysis uses the above concepts to analyse organisational problems in a more or less rigorous way. Checkland[14], in 1972, split the approach to the analysis into three stages. Firstly, the problem is formulated, secondly the relevant system and its subsystems are defined and thirdly, the wider system within which the problem system lies is defined.

Deutsch[15] in 1952 and subsequently Churchman[2] in 1954, used communication models for analysing a variety of organisations. However, both researchers encountered problems of model accuracy which, in the main, seemed to be dominated by the methods of data collection employed - either interview, direct observation or both. Marcosson[16] in 1920, and later Nejelski[17] in 1947, performed experiments, published and concluded that direct inquiry about specific types of communication were more effective than a series of general questions and that successful interviews seemed to be those which inquire about a specific order (such as materials). However, Chapple[20] in 1940 and subsequently Bales[18] and Bavelas[19] during the period 1948 to 1950, showed that interviews may disrupt the communication process in small groups and may fail to reveal pertinent forms of communication in large groups. Their general conclusions were that direct observation is a good check (an essential) on the accuracy of the interview response.

Among the principal aims of this research are those to investigate information feedback both within individual subsystems and in the company system as a whole and to investigate the feasibility of introducing computer facilities to assist in the development of such feedback.

Stark[21] in 1971 discussed earlier research by Ackoff[22] which questioned the motives for introducing computer systems and attempted to show that management may not lack information, neither may they benefit from the creation of formal lines of information feedback. The implication being that management establish their own lines of informal communication within an organisation, lines which may not show up in an investigation and which may be disrupted by the introduction of formal communication. Oxley and Poskitt[23], in 1969, hypothesised that in large organisations computer aided systems may be a necessity so that the future objectives of the organisation can be achieved. However, they qualified their hypothesis by indicating that if computer data processing and analysis is a necessity, a much higher degree of control is necessary within the organisation. This point was made by Churchman[2] as early as 1954.

1.7.2 Work Study, C.P.M. and PERT through to Simulation

Although a wealth of documented Work Study Techniques have been available since Jean R. Peronet[in Dudley 24] studied the metal pin making process in 1760, the construction industry only started to take them seriously in the late 1950's. In 1962, the Institute of Building first introduced Work Study into the syllabus for the Final Part II examinations. Subsequently, the Construction Industry Training Board and other academic institutions began to provide Work Study courses specifically for the construction industry. However, as indicated by Geary[25] in 1969, the industry was slow to realise the potential and, at that time, was still at the "stop watch and activity sampling" stage in its development of work study expertise.

As will be shown later, this apathy on the part of the construction industry could be the cause of its slow development of modern planning and estimating techniques.

The basic principles of network analysis were first used by Gautt[24] to study troop movements during the first world war. However, the wide implications of network analysis were not recognised until the late 1950's. In 1956, Flagle[26] published work on probability based tolerances for estimating. Following this in 1958, a research team from the Bureau of Naval Weapons[27] began to develop PERT (Program Evaluation and Review Technique) for the Polaris project. Malcolm[28], in 1959, produced further work on the applications of PERT to other industries.

During the years 1957 and 1958, the du Pont Company and Remington Rand Univac developed a second set of network analysis techniques, CPM.

During the period 1959-1962, the DOD and NASA Guide[31] was published. It described methods of allocating cost to PERT and CPM. In 1963, Beutel[32], applied the techniques to construction.

Acceptance of CPM and PERT by the construction industry gradually grew throughout the mid and late 1960's. During this time, many authors, Rist[33] and Baker[34], in 1969 and subsequently Macbride[35] in 1970, proclaimed the potential values of CPM and PERT to the construction industry.

Inevitably, in the late 1960's, just as CPM and PERT were beginning to win acceptance by the construction industry, stochastic models for simulating construction were developed. The first by Gaarslev[36] in 1969 dealt with materials handling and transportation problems. In 1970, Sussman[37] produced a paper explaining the value of simulation in such an uncertain environment as design and construction. Fine[38], also in 1970, produced a computer based management game which simulated a theoretical construction project containing twenty similar structural units built by ten similar sized gangs. The simulation considers such construction delay variables as weather, delivery, schedule dates, crew sizes etc. In 1971 Willenbrock[39] published a paper explaining an earthworks simulation model dealing with an excavation unit feeding several trucks. Parti and Tung Au[40], in 1972, took simulation one step further and produced work dealing with the simulation of a complete construction project.

There is little doubt that the advent of widespread use of the computer and work study techniques in the 1960's promoted interest in CPM and PERT and subsequently, simulation. In the construction industry the growth of interest in these techniques has been slow. However, the indications are, that with more sophisticated computer "hardware" and the development of higher levels of "software", the techniques will continue to advance and materially augment existing methods.

1.7.3 Computer Aided Cost Estimating and Value-Cost Monitoring

The development of computer aided planning and scheduling techniques and the subsequent value-cost additions, explained earlier, have lead to developments in estimating techniques, but at a much slower rate.

In 1962, the American Society of Civil Engineers (Construction Division) set up a Committee[41] "to investigate, correlate and improve methods and procedures for cost estimating, recording and control as related to civil engineering work, and to make such information available to the profession". During the early stages of the Committee's proceedings, it foresaw an inevitable increase in the use of computer aided systems. Subsequently, in 1966 a further report was published by the Committee[42] in which it endorsed its initial findings.

It has been known, in this country, since the mid 1960's (Banwell report) that the present practices and use of the Bills of Quantity and Methods of Measurement have somewhat impeded the progress of more effective management techniques in civil engineering. In 1968 the Construction Industry Research and Information Association set up two projects (amongst others), the first to investigate cost control for contractors, and the second to investigate civil engineering Bills of Quantity[42]. Both of these proposed changes in the Bills of Quantity structure and placed emphasis on "operations" oriented methods of estimating as opposed to "unit cost" methods. Subsequently Stark[43], in 1972, in a paper discussing British approaches to project planning uncertainties shows, using Fines[38] management game, how the Bills of Quantity distort project planning and thereby project estimating and cost control, as all are synonymous.

By far the most significant work on computer aided cost estimating was produced by Boyer and Volkman[44] in 1972. Their suite of programmes utilised established payroll, account and CPM packages to create a historical data base from which their estimating programme selects the relevant gang size and production information. However, the estimating procedure is essentially a 'unit cost' system. It is, therefore, insensitive to rapid inflation and different construction techniques for similar work. Such a system requires an extremely effective and rapid data retrieval system to back it up. As will be shown later in Chapter six, extrinsic shortcomings imposed on the system slow it down, no matter how rapid the computer process may be.

In conclusion, there are two main methods of estimating. Firstly "Unit Pricing" which conforms to the existing structures of many Bills of Quantity, yet is insensitive to rapid price variations and changes in construction methods. Secondly, "Operational Pricing" which depends on the actual construction method and resources employed. Although the latter method requires more explicit information and more sophisticated estimating techniques, it seems to be finding wider acceptance within the industry.

CHAPTER 2

ANALYSIS OF THE ORGANISATION

Summary

The organisation is analysed to establish the existing communication structure. The findings are then compared with an idealised structure to establish where additional "feedback" communication is required in a proposed communication structure.

CHAPTER 2

ANALYSIS OF THE ORGANISATION

2.1 Introduction

The structure of an organisation, whether it be mechanistic or organic consists of a lattice of lines of communication connecting interdependent functions of management - financial control, administration or ancillary services etc. Interdependence is created by each function attempting to reach or maintain certain objectives which are determined by both the nature of the work undertaken and the overall objectives of the organisation operating in an industrial environment.

Communication in a working organisation falls into two categories depending on the quality, quantity and, to a certain extent, the urgency of the information required by interdependent functions. They are:-

(1) Formal Communication - The transfer of information in a specified way (letter, form or report) determined by the operating needs or dependent functions;

(2) Informal Communication - The transfer of information in an unspecified way (corridor conferences) determined by the immediate requirements of interdependent functions.

Both forms of communication are integral parts of an organisation's structure. As the organisation develops, the lines of communication become long and complex and often require the unquestioning participation of many functions in which the personnel often know little about the origins or final destination of the information transmitted.

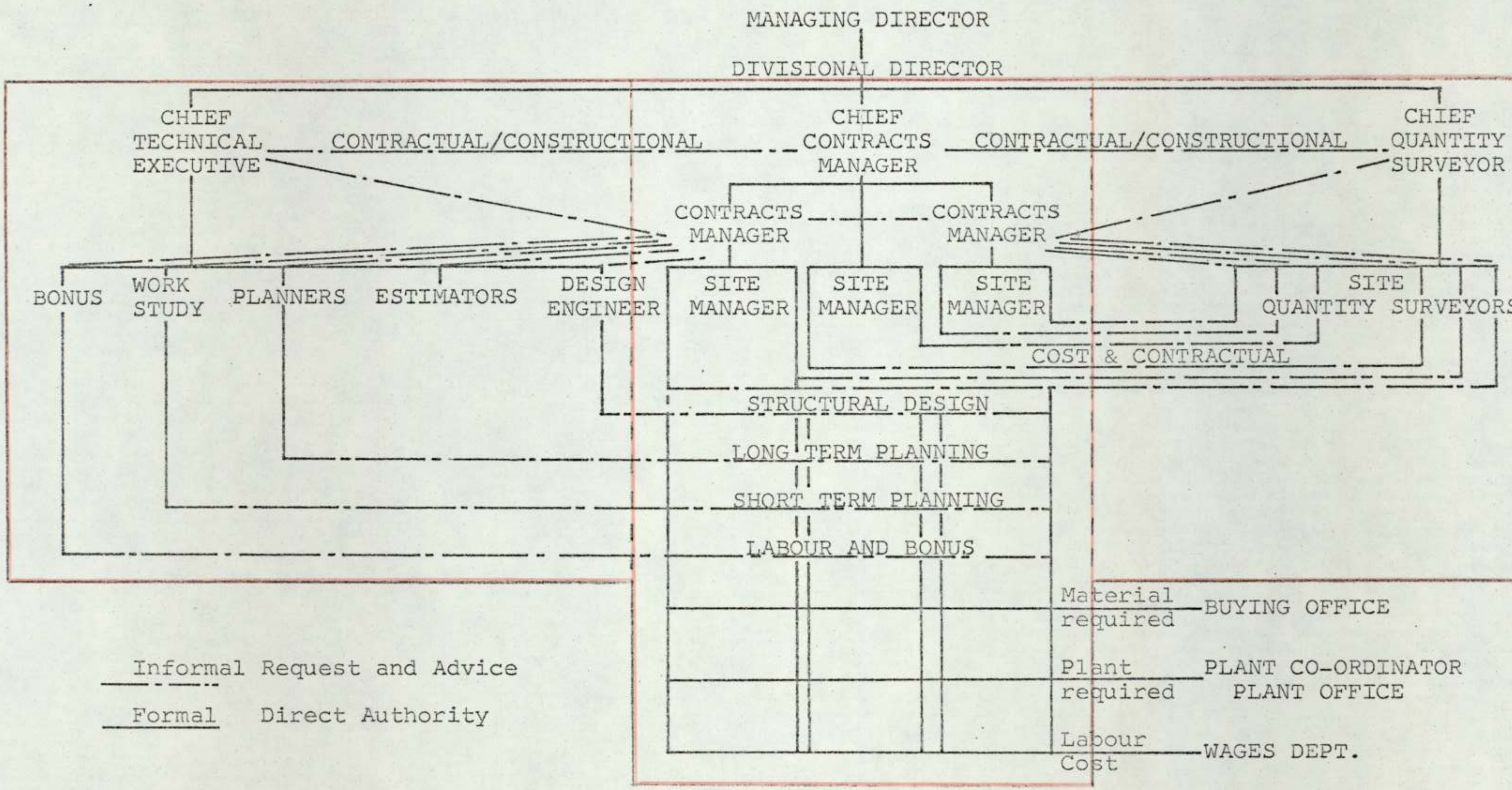
In the constantly changing industrial environment, the objectives of the organisation and, to a lesser extent, management functions are amended, but often proposed methods of realising them are impeded by the complexity of the existing communications network.

The following sections of this chapter are devoted to the analysis of the organisation in an attempt to establish new lines of communication which will provide inter-dependent management and ancillary functions with the information they require to assimilate and develop in line with their new objectives.

The structure of the organisation is studied to determine the hierarchy of authority. The constituent functions are then grouped, bounded by their common objectives. Existing lines of formal communication are established between functions to determine the faults which exist and their future needs. An idealised model and methods of implementating it are then proposed.

2.2 The Organisation Structure

In the traditional organisation structure (figure.1.), formal communication exists vertically, but formal communication across the lines of authority is not always present.



ORGANIZATION STRUCTURE

Figure.1.

Therefore, informal communication is fundamental in maintaining a feedback of information between functions.

Some lines of communication have been omitted from the diagram for clarity.

The diagram indicates the key people within the organisation, thus providing a starting point for more detailed studies involving the communication between functions irrespective of the hierarchy of authority.

It is evident that the organisation structure is divided into three distinct sub-structures connected only by informal lines of communication. This apparent demarcation seems to be caused by the distinctly different objectives of each management function. In fulfilling the requirement of the contractual process, the Chief Technical Executive controls the interpretation, synthesis and evaluation of the clients' requirements. Whereas the Chief Contracts Manager and Quantity Surveyor are primarily concerned with the physical construction and financial monitoring of the project respectively.

2.3 Objectives

Management function objectives are determined by the contractual process and by the influence of the overall industrial environment. This section defines the management function objectives which must be maintained in a new communication structure. Subsequently, additional amendments to the objectives are established resulting from the pressures imposed on the organisation by the changing industrial environment.

2.3.1 Pre-Contract Appraisal

Pre-Contract Appraisal is the first objective in the contractual process. It is achieved in two separate, but similar, stages.

(i) The pre-tender stage in which the client's brief (the Bills of Quantity, Specifications and Tender Drawings) is analysed. The requirements specified are then synthesised into a hypothetical model which is evaluated in financial terms. Finally, the results are returned to the client for comparison with similar tenders submitted by other Contractors.

(ii) The post-tender pre-contract stage, which takes place if the tender submitted is accepted by the client. The analysis, synthesis and evaluation stages are repeated in more detail to provide actual working information (programme of work, labour, plant and material schedules etc.) required to achieve production objectives.

2.3.2 Post-Contract Production

Both this and the financial control objectives are achieved simultaneously and tend to overlap. However, Post-Contract Production is achieved by constructing the project to comply with the instructions and specifications of the client and production levels anticipated by the contractor.

2.3.3 Post-Contract Financial Monitoring

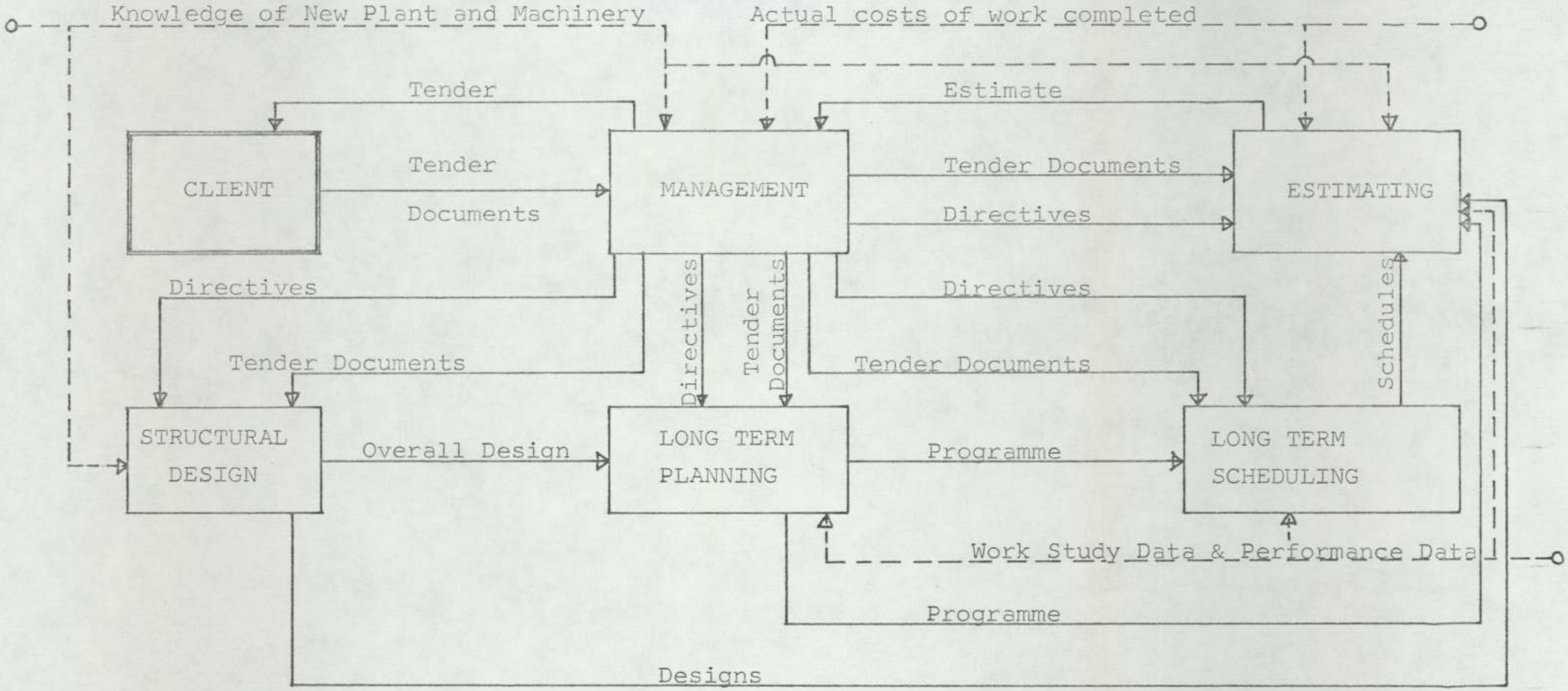
Achieved by monitoring the permanent work completed and resources required. It is independent of the production objectives in that location or complexity of work is of minor importance. However, overlapping does occur as both are influenced by the resources used and production rates achieved.

2.4 The Existing Communications Systems

The communication models (Figures.2.,.3.,.4.) determined by both direct observation and interview,depict the formal communication existing between interdependent functions bounded by their common objectives.

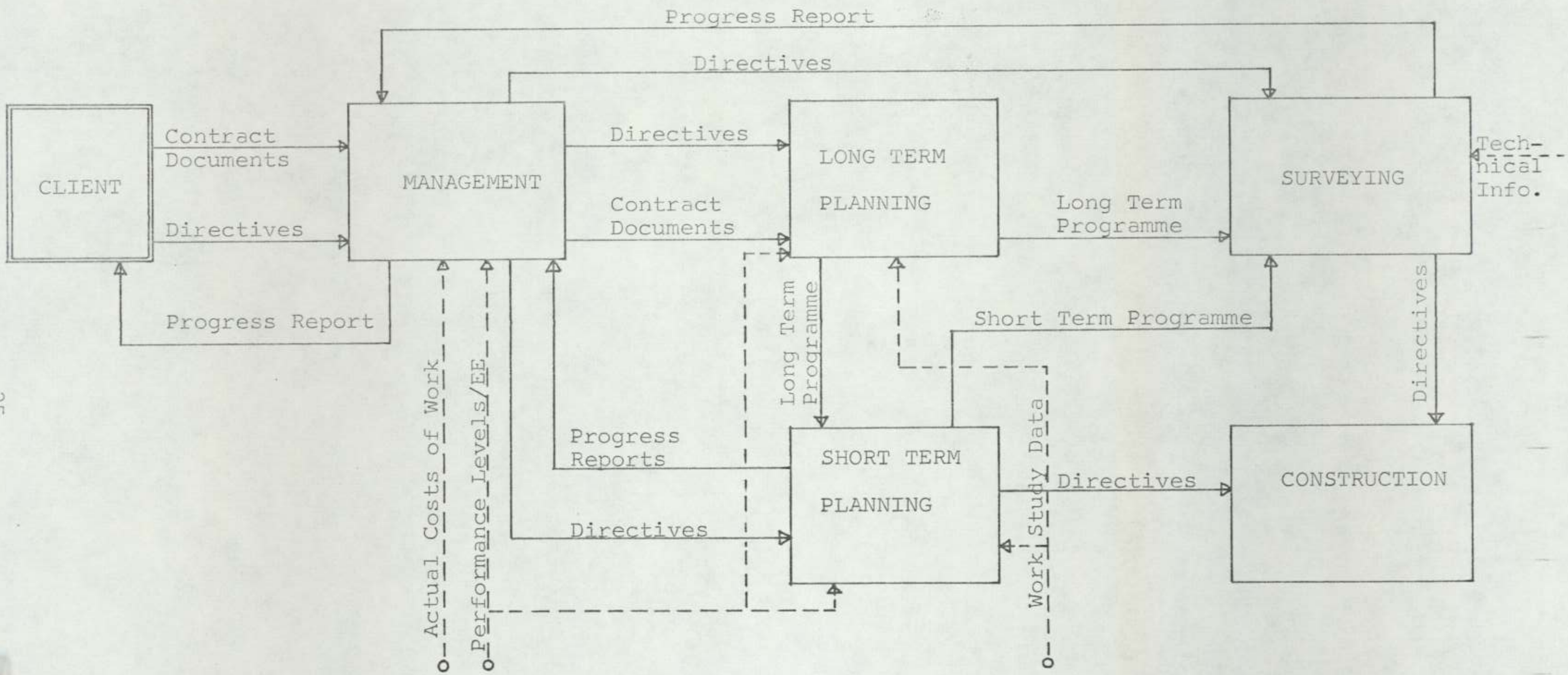
All three models exhibit a high degree of independence from each other (indicated by the lack of outgoing communication). Formal communication does not exist between different management functions or between highly interdependent functions such as planning and work study, estimating and work study or bonusing and work study. Obviously, if no communication existed, the organisation would not function.

Studies indicate that only informal communication exists between the work study and other dependent functions. This is caused by 'personal files' of information which Estimators and Planners tend to accumulate from various sources - material and plant rates from manufacturers and suppliers, labour and production rates from sub-contractors. Bonus Surveyors accumulate labour and production rates from sites. The various functions rarely communicate formally, consequently, rates are not compared. This independence



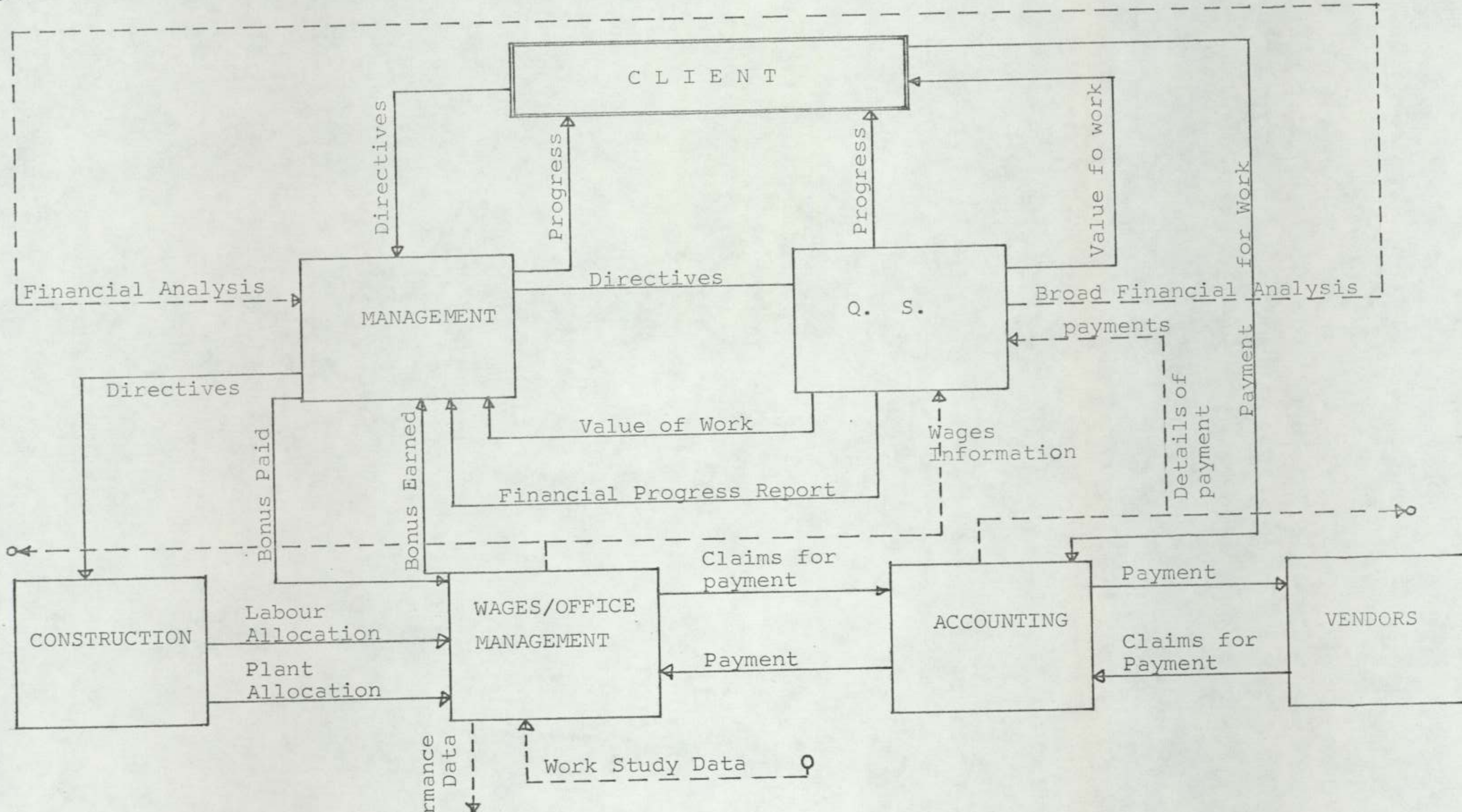
PRE-CONTRACT APPRAISAL

Figure.2.



POST-CONTRACT PRODUCTION

Figure.3.



POST-CONTRACT FINANCIAL PRODUCTION

Figure.4.

often creates situations in which two people, say a Planner and an Estimator, are working on the same project analysis using different production rates.

Although informal communication is an essential part of an organisation and is the established way of passing on advice and suggestions, it does possess several major disadvantages. They are:-

(i) It is often briefly described and too often accepted without question, leading to wrong application in many instances.

(ii) It is not usually documented, consequently it is forgotten and the communication process must be repeated if the information is required again.

(iii) It is not retraceable. If it is found to be inaccurate, there is no means of finding the source to effect amendments.

2.5 Faults in the Existing System

The high degree of independence exhibited by each of the management functions, together with the presence of personal data files, are responsible for two major faults within the communication structure. Firstly, there is no apparent system of information feedback either between respective management functions or between interdependent functions, particularly in the pre-contract appraisal phase. As a result, the work study function is effectively cut off and is unable to contribute significantly to the updating of the planning, estimating or the bonusing functions' data files. Secondly, financial data is not cycled through the various management functions, therefore, substantially reducing the amount of information available for modifying production or contract appraisal policy.

The feedback of production information is essential in the construction industry which is affected constantly by unpredictable uncertainties such as weather, wage and prices variations, productivity of plant and labour, knowledge of which is unlikely to substantially affect the outcome of current work, but may well lead to a better appreciation of the risks involved in future contracts.

2.6 Functional Objectives in an Idealised System

Analysis of the existing communication diagrams indicates possible faults in the formal communication procedures, rarely detected by the people involved in the continuous day to day functioning of the organisation. This is due primarily to remedial effect of informal communication (if information is not transferred due to the lack of formal communication, informal lines of communication are automatically created) which, once established, tends to become part of the normal routine.

The shortcomings of the existing system tend to appear when individual functions are questioned about their objectives and capabilities if given an ideal communications system.

Hence, each function was re-analysed, independent of the existing communication structure, and two questions were asked:-

(1) What additional information is required which would increase and update the function's data files?

(2) What additional information does the function produce which is not transmitted by the existing formal communications system.

The results of the analysis are given in Table.1.

The additional lines of formal communication required (shown dotted in Figures.2.,.3., and .4.) indicate that the system is capable of fulfilling its own needs, given that formal communication can be introduced. This is shown more clearly in Figure.5.

2.7 The Proposed Model (Figure.5.)

The work study function now plays a major part in the communications' structure, supplying each dependent function with information. Pre-Contract Appraisal and Post-Contract Production are now dependent on Post-Contract Financial Monitoring which is capable of producing costs and values of completed work as well as production performance levels.

The proposed lines of formal communication can be grouped according to the type of information feedback, financial (shown dotted) - of use to the management functions and work measurement - of use to ancillary functions (planning, estimating and bonusing).

2.8 Work Measurement Feedback

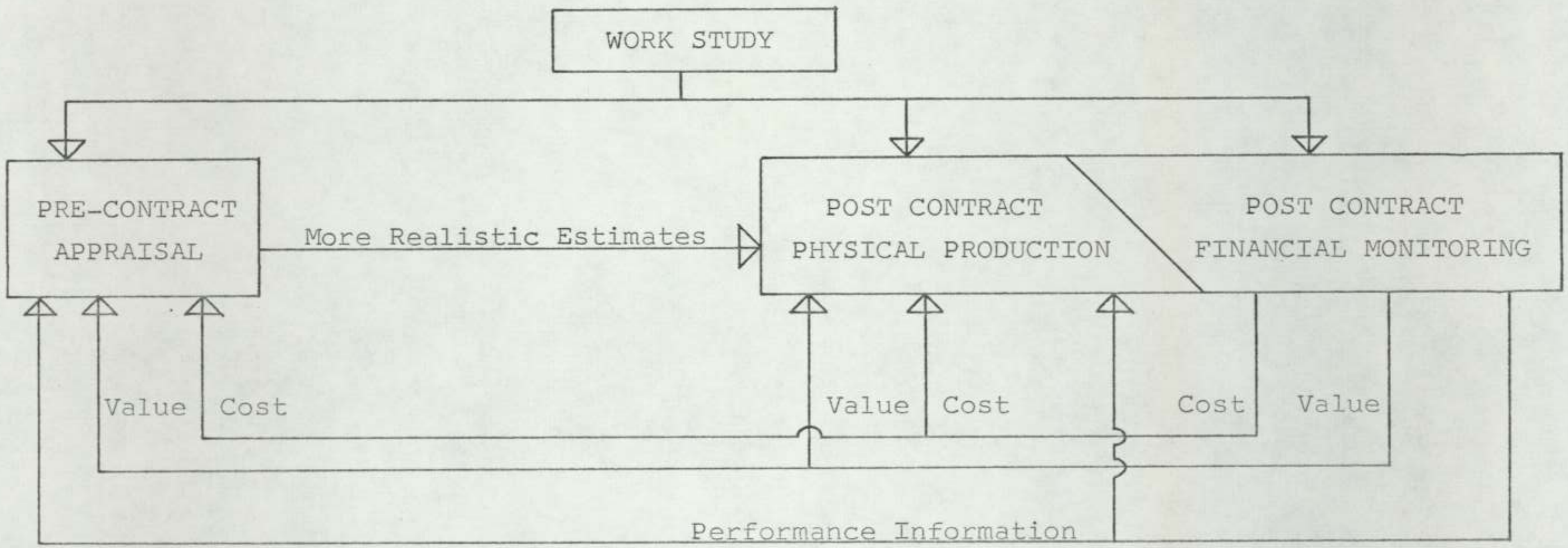
Work measurement and performance information, being

TABLE. 1.

Objective	Function	Information Required	Information Produced
Pre-Contract Appraisal	Management	Actual costs of work completed.	Directives on method changes.
	Long Term Planning and Scheduling	Work study data. Performance data.	More realistic programme of work.
	Estimating	Work Study data. Actual cost of work completed.	More realistic and detailed estimates.
	Structural Design	Information on the success or failure of current methods.	Better and more practical designs.
Post-Contract Production	Management	Actual costs of work completed. Actual performance levels achieved. Effects of environment on production.	Detailed financial progress of project. More explicit and confident directives.
	Long term Planning and Scheduling	Work study data. Performance date.	More realistic programmes.
	Short term Planning and Scheduling	Work measurement data. Performance data.	More realistic programmes.
	Surveying	-	-

TABLE.1.(Contd.)

Objective	Function	Information Required	Information Produced
Post-Contract Financial Monitoring	Management	Cost and value of work completed.	More confident and explicit directives.
	Quantity Surveying	Cost of work completed, details of payments made.	Cost analyses. Financial projections.
	Bonusing and Wages	Work measurement data.	Performance data. Effects of environment on production. Details of wages.
	Accounting		Details of payments received and made to Vendors.



IDEALISED FORMAL COMMUNICATION DIAGRAM

Figure.5.

fundamental to the planning, estimating and bonusing functions, should attempt to serve each function from a single data base, as a standard presentation would make subsequent data comparisons easier.

The bonusing and planning functions deal directly with actual and anticipated work activities, therefore they require information presented in similar ways.

Estimating is somewhat complicated by the Bill of Quantities, (which quantifies the permanent work to be completed) a document independent (in its structure) of the construction methods adopted by the contractor. To alleviate this problem, Estimators and Planners must work in close liaison. Estimators and Planners combine Bill items such that the groups represent work activities. A programme of work, together with resource schedules is produced, the anticipated cost of the activities is then calculated, contingencies and profit added and the result is apportioned over the respecitve Bill items.

The present estimating and planning procedures are manual and the time available for their preparation is usually limited to a few weeks. It was found that continuous feedback tends to disrupt the estimating process, often forcing Estimators and Planners to estimate sections of work several times. Consequently, the time available for considering alternative construction methods or new materials is reduced.

Bearing in mind the need for a flexible data base, the different needs of each interdependent function and the difficulties caused by new feedback information, a prototype communications model (Figure.6.), aided by computer facilities, was devised.

2.9 Introduction of Work Measurement Feedback and Control

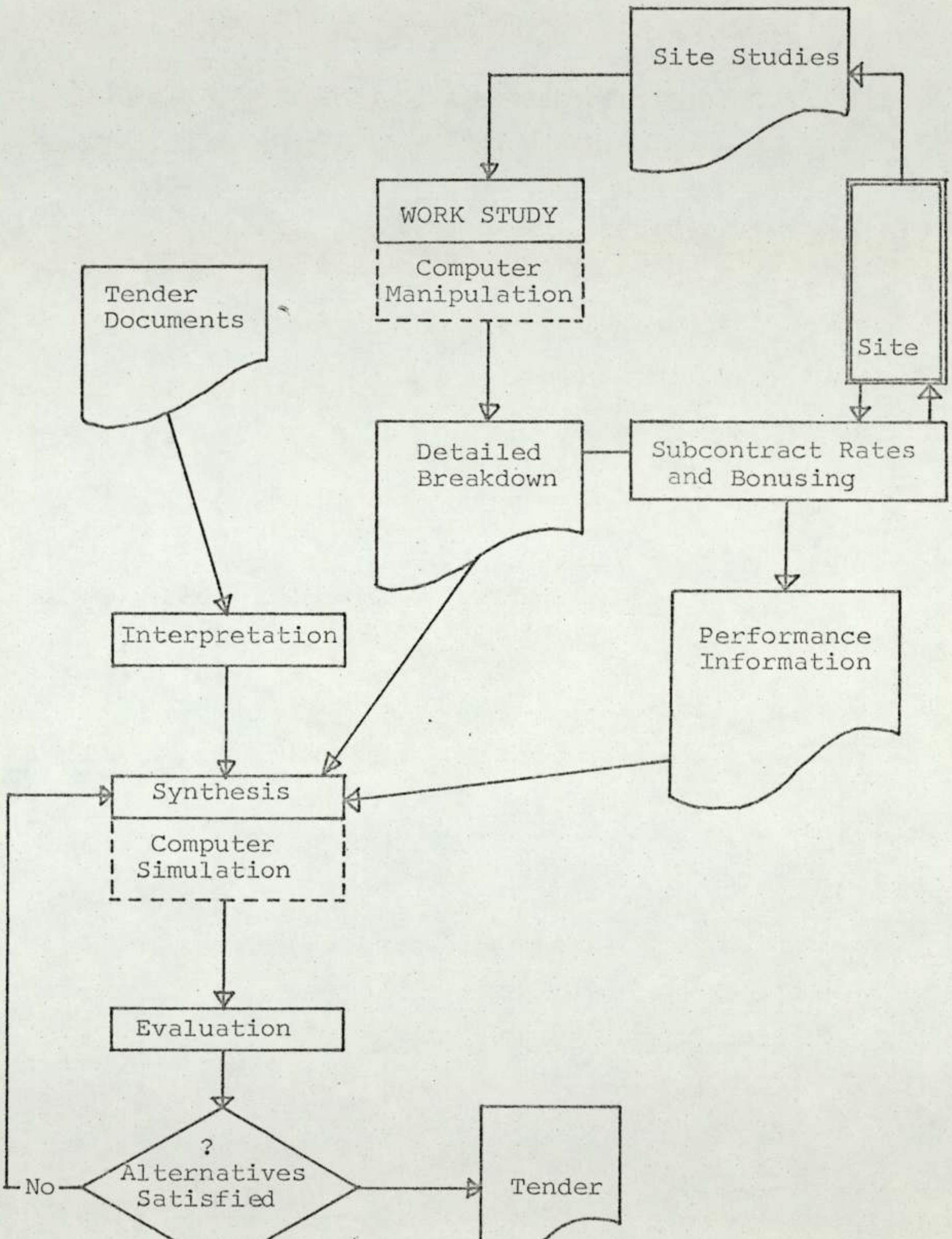
Several practical planning and estimating studies carried out by the author revealed two major drawbacks in the prototype model. Firstly, the existing estimating and planning procedures were unable to use the performance feedback because of both the limited time available for pre-contract appraisal, and the complex nature of many of the calculations necessary to interpret the effects of operative, site performance, absenteeism etc. Secondly, the large number of variables to be considered when producing a production rate for an activity from raw work measurement date proved a long and laborious task. Therefore, two computer systems were proposed, one to handle the manipulation of the work measurement information and produce production rates, and the other capable of simulating a working site. The computer systems are presented in more detail in subsequent chapters.

2.10 Financial Feedback

Retrieval and feedback of financial information requires the participation of many interdependent functions. In some respects, this is a much more complex task than work measurement and performance feedback, which primarily relies on participation of two functions (work study and bonusing).

Financial feedback must be accurate, concise and fed back quickly so that the information reflects the current

FIGURE. 6.



PROTOTYPE MODEL - ESTIMATING AND PLANNING
WORK MEASUREMENT FEEDBACK

financial position of the contractor. As will be shown in Chapter six, this is very difficult to accomplish manually in a large organisation.

All organisations document financial information, therefore, in establishing a feedback system the emphasis is not on data creation, but on presentation and manipulation, both of which are repetitive and the latter easily undertaken by a computer.

Introduction of the financial feedback system is dealt with in Chapter six.

Constantly changing construction methods and the use of new materials make production feedback an essential part of the contractual process. The computer is capable of playing a key role in the development of such systems, providing the facilities it produces are designed to fit the organisation.

CHAPTER 3

THE DATA BASE

Summary

This Chapter describes the method adopted, allowances and assumptions made in establishing two data bases to be used for both manual and computer aided estimating and planning.

CHAPTER 3

THE DATA BASE

3.1 Introduction

Data Base - a file of data which is not designed to satisfy a specific limited application. The aim of this chapter is to set up two data bases fundamental to the estimating and planning processes. They are:

(i) Work Measurement Data Base

This is created from field studies of main drainage operations. Its aim is to establish a file of information detailing gang sizes and construction times for individual elements of the drainage operation. The structure of the data base being general enough to facilitate the analysis of any drainage construction commonly used in the civil engineering industry.

(ii) Predictable Uncertainties or Performance Data Base

This is created both from field studies and from historical records. Its aim is to establish a quantitative measure of adjustments to be made to the work measurement data base in order to predict actual work outputs and resource levels.

The chapter is divided into three sections. The first defines the major elements of the drainage construction. The second describes the methods adopted for establishing the Work Measurement Data Base and the final section describes the Predictable Uncertainties Data Base, subsequently termed the Performance Data Base.

Once established, the data bases are intended for use in both manual and computer aided estimating and planning.

3.2 The Elements of Drainage Construction

Drainage construction is divided into two structural components: (1) Pipeline construction; (2) Manhole construction, each of which contain several main construction elements.

3.2.1 Pipeline Construction

This contains six construction elements. (See Figure.7.)

(i) Road Breakout: This operation element is performed usually by operatives using medium duty pneumatic equipment. Large quantities of material are often broken out by heavy, machine mounted breaking equipment.

(ii) Excavation: Today this is performed primarily by hydraulic excavators, although manual excavation is sometimes used in urban areas where there are frequent obstructions and working space is limited. In many instances, the excavation stage is independent of the other construction elements. However, the excavation machine may help with pipelaying and the excavation support elements. The excavation machine is invariably assisted by an operative (known as a Banksman) who is responsible for guiding the machine and for trimming the trench after bulk excavation.

(iii) Excavation Support:

This construction element is usually performed manually in excavations less than 4 m in depth. Excavation machines or cranes often assist the gang at greater depths. The degree of support required depends on the strength of the strata. Broadly, there are three excavation support configurations used, (Figure.8.).

(1) Close Sheeted

The trench sheets are either interlocked or simply butted up to each other.

(2) Medium Sheeted

Alternate trench sheets are omitted leaving a gap of approximately 0.33 m between each.

(3) Open Sheeted

Two trench sheets are omitted leaving a gap of 0.66 m between each trench sheet.

(iv) Pipe Laying: This operation element is performed by semi-skilled operatives. Most pipes commonly used today are flexibly jointed. (Figure.9a .). However, some ridgidly jointed (Figure.9b .) constructions are sometimes used for small diameter pipes (up to 150 mm). Flexibly jointed pipes up to 300 mm are jointed by hand, but larger diameters require special jacking equipment. Pipes over 300 m diameter are too bulky and/or too heavy to be lowered into the excavation by hand, therefore, an excavation machine or a crane is used.

(v) Pipe Bedding: This operation entails bedding the pipe on a suitable material which acts as a load transfer and support media. There are three types of material used:-

(1) Concrete (Class A)

(2) Granular (Class B)

(3) Selected Backfill (Class C)

The shape of the bedding structure is an important part of the design. Many different shapes are used together with

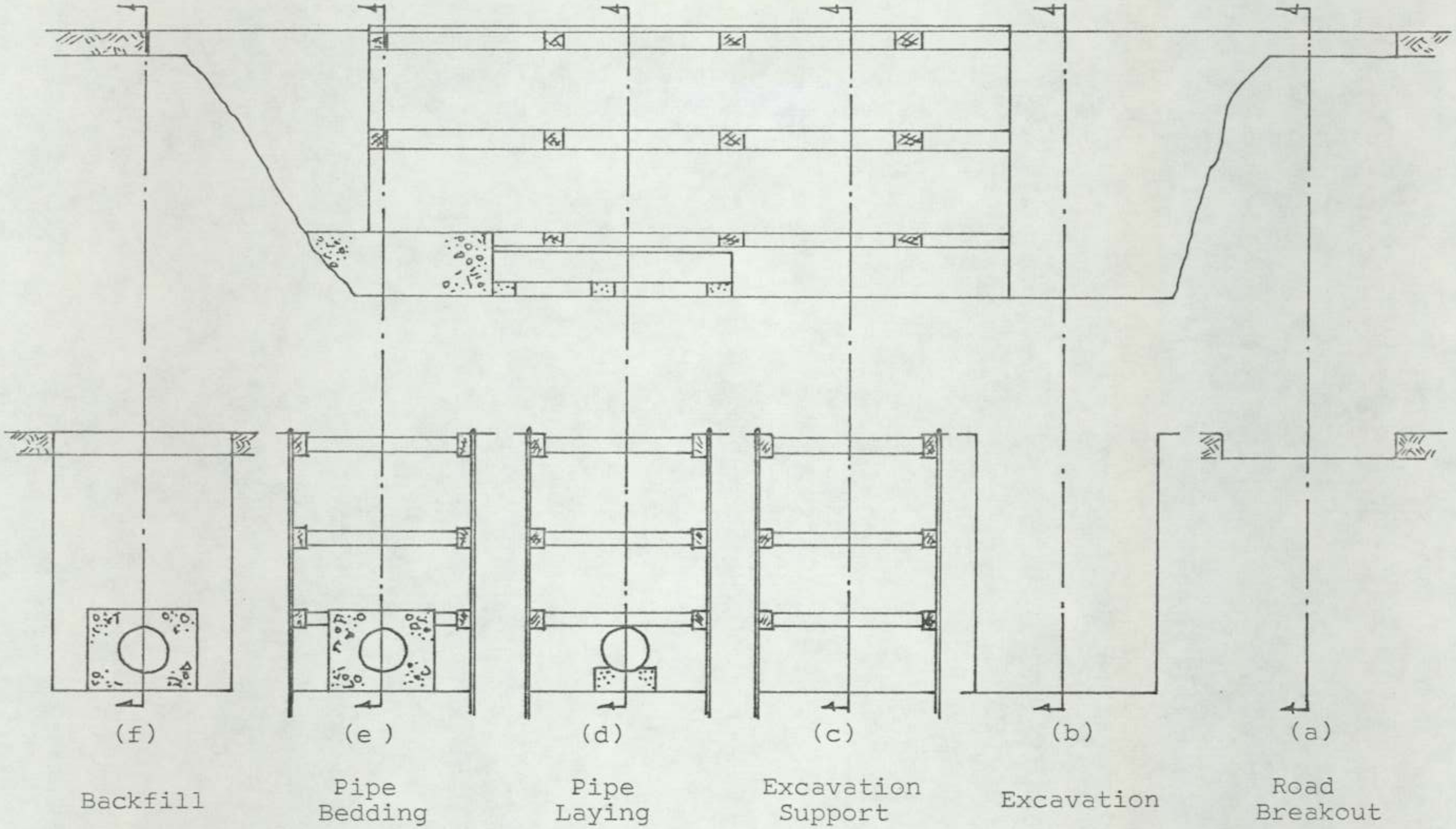
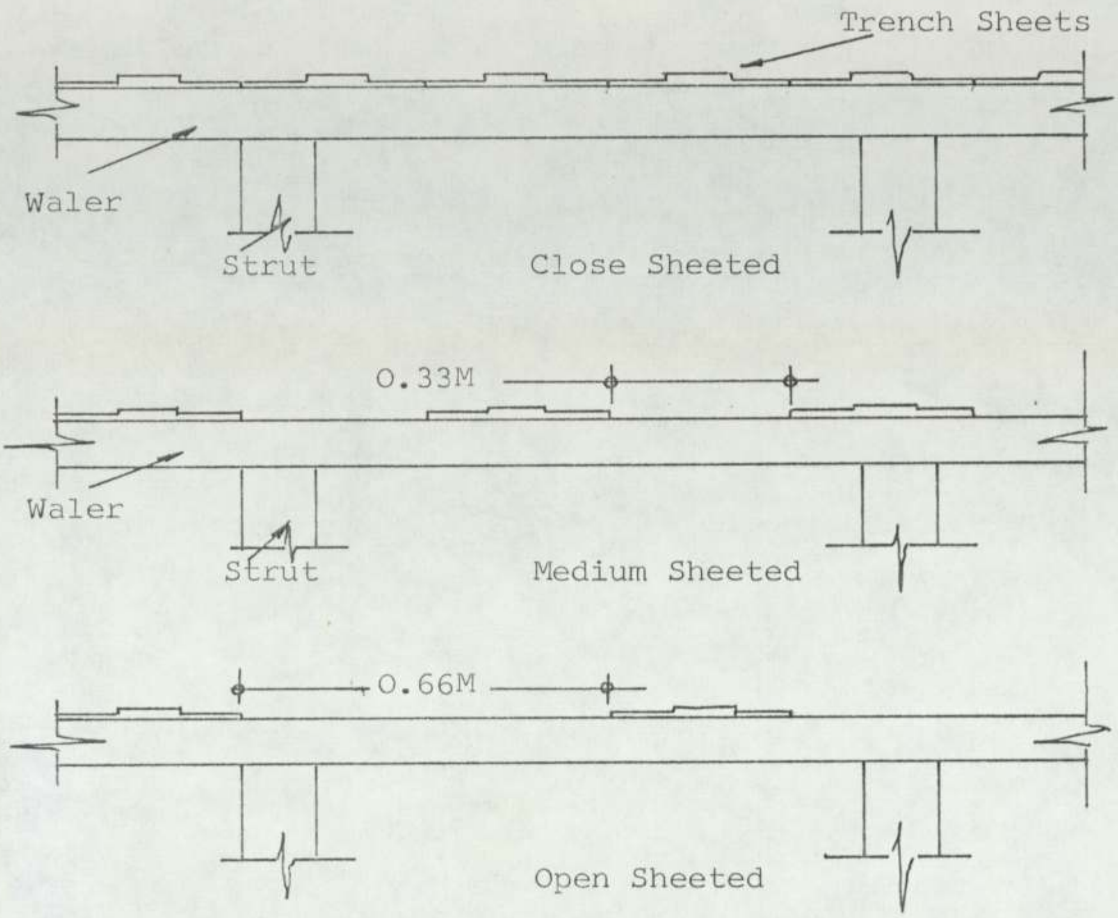
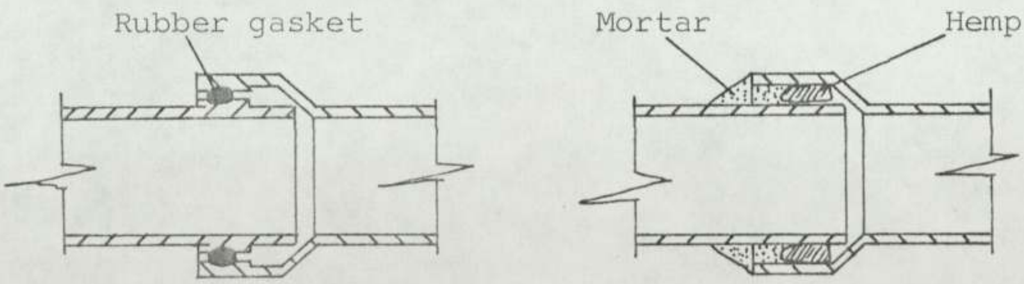

(f)
(e)
(d)
(c)
(b)
(a)
Backfill
Pipe Bedding
Pipe Laying
Excavation Support
Excavation
Road Breakout

FIGURE.7.

FIGURE.8.



An Isometric view of the excavation support configuration is shown in Chapter 4.



Flexible Joint

Figure.9a.

Rigid Joint

Figure.9b.

different combinations of the three types of material[56,57]. Pipe bedding is usually manual, but large quantities are often placed by machine.

(vi) Backfill: From a structural point of view, this is considered to be the most important construction element by most Designers, but its importance is rarely reflected in the construction methods adopted on site. An excavation machine or a tracked loader is often used, assisted by two operatives. Although hand backfilling is often specified by Engineers, it is rare.

3.2.2 Manhole Construction

This contains eleven construction elements, four of which (excavation, excavation support, backfill and road breakout) are defined earlier. The following elements are shown diagramatically in Figure.10 .

(i) Base Blinding: This element involves placing concrete at formation level to form a solid permeable base for the manhole structure. It is essentially a manual operation, but for large manholes, plant is often used to assist the gang.

(ii) Channel Construction:

This involves bedding and levelling

the pipes into and out of the manhole and moulding a flow channel from concrete. It is a manual operation but plant may be employed for large manhole structures.

(iii) Manhole Structure Construction:

The manhole structure is usually constructed of engineer bricks or pre-cast concrete rings (Figure.10.). Brick manhole construction is essentially a manual procedure, whilst pre-cast concrete ring manholes require plant assistance.

(iv) Insitu Concrete Surround/Slab Construction

Brick manholes are not usually surrounded with concrete but pre-cast concrete ring manholes often are. The operation is usually performed manually and pre-made concrete formwork often used. Pre-cast ring manholes do not usually require cast insitu concrete chambers or shafts.

(v) Benching: This operation involves finishing the channel construction. Fine concrete is usually used, granite aggregate being placed and floated by hand.

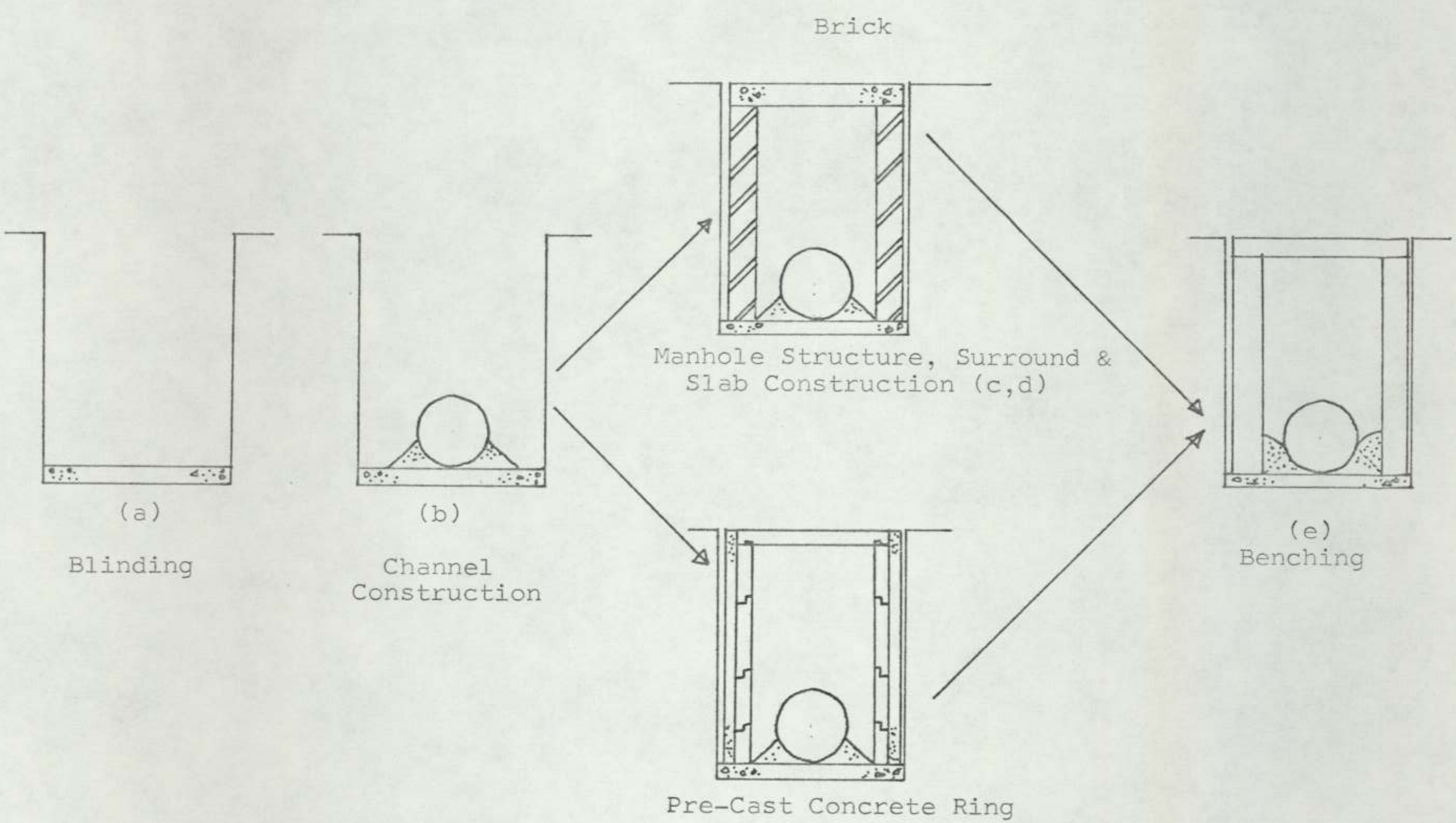

Brick
(a)
Blinding
(b)
Channel
Construction
Manhole Structure, Surround &
Slab Construction (c,d)
Pre-Cast Concrete Ring
(e)
Benching

FIGURE.10.

3.3 Work Measurement in Construction

Work Measurement comprises a group of associated techniques (Time Study, Synthesis, Analytical Estimating, Pre-determined Motion Time Systems) which, although theoretically applicable to all industries, are not fully utilised in the civil engineering industry. Although work measurement is fundamental to the estimating and planning procedures, neither Estimators nor Planners fully appreciate the value of the techniques available. This is, in part, due to the assumption on which work measurement techniques are based and which(many Estimators argue) render the techniques difficult to apply in practice.

Many construction workers are unskilled, they are required to move from job to job at short notice. They sometimes work alone or in gangs on similar operations. The work they undertake is often interrupted by absenteeism, material shortage, inadequate supervision or by their own lack of construction "know-how", they often have little time to become competent. All these are given as reasons for not applying rigorous work measurement techniques in construction but are, in the writer's opinion, arguments for increasing the rate of their introduction.

The factory production line environment provides the researcher with the opportunity to study repetative, uninterrupted operations. In civil engineering, two operations are rarely similar enough to compare accurately and often not repeated for long periods.

To attempt to alleviate the obvious difficulties of studying site operations and after some weeks spent on site observing and performing pilot studies, the author prepared a pre-work measurement study design methodology, (Figure.11.), which was aimed at preparing the operations for rigorous time studies.

Activity Sampling preceded all time studies in an attempt to determine the minimum practical gang size required to complete the operation. Existing work measurement data bases[58] tend to rely on man-hour durations, the assumption being that the required gang duration can be determined by dividing it by the number of men. This is unreliable and inaccurate as the law of diminishing returns, so aptly explained by Pilcher,[59] illustrates.

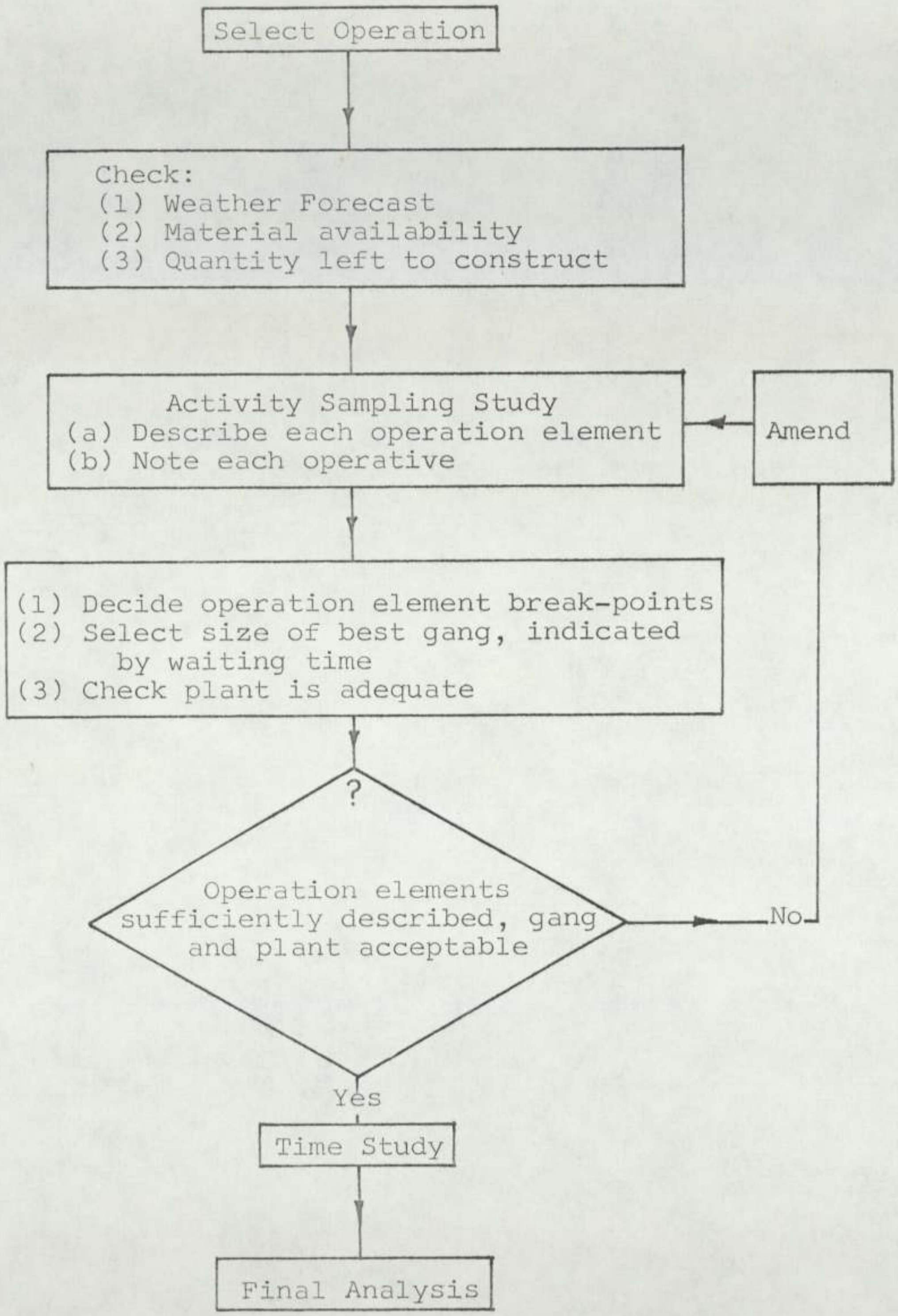

Select Operation
Check:
(1) Weather Forecast
(2) Material availability
(3) Quantity left to construct
Activity Sampling Study
(a) Describe each operation element
(b) Note each operative
Amend
(1) Decide operation element break-points
(2) Select size of best gang, indicated by waiting time
(3) Check plant is adequate
?
Operation elements sufficiently described, gang and plant acceptable
No
Yes
Time Study
Final Analysis

Figure.11.

3.4 Time Study Approach

Total Operation Time Studies followed successful Activity Sampling. The operation was split into its different construction elements which in turn, were split into smaller components. For example:

Construction Element	Component
	1 Prepare Base
	2 Lower Blocks /2 m
	3 Place-level Blocks
Pipe Laying	4 Lower-position pipe /2 m
	5 Lower-position pipe /4 m
	6 Place Gasket
	7 Lubricate Socket
	8 Set Jack
	9 Jack
	10 Release Jack
	11 Lower Traveller
	12 Bore
	13 Lift Traveller
	14 Adjust Pipe
	15 Remove Sling
	16 Check Level

Each component was then timed and the operatives engaged on the work rated. Many of the tests lasted two days, none less than one day. The excavation support studies often lasted a week.

Although time studying small construction components prolonged the study period, the effect of interruption due to unforeseen material shortages or plant breakdowns could be monitored more readily. Therefore, their effect on the results were minimised.

3.5 Relaxation and Contingency Allowance (60)

The basic minute data retrieved from the time studies is adjusted by applying relaxation allowances used by the company (Table.2.). In addition, Work Contingency Allowances of 1% and Delay Contingencies of 2% are applied to yield the work content. The following allowances are made to individual construction elements.

Operation Element	A	B	C	D	E	F	(%) Total	Work Cont.%	Delay Cont.%
Excavation	8	2	4	2	0	1	17	1	2
Excavation Support	8	2	0	4	4	0	18	1	2
Pipe Laying	8	2	5	4	4	0	23	1	2
Pipe Bedding	8	2	0	4	4	0	18	1	2
Backfill	8	2	0	4	2	0	16	1	2
Road Breakout	8	2	0	4	4	0	18	1	2
Base Blinding	8	2	4	4	4	0	22	1	2
Channel Construction	8	2	4	2	1	0	17	1	2
Manhole Structure	8	2	4	4	4	0	22	1	2
Concrete Surround	8	2	0	4	4	0	18	1	2
Concrete Slabs	8	2	0	4	4	0	18	1	2
Bending	8	2	5	2	1	0	18	1	2
Fitting	8	2	0	4	1	1	16	1	2
Miscellaneous	8	2	0	4	4	0	18	1	2

A complete catalogue of the work measurement data collected is given in Appendix.1.

TABLE. 2 .

WORK STUDY SECTION

Standard Relaxation Allowances

A.	Personal	
	Attending to personal needs - toilet etc.	8%
B.	Position	
	Standing normally or walking.	2%
	Ditto - but including crouching or bending:-	
	I occasionally	3%
	II frequently	4-5%
C.	Attention	
	I Fairly fine (e.g. plumbing, levelling)	0-2%
	II Fine or exacting (e.g. intricate carving, dressing stone, etc.)	3-6%
	III Very fine/very exacting,(e.g. watchmaker - not usually applicable to building.	7-10%
D.	Conditions	
	Indoor or partially protected situations.	0-3%
	Outdoor work (average over whole year)	4%
	Particularly trying conditions of excessive heat or cold (if always applicable to that job)	5-10%
E.	Weight	
	Allowances for effort expended in lifting, pulling or pushing, i.e. allowance is for duration of time which the particular weight is fully supported by one individual.	

lbs	
5	0%
10	1%
15	2%
20	3%
25	4%
30	5%
35	7%
40	9%
45	11%
50	13%
60	17%
70	22%
112	45%

F.	Frequency		
	Where monotony occurs	i low	0-1%
		ii medium	2-4%
		iii high	5-7%

(Note: This is not generally encountered in the building industry and it is applied only when very short cycle repetitive operations occur, with the high allowance being applied only in exceptional circumstances).

3.6 Performance Data

The term 'Performance Data' will be used in this and subsequent chapters to describe all the following variables.

(i) Operative Performance Index (OPI)

This is the ratio of the standard time allotted to an operative or gang of operatives to complete an operation, and the actual productive time spend on the operation. It is expressed as a multiple of 100.

(ii) Site Performance Index (SPI)

This is the ratio of the standard time allotted to an operative or gang of operatives to complete an operation and the total time spent on the operation. It is expressed as a multiple of 100.

(iii) Productive Unmeasured Time

This is the amount of time an operative or gang of operatives spend on productive work which is either too complex or too insignificant to measure.

(iv) Inclement Weather Lost Time

This is the amount of time documented by the operatives themselves, loss due to inclement weather. No distinction is made between rain, snow, frost etc.

(v) Absenteeism or Overloading

This is the percentage deviation from the minimum practical gang size stipulated in the work measurement description.

3.7 Performance Data Collection

All performance data, with the exception of absenteeism and overloading, was collected weekly from site using standard forms, (Figure.12.), the forms being completed by Production Surveyors from information contained on allocation sheets which were completed daily by the operatives. The absenteeism and overloading information was supplied by the Site Clerk from the attendance register and clock cards.

The OPI and SPI give some indication of the calibre of the labour employed and the capacity of the line management to maintain a flow of productive work.

When the author joined the company, weekly values of OPI and SPI were being calculated as a by-product of the incentive scheme, (Figure.13.).

Nothing specific came out of the documentation, consequently it was viewed with a great deal of suspicion by the line management.

The accuracy of the performance data is primarily dependent on the operatives on site who are required to allocate productive time, waiting time and wet time. Consequently, the accuracy of the final values of OPI, SPI, productive unmeasured and the inclement weather lost time must be interpreted with caution.

Twenty-two projects provided the performance data, the majority of which were situated within a 50 mile radius of

Birmingham. Therefore, the various labour characteristics and inclement weather conditions must be assumed to apply to this area only. Although several projects outside this area were studied, not enough information was available to perform area analyses.

3.8 Performance Data Analysis

For analysis purposes, tradesmen and labourers are considered separately.

Although both tradesmen and labourers seem to attain virtually the same mean OPI value, the tradesmen's OPI distribution is more widely dispersed (Tables.3. and .4.). The SPI distributions indicate that line management organise the tradesmen's work load more effectively than they organise that of the labourers. This is understandable because their work is often immediately productive, but when one considers that in civil engineering half the labour force consists of labourers, more effort should be made to plan the labourers' work load on the same basis as that of the tradesmen.

The OPI and SPI distribution are symmetrical but X^2 tests at 0.05 significance level indicate that they cannot be assumed normal, as half of the tests fulfill the null hypothesis and half do not (Tables.5. and .6.).

Information for productive unmeasured inclement weather time and absenteeism could not be obtained from all the projects because either they were too advanced to change the documentation procedure or no full-time Production Surveyor was available. However, information from twelve projects was analysed, (Table. 7 .). On average, the productive unmeasured time is substantial (10%), but the time loss due to inclement weather constitutes 3% of the total time. The problem of absenteeism and overloading of gangs is one which line management understand but find impossible to solve. Although the mean absenteeism on a global basis is only 1%, the local effects of rapid changes in absenteeism and rapid overloading are critical. Most line Managers interviewed thought it to be the most difficult problem with which they had to deal.

With the possible exception of the time lost due to inclement weather, the extent to which the Operative Performance and Site Performance indices affect production can only be assessed using computer facilities. Subsequently, in Chapter 5) it will be shown by simulation that the effect of varying performance can be substantial.

WEEKLY PRODUCTION ANALYSIS

W.E. May 12th 1972

Leeds Inner Ring Road

Site	Gang Size	Operative Performance			Bonus Paid	Site Performance Index			Interpretation of Site Index Coding	Remarks
		STD/HRS	MAN/HRS	INDEX		STD/HRS	MAN/HRS	INDEX		
Fitter	1		(61)		3.00	) Not Calculated				
Drivers	8		(435)		23.13	)				
Chainmen/Canteen	4		(163)		-	)				
Breen (Lab)	5	182	209	86	19.02	188	238	79	2	
Harran (Drains)	4	123	148	83	14.06	123	148	83	2	
Keogh (Gen Ops)	3	41	48	85	6.63	93	124	75	2	
Baston (Joiner)	4	153	159	96	25.92	162	183	89	2	
Lynch (Joiner)	2	74	73	100	13.38	75	92	81	2	
Ladwa (Joiner)	3	75	98	76	8.50	86	117	73	3	
Eaves (Lab)	8	212	310	68	19.25	215	353	60	3	
	42	860	1045	82	132.89	942	1255	75		

FIGURE.12.

Productive Measured	1022	52	% of Total
Non-Productive	102	5½%	
Wet Time			
Lost Time			
Productive unmeasured measurable omitted from Prod. Return	143) 292) 435	21½%	
Productive unmeasured not measurable	88¾	4½%	
Preliminaries	303	15½%	
Omissions	17	1%	
Total Hours	1968	100	

FIGURE.12. (Contd.)

CONTRACT Paradise Circus

JOB No 3190 DATE 12th July, 1970

WEEKY PRODUCTION RETURN

TRADE	PRODUCTION EFFICIENCY			
	Standard Hours	Actual Man Hours	Operative Performance Index	Operative Performance Index
Bricklayers	67	90	72	74
TOTAL				

NOTES:-

SITE PERFORMANCE INDEX
(Minimum Acceptable Performance = 75

74

FIGURE.13.

Description	No. of Readings	OPI				SPI			
		MIN	MAX	MEAN	STD.DEV	MIN	MAX	MEAN	STD.DEV
Balsall Common	60	21	164	75	28	21	164	69	27
Milcote	20	61	148	109	42	61	148	107	43
Barnhurst	273	33	159	102	19	25	137	77	22
Swindon	310	12	164	77	29	12	161	73	25
Centre City	53	24	165	74	35	25	164	70	27
Walsall Road	67	24	115	82	18	16	100	58	19
Leeds	206	18	157	102	38	16	150	77	31
Hockley	24	65	164	116	33	65	162	110	24
Droitwich	20	30	127	80	29	30	118	69	25
Northern Loop	235	20	150	99	36	10	144	76	28
Kenilworth	107	27	155	103	35	27	155	97	34
Clapgate	21	20	156	75	33	14	132	68	28
Ravensmere	27	30	162	93	49	18	162	79	49
Wynyates	60	12	150	86	38	17	140	84	38
Peterborough	127	17	198	91	31	17	177	76	30
Walsall Wood	27	52	189	116	35	49	170	100	33
Cranmore Boulevard	26	30	102	72	31	12	90	70	25
Matchborough	20	66	184	123	46	46	180	119	50
Lancaster Place	25	28	129	80	25	26	113	67	21
Paradise Circus	233	25	193	93	44	24	193	83	42
Mansfield	16	16	133	84	35	16	112	72	19
Handsworth	73	27	131	97	17	21	131	89	19
TOTAL									
MEAN				92.23	33.00			81.36	30.18
STANDARD DEVIATION				15.14	8.47			15.90	9.06

TRADESMEN

TABLE. 3 .

Description	No. of Readings	OPI				SPI			
		MIN	MAX	MEAN	STD.DEV	MIN	MAX	MEAN	STD.DEV
Balsall Common	46	35	148	90	22	27	97	65	17
Milcote	59	59	141	90	17	42	141	75	17
Swindon	583	10	150	89	27	17	140	75	25
Barnhurst	200	43	128	101	13	33	118	77	17
Jennens Row	12	37	140	83	29	12	97	73	24
Centre City	18	38	120	72	23	36	78	63	19
Walsall Road	181	22	128	77	18	11	120	56	21
Leeds	214	37	138	88	16	10	111	66	22
Hockley	10	43	157	91	36	31	82	59	24
Northern Loop	350	18	160	100	21	15	120	66	26
Droitwich	29	14	136	89	25	13	118	66	30
Kenilworth	108	23	166	84	25	32	140	78	19
Clapgate Lane	200	15	154	90	33	15	120	72	25
Ravensmere	140	20	150	78	26	13	134	72	23
Wynyates	89	25	167	92	31	25	161	82	25
Peterborough	359	16	170	73	28	12	130	59	24
Walsall Wood	51	31	144	90	24	13	133	69	29
Cranmore Boulevard	23	64	170	91	24	14	96	71	18
Matchborough	31	33	151	86	27	22	110	69	23
Lancaster Place	12	36	160	107	32	36	159	100	32
Paradise Circus	281	13	150	75	29	12	123	54	21
Swindon Inc.	19	47	112	88	21	27	103	67	24
Mansfield	16	86	170	113	24	70	100	85	19
Handsworth	19	84	124	106	21	59	121	91	16
TOTAL									
MEAN				89.29	24.67			71.25	22.50
STANDARD DEVIATION				10.59	5.59			10.79	4.29

LABOURERS

TABLE. 4 .

Description	TRADESMEN					LABOURERS				
	ν	X^2	$X^2 0.95$	reject Ho	accept Ho	ν	X^2	$X^2 0.95$	reject Ho	accept Ho
Balsall Common	10	11.33	18.30		•	7	13.79	14.1		•
Milcote	7	11.49	14.1		•	6	4.66	12.6		•
Swindon	15	56.96	25.0	•		15	65.25	25.0	•	
Barnhurst	11	73.75	19.7	•		7	63.59	14.1	•	
Jennens Row	5	10.10	11.1		•	5	9.56	11.1		•
Centre City	11	26.74	19.7	•		6	3.19	12.6		•
Walsall Road	8	47.13	15.5	•		9	6.53	16.9		•
Leeds	14	48.12	23.7	•		8	64.82	15.5	•	
Hockley	5	8.74	11.1		•	4	13.71	9.49	•	
Northern Loop	16	40.45	26.3	•		13	24.03	22.4	•	
Droitwich	8	5.97	15.5		•	6	5.72	12.6		•
Kenilworth	13	24.23	22.4	•		11	34.39	19.7	•	
Clapgate Lane	12	18.27	21.0		•	13	14.71	22.4		•
Ravensmere	9	11.02	16.9		•	10	13.36	18.30		•
Wynyates	13	19.72	22.4		•	13	26.21	22.4	•	
Peterborough	15	27.95	25.0	•		14	62.06	23.7	•	
Walsall Wood	9	12.76	16.9		•	8	14.72	15.5		•
Cranmore Boulevard	9	105.21	16.9	•		5	218.08	11.1	•	
Matchborough	6	11.7	12.6		•	9	6.44	16.9		•
Lancaster Place	6	16.09	12.6	•		2	101.09	5.99	•	
Paradise Circus	13	64.13	22.4	•		15	14.55	25.0		•
Swindon Inc.	6	11.01	12.6		•	4	14.22	9.49	•	
Mansfield	7	8.76	14.1		•	7	9.45	14.1		•
Handsworth	6	39.77	12.6	•		6	2.81	12.16		•

OPERATIVE PERFORMANCE INDEX

TABLE. 5 .

Description	ν	TRADESMEN x^2	TRADESMEN $x^2_{0.95}$	TRADESMEN reject Ho	TRADESMEN accept Ho	ν	LABOURERS x^2	LABOURERS $x^2_{0.95}$	LABOURERS reject Ho	LABOURERS accept Ho
Balsall Common	10	28.38	18.3	•		5	6.37	11.1		•
Milcote	7	11.59	14.1		•	6	180.31	12.6	•	
Swindon	15	171.9	25.0	•		15	746.95	25.0	•	
Barnhurst	9	12.26	16.9		•	7	18.62	14.1	•	
Jennens Row	4	9.31	9.49		•	4	9.51	9.49	•	
Centre City	9	126.37	16.9	•		2	3.79	5.99		•
Walsall Road	6	14.82	12.6		•	9	27.66	16.9	•	
Leeds	13	24.37	22.4	•		9	29.15	16.9	•	
Hockley	6	9.84	12.6		•	2	1.90	5.90		•
Northern Loop	13	43.04	22.4	•		14	16.13	23.7	•	
Droitwich	5	9.66	11.1		•	8	10.06	15.5		•
Kenilworth	13	36.37	22.4	•		9	17.79	16.9	•	
Clapgate Lane	7	4.31	14.1		•	11	6.39	19.7		•
Ravensmere	7	21.52	14.1	•		11	10.06	19.7		•
Wynyates	12	30.89	21.0	•		11	41.76	19.7	•	
Peterborough	14	46.45	23.7	•		10	14.12	18.3		•
Walsall Wood	8	9.12	15.5		•	10	9.10	18.3		•
Cranmere Boulevard	10	991.27	18.3	•		3	64.01	7.81	•	
Matchborough	7	8.80	14.1		•	5	10.87	11.1		•
Lancaster Place	6	11.77	12.6		•	4	265.39	9.49	•	
Paradise Circus	14	73.03	23.7	•		10	19.68	18.3	•	
Swindon Inc.	5	9.18	11.1		•	5	5.87	11.1		•
Mansfield	4	6.29	9.49		•	1	1.35	3.84		•
Handsworth	4	5.71	9.49		•	9	77.44	16.9	•	

SITE PERFORMANCE INDEX

TABLE. 6 .

SITE	PRODUCTIVE UNMEASURED WORK (%)				WET/WAITING TIME (%)				ABSENTEEISM AND OVERLOADING (%)			
	MIN	MAX	MEAN	STD. DEV.	MIN	MAX	MEAN	STD. DEV.	MIN	MAX	MEAN	STD. DEV.
Balsall Common	0.00	10.00	4.31	2.62	0.00	9.78	3.53	0.79	-10.61	15.41	4.62	6.52
Swindon	0.00	13.68	2.99	3.51	0.00	30.17	3.07	5.92	- 2.86	15.51	3.59	6.21
Barnhurst	0.00	12.00	2.19	3.69	0.00	40.00	6.24	7.70	- 2.78	12.28	2.79	2.91
Walsall Road	0.00	39.00	6.95	9.51	0.00	26.75	2.88	4.88	-62.50	13.46	-0.94	13.52
Leeds	0.00	25.00	5.40	5.98	0.00	23.00	2.41	4.67	-32.00	16.22	0.05	6.42
Hockley	0.00	25.63	14.73	7.58	0.00	3.50	1.92	1.41	-14.78	18.49	-0.72	3.93
Northern Loop	0.00	38.00	13.85	11.57	0.00	26.00	3.70	5.57	-31.71	27.91	-2.83	12.75
Droitwich	0.00	19.00	9.11	6.37	0.00	2.00	0.56	0.72	- 4.35	7.89	1.96	3.93
Peterborough	0.00	38.65	19.52	8.46	0.00	21.00	5.27	4.16	-25.61	19.87	3.51	6.58
Mansfield	0.00	28.00	14.19	7.53	0.00	4.17	2.33	1.56	-14.07	8.59	-2.71	4.16
Handsworth	2.00	66.00	16.74	16.83	0.00	4.00	0.57	1.09	-12.50	3.70	-0.75	3.28
Middle Ring Rd.	0.00	22.00	4.62	6.26	0.00	27.00	2.62	7.39	- 4.35	20.83	3.23	6.25
MEAN			9.55				2.93				0.98	

TABLE. 7 .

CHAPTER 4

COMPUTER GENERATION OF ESTIMATING INFORMATION

Summary

The presentation and use of two computer programmes which produce standard time, gang size and material quantity information. These are to be used for planning and estimating drainage operations.

CHAPTER 4

COMPUTER GENERATION OF ESTIMATING INFORMATION

4.1 Introduction

For many years the most common method of estimating used in the civil engineering industry has been 'unit pricing' - the application of a money rate to a quantity oriented Bill of Quantity item. However, during recent years, rapid changes in the types of material and plant used, escalating labour, materials and plant costs have shown the method to be inaccurate and insensitive to construction methods.

Many Estimators argue that the 'swings and roundabouts' effect, predominant in estimating, compensates for many of the inaccuracies exhibited by the method. This argument is rarely accepted by clients and cost conscious Contracts Managers who require correctly priced Bills of Quantity for comparing different tenders and for value-cost monitoring and control.

The structure of many Bills of Quantity used in civil engineering do little to promote effective 'operational pricing' of projects - a method which involves applying time derived money rates to an operation. It assumes that the construction time for the individual components of the operation are constant at a given performance and that the operational price is derived from the manipulation of the components in a way which synthesises the anticipated construction procedure. Consequently,the financial rates are only applied once it is finalised. Operational pricing is sensitive to the construction procedure, resource requirements are known and because money rates are applied at the end of the process; current costs are used.

Estimators dislike 'operational pricing' because manual manipulation of work measurement information is time consuming, laborious and the method requires a large amount of detailed work measurement data.

Two computer programmes (PIPELINE AND MANHOLE) are presented in this chapter. They use the work measurement data given earlier to calculate estimating information for drainage pipelines and manholes.

The chapter is presented in two broad sections, the first (4.2 to 4.9) dealing with the theoretical structure and use of the pipeline programme, and the second (4.11 to 4.15) dealing with the theory,structure and use of the manhole programme.

4.2 <u>The Pipeline Analysis Programme</u> (PIPELINE)

This programme is designed to fulfill four objectives. Firstly, to store the work measurement information collected from site and in so doing, permanently record it for future use. Secondly, to receive the limited amount of data available to Estimators and Planners during the pre-contract appraisal stage. Thirdly, to produce material quantities, construction times at a given performance and minimum practical gang sizes. Fourthly, it is designed to produce estimating information which is of use to both the Contractor's Estimators and Planners when preparing tenders and to the Client's Designers and Estimators, thus allowing them to analyse several feasible designs in constructional terms, thereby showing the relative benefits of each.

The programme processes the pipeline operation in technological sequence. To maintain flexibility, all elements of the operation are processed in 'sub-programmes' each of which contain several 'element subroutines' which store the work measurement information, calculate material quantities and determine the gang sizes. The 'element subroutines' are supported by 'ancillary subroutines' which prepare the input and output information. The sub-programmes deal with:-

(1) Road Breakout
(2) Excavation
(3) Excavation Support
(4) Pipe Laying
(5) Pipe Bedding
(6) Backfill

All 'element subroutines' and most of their associated 'ancillary subroutines' are controlled from the master programme segment (Figure.14.). After processing each element of the pipeline operations, the ancillary subroutines produce a comprehensive output and, on completion of the analysis, a general summary is given.

The programme produces several alternative methods for the Road Breakout, Excavation Support and Backfill operation elements, thus permitting the user to specify the method used. On completing the pipeline analysis, the programme gives overall construction time and the labour and plant required.

The follow ng sections of this chapter present the theory and a detailed breakdown of each sub-programme, the associated flow diagram being referenced to the master segment flow diagram,(Figure.14.).

4.3 Road Breakout Sub-Programme

This, (Figure.15.) contains two 'element subroutines', each storing the work measurement information given in Appendix one. The first calculates the standard breakout time for a gang using medium breakers (essentially a manual process). The second calculates the standard breakout time for a gang assisted by a machine. Both results are output and the user selects the one applicable.

The sub-programme determines the breakout time and gang size for either flexible or rigid road construction. The quantities of breakout do not allow for over dig.

4.4 Excavation Sub-Programme

This sub-programme contains four 'element subroutines':-

(i) Machine Selection

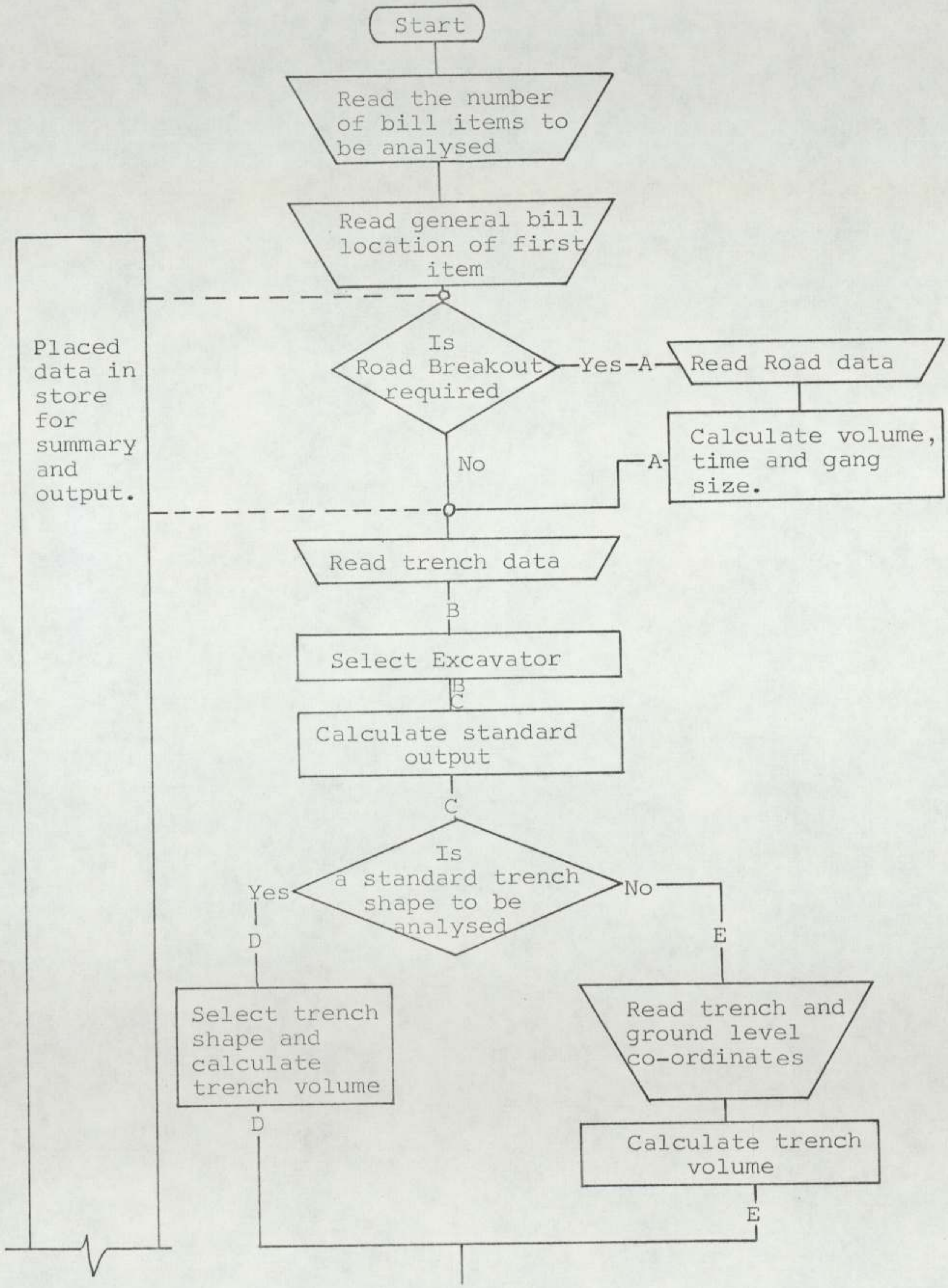
(ii) Excavation Rate

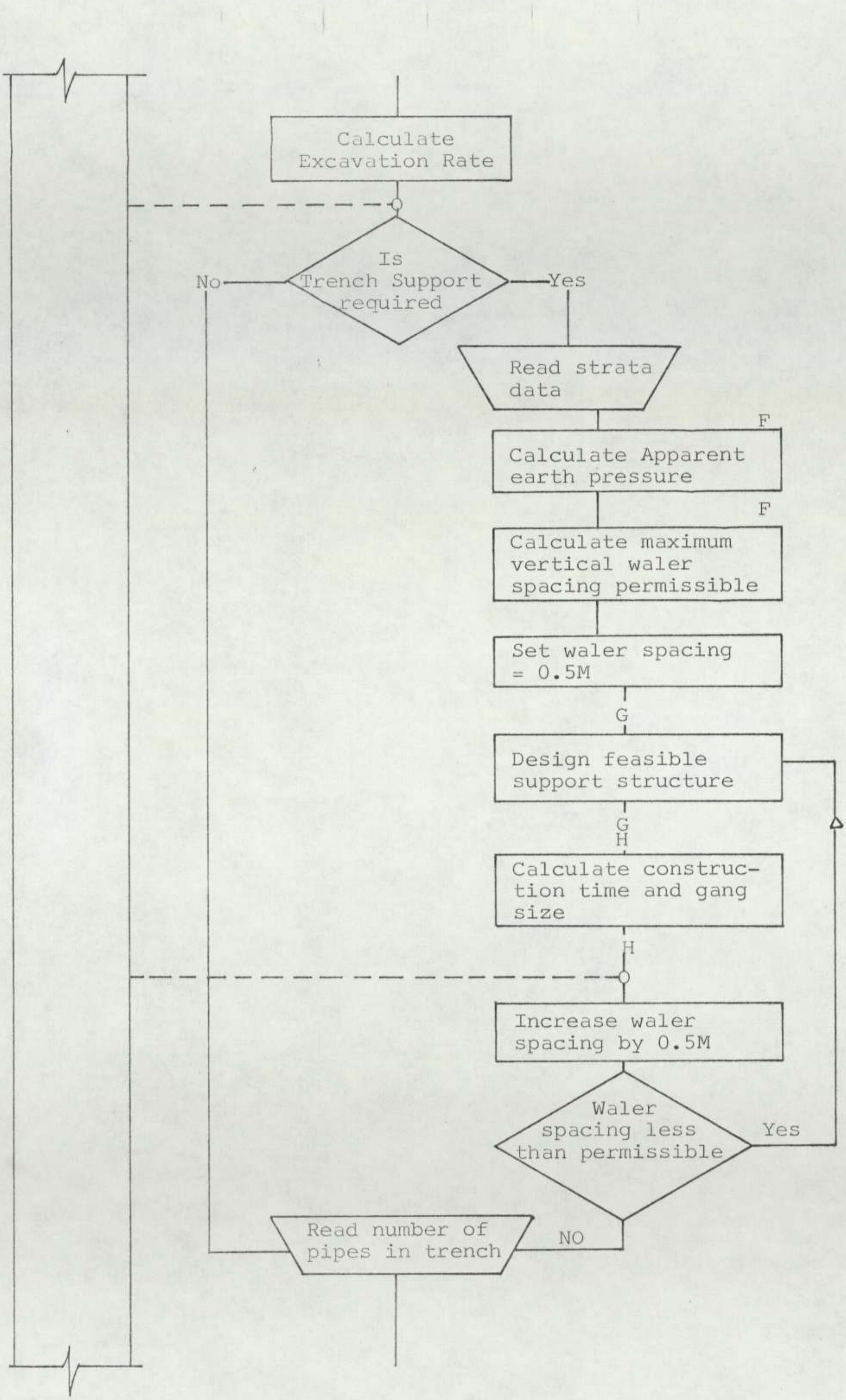
(iii) Standard Trench Shape Volume

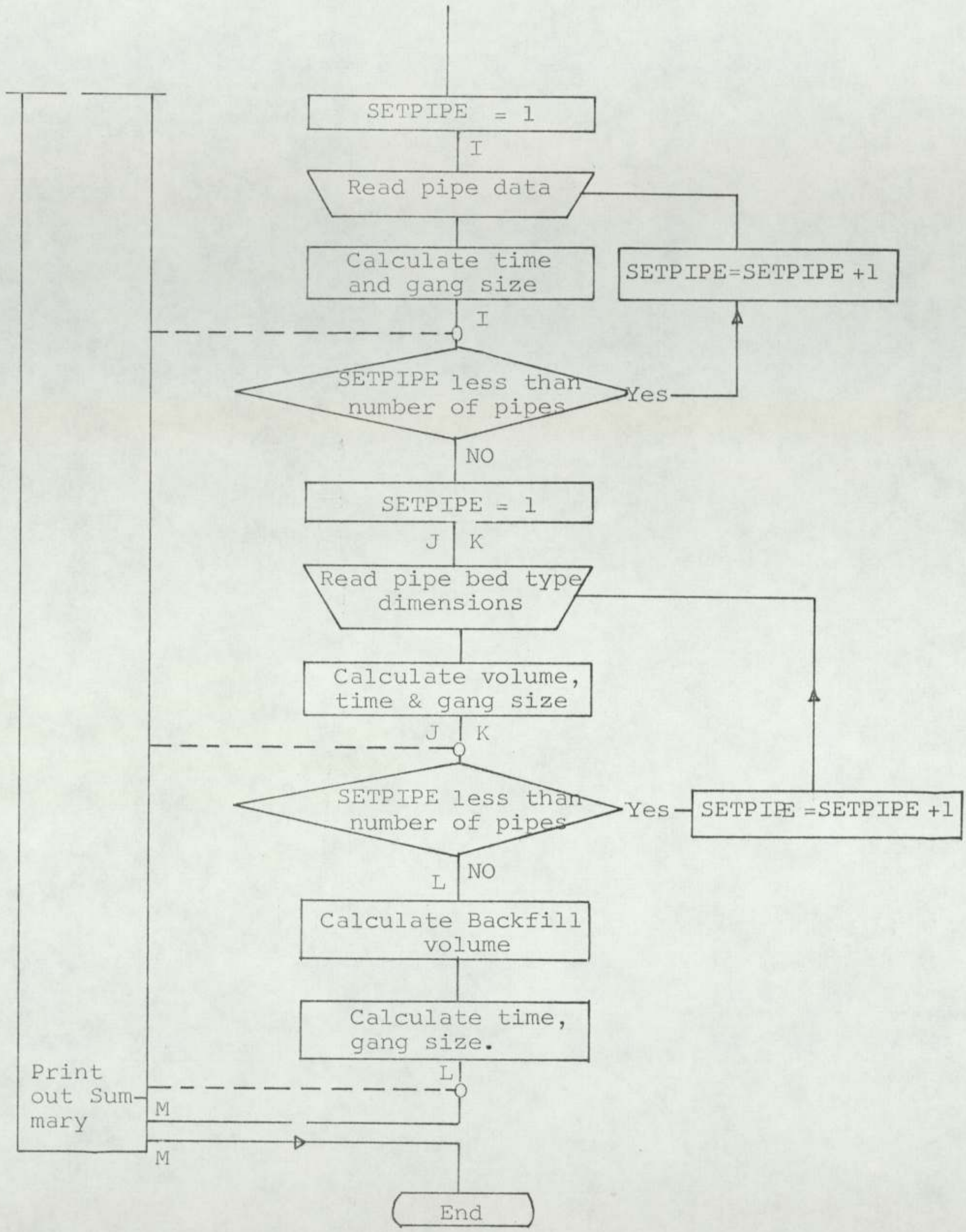
(iv) Unique Trench Shape Volume

FIGURE.14.

STRUCTURE OF MASTER SEGMENT




Calculate
Excavation Rate
Is
Trench Support
required
No
Yes
Read strata
data
F
Calculate Apparent
earth pressure
F
Calculate maximum
vertical waler
spacing permissible
Set waler spacing
= 0.5M
G
Design feasible
support structure
G
H
Calculate construc-
tion time and gang
size
H
Increase waler
spacing by 0.5M
Waler
spacing less
than permissible
Yes
Read number of
pipes in trench
NO


SETPIPE = 1
I
Read pipe data
Calculate time and gang size
SETPIPE=SETPIPE +1
I
SETPIPE less than number of pipes
Yes
NO
SETPIPE = 1
J K
Read pipe bed type dimensions
Calculate volume, time & gang size
J K
SETPIPE less than number of pipes
Yes
SETPIPE =SETPIPE +1
NO
L
Calculate Backfill volume
Calculate time, gang size.
L
Print out Summary
M
M
End

Structure of Road Breakout Subroutines

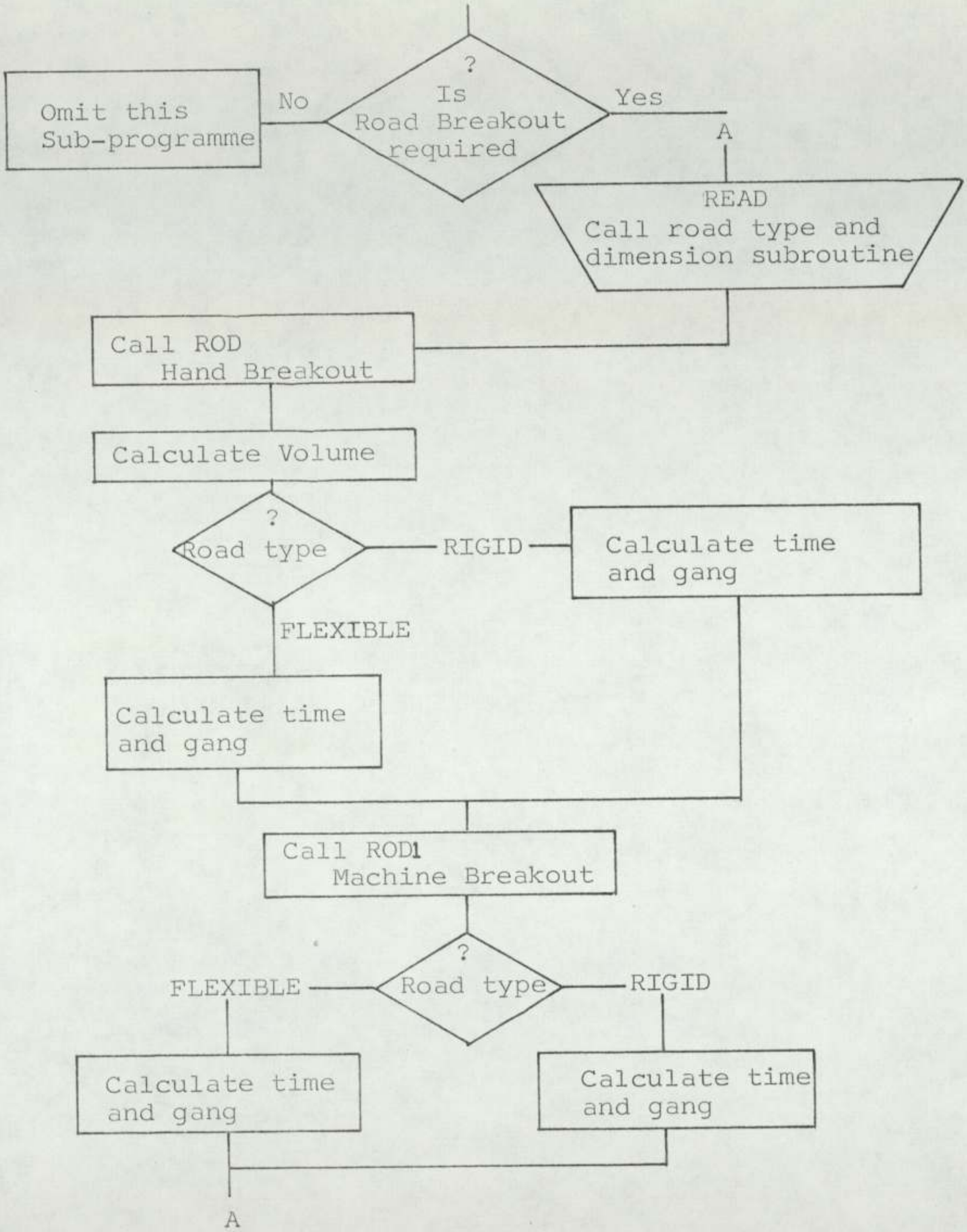


FIGURE.15.

A - A reference figure.14.

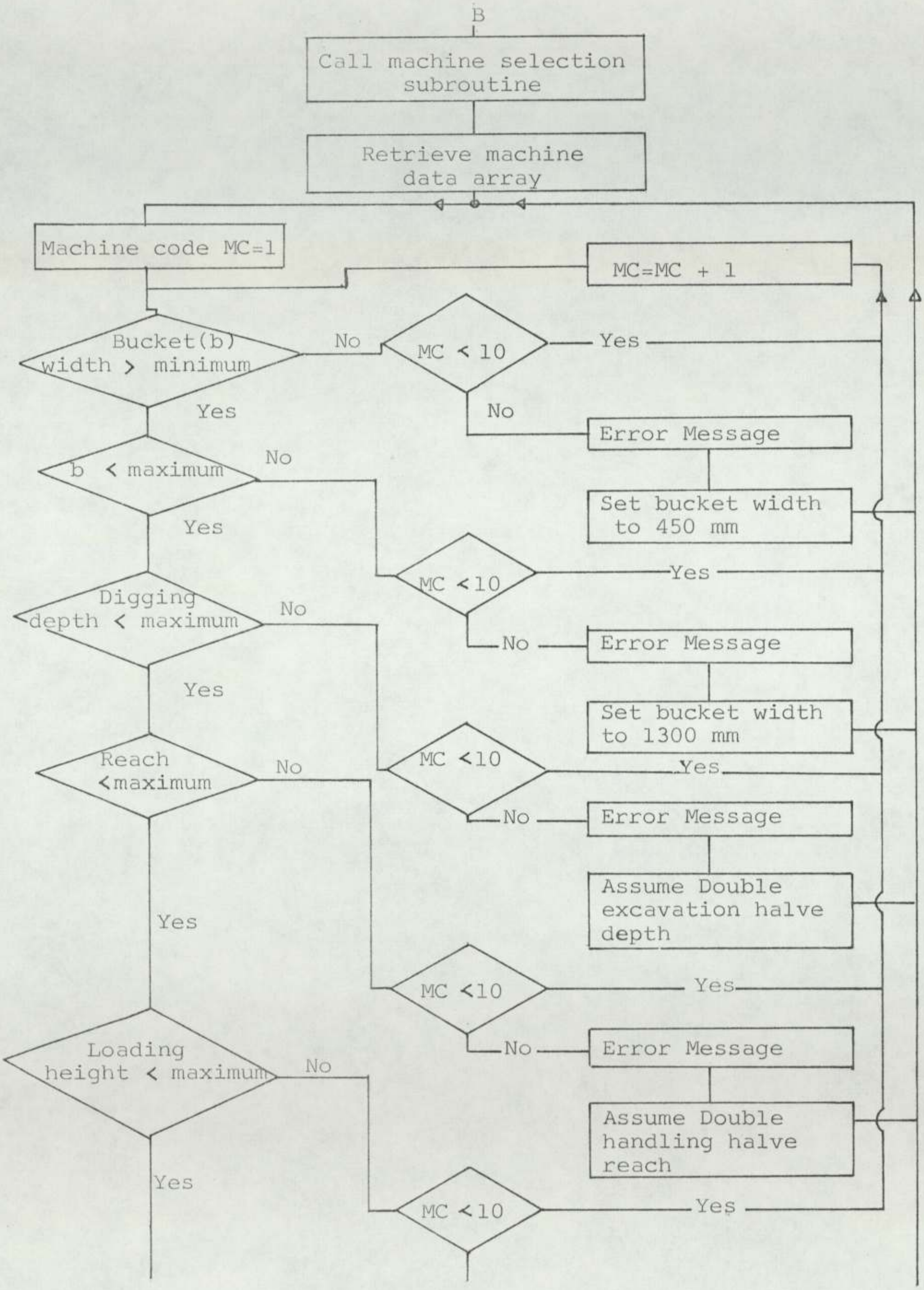
4.4.1 Machine Selection Element Subroutine

The excavation machine required is selected from 10 hydraulic excavators most used by the company. Their physical characteristics (Appendix 1) are stored within the 'element subroutine' (Figure.16.). The machines considered are:-

(1) JCB 3
(2) JCB 3C
(3) JCB 3D
(4) JCB 5C
(5) JCB 7B
(6) Hy-Mac 580
(7) JCB 6C
(8) JCB 6D
(9) JCB 7C
(10) RH 6

The machine is selected using the depth, bucket width, loading height and horizontal reach information supplied by the user. Several 'ancillary subroutines' detect and inform the user if a machine to satisfy the requirements cannot be found. The errors are non-fatal but are necessary to indicate where excess demands have been made on the element subroutine. If the bucket width requested is too large or too small, maximum or minimum widths are assumed from the data stored. Similarly, if the digging depth, horizontal reach and/or the loading height requested is too great, they are halved, thus assuming double handling of excavated material.

Machine Selection



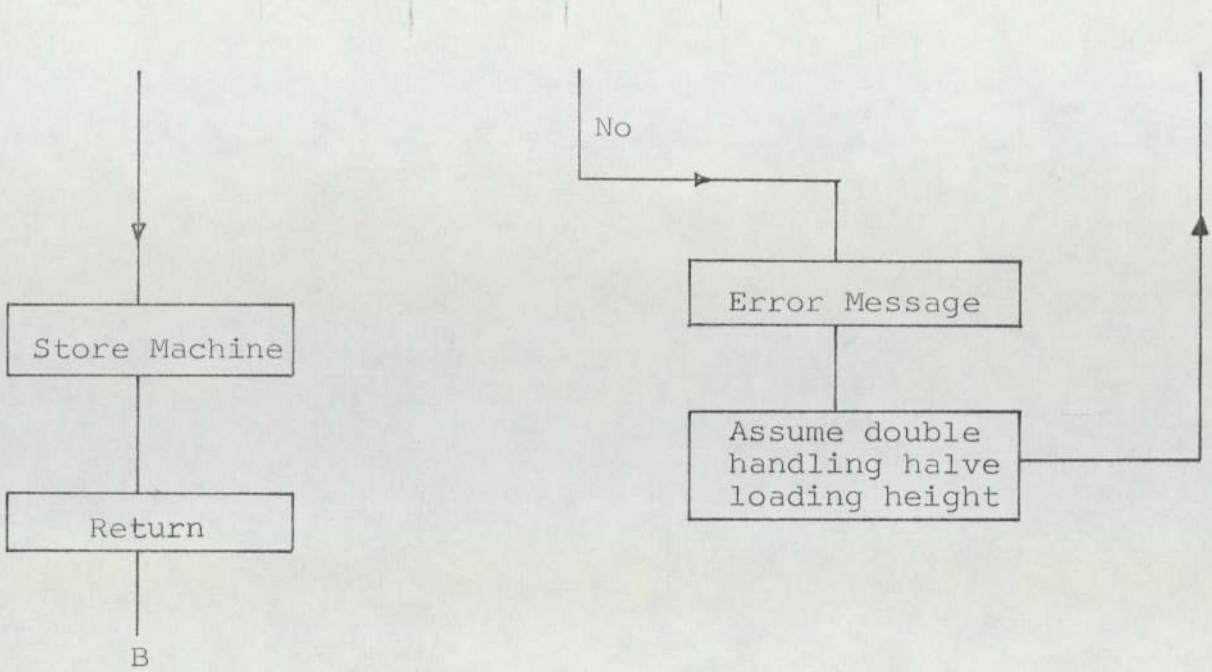

No
Error Message
Store Machine
Assume double handling halve loading height
Return
B

FIGURE.16.

4.4.2 Excavation Rate Element Subroutine

The standard mean rate of excavation (Rs) expected from the machine selected is determined analytically.

In general terms, the standard mean rate of excavation at a depth 'D_i' is assumed to be given by:-

$$R_{si} = Qe/C_{Ti} \qquad \text{.............(1)}$$

where $$C_{Ti} = U_T + E_{Ti} \qquad \text{.............(2)}$$

Hence, the mean standard rate of excavation at a total trench depth of 'D' is given by the mean rate observed from 'n' depth increments in the form:-

$$R_s = \frac{Qe}{n} \sum_{i=1}^{i=n} \frac{1}{U_T + E_{Ti}} \qquad \text{.........(3)}$$

The quantity of material excavated (Qe) is dependent upon the theoretical bucket volume (Bc) and the type of strata being excavated (s). Relationships between bucket width (b) and their theoretical capacity (Bc) produced by the machine manufacturers are given in Figure.17.

The proportion of the theoretical bucket volume utilised (bc) was determined by site investigation (Appendix 1, Table.3.), the strata excavated being categorised according to Table. 8. The bc/s relationship used in the element subroutine is given in Figure.18.

Studies indicated that the above ground cycle time component (U_T) is primarily dependent upon the slewing action of the excavation machine. Machine types (1) to (3) inclusive exhibit 'centre post' slewing actions, (the body of the machine remains stationary, only the digging arm moves),

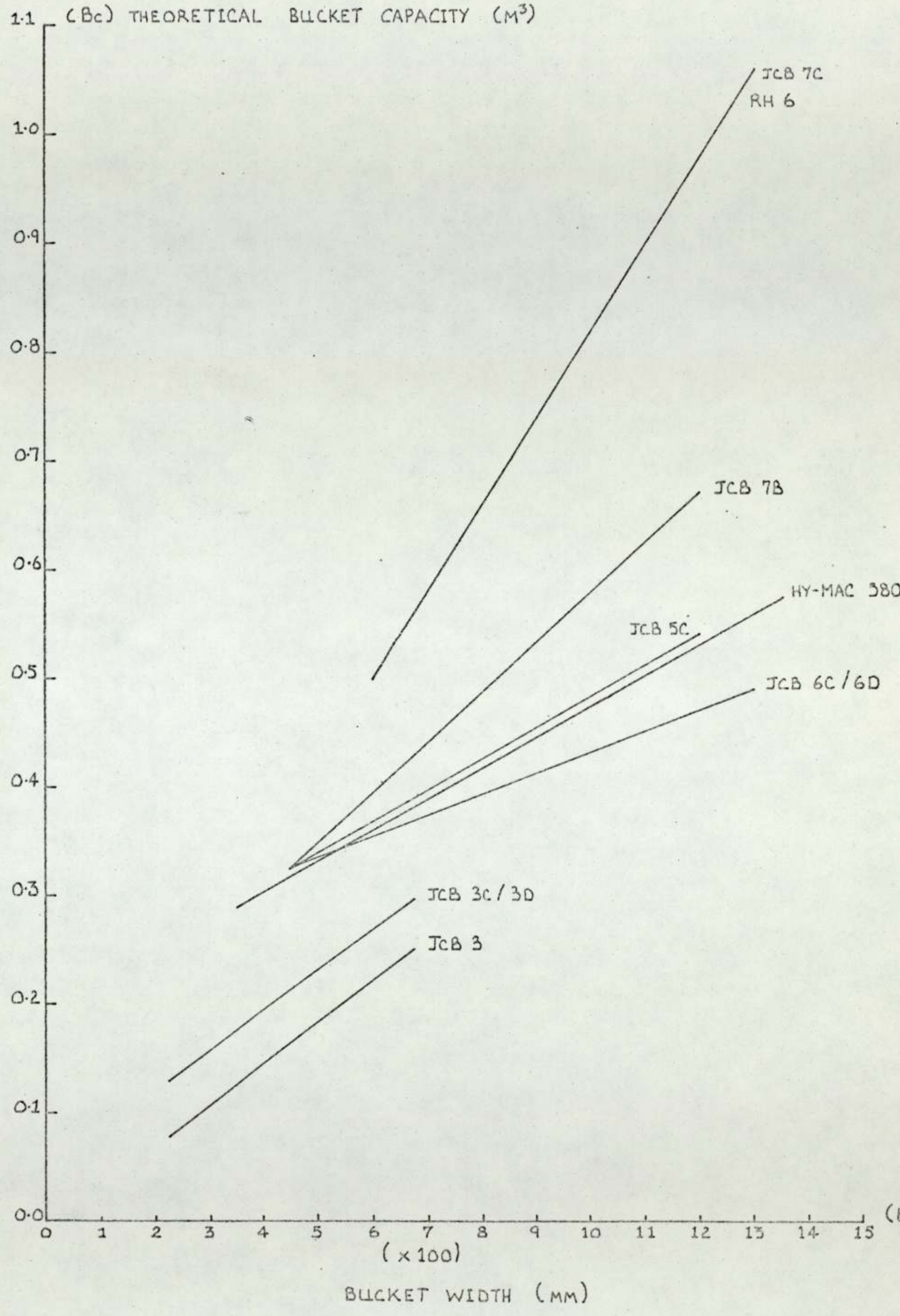

(Bc) THEORETICAL BUCKET CAPACITY (M³)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
JCB 7C
RH 6
JCB 7B
HY-MAC 580
JCB 5C
JCB 6C / 6D
JCB 3C / 3D
JCB 3
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
(b)
(x 100)
BUCKET WIDTH (MM)

Figure .17.

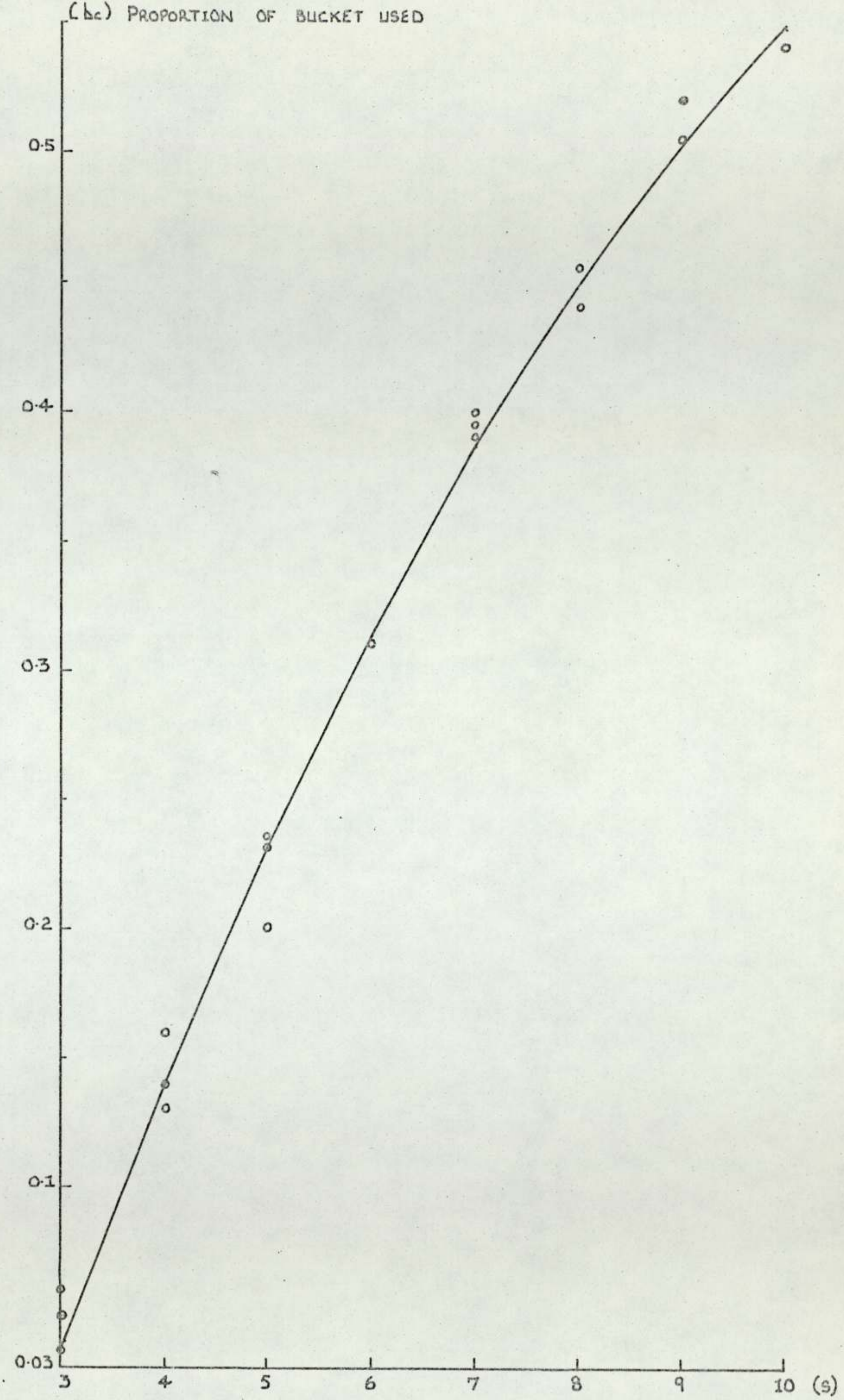

(bc) PROPORTION OF BUCKET USED
0·5
0·4
0·3
0·2
0·1
0·03
3
4
5
6
7
8
9
10
(s)
STRATA GRADING

Figure .18.

the remainder exhibit a 'Radial' slewing action (the body of the machine and the slewing are moved). Figures.19. and .20. show the relationships between (U_T) and the working radius for both slewing configurations.

The below ground excavation time component (E_T) is assumed to be independent of the type of excavation machine used, but dependent upon the trench shape (defined by the depth/width ratio (N)) and the frequency of obstructions, five categories of obstruction grading (øf) are used (Table.9.). The relationship between E_{Ti}/N for the obstruction gradings is given in Figure.21.

The element subroutine stores all the relationships and the method used for calculating the mean standard rate of excavation is presented in flow diagram form in Figure.22.

4.4.3 Standard and Unique Trench Shape Volume Element Subroutine

The volume of excavated material is calculated in one of two ways. Firstly it can be determined from basic data input by the user which is associated with specified standard trench shapes (Figure.23.), or secondly, by using change in level co-ordinates supplied by the user, (Figure.24.).

4.5 Excavation Support Sub-Programme

This sub-programme contains three 'element subroutines' which determine:-

(1) The apparent earth pressure

(2) Several feasible support structures

(3) The erection time, gang size and plant requirements.

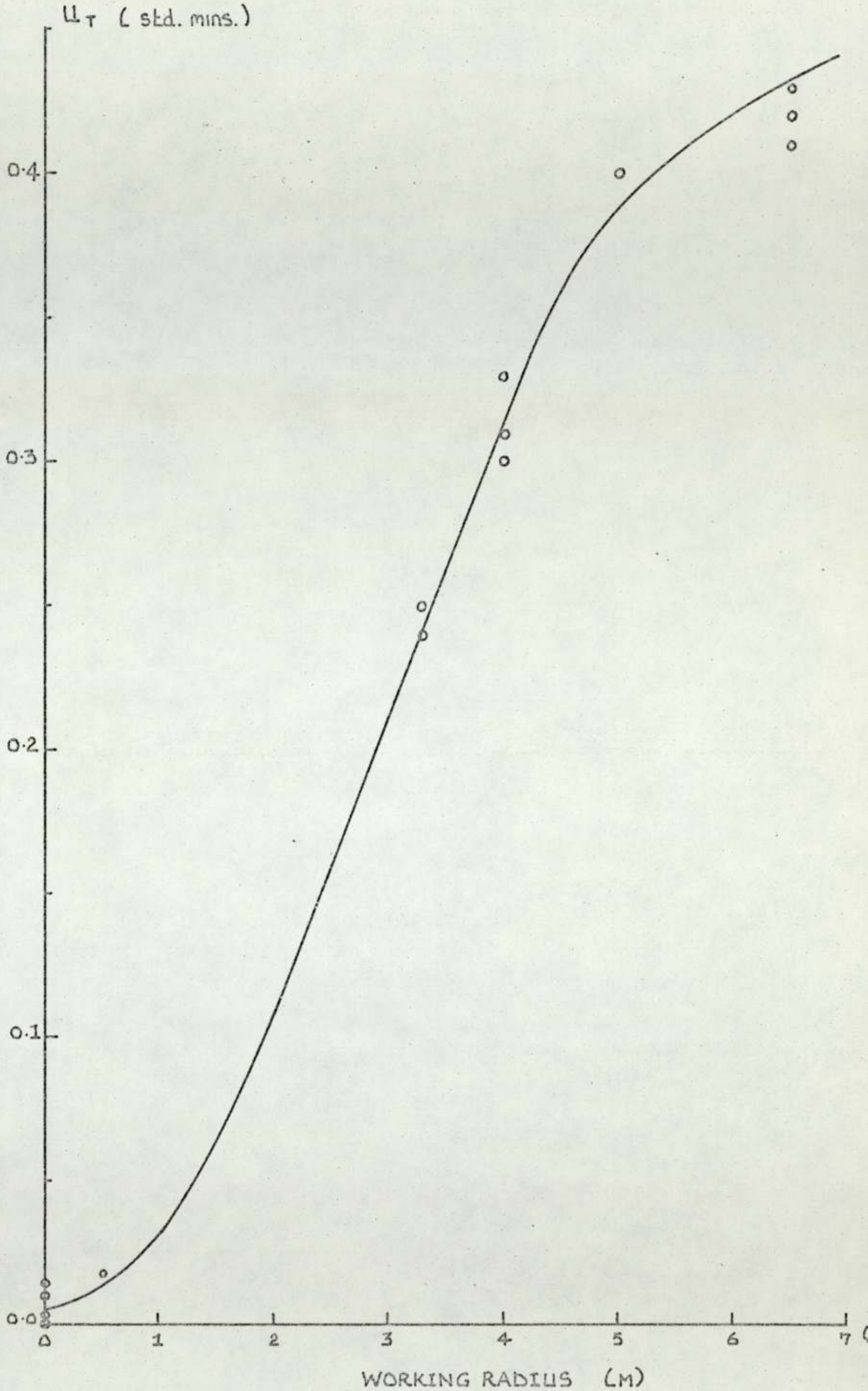


Figure .19.

RADIAL EXCAVATORS

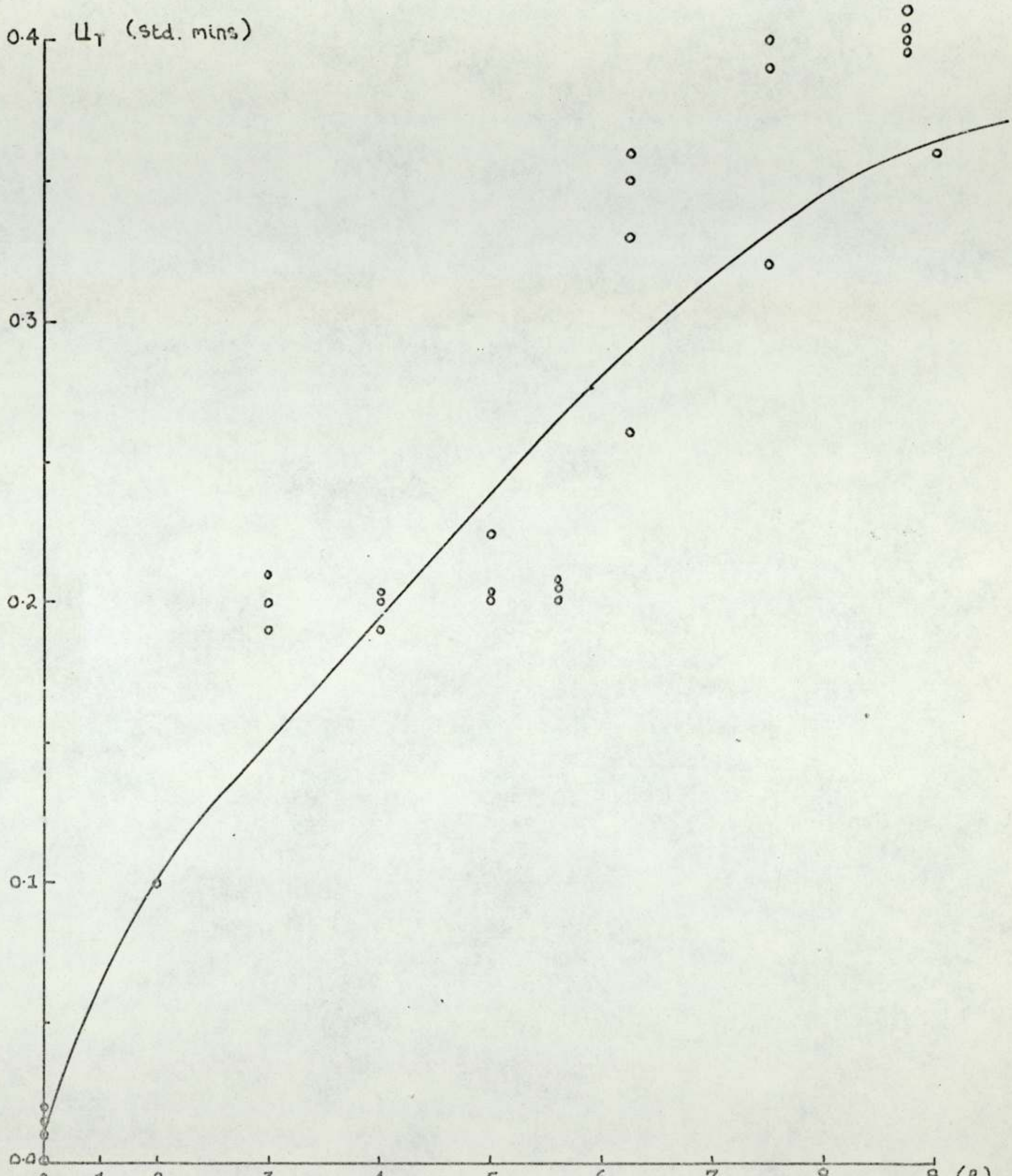


Figure .20.

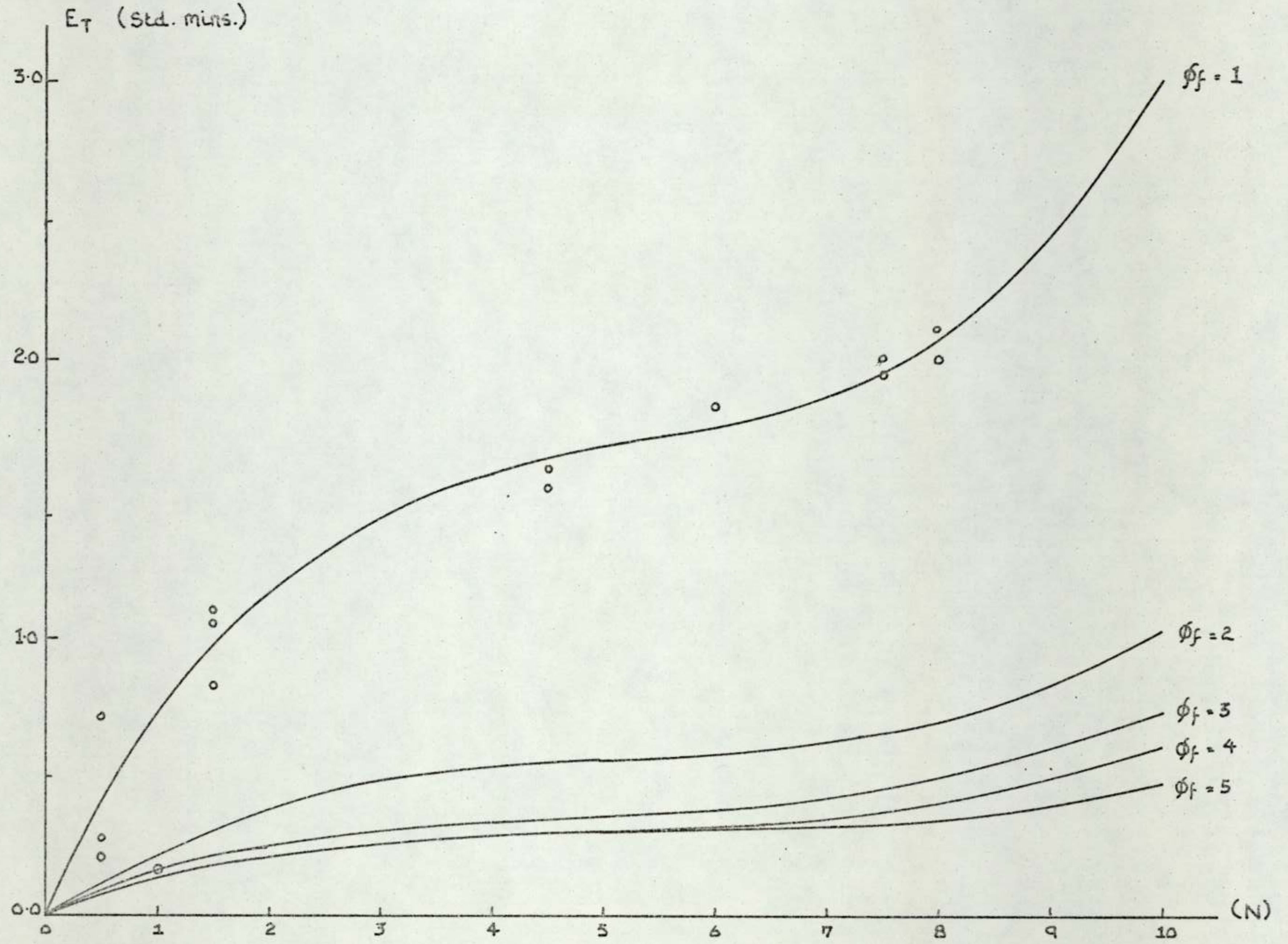

E_T (Std. mins.)
3·0
2·0
1·0
0·0
0
1
2
3
4
5
6
7
8
9
10
(N)
DEPTH / WIDTH RATIO
ϕf = 1
ϕf = 2
ϕf = 3
ϕf = 4
ϕf = 5

Figure .21.

TABLE.8.

STRATA GRADING

DESCRIPTION	GRADING
'ROCK shall mean those geological strata and individual boulders exceeding 6 cubic feet (0.17m) in size or other masses of hard material outside those strata which necessitate the use of blasting or approved pneumatic tools for their removal.*	1
'MEDIUM ROCK' As 'A' above but not exceeding 6 cubic feet (0.17m) but exceeding 1 cubic foot (0.028m).	2
'SOFT ROCK' As 'B' but not exceeding 1 cubic foot (0.028m) and possessing bedding plains to allow breakage.	3
'SOFT LAMINATED ROCK' As 'C' but with excess laminations or bedding plains (slate, soft sandstone, shale).	4
'COHESIVE SOIL' (stiff) includes clays and marls with up to 20 per cent of gravel having a moisture content not less than the value of the plastic limit (BS 1377) minus 4; also chalk having a saturation moisture content of 20 per cent or greater.*	5 - 6
'SOFT COHESIVE SOIL' (medium) As '5-6' but excluding marls and including all clays and approximately 10 per cent sand or below.	7
Well-graded granular and dry cohesive soils, include clays or marls containing more than 20 per cent gravel.*	8
Well-graded sand and gravels with uniformity coefficient exceeding 10, also clinker and spent domestic refuse	9
Uniformity graded material includes sands and gravels with uniformity coefficient of 10 or less, all silts and pulverised fuel ashes.*	10

* "Specification for Road and Bridge Works". 1969. Clause 601, 1.(iv), 2.(i), 2.(ii), 2.(iii).

TABLE. 9.

OBSTRUCTION GRADING

DESCRIPTION	GRADING
Excavation involving the breaking out of metalled road surfaces or other such obstructions situated on top of frequently occurring services.	1
Excavating in ground possessing frequently occurring major services and house connection.	2
(a) Excavating in ground possessing infrequent major services but frequently occurring house services. (b) Excavating in ground possessing infrequent major services and infrequent minor services. (c) Excavating in ground possessing infrequent minor services and for tree roots etc.	3
Excavating in ground possessing minor obstructions only, i.e. tree roots, small quantities of hard core, etc.	4
Excavating in ground possessing no obstructions other than those which are an integral part of the strata.	5

Excavation Rate Subroutine

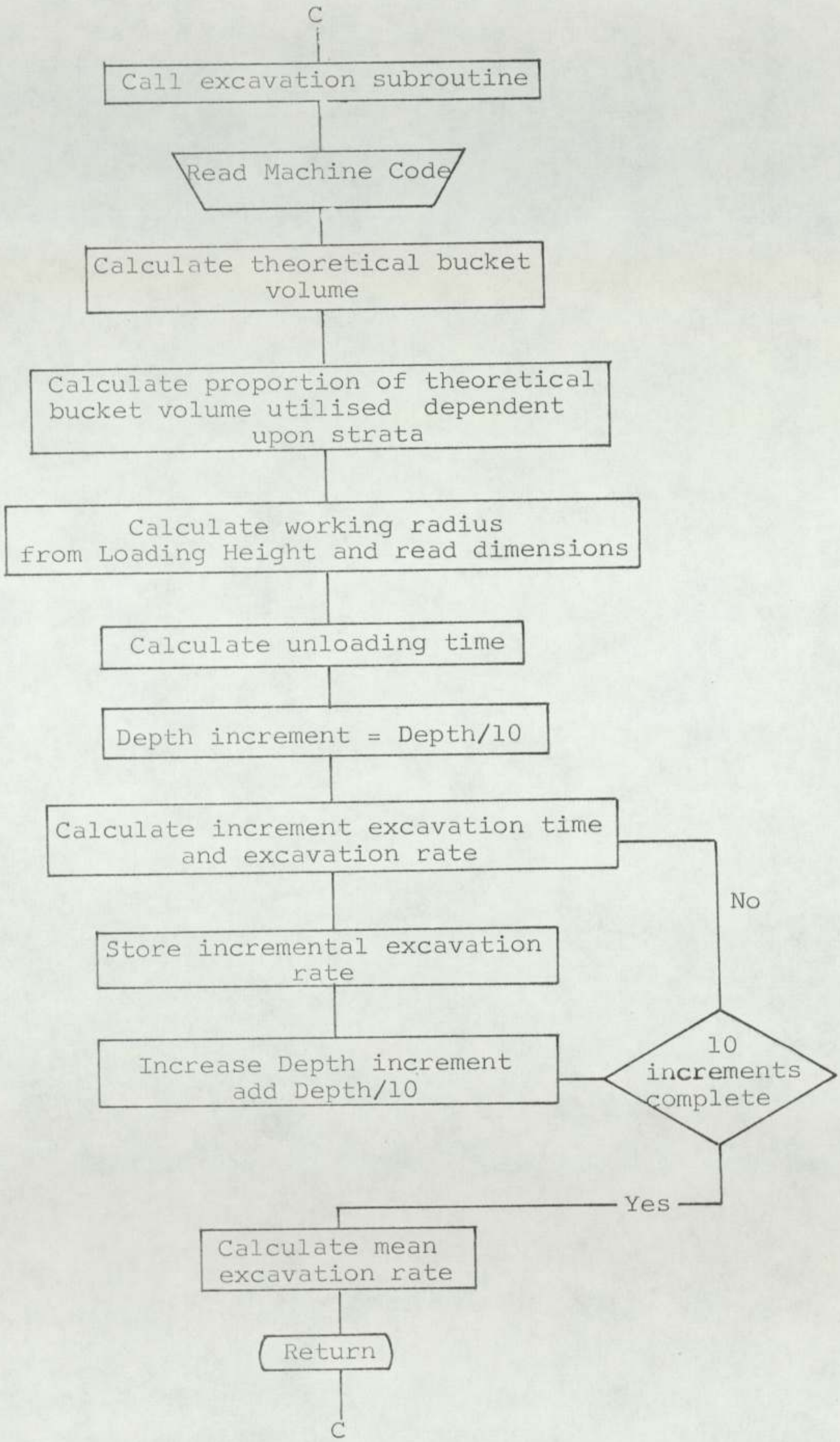


FIGURE. 22.

Standard Trench Shape

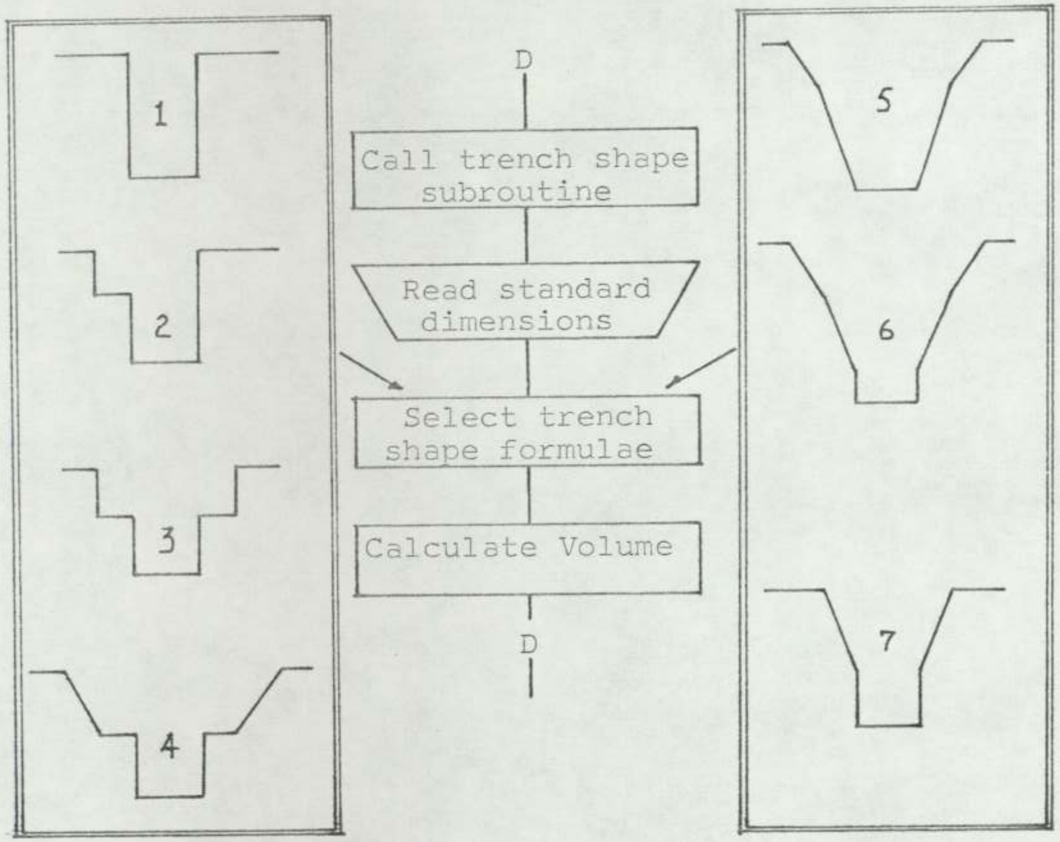


FIGURE.23.

Unique Trench Shape

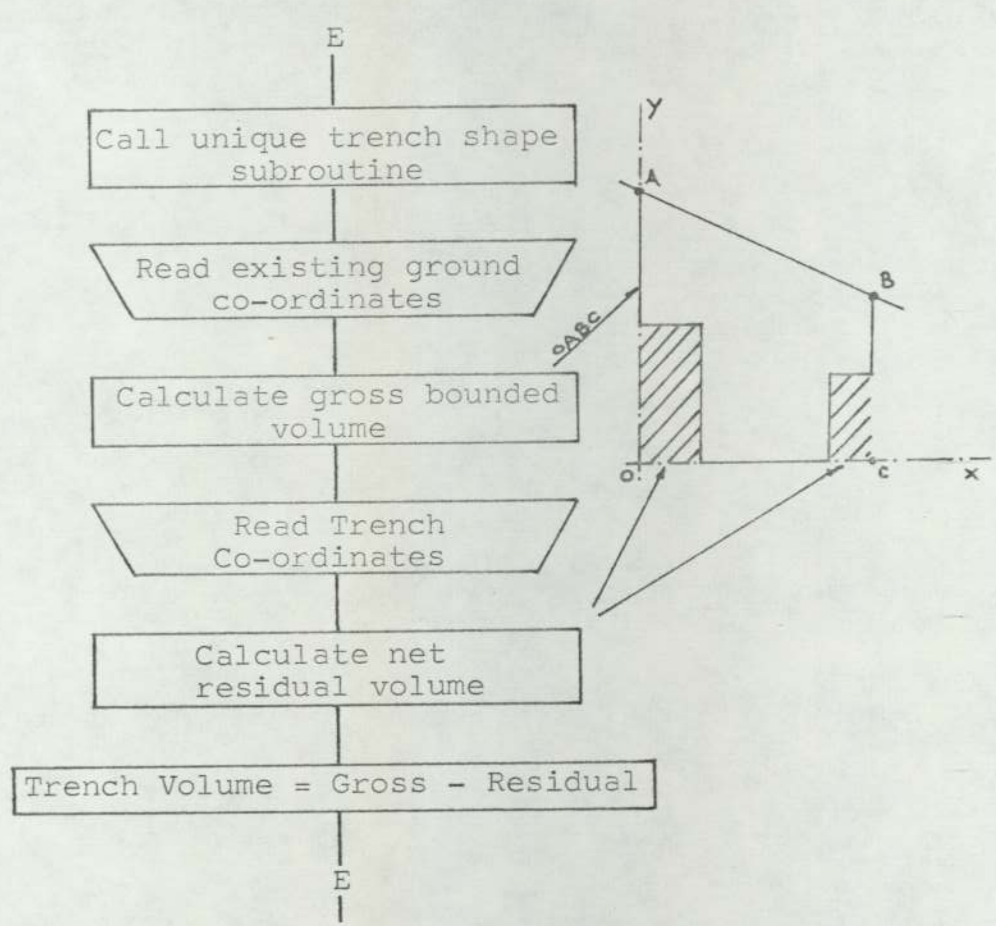


FIGURE.24.

4.5.1 Apparent Earth Pressure Element Subroutine

The apparent earth pressure (Ap) is calculated using:-

$$Ap = C.K_A.\gamma.D \quad ....(4)$$

The element subroutine (Figure.25.) permits the user to specify which strata grading (Table. 8.) is predominant. However, it is permissible to combine gradings to produce a more accurate representation of a strata which may possess several characteristics.

The pressure distributions are assumed to be rectangular. If the density, cohesion and angle of internal friction are unknown, values of 2082.6 kg/m^3, 1400.0 kg/m^2 and 25 degs. are assumed by the element subroutine.

4.5.2 Support Structure Design Element Subroutine (Figure.26.)

The element subroutine produces several feasible design structures. Starting with a vertical strut/waler spacing of 0.5 m, increasing in increments of 0.5 m to the maximum permissible, the designs being intended for estimating and planning purposes only. A basic structural configuration (Figure.27.) is hypothesised based on the following design assumptions.

(a) B.S.P. type T5 trench sheets are used.

(b) The horizontal strut spacing is 2.5 M (the normal length of one pipe).

(c) Each 2.5 M structural unit is independently assembled.

Apparent Earth Pressure Subroutine

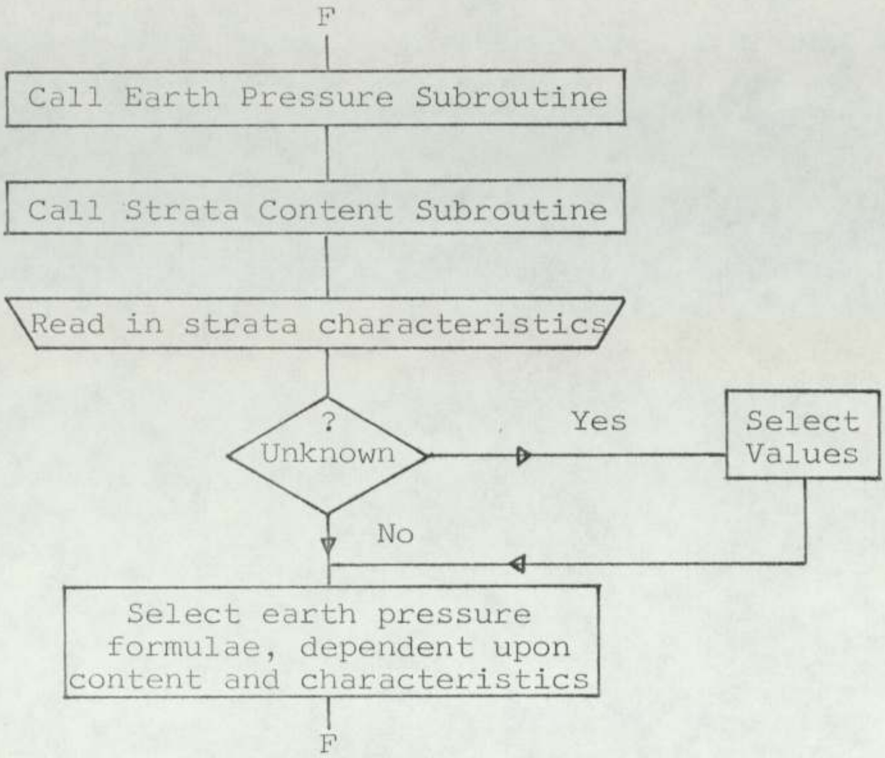


FIGURE. 25.

Trench Support Structure

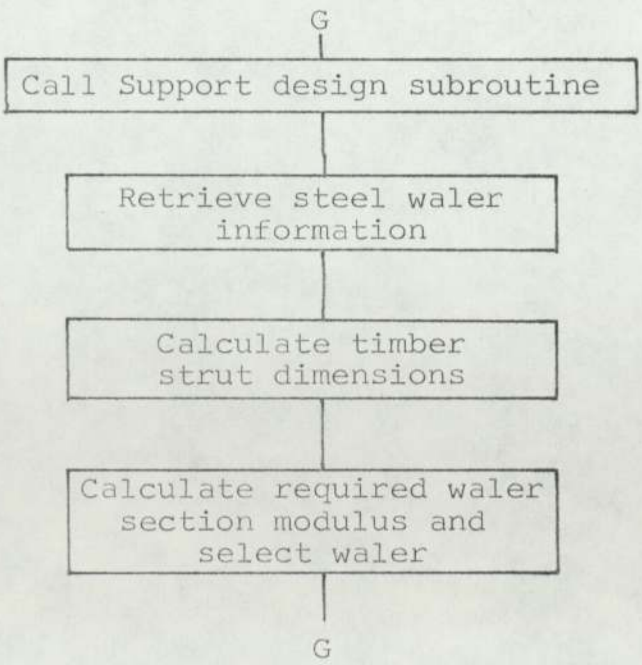


FIGURE.26.

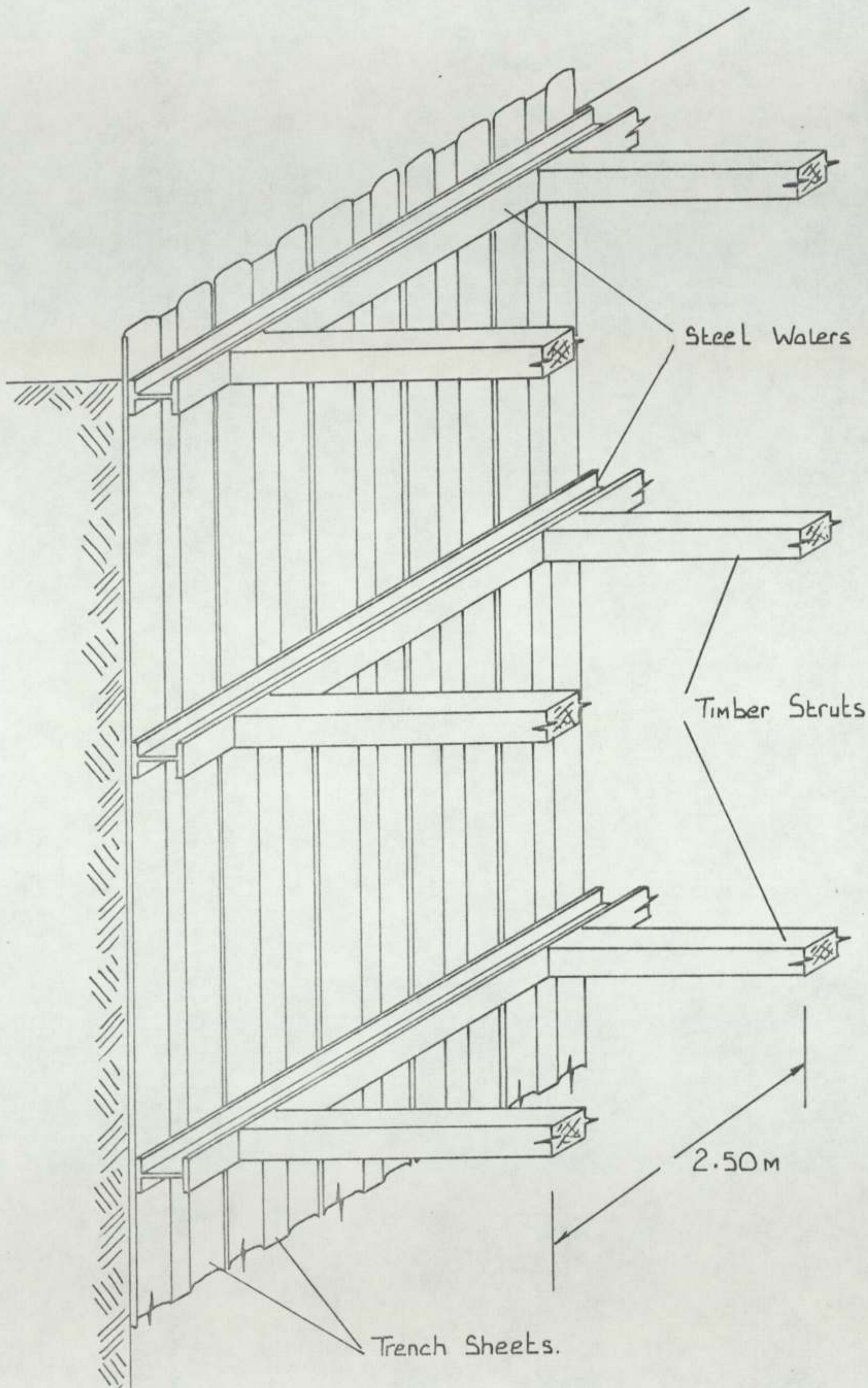


Figure.27.

(d) Grade 43 steel walers are used whose magnitude is given by:-

$$Z_r \geqslant 4.734.Ap.L_D \text{ --}(cm^3) \quad \ldots\ldots\ldots\ldots\ldots(5)$$

(e) Grade 2 square section struts are used where:-

$$B \geqslant 22.9833 \sqrt{Ap.L_D} \geqslant 0.03849.w \text{ --}(mm) \quad \ldots.(6)$$

(f) The trench sheets are pin jointed at each waler.

(g) Collapse takes place on one side of the trench only.

(h) The maximum vertical waler/strut spacing is given by:-

$$L = 15.43 / \sqrt{Ap} \text{ ---}(m) \quad \ldots\ldots\ldots\ldots\ldots(7)$$

The derivation of equations 5, 6 and 7 are given in Appendix 2.

4.5.3 Erection Time, Gang and Plant Requirements Element Subroutine

This subroutine (Figure.28.) uses the various design configurations produced by the design subroutine. It calculates the number of structural members required and uses stored work measurement data (Appendix 2) to determine the standard erection time and resources requirements. The user then selects the design configuration to be used in the total pipeline operation analysis.

4.6 Pipelaying Sub-Programme

This (Figure.29.) stores the work measurement inform-

Trench Support Construction Time

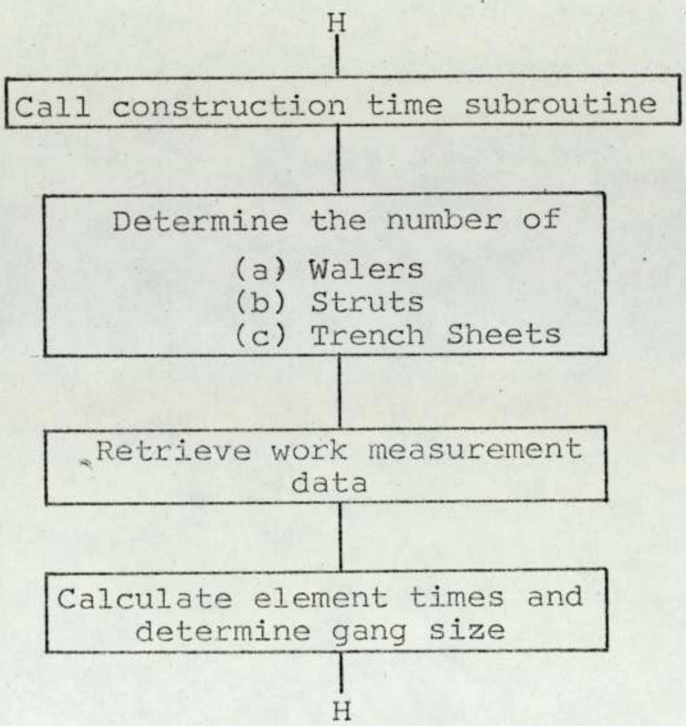


FIGURE.28.

Pipe Laying Time

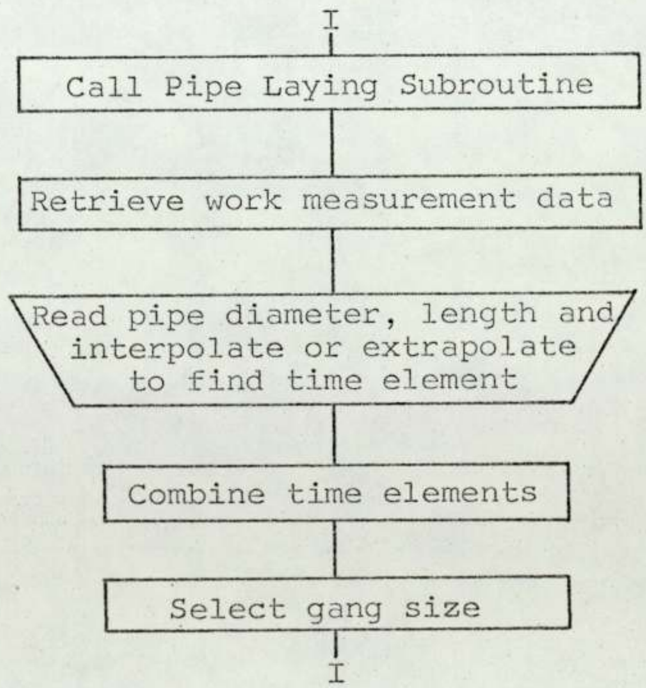


FIGURE.29.

ation (Appendix 1) for 16 different elements of the pipe-laying operation. It calculates the construction time for any number of pipes, for pipe diameters ranging from 100 to 2100 mm and any pipe length specified. The times and gang sizes produced depend on the diameter of the pipes and the depth to which they are laid. A detailed summary is produced for each pipe analysed culminating in an intermediate summary at the end of the pipe laying element.

4.7 Pipe Bedding Sub-Programme

Two 'element subroutines' deal with this construction element. The first (Figure.30 .) calculates the volume of material to be used (excluding wastage) and the second (Figure.31.) calculates the construction time and gang size required. The material volumes calculated are based on eight (Table.10.) structural shapes most commonly used. The construction time and gang size calculations depend on the material used and the depth at which it is laid. One of three material types are considered:-

(1) Concrete

(2) Granular

(3) Selected backfill

The user can input specific bedding structure dimensions based on the shapes available or use the standard minimum dimensions given in Table.10.

4.8 Backfill Sub-Programme

This sub-programme contains one 'element subroutine' (Figure.32 .) which calculates the volume of the backfill

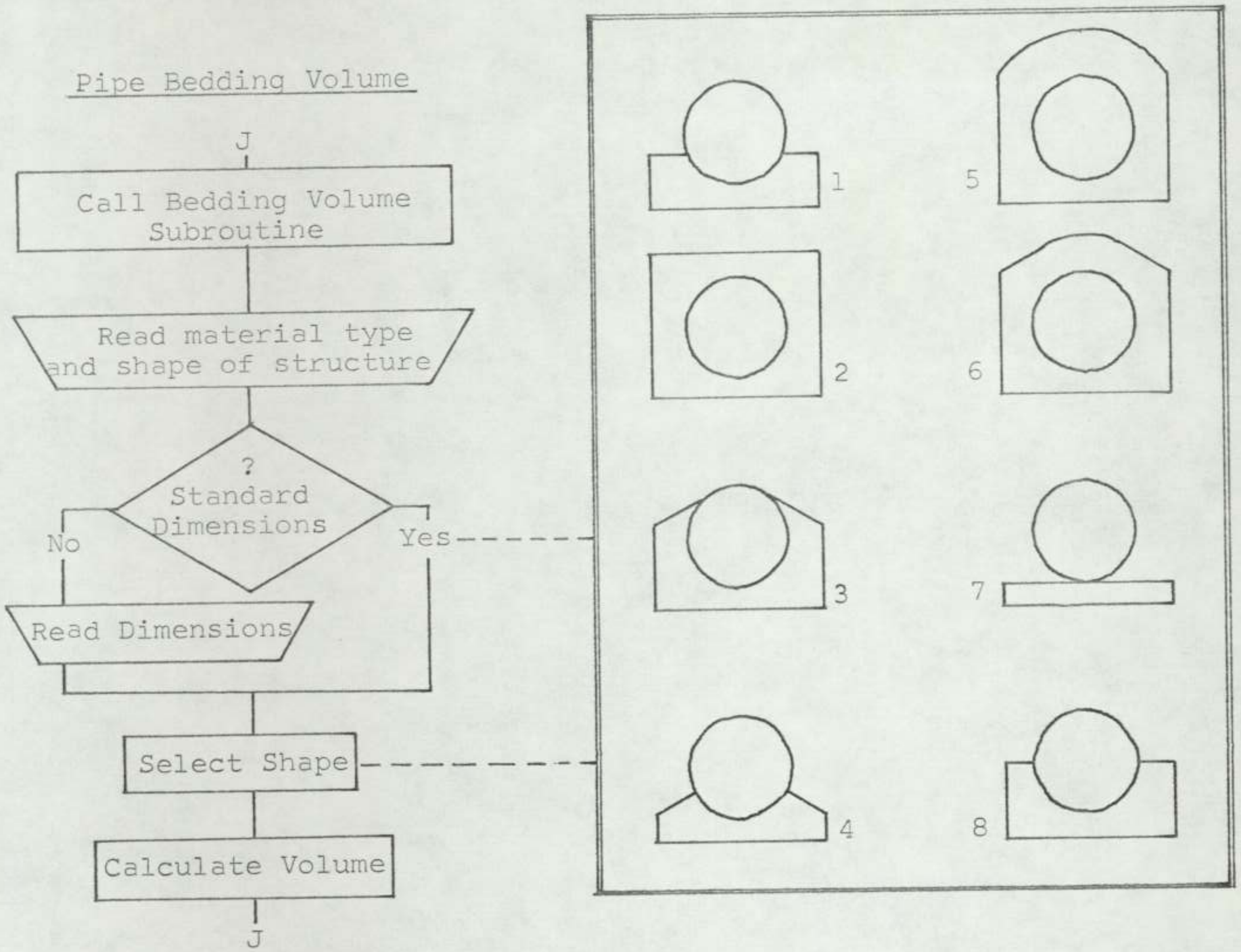


FIGURE.30.

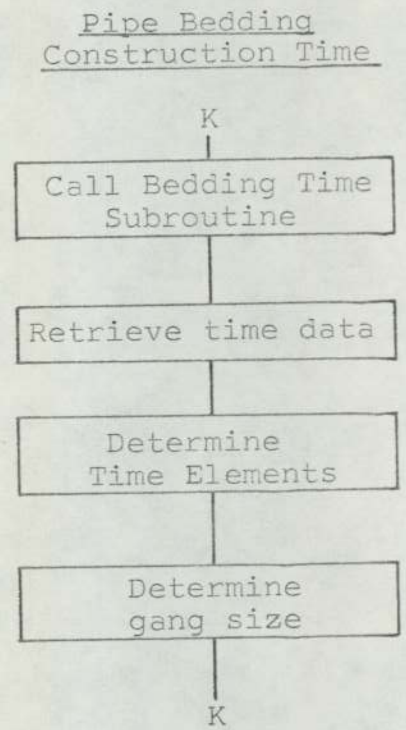
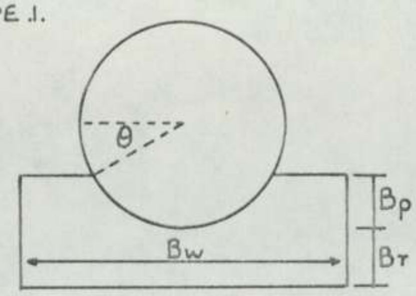
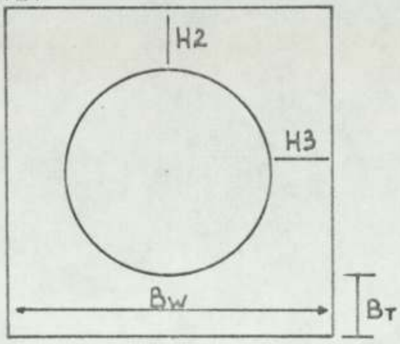
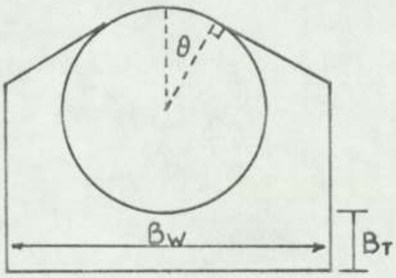
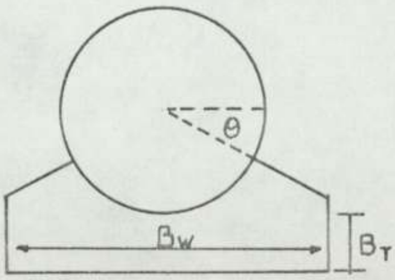
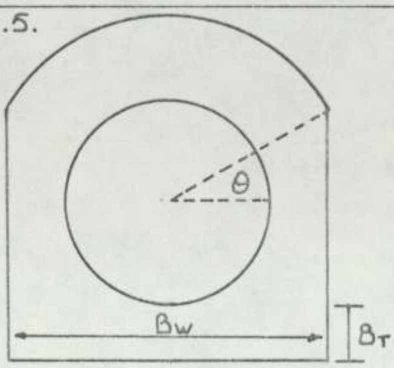


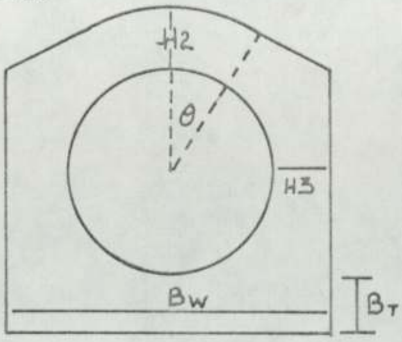
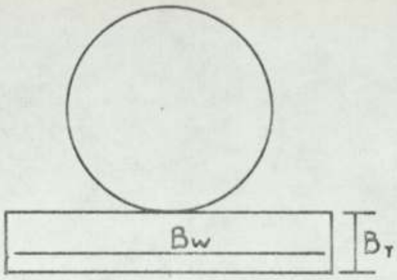
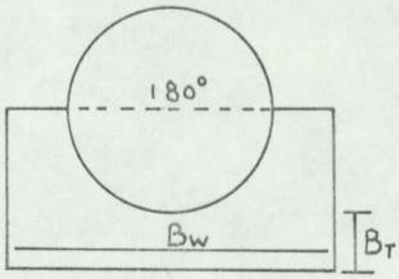
FIGURE.31.

TABLE. 10.

STANDARD BEDDING STRUCTURES

TYPE	STANDARD DIMENSIONS
	D = Internal diameter of pipe Bc = External diameter of pipe
TYPE. 1. 	$B_P = 0.25\,B_C$ $B_T = 0.25\,D$ (100MM min) $B_W = 1.25\,B_C$ or $B_C + 200$MM (which ever is greater) $\theta = 30°$
TYPE. 2. 	$H_3 = (B_W - B_C)/2.0$ $H_2 = H_3$ $B_T = 0.25\,D$ (100 MM min) $B_W = 1.25\,B_C$ or $B_C + 200$ MM
TYPE. 3. 	$B_T = 0.25\,D$ (100 MM min) $B_W = 1.25\,B_C$ or $B_C + 200$ MM $\theta = 30°$
TYPE. 4. 	$B_T = 0.25\,D$ (100 MM min) $B_W = 1.25\,B_C$ or $B_C + 200$ MM $\theta = 30°$
TYPE. 5. 	$B_T = 0.25\,D$ (100 mm min) $B_W = 1.25\,B_C$ or $B_C + 200$ MM $\theta = 30°$

continued over leaf.

TYPE.6. 	$H3 = (B_W - B_C)/2.0$ $H2 = H3$ $B_T = 0.25D$ (100MM MIN) $B_W = 1.25\,B_C$ or $B_C + 200$ mm $\theta = 30°$
TYPE.7. 	$B_T = 0.25D$ (100 mm min) $B_W = 1.25\,B_C$ or $B_C + 200$ mm
TYPE.8. 	$B_T = 0.25D$ (100 mm min) $B_W = 1.25\,B_C$ or $B_C + 200$ mm.

material and produces four backfill methods, one of which is selected by the user. The construction time is calculated for each gang and is based on the thickness of the compaction layers. Individual summaries are produced, the main items of information being stored to produce an overall pipeline operation summary on completion of the analysis.

4.9 Overall Standard Output and Resources for the Pipeline Operation (Figure.33.)

After processing the individual elements of the pipeline operation, the construction times and gang sizes are stored. The user specifies which Road Breakout, Excavation Support and Backfill method is to be used. The programme then calculates the overall standard output and the resources required. A single gang is assumed.

The programme processes only the main construction elements of pipeline operation, hence the resultant gang size is based on the actual productive work anticipated. In practice, many minor ancillary operations take place which are non-productive, tidying up, removing the occasional obstacle, checking the excavator etc. These occur infrequently and are, to a certain extent, allowed for when standardising the work measurement data. However, site observations indicate that the flexibility produced by not minimising the waiting time is necessary.

4.10 Computer Analysis of Pipeline Construction

Several illustrated examples are described below in an attempt to show the analytical powers of the computer programme. All the examples were prepared assuming the following

Backfill Volume and Construction Time

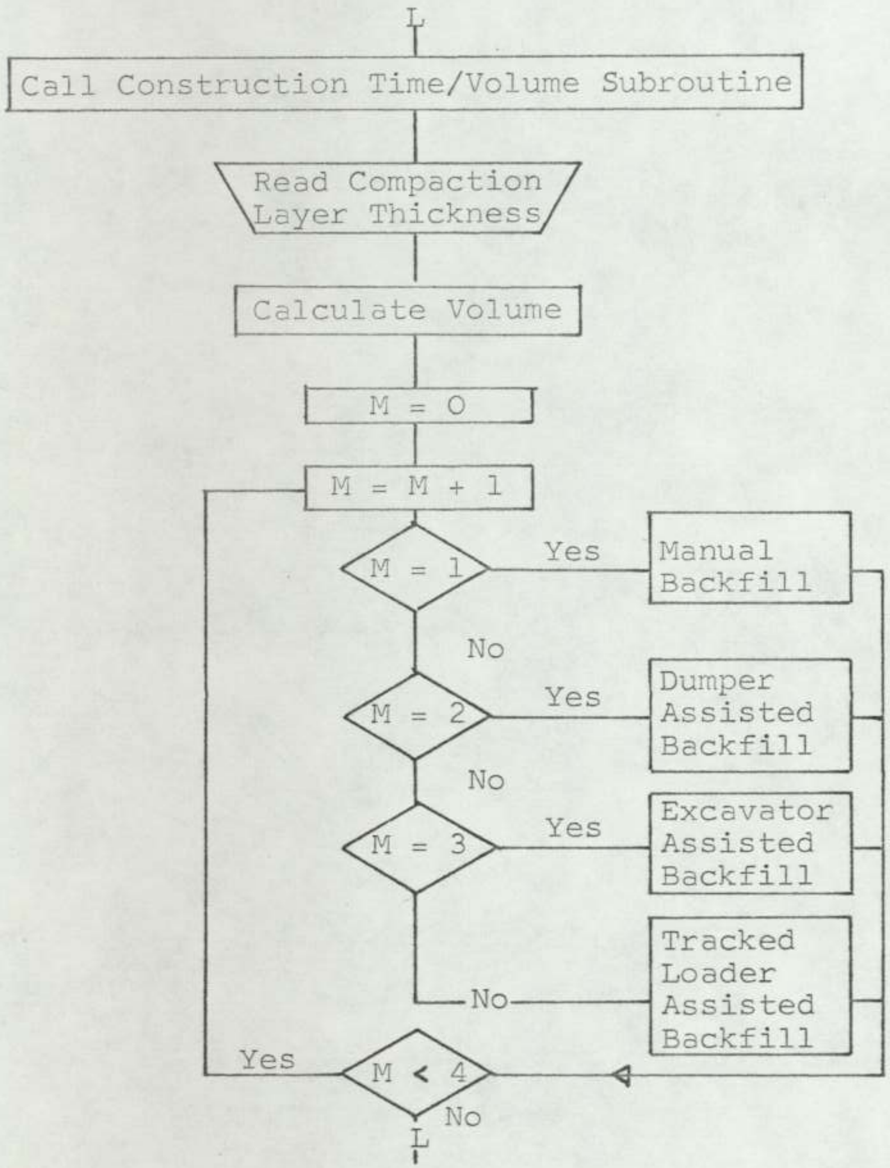


FIGURE.32.

Summary Preparation

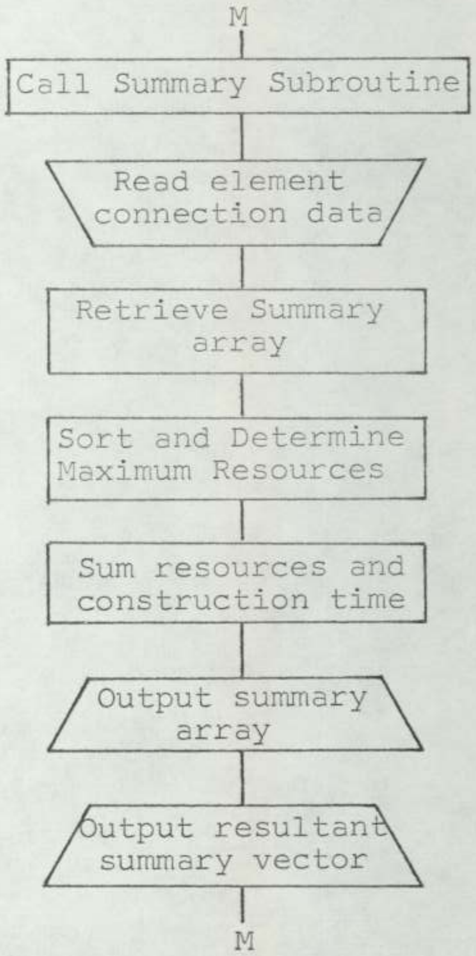


FIGURE.33.

parameter to be constant:-

(1) Flexible road surface, 500 mm thick.

(2) Medium breakers used for road breakout.

(3) Strata grading type 7 (Table.8 .).

(4) Obstruction grading type 5 (Table. 9.).

(5) The excavation is supported by a structure containing three equally spaced walers.

(6) Backfill compaction is 150 mm layers.

(7) Backfill performed by the excavator.

(8) Bedding structures of minimum permissible dimensions.

4.10.1 Close, Medium or Open Excavation Support

Changing the type of excavation support system from open to closed (Figure.34.) tends to increase the construction time by 10% for pipes of 300 mm diameter or less. At such small diameters, the support system is a significant part of the whole pipeline operation. However, as the pipe diameter increases, the pipe laying and bedding elements become predominant. Consequently, the effect of changing the type of support system is reduced. At diameters in excess of 1500 mm, the construction time increases by approximately 5%.

The excessive concavity of the 1500 mm diameter pipe is caused by the introduction of a crane to assist in the pipe laying elements. At small diameters, pipe laying is either manual or excavator assisted.

4.10.2 Excavation Support or Battered Open Cut

The problem of when to support an excavation and when to batter the sides (and the degree of batter) is one which Estimators and Planners often face. Two examples were analysed. The first studied the effect of battering the sides of the excavation at 45° from half the trench depth or 2 m from the formation, whichever is the lesser (Figure.35.). The second to analyse the effect of battering the sides of the excavation at 60° to the horizontal (Figure. 36.) from the same depth as the first example.

The curves show that if a 45° batter is used, open cutting is considerably better than supporting the excavation at depths less than 5 m. However, open cutting using a 60° batter is better down to a depth of approximately 7 m.

Although the construction time increases rapidly with increases in construction depth and pipe diameter, the 'break point' (shown chain dotted on figures.35. and .36.) between when to support and when to batter the excavation remains fairly constant.

4.10.3 Low Strength Pipe and High Strength Bed or High Strength Pipe and Low Strength Bed

It is often feasible when designing a pipeline to reduce the strength of the bedding material, increase its volume and the strength of the pipe and fulfill the same stability requirement on a design containing lower strength pipes and high strength, low volume bedding material.

Changing from concrete (low volume) to granular (high volume) bedding material (Figure.37 .) increases the

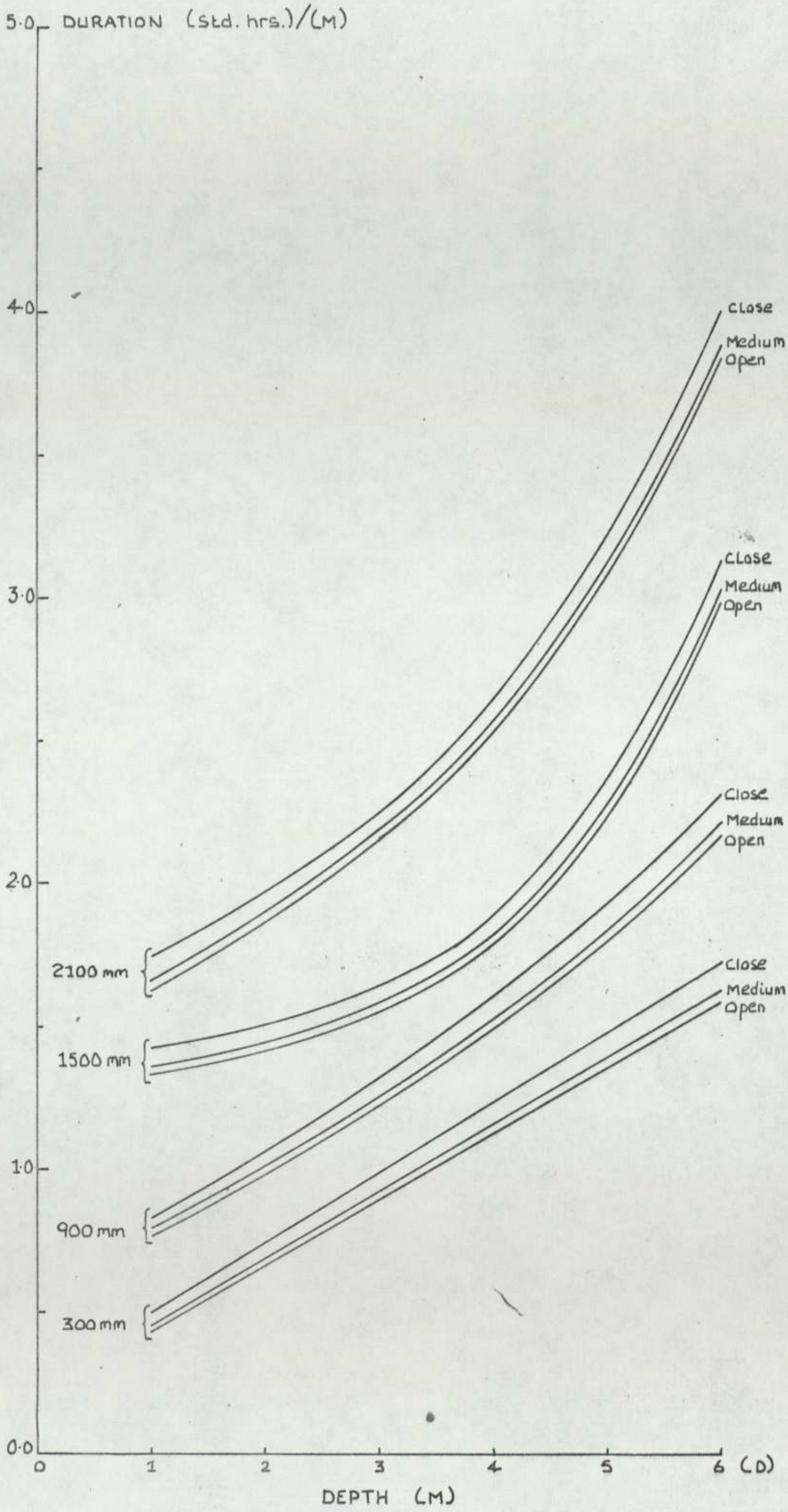

DURATION (Std. hrs.)/(M)
5.0
4.0
3.0
2.0
1.0
0.0
0
1
2
3
4
5
6 (D)
DEPTH (M)
2100 mm
1500 mm
900 mm
300 mm
Close
Medium
Open
Close
Medium
Open
Close
Medium
Open
Close
Medium
Open

Figure . 34.

SUPPORT - 45° BATTER.

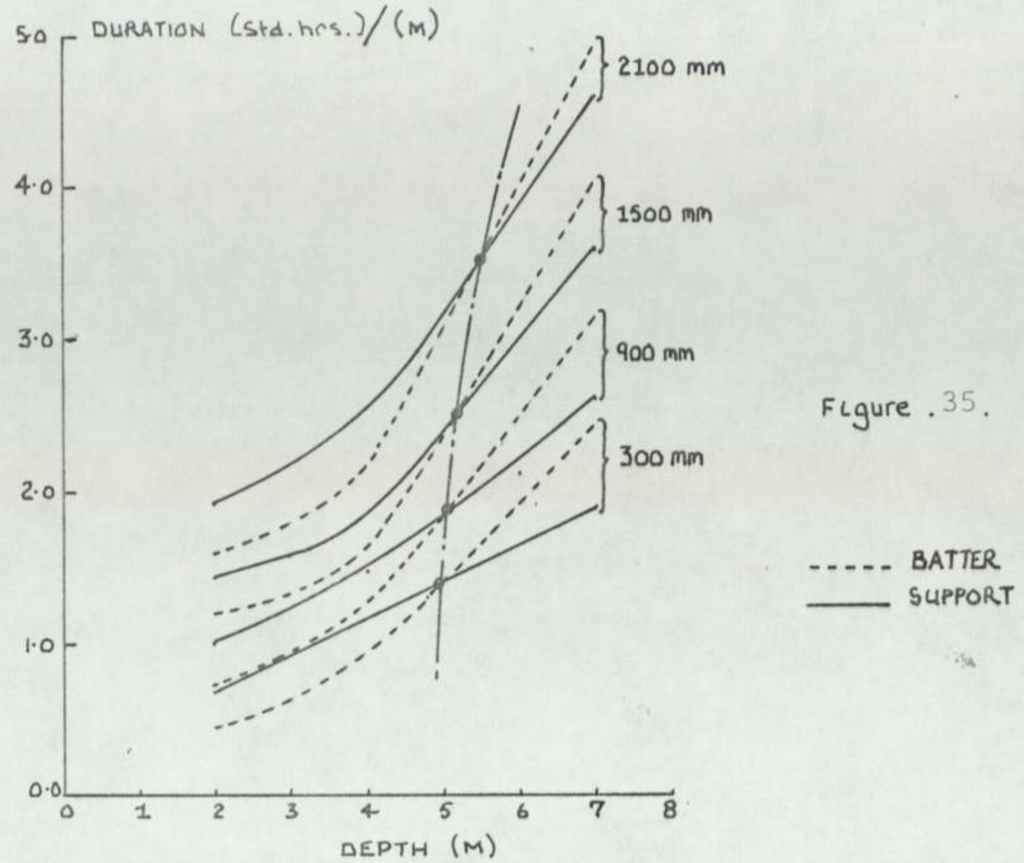


Figure .35.

SUPPORT - 60° BATTER.

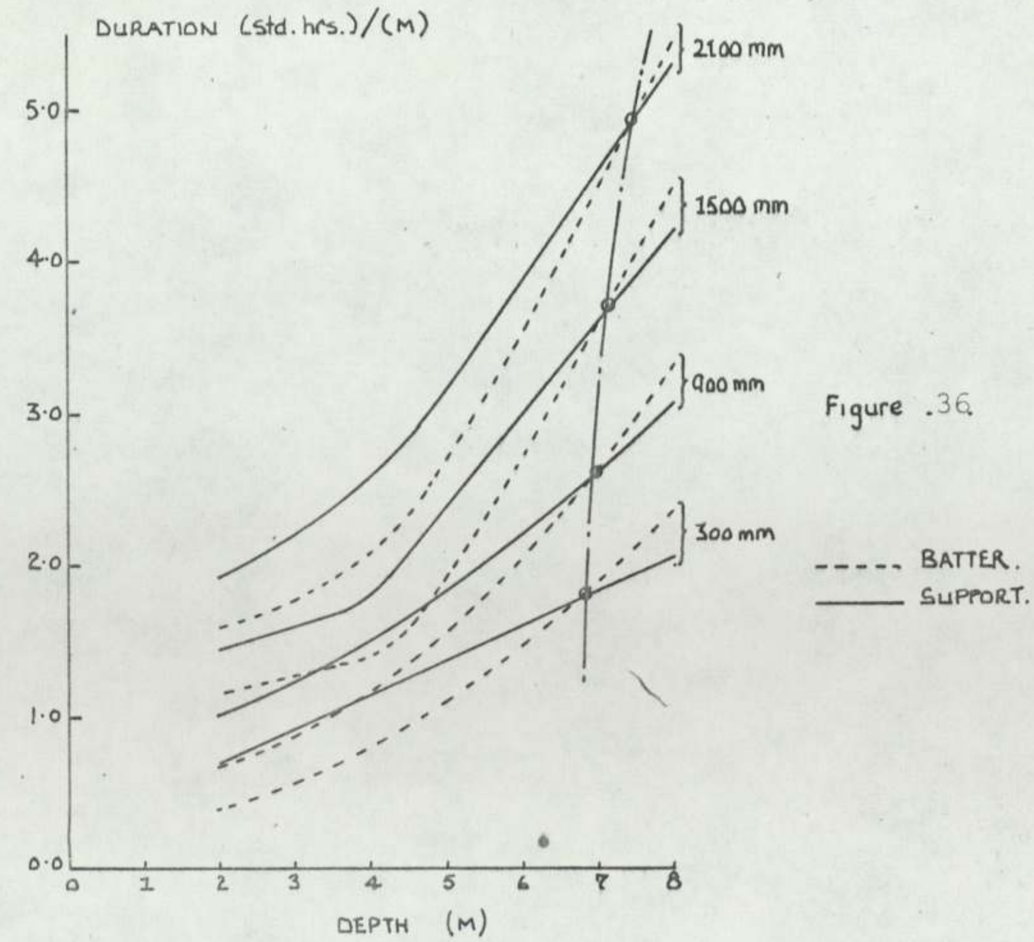


Figure .36

construction time by 10%. However, the material cost is reduced by a minimum of 50% and if it is assumed that labour, material and plant each constitute 33% of the construction cost, using granular material reduces the overall cost of construction by at least 10%.

In rural areas it is often possible to use selected backfill instead of concrete as a pipe bedding material (Figure.38.). This results in a 25% reduction in construction time and at least a 25% reduction in cost.

4.10.4 Increasing the Length of the Pipes

During the past three years, manufacturers have placed a great deal of emphasis on longer, lighter and stronger pipes. The conventional 2.44 m pipe is still commonly used but 5 m and 7.5 m pipes are becoming more popular with designers.

Increasing the length of the pipes from 2.44 m to 5 m (Figure.39.) reduces the construction time by an average of 4% for pipes less than 300 mm diameter. For pipes of 2100 mm diameter, the reduction increases to at least 10%. Increasing the pipe length from 2.44 mm to 7.50 mm (Figure.40.) decreases the overall construction time by an additional 2% (making a 6% reduction for pipes less than 300 mm diameter and 12% reduction for 2100 mm diameter pipes). The savings made by increasing the pipe lengths can only be realised if excavation support is either omitted or special support systems designed to allow for the additional strut spacing necessary.

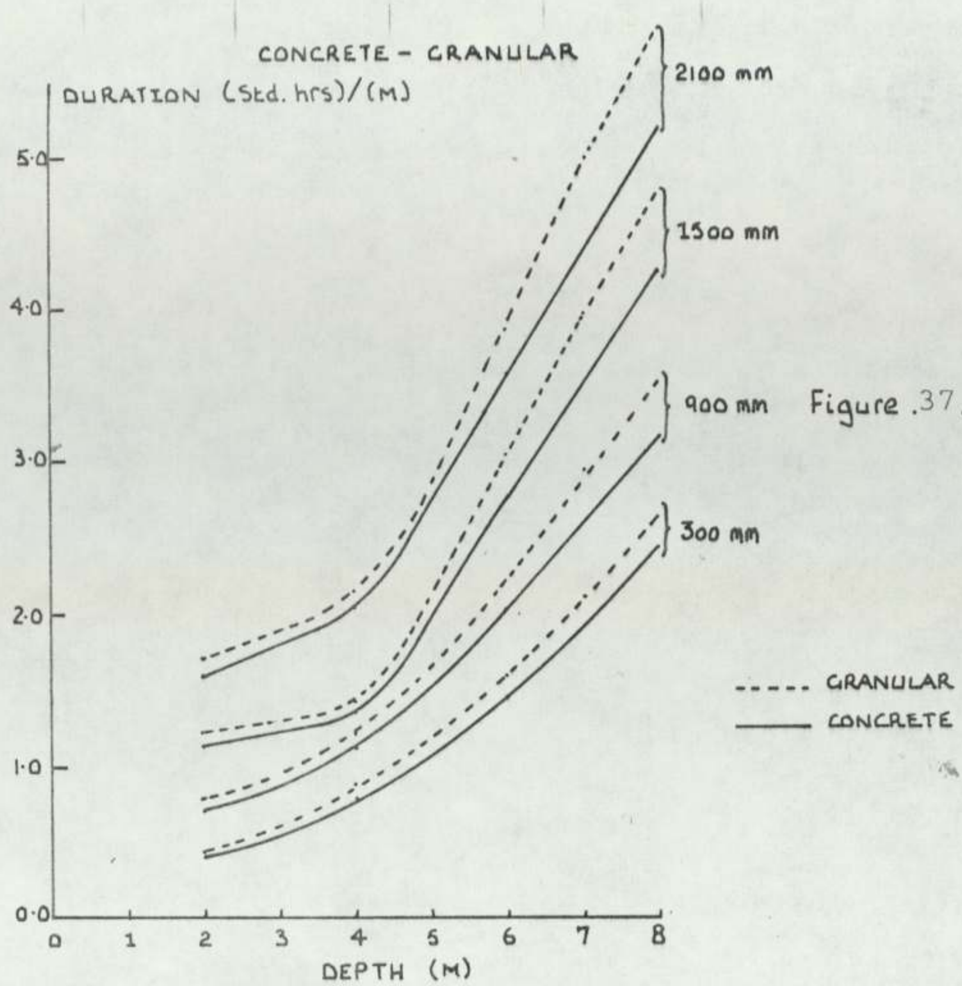


Figure .37.

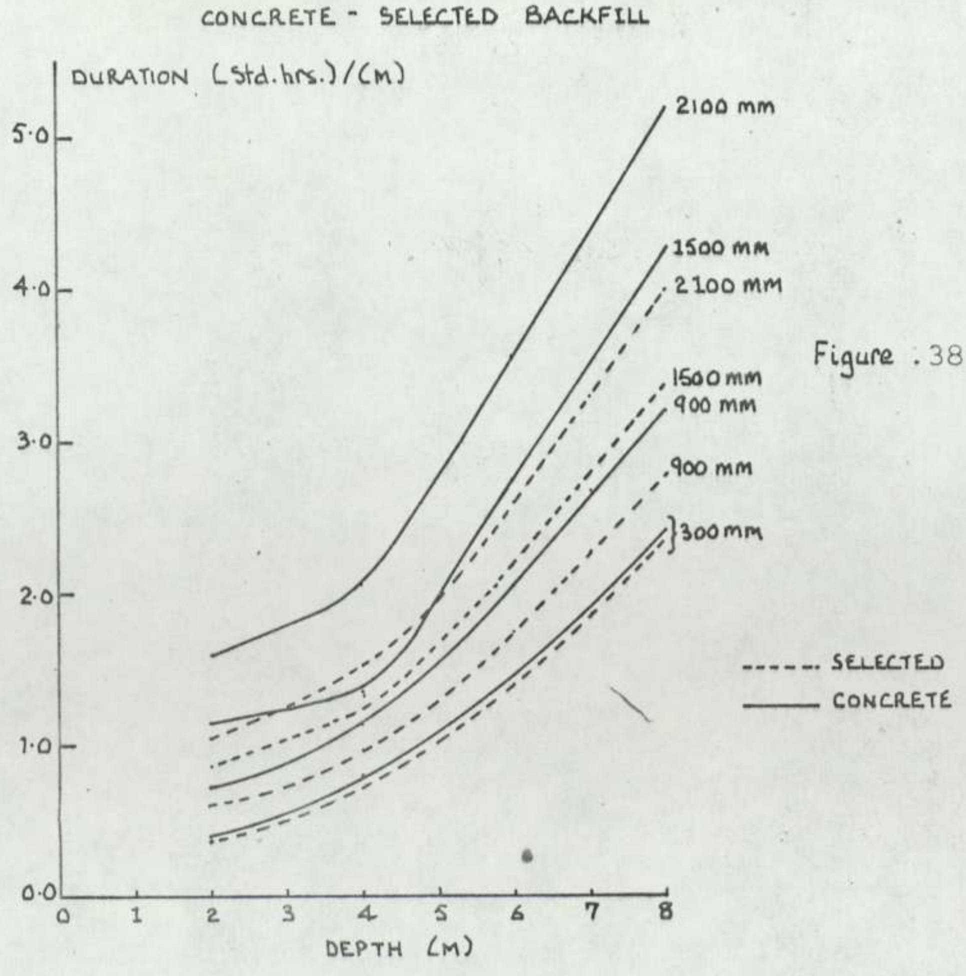


Figure .38.

2·44 M - 5·00 M

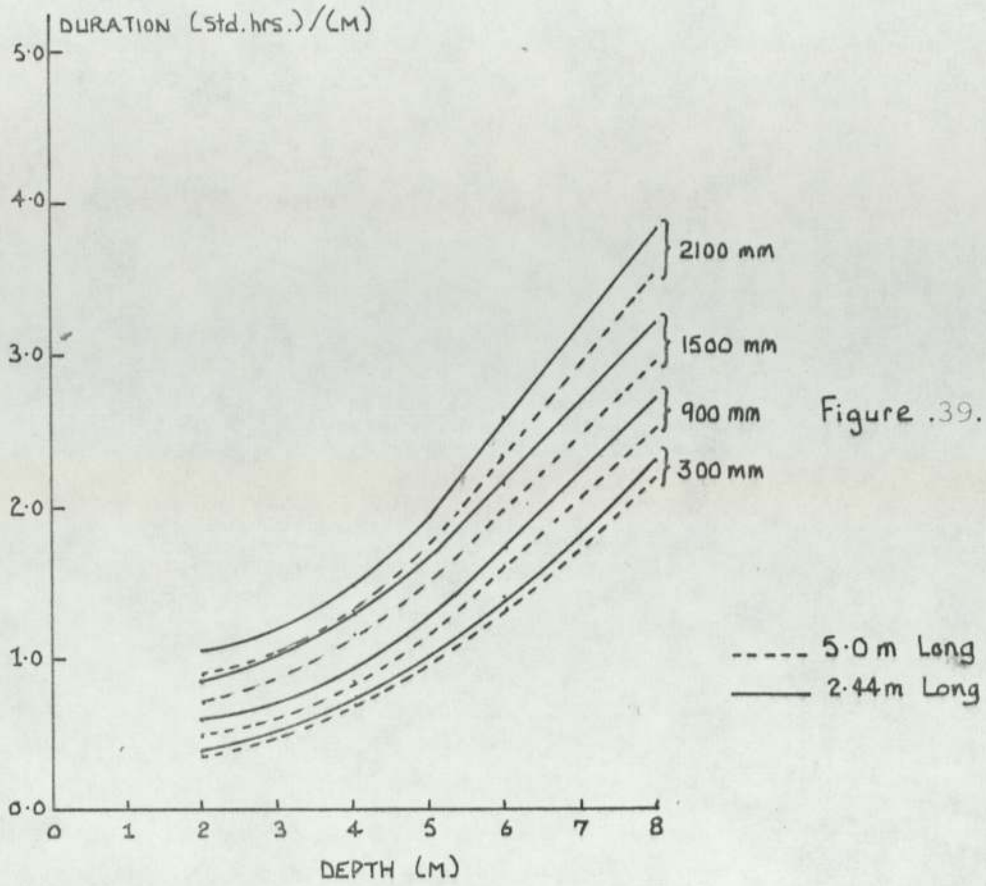


Figure .39.

2·44 M - 7·50 M

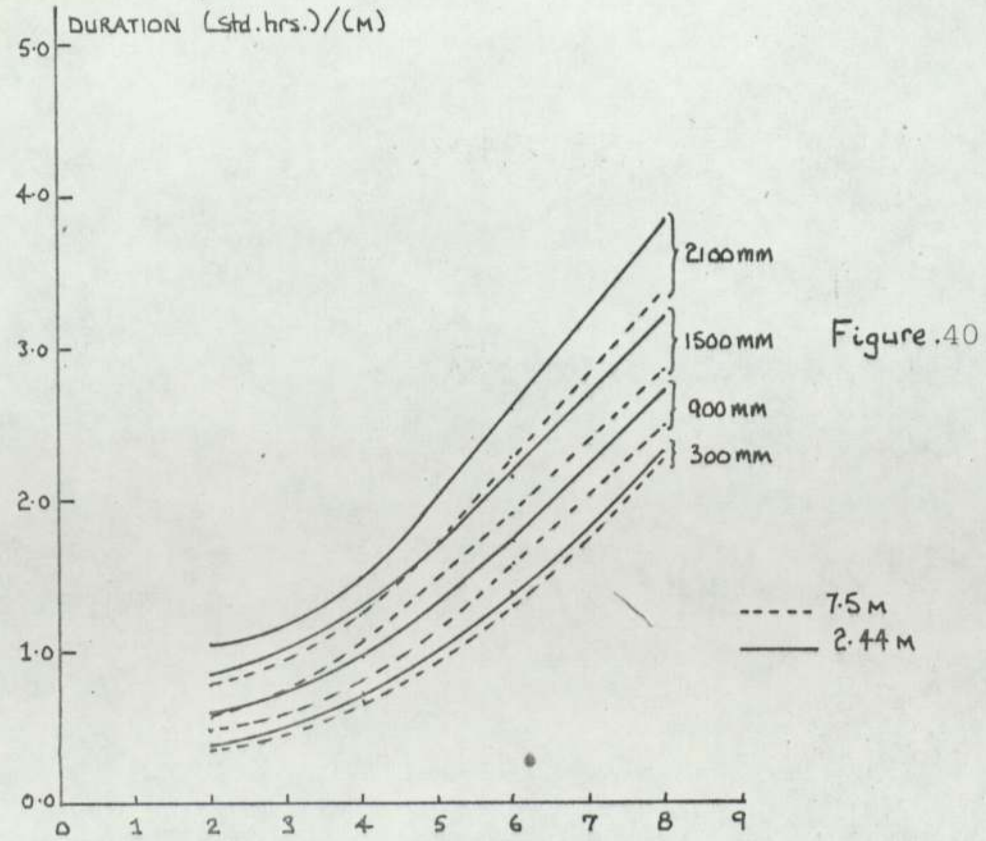


Figure .40.

4.11 Manhole Analysis Programme

This programme (Figure.41.) contains eleven sub-programmes, each of which analyse different manhole construction operations. Each sub-programme contains one or more 'element subroutines' to calculate material quantities, gang sizes and construction times, data input and output being controlled by 'ancillary subroutines'.

The sub-programmes are:-

(1) Road Breakout

(2) Excavation

(3) Excavation Support

(4) Base Blinding

(5) Channel Construction

(6) Pre-Cast Concrete Ring Manhole Analysis

(7) Brick Manhole Analysis

(8) Insitu concrete slab construction

(9) Concrete Surround

(10) Benching and Finishing

(11) Backfill

The sub-programmes which analyse the road breakout, excavation support and backfill are similar to those presented earlier for pipeline analysis.

Work measurement information (Appendix 1) is stored within each sub-programme and detailed analyses of each construction element is output after each is processed. Although the object of this programme is primarily to produce gang sizes and construction times, a great deal of emphasis is placed on calculating the net material quantities (excluding wastage).

Each sub-programme contained in the manhole analysis programme is now discussed in more detail.

4.12 Base Blinding, Channel Construction and Benching

Although these sub-programmes deal with different construction elements, their individual structures are similar.

Each sub-programme contains one element subroutine which calculates the material quantity, gang size and construction time at standard performance from stored work measurement data and the relevant dimensions provided by ancillary subroutines. A detailed output is produced after each is processed, the main items being stored so that an overall summary of the manhole construction can be produced.

4.13 Pre-Cast Concrete Ring Manhole Analysis Sub-programme

This sub-programme (Figure.42.) contains six element subroutines, each dealing with separate structural elements.

(1) Chamber Rings

(2) Straight Backed Tapers

(3) Shaft Rings

(4) 75 mm Flat Slabs

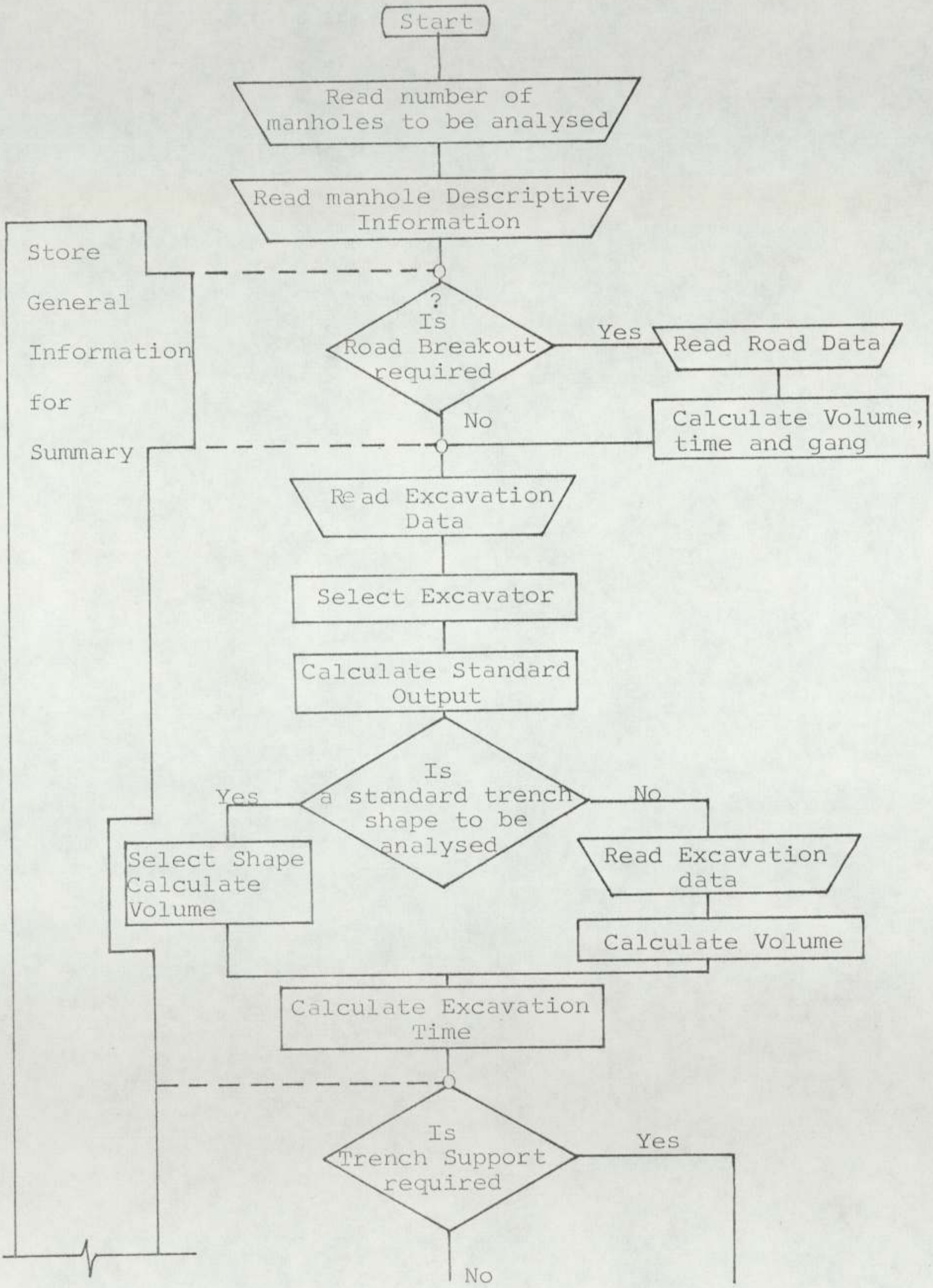
(5) 150 mm Flat Slabs

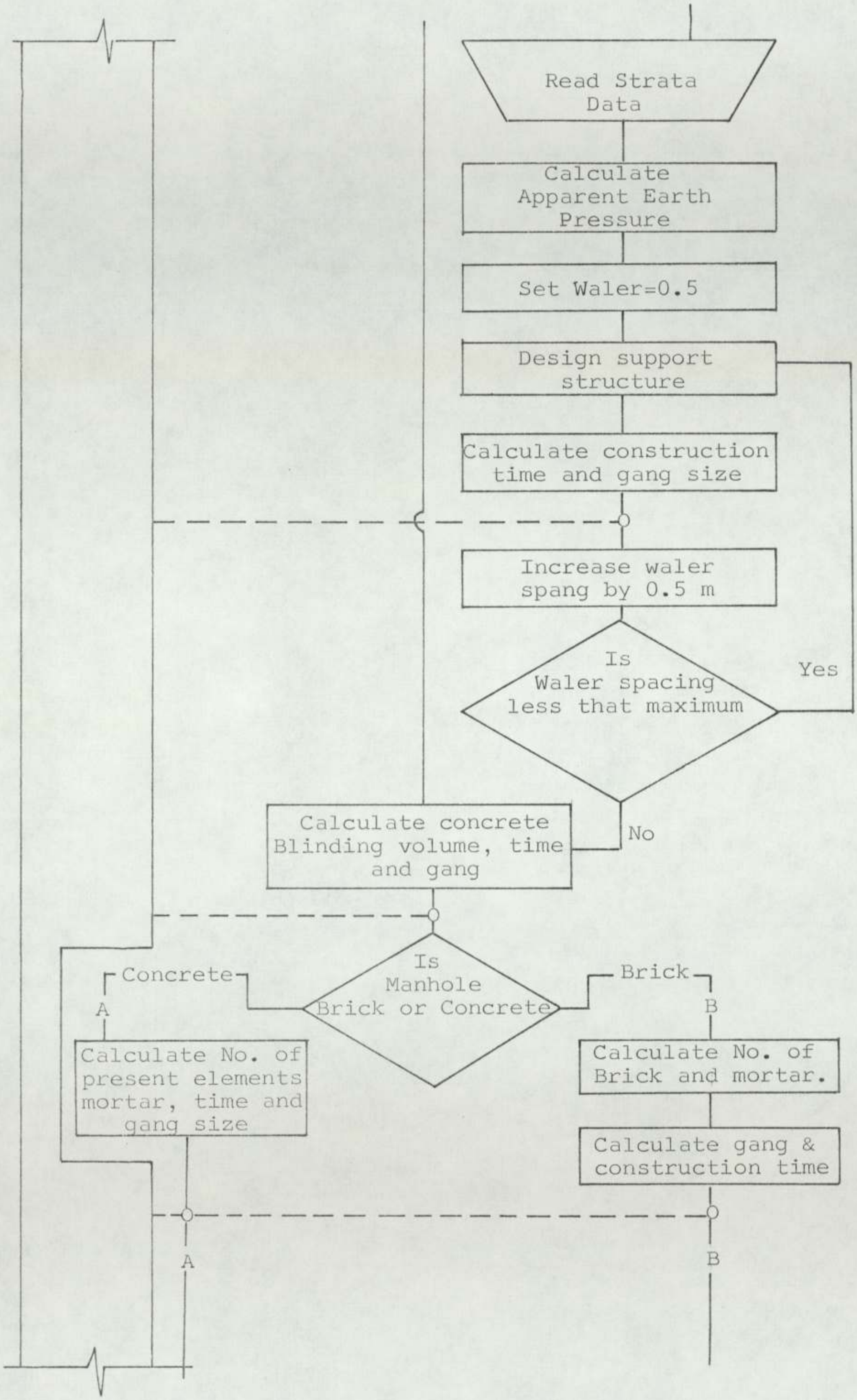
(6) Base Units

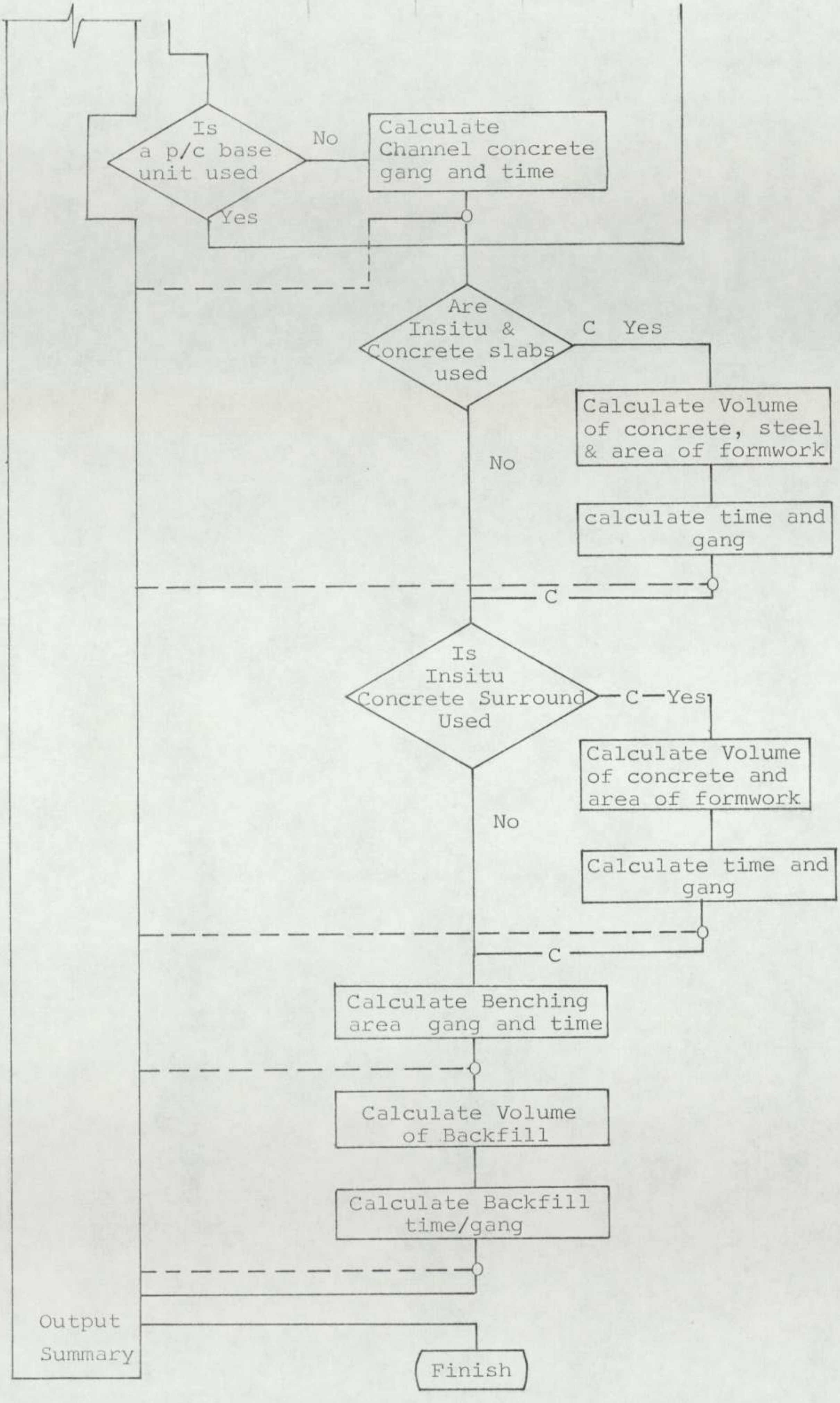
Any combination of the various structural elements may be specified. If pre-cast base units are used, the channel analysis sub-programme (described in 4.12) is omitted from the analysis.

FIGURE.41.

Structure of Master Segment




Read Strata Data
Calculate Apparent Earth Pressure
Set Waler=0.5
Design support structure
Calculate construction time and gang size
Increase waler spang by 0.5 m
Is Waler spacing less that maximum
Yes
No
Calculate concrete Blinding volume, time and gang
Is Manhole Brick or Concrete
Concrete
Brick
A
B
Calculate No. of present elements mortar, time and gang size
Calculate No. of Brick and mortar.
Calculate gang & construction time
A
B


Is a p/c base unit used
No
Yes
Calculate Channel concrete gang and time
Are Insitu & Concrete slabs used
C Yes
No
Calculate Volume of concrete, steel & area of formwork
calculate time and gang
C
Is Insitu Concrete Surround Used
C
Yes
No
Calculate Volume of concrete and area of formwork
Calculate time and gang
C
Calculate Benching area gang and time
Calculate Volume of Backfill
Calculate Backfill time/gang
Output Summary
Finish

Pre-Cast Concrete Ring Manholes

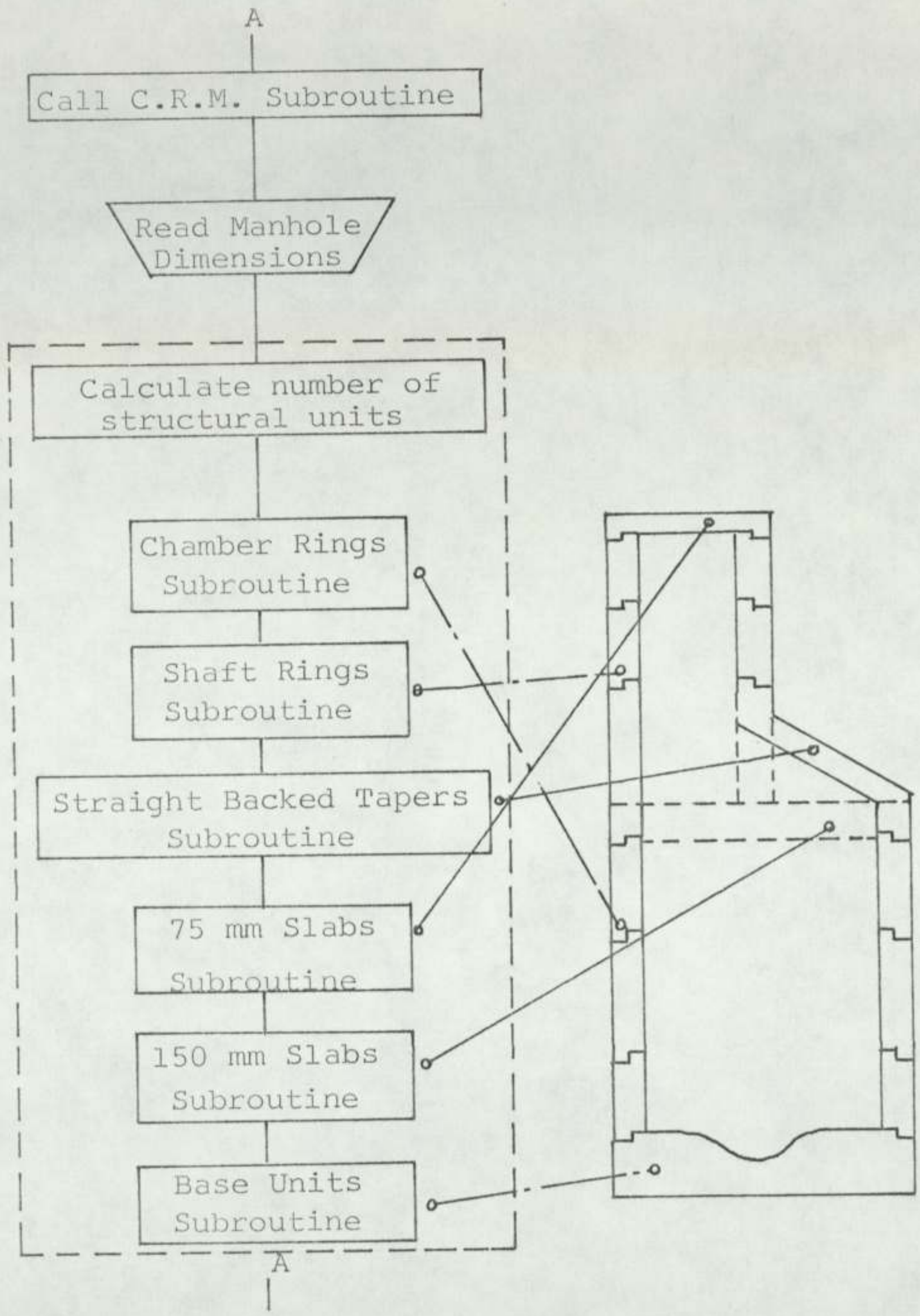


FIGURE.42.

4.14 Brick Manholes Sub-programme

From manhole dimensions obtained either from the Bills of Quantity or detail drawings, this group of element sub-routines calculates the number of bricks, step irons, volume of mortar, construction time and gang size. The sub-programme (Figure.43.) is capable of analysing single or dual chamber manholes. All material quantities calculated do not include wastage and the construction time is based on standard work measurement data, (Appendix 2).

4.15 Insitu Concrete Slabs and Surround Sub-programme

These sub-programmes (Figure.44.) contain two element subroutines, one calculates the material quantities and the area of formwork required. The second element subroutine determines the construction time and gang size necessary. Both sub-programmes are optional.

4.16 Computer Analysis of Manhole Construction

Several analyses were carried out using the manhole programme.

4.16.1 Open, Medium or Close Excavation Support

The construction time for both brick and pre-cast concrete ring manholes is dominated by the physical construction of the manhole chamber. Consequently, changes in the support system configuration do not significantly affect the overall construction time or cost.

Brick Manholes

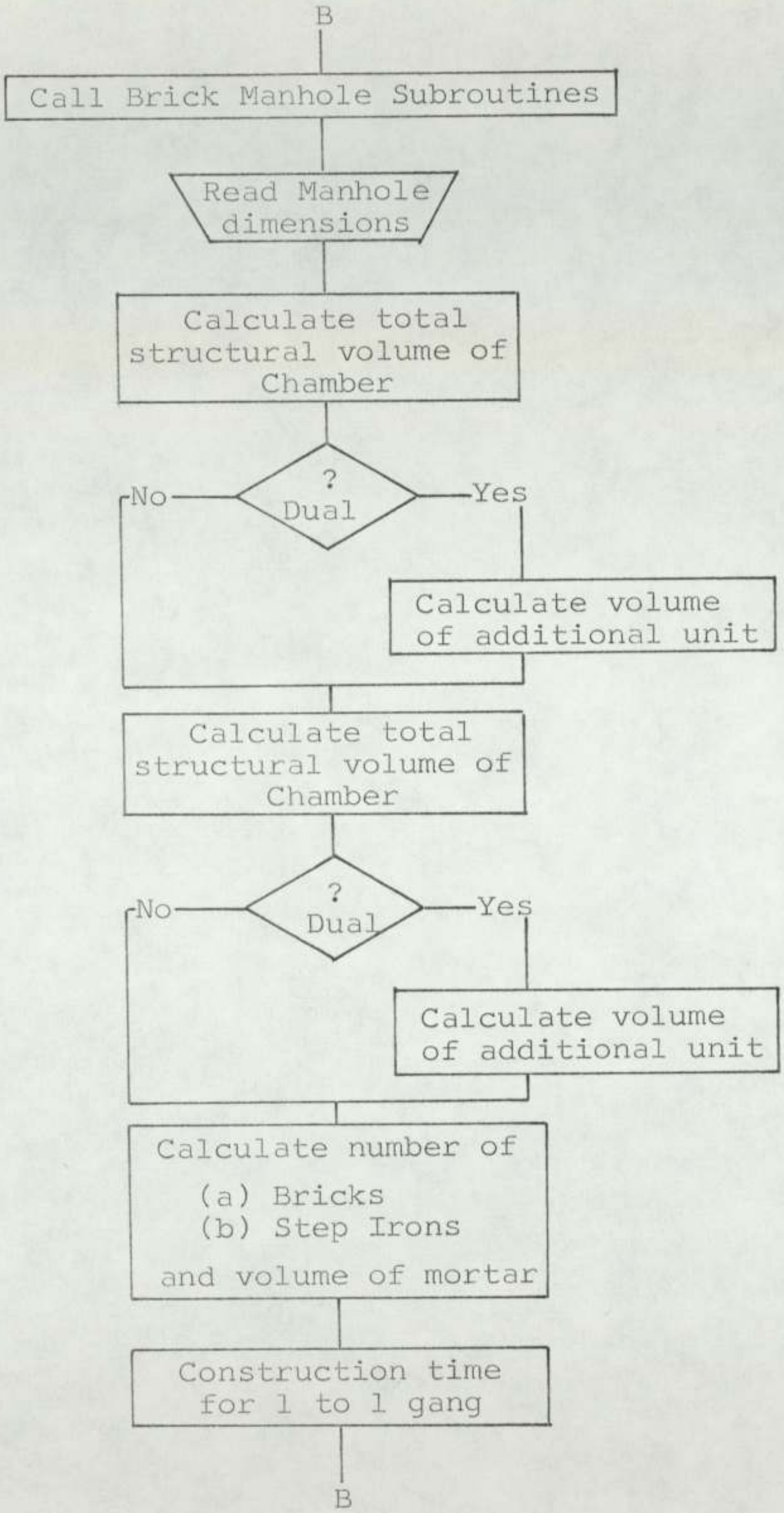


FIGURE.43.

Insitu Concrete Slabs and Surround

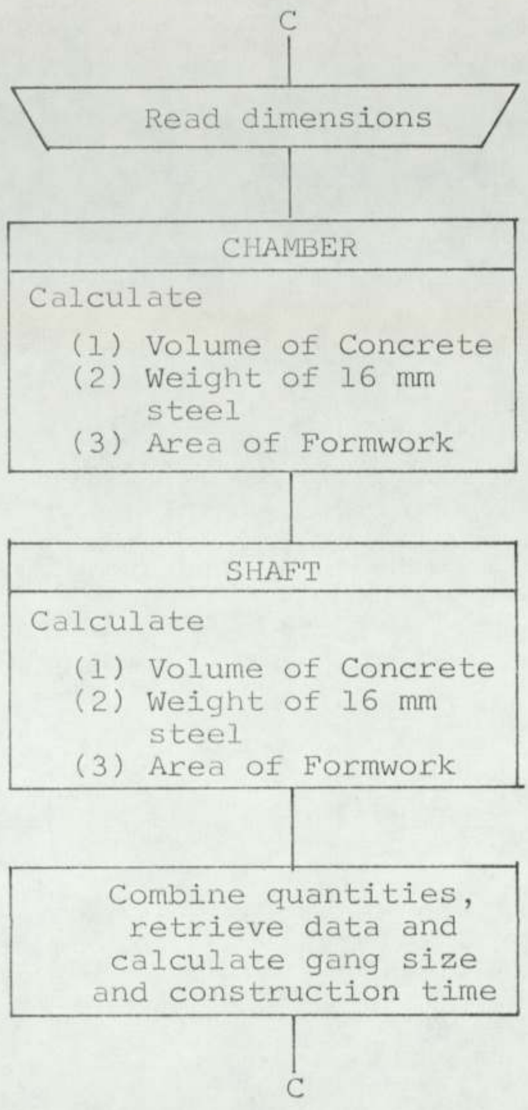


FIGURE. 44.

4.16.2 Excavation Support or Battered Open Cut

At depths of 4 m (Figure.45.) or less, there is no significant difference between supporting and open cutting the excavation for brick manhole construction. At such depths the benefits accrued by not supporting the excavation are diminished by the additional road breakout, excavation and backfill volumes. At depths in excess of 4 m the construction time is reduced by an average of 6% if the excavation is supported (as opposed to being open cut). This increases the material cost by 1½% but results in an overall cost reduction of at least 3½%. From a construction time point of view, it is always better to support pre-cast manhole excavations (Figure.46.). This results in a 6% reduction in construction time and at least a 3.5% reduction in cost.

4.16.3 Brick or Pre-Cast Concrete Ring Manholes

The construction of pre-cast concrete ring manholes take considerably less time than the construction of brick manholes (Figure.47.). At a depth of 6 m, the construction time is more than halved. However, this drastic reduction in construction time is not reflected in construction costs (Figure.48.). From a cost point of view, manholes of internal chamber dimensions of 1.0 m or less, pre-cast concrete ring manholes are less costly to construct irrespective of depth. Similarly, pre-cast concrete ring manholes of internal dimensions 1.5 m, 2.0m, 2.5 m, 3.0 m at depths in excess of 2.5 m, 5.5 m, 6.5 m and 7.5 m respectively are significantly cheaper to construct than brick manholes, brick manholes being significantly less costly at smaller depths.

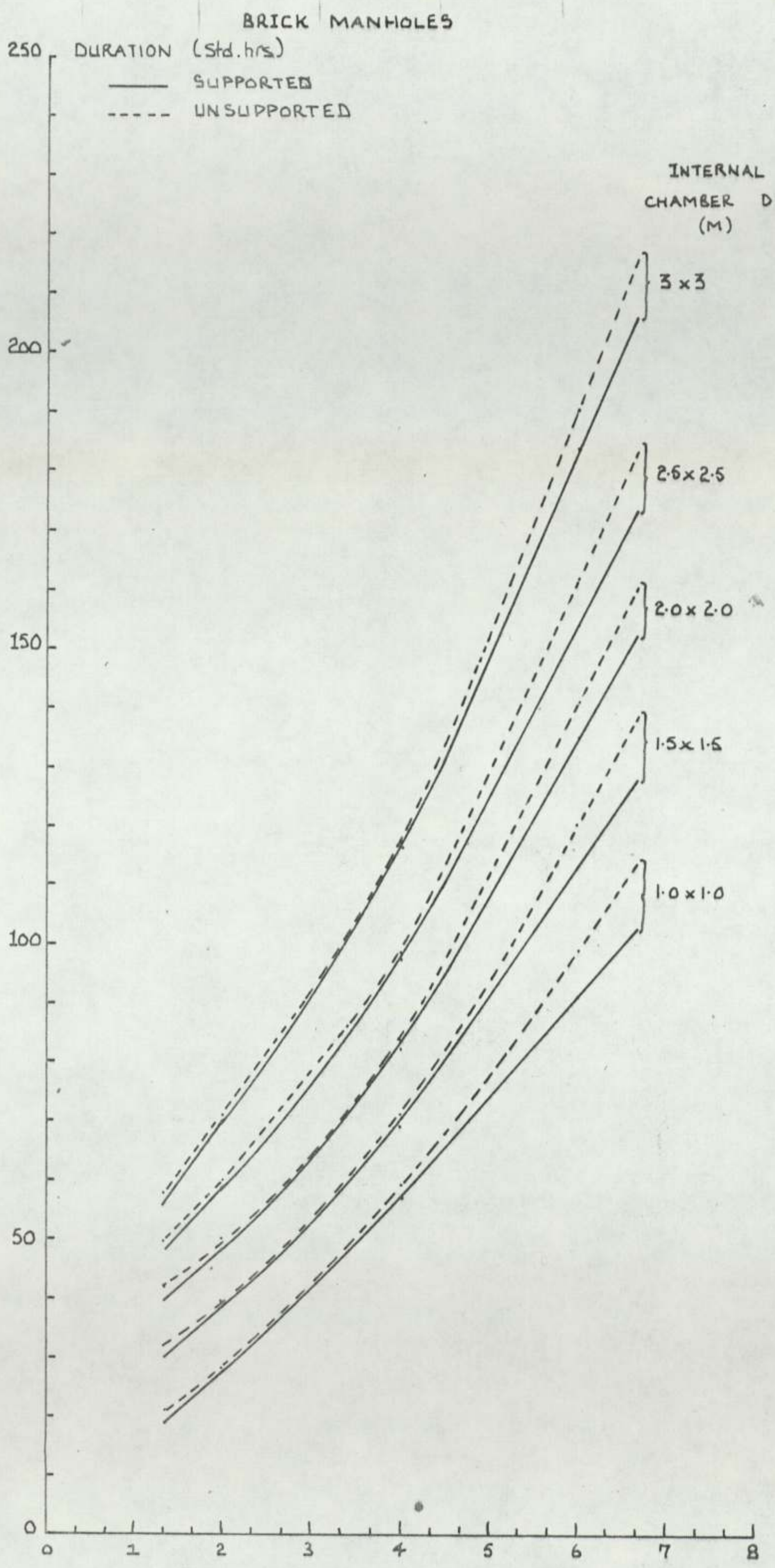

BRICK MANHOLES
DURATION (Std. hrs)
SUPPORTED
UNSUPPORTED
INTERNAL CHAMBER DIMS. (M)
3 x 3
2.5 x 2.5
2.0 x 2.0
1.5 x 1.5
1.0 x 1.0
0
50
100
150
200
250
0
1
2
3
4
5
6
7
8
DEPTH (M)

Figure .45.

PRE-CAST CONCRETE MANHOLES

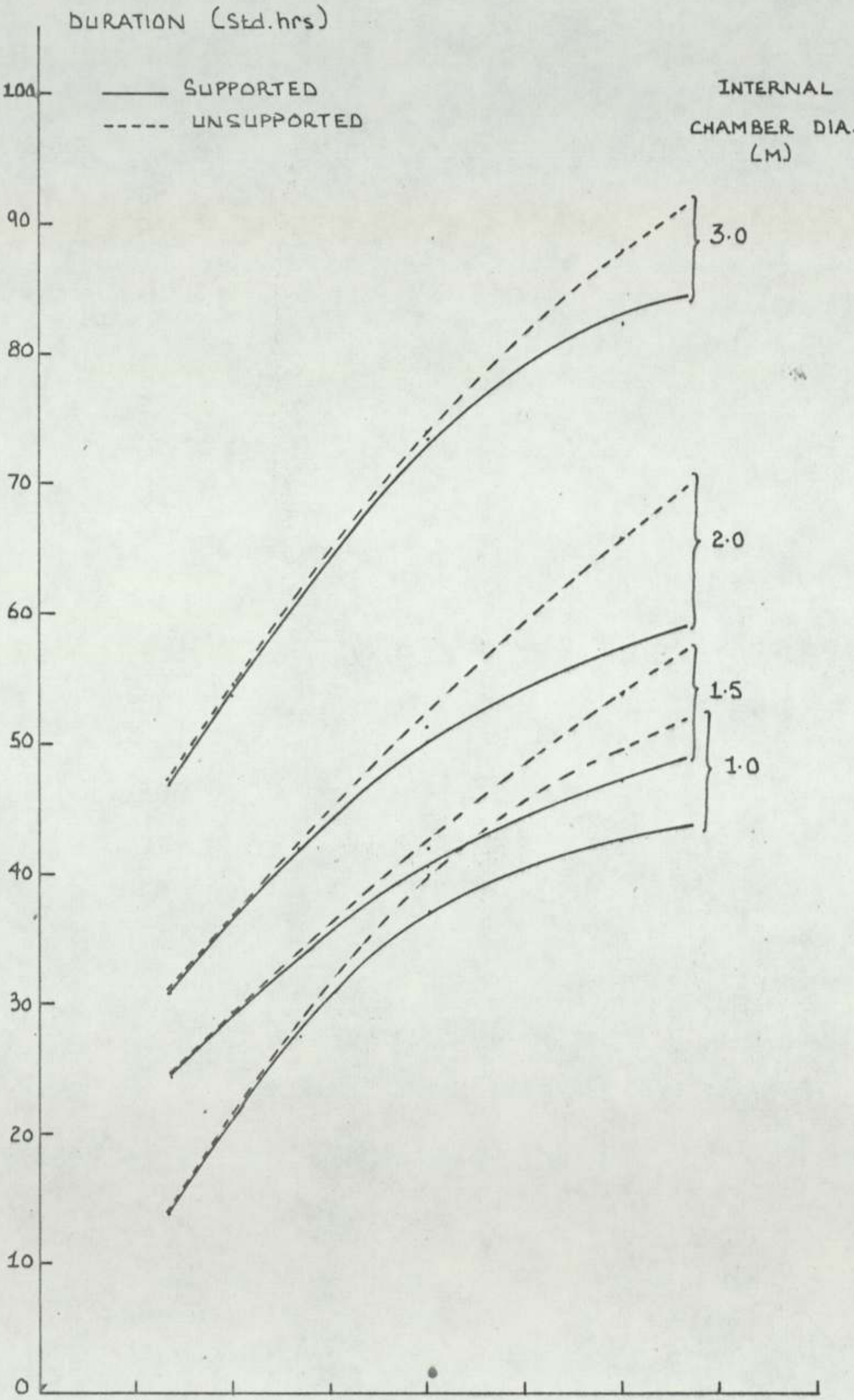


Figure .46.

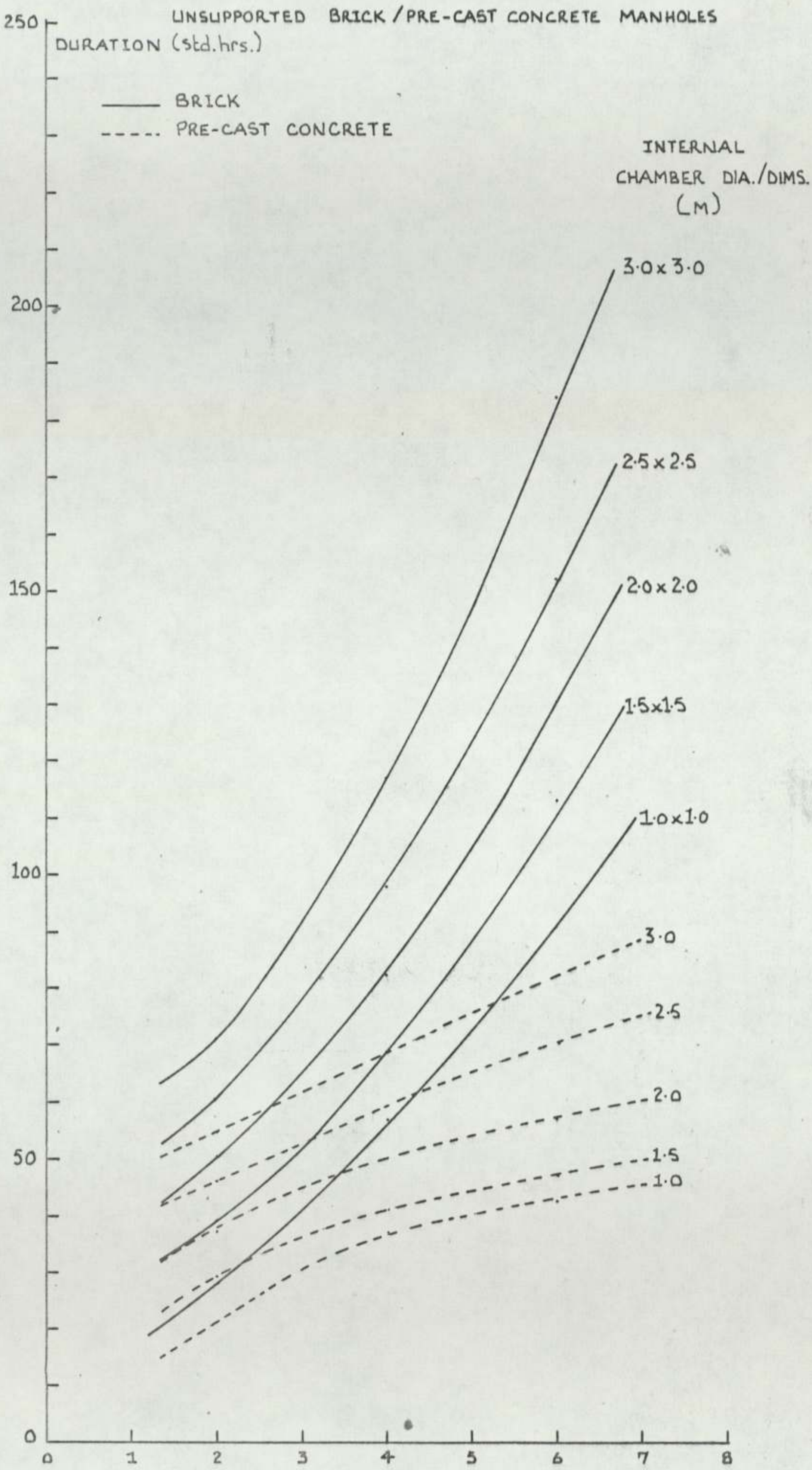

UNSUPPORTED BRICK / PRE-CAST CONCRETE MANHOLES
DURATION (std. hrs.)
250
200
150
100
50
0
BRICK
PRE-CAST CONCRETE
INTERNAL CHAMBER DIA./DIMS. (M)
3·0 x 3·0
2·5 x 2·5
2·0 x 2·0
1·5 x 1·5
1·0 x 1·0
3·0
2·5
2·0
1·5
1·0
0
1
2
3
4
5
6
7
8
DEPTH (M)

Figure .47.

UNSUPPORTED BRICK / PRE-CAST CONCRETE MANHOLES

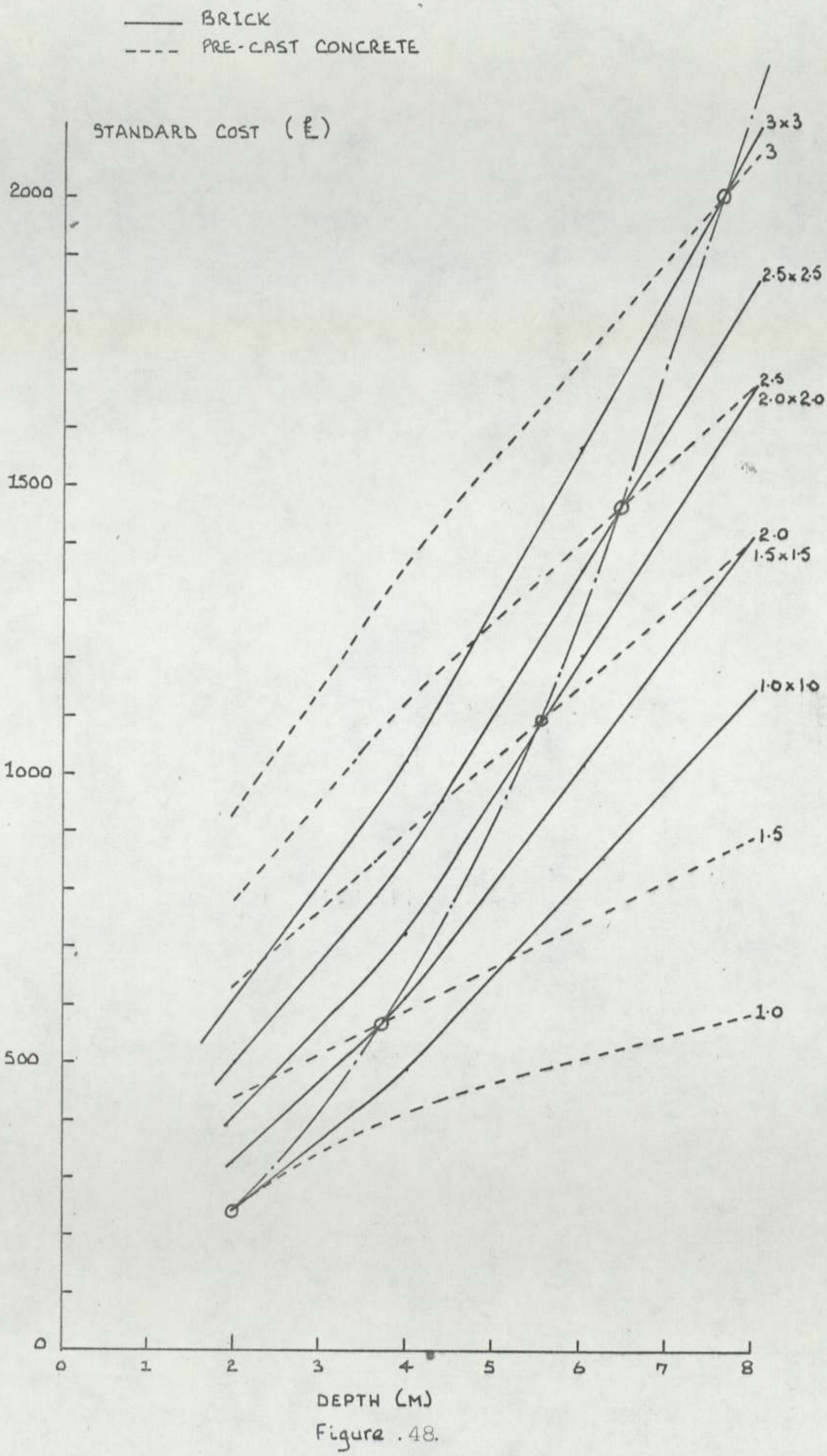


Figure .48.

CHAPTER 5

PRE-CONTRACT APPRAISAL BY SIMULATION

Summary

Presentation of a Computer Programme to be used for simulation of projects.

CHAPTER 5

PRE-CONTRACT APPRAISAL BY SIMULATION

5.1 Introduction

Pre-Contract Appriasal envelopes two specialist disciplines - Planning and Estimating. From receipt of the tender documents to the signing of the contract, Estimators and Planners are engaged in a series of analysis, synthesis and evaluation procedures, initially aimed at producing a viable competitive bid and subsequently at producing detailed production information for project line management.

The Client's requirements are specified in the Bills of Quantity, Tender Drawings and Specifications. Therefore, the task of analysing the requirements is, in the main, straightforward. However, synthesis and subsequent evaluation of the project are complex procedures requiring a systematic approach, adequate historical information, site experience and, above all, time. The time allotted by clients for preparation of bids is often so short that current manual methods of estimating and planning are only capable of yielding a single, purely deterministic cost estimate.

Planners, Estimators and Management are fully aware that the performance of operatives, site management, the effects of weather, absenteeism, material shortages and alternative construction methods may drastically affect the project. In an attempt to make the necessary adjustments, they use mean values and pure speculative allowances, which are often inaccurate and theoretically incorrect.

This chapter presents a suite of computer programmes which attempt to simulate a working project, the information they require being readily produced by the company. The ultimate aims are to make better use of the limited pre-contract appraisal time available and allow the effect of the various performance and environmental random variables to be assessed.

5.2 The Simulation Programme Structure

The suite of programmes is designed to afford maximum flexibility to the Pre-Contract Appraisal Sub-system. The programming objectives being to:-

(i) Duplicate the current synthesis and evaluation procedures adopted by Planners and Estimators, so that the suite of programmes can be adopted by the company.

(ii) Speed up the synthesis and evaluation procedures.

(iii) Consider and quantify the effects of operative and performance, absenteeism, gang overloading etc.

(iv) Add flexibility to the current Pre-Contract Appraisal Sub-system so that alternative design, construction methods and new developments in materials and plant can be assessed prior to bidding.

(v) Produce realistic net cost rates for the labour, material, plant, sub-contractors and preliminaries necessary for constructing the project.

(vi) Be capable of considering all categories of labour, plant and material etc.

(vii) Be capable of quantifying the effect of anticipated increases in costs.

(viii) Be capable of assessing the financial status of a project in progress and of predicting the anticipated outcome.

The suite (Figure.49.) contains eight programmes, each of which deal with a different aspect of the project simulation. Information generated by each programme is entered and stored on ten data files which either output it to the lineprinter or retain it for future use. The information stored in each data file is given in Table.11.

5.3 Day by Day Project Simulation Programme (SIMCOMP)

The simulation is based on the interdependence exhibited by the various project activities. Consequently, it requires a Precedence Network for the project as a whole and standard man-hours, gang sizes and quantities for each project activity. Initially the project is simulated in daily increments (Figure.50.) which are subsequently sorted into weekly summaries.

The programme configuration (Figure.51.) contains three

TABLE.11.

FILE NAME	DATA STORED
DAYTA	(1) Day Number (2) Activity Number (3) Ideal Gang Size (4) Actual Gang Size (5) Productive Man-Hours (6) Operative Performance Index (7) Overloaded forced waiting man-hours (8) Performance forced waiting man-hours (9) Total forced waiting man-hours (10) Productive Unmeasured Hours (11) Site Performance Index (12) Quantity of Activity Produced (13) Quantity left to produce (14) Labour Cost
PERTA	(1) Lost daily period recorded
ACTRATE	(1) Activity Number (2) Man-hours per unit of production (3) Total number of units to be produced
COUNT	(1) Total number of different activities occurring each week
WEEK	(1) DAYTA information summarised & grouped into week numbers
LCOSTA	(1) WEEK information grouped into week numbers and activity numbers (2) Week Number (3) Activity Number (4) Quantity of activity produced (5) Labour Cost
LPCOSTA	(1) LCOSTA plus plant cost information
LMPCOSTA	(1) LPCOSTA plus material cost information
LMPSCOSTA	(1) LMPCOSTA plus sub-contractor cost information
LMPSPCOSTA	(1) LMPSCOSTA plust cost of preliminaries

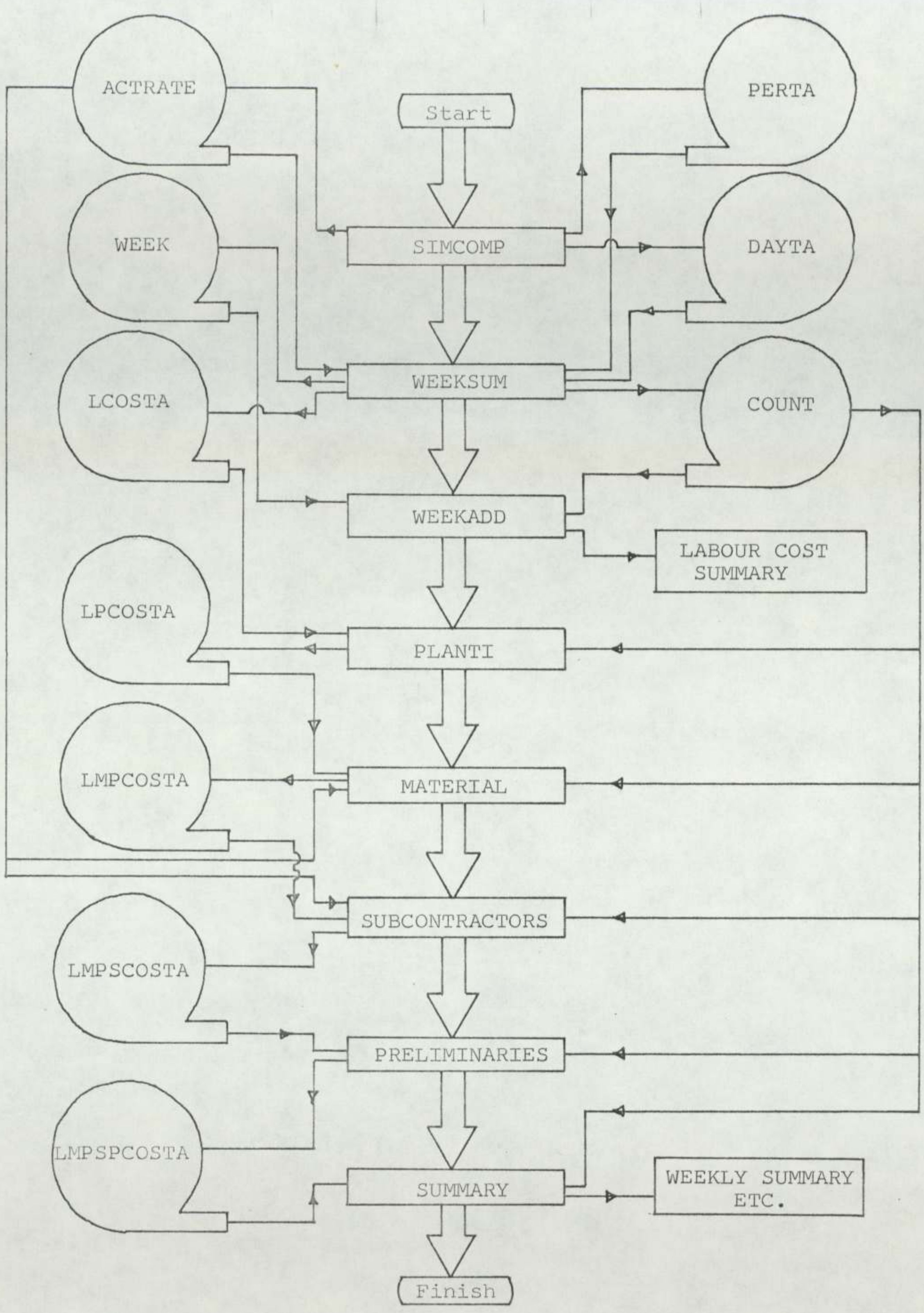
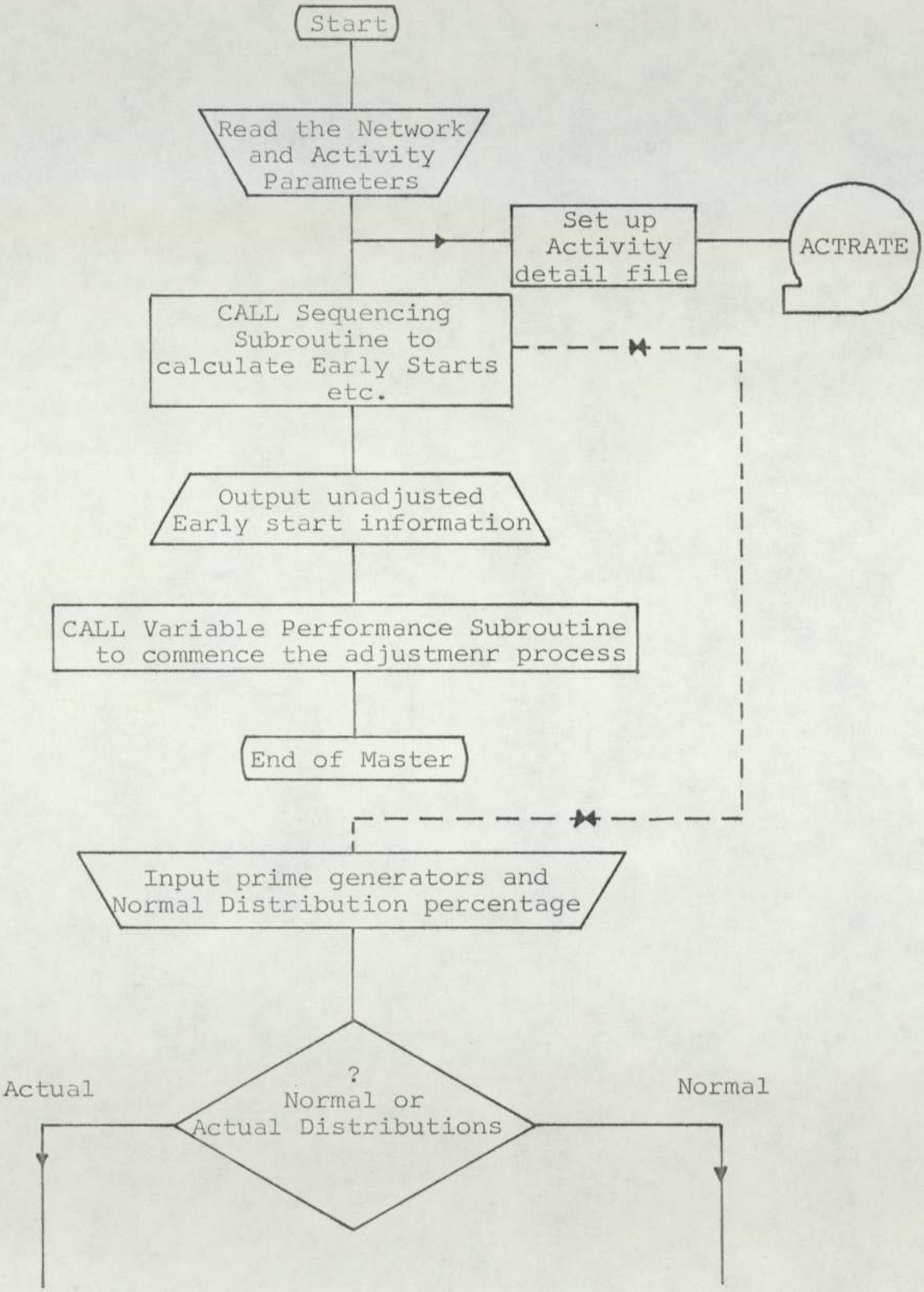
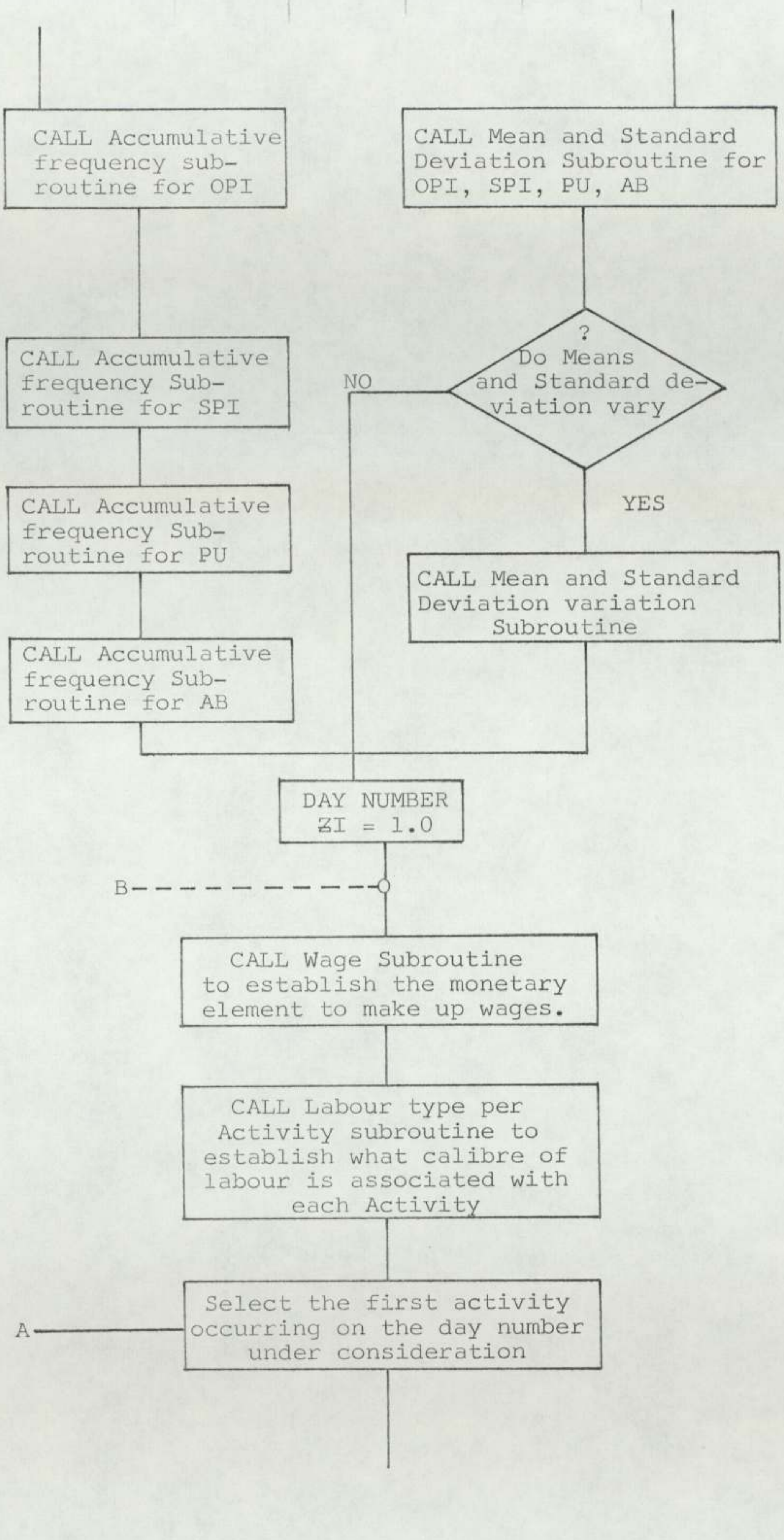

ACTRATE
Start
PERTA
WEEK
SIMCOMP
DAYTA
LCOSTA
WEEKSUM
COUNT
WEEKADD
LABOUR COST SUMMARY
LPCOSTA
PLANTI
LMPCOSTA
MATERIAL
SUBCONTRACTORS
LMPSCOSTA
PRELIMINARIES
LMPSPCOSTA
SUMMARY
WEEKLY SUMMARY ETC.
Finish

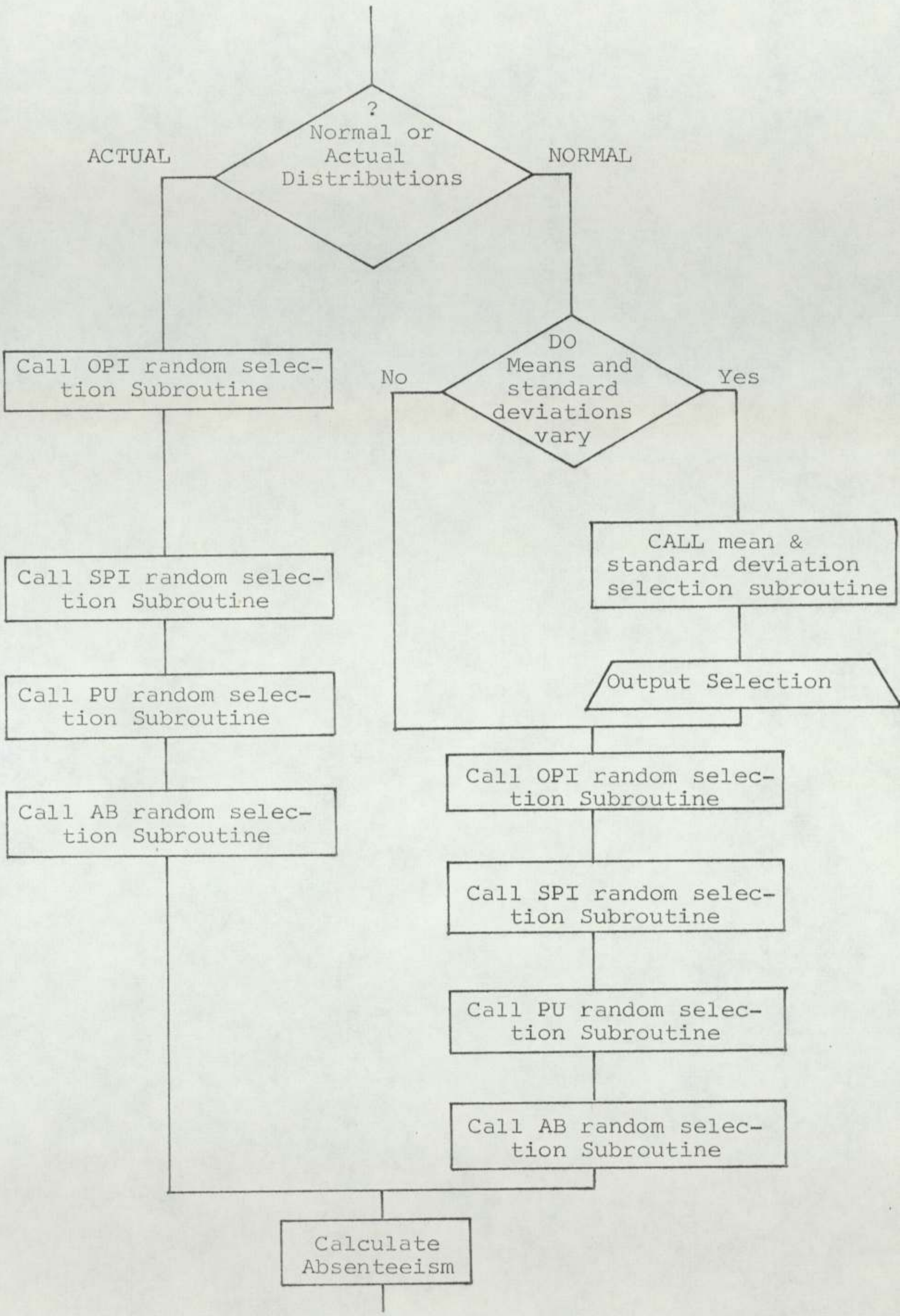
Figure.49.

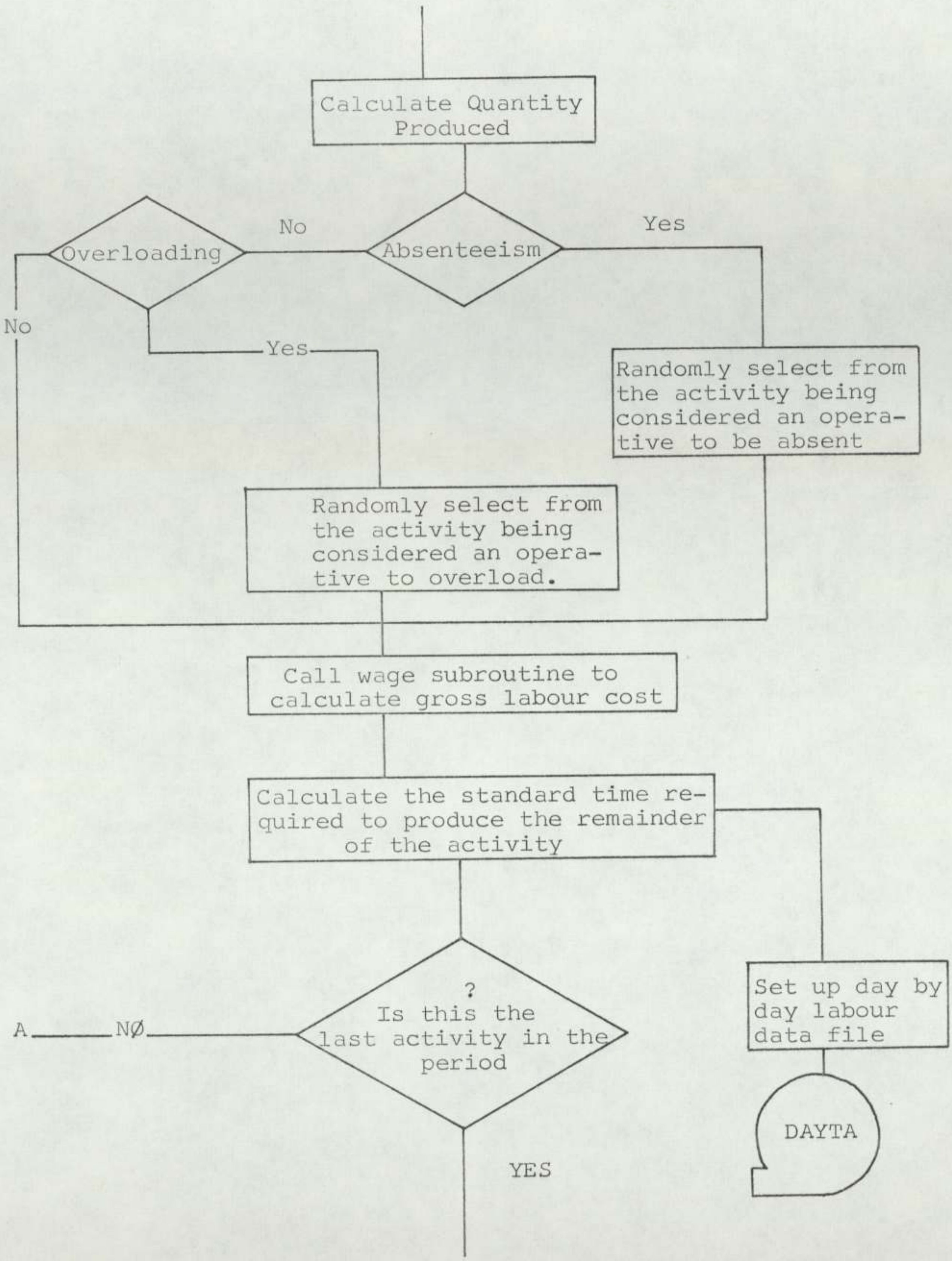
(SIMCØMP)

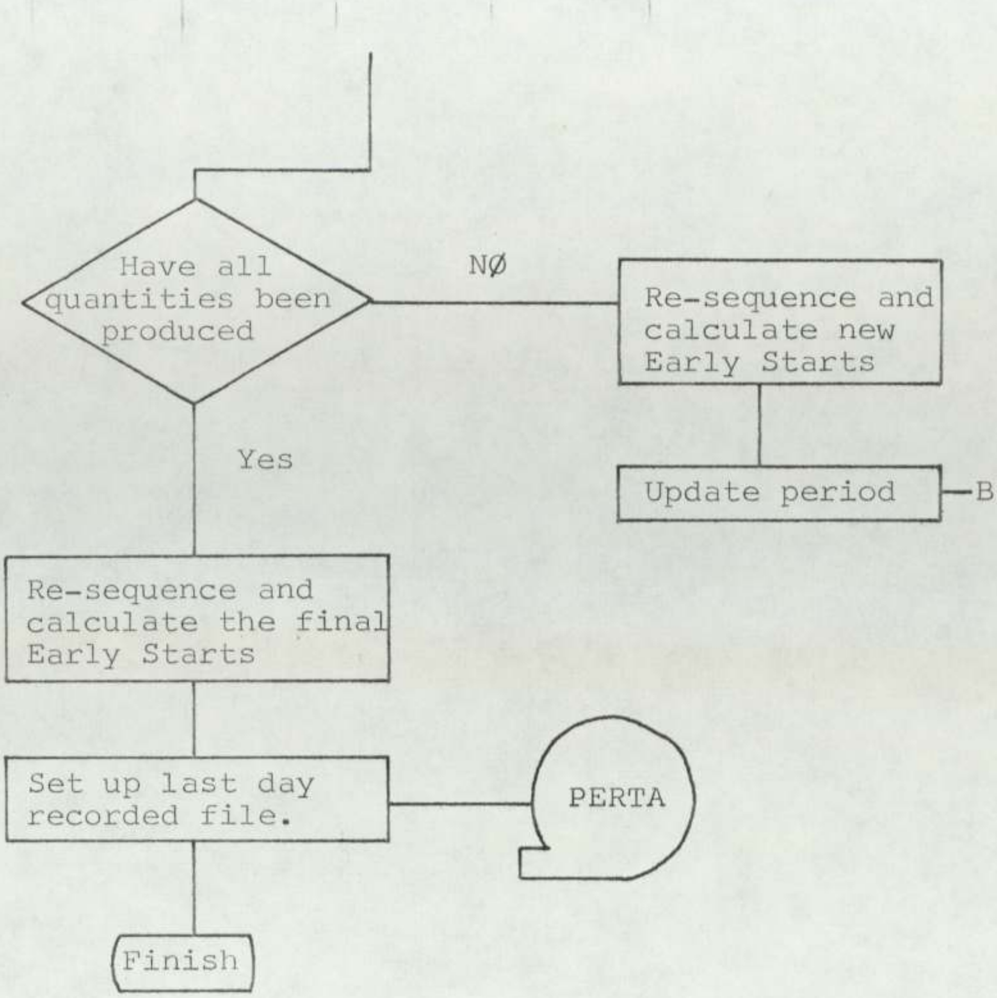
Figure.50.




CALL Accumulative frequency subroutine for OPI
CALL Mean and Standard Deviation Subroutine for OPI, SPI, PU, AB
CALL Accumulative frequency Subroutine for SPI
NO
? Do Means and Standard deviation vary
YES
CALL Accumulative frequency Subroutine for PU
CALL Mean and Standard Deviation variation Subroutine
CALL Accumulative frequency Subroutine for AB
DAY NUMBER ZI = 1.0
B
CALL Wage Subroutine to establish the monetary element to make up wages.
CALL Labour type per Activity subroutine to establish what calibre of labour is associated with each Activity
A
Select the first activity occurring on the day number under consideration

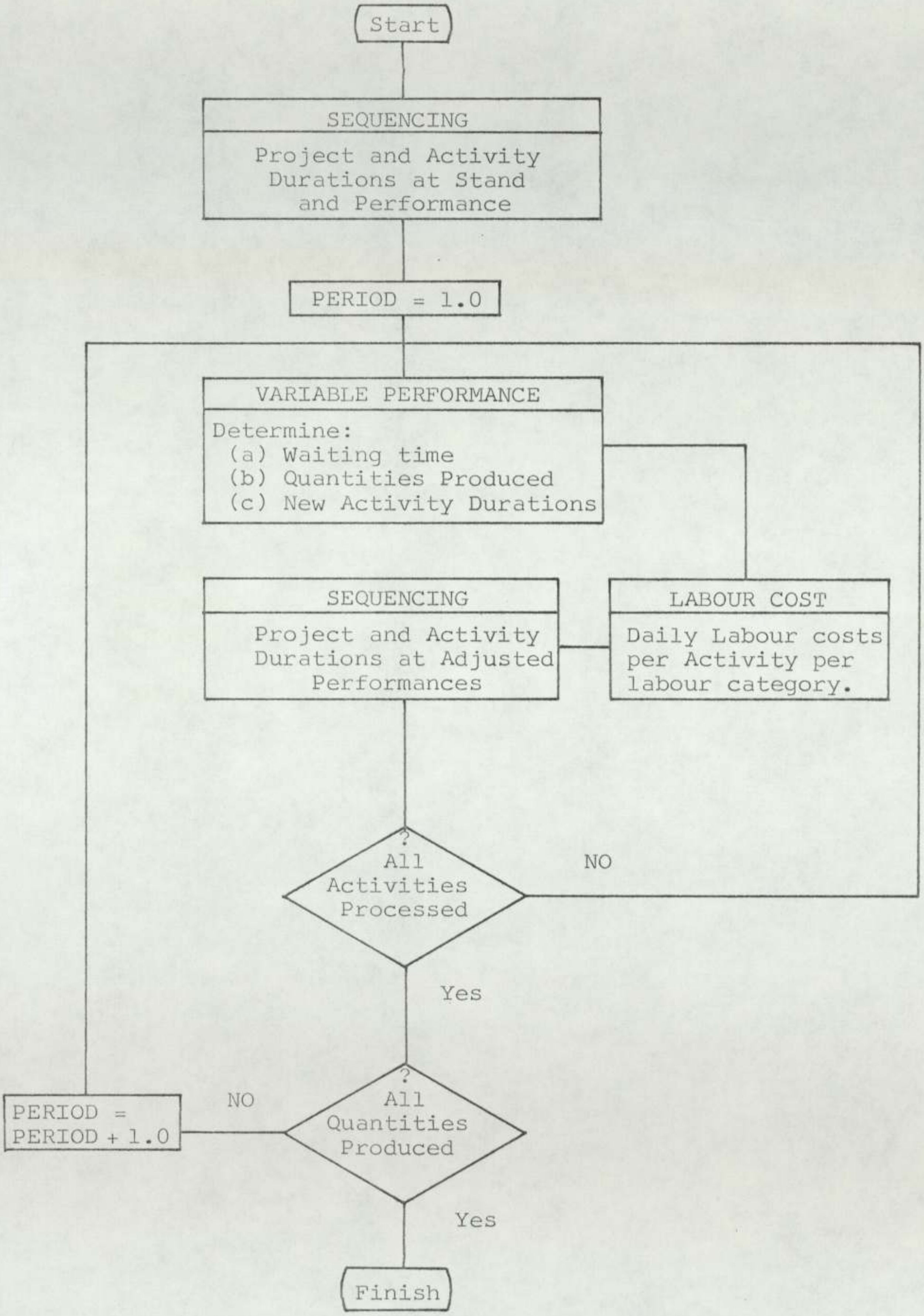

?
Normal or
Actual
Distributions
ACTUAL
NORMAL
Call OPI random selec-
tion Subroutine
DO
Means and
standard
deviations
vary
No
Yes
CALL mean &
standard deviation
selection subroutine
Output Selection
Call SPI random selec-
tion Subroutine
Call PU random selec-
tion Subroutine
Call AB random selec-
tion Subroutine
Call OPI random selec-
tion Subroutine
Call SPI random selec-
tion Subroutine
Call PU random selec-
tion Subroutine
Call AB random selec-
tion Subroutine
Calculate
Absenteeism


Calculate Quantity Produced
Absenteeism
No
Yes
Overloading
No
Yes
Randomly select from the activity being considered an operative to be absent
Randomly select from the activity being considered an operative to overload.
Call wage subroutine to calculate gross labour cost
Calculate the standard time required to produce the remainder of the activity
Set up day by day labour data file
DAYTA
? Is this the last activity in the period
A
NØ
YES


Have all quantities been produced
NØ
Re-sequence and calculate new Early Starts
Update period
B
Yes
Re-sequence and calculate the final Early Starts
Set up last day recorded file.
PERTA
Finish

General Simulation Configuration

Figure. 51.



prime components:-

(a) Project Sequencing

(b) Variable Performance Selection and Manipulation

(c) Labour Cost

5.3.1 Project Sequencing Sub-Programme

Project sequencing is used twice during the simulation. Firstly, to provide a framework of the project at standard performance. Secondly to adjust the project and activity duration according to pre-selected levels of performance.

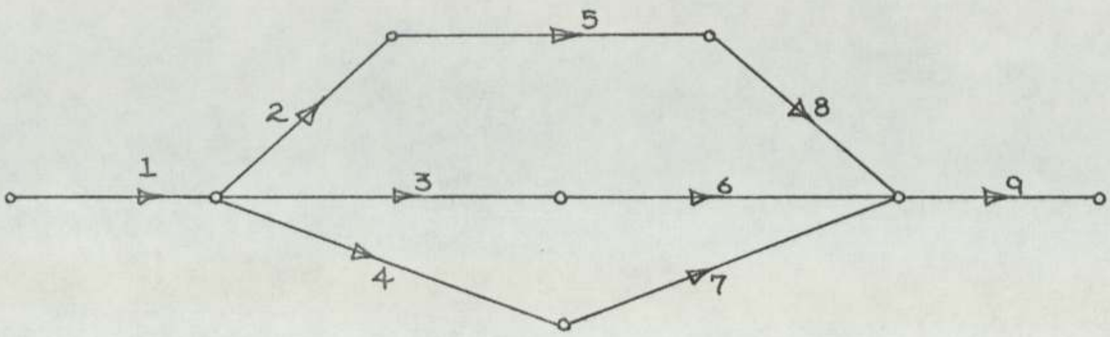
The precedence network is input in matrix form (Figure.52.) in which each activity is positioned by the number and description of its immediate predecessors.

Initially, the 'Early Starts' for each project activity are calculated at standard performance. At this stage, no production losses due to varying performance levels are considered.

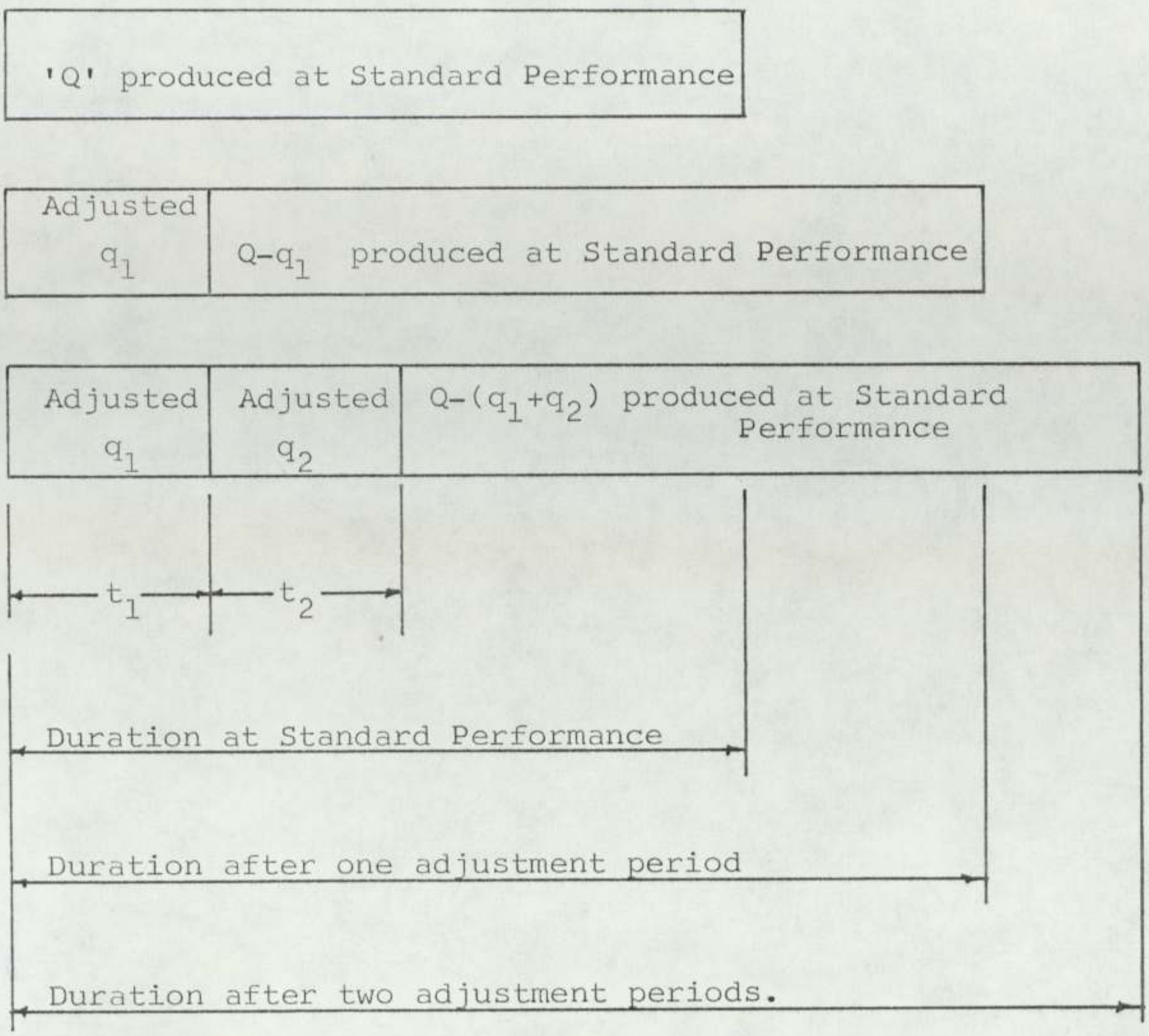
The simulation start 'PERIOD' (Figure.51.) is set to unity and all activities occurring within it are processed in turn, the adjusted activity duration being determined in the following way:-

FIGURE.52.

Precedence Network Matrix



Activity Number	Immediate Predecessors			Total Number
1	0			1
2	1			1
3	1			1
4	1			1
5	2			1
6	3			1
7	4			1
8	5			1
9	6	7	8	3



Hence, the construction duration time 'Tm' for a single project activity after 'm' periods of simulated adjustment is given by:-

$$Tm = \sum_{i=1}^{i=m} t_i + \frac{Su}{n} \cdot (Qm) \quad \ldots\ldots\ldots\ldots\ldots (8)$$

As the period increments are integer steps only, the totally adjusted construction duration 'Tc' occurs when the quantity left to produce becomes zero. This may occur only rarely on an integer step and hence requires adjusting for 'overrun'. (Quantity left becoming zero after 'm' integer steps and before 'm+1' integer steps). Hence:-

$$Tc = Tm \quad \text{if} \quad \frac{Su}{n}.(Qm) = 0.0 \qquad \ldots\ldots\ldots\ldots\ldots(9)$$

$$\text{or} \quad Tc = Tm + e \quad \text{if} \quad \frac{Su}{n}.(Qm) < 0.0 \qquad \ldots\ldots\ldots\ldots(10)$$

$$\text{where} \quad \frac{Su}{n}.(Qm) = \frac{Su}{n}.(Q - \sum_{i=1}^{i=m} qi) \qquad \ldots\ldots\ldots\ldots\ldots(11)$$

$$\text{and} \quad e = \frac{t}{\left\{\frac{Qm-1}{Qm} + 1\right\}} \qquad \ldots\ldots\ldots\ldots\ldots(12)$$

Equations 8 to 12 inclusive primarily depend on the project activity quantity produced, which in turn is determined by the production, various waiting times incurred and the degree of absenteeism or overloading of labour resources.

5.3.2 Variable Performance Selection and Manipulation Sub-Programme

Performance data required for adjusting the standard production rates are randomly selected from either normal or actual (Chapter 3) accumulative frequency distributions using the Inverse Transformation Method, which assumes that the probability that a variate according to F(x) as its density function is less than, or equal to, 'x' in the form:-

$$P\left\{F^{-1}(r) \leqslant x\right\} = P\left\{r \leqslant F(x)\right\} = F(x) \ldots (13)$$

where

r = Psuedo Random Fraction

x = The Dependent Variate

Psuedo-random numbers 'R' being generated using the Multiplicative Congruential Method[(62)(63)], which takes the form:-

$$R = a.R_{i-1} \pmod{M} \qquad \text{.............} (14)$$

where Ro = Positive Integer

a = Positive Integer

|M| = Large Positive Integer

Psuedo-random fractions (r) are, therefore, created by forming the sequence $\{Ri/M\}$.

After selecting the relevant performance data for the activity being considered, the quantity produced (q) is calculated and subtracted from the total quantity (Q). All activities occurring are processed in turn in a similar way. The quantity produced and total waiting time incurred are dependent upon the performance levels anticipated.

Quantity Produced and Total Forced Waiting Time

Performance data is selected at random either from Normal or Actual Distributions and is used to determine the quantity produced in any one period in the following way:-

Let ∅ = Operative Performance Index

S = Site Performance Index

Z = Work day per man (hrs.)

pu = Productive Unmeasured Time (hrs.)

n = Minimum Practical Gang Size

na = Actual Gang Size

Su = Standard Man-hours allowed per unit

q = Quantity of work produced

Ap = Actual Productive Man-hours

fw = Performance waiting time

by definition

$$S = \frac{100.Su.q}{Ap + Tfw} \quad ....(15)$$

$$\varnothing = \frac{100.Su.q}{Ap} \quad ....(16)$$

The Total Attendance Man-hours is given by:-

$$Z.na = Ap + Tfw + na.pu \quad ....(17)$$

Now from equations (15) and (16):-

$$Tfw = 100.Su.q. \left\{\frac{1}{S} - \frac{1}{\varnothing}\right\}$$

Hence $$Tfw = \frac{100.Su.q.}{S} \left(1 - S/\varnothing \right) \quad ....(18)$$

and $$q = \frac{S.Tfw}{100.Su.(1-S/\varnothing)} \quad ....(19)$$

The total force waiting time 'Tfw' is assumed to have two prime components:-

(a) ∅fw or ufw, one or the other depending on whether the gang is overloaded or under-loaded respectively.

(b) fw, natural or performance forced waiting derived from the differences in performance between '∅' and 'S'.

When there is no absenteeism or overloading, the total forced waiting time 'Tfw' is dependent upon the performance differences only.

$$Tfw = fw = na.(Z - pu).(1 - S/\varnothing) \quad ......(20)$$

However, if the gang becomes overloaded 'Tfw' is modified depending upon the degree of overloading.

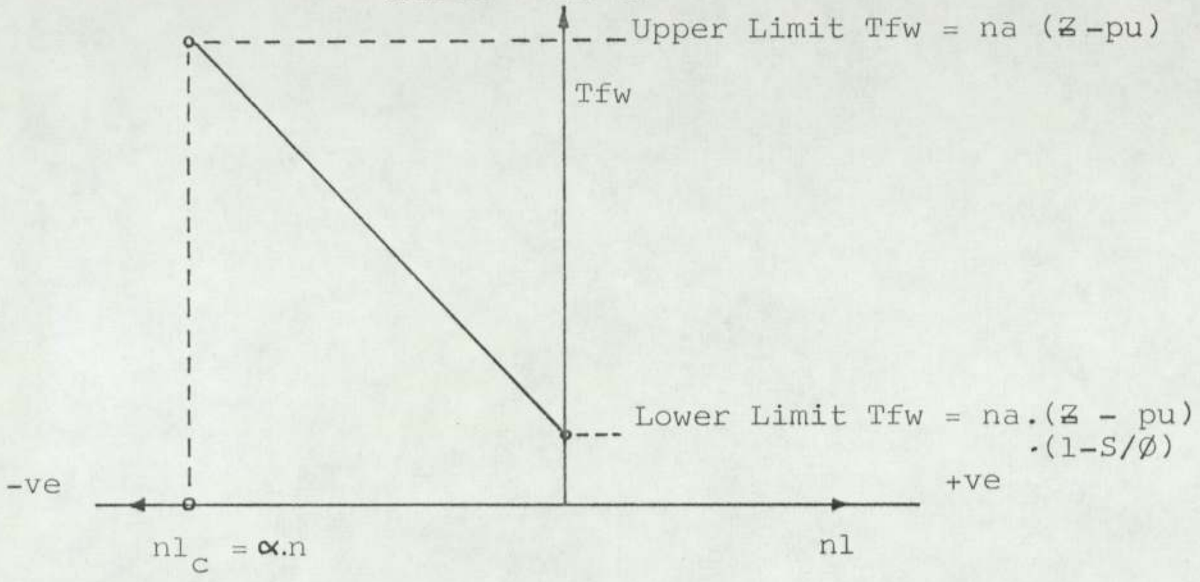
$$Tfw = fw + \emptyset fw$$

$$\therefore \quad Tfw = na.(Z - pu).(1 - S/\emptyset) + (na - n).(Z - pu)$$

$$\underline{Tfw = (Z - pu).\{na.(1-S/\emptyset) + (na-n)\}} \quad \ldots\ldots\ldots (21)$$

If there is absenteeism, the total forced waiting time is again increased, but only to a certain critical point at which production must cease. This level is denoted by 'α' and the relationship between the forced waiting time 'fw' is assumed to be linear.

Let $nl = na - n$



Hence $\quad Tfw = -m'.nl + C'$

where $\quad C' = na.(Z - pu).(1 - S/\emptyset)$

$$m' = \frac{na.(Z - pu) - na.(Z - pu).(1-S/\emptyset)}{\alpha.n}$$

$$m' = \frac{na(Z - pu)}{\alpha.n}.(1 - (1 - S/\emptyset))$$

$$m' = \frac{na.(Z - pu).S}{\alpha.n.\emptyset}$$

$$Tfw = na.(Z - pu).(1 - S/\emptyset) - \frac{na(Z-pu).S.(na-n)}{\alpha.n.\emptyset}$$

$$Tfw = na(Z - pu) . \left\{ (1-S/\emptyset) - \frac{S(na-n)}{\alpha.n.\emptyset} \right\}$$

$$Tfw = na (Z - pu). \left\{ 1-S/\emptyset - \frac{S(na-n)}{\alpha.n.\emptyset} \right\} \quad ....(22)$$

Several tests were carried out using equation (22) to establish 'α', the data (Table.12.) used being obtained from site, (Chapter 3, Figure.12.). An average value of $\alpha = -0.5950$ was established which implies that production ceases when:-

$na = 0.4050.n$ (or 59.5% absenteeism)

5.3.3 Labour Cost Sub-Programme

The programme (SIMCOMP) accepts five labour types, all of which are commonly used during estimating. They are:-

(1) Working Foreman

(2) Gangers

(3) Tradesmen

(4) Skilled Labourers

(5) Labourers

All direct labour in the above categories is included in a 100% incentive scheme operated by the Company's Production Department.

Let	b	=	Basic Rate	(p/hr.)
	p	=	Plus Rate	(p/hr.)
	g	=	Guaranteed Bonus	(p/hr.)
	c	=	Cost of Living Allowance	(£/week)
	f	=	Fall Back Bonus	(p/hr.)
	w	=	Work Overtime	(hrs./week)
	s	=	Subsistance Allowance	(£/week)

Ideal Gang n	Actual Gang na	Standard Man-hours	Productive Man-hours	Total Man-hours	Productive Unmeasured Pu	z	α
24	23	762	994	1196	8.75	46.25	-0.88
33	25	785	1158	2112	8.00	46.25	-0.30
43	42	1381	1748	2077	7.00	46.25	-0.83
40	38	1278	1597	1963	12.50	46.25	-0.79
40	39	1132	1357	1808	7.00	46.25	-0.97
42	41	1153	1377	1876	14.00	46.25	-0.44
48	47	1434	1573	2267	2.00	46.25	-0.74
46	45	1804	1916	2343	0.01	46.25	-0.77
49	48	1691	1856	2338	2.50	46.25	-0.98
67	66	1944	2222	2843	13.50	46.25	-0.70
24	23	636	689	939	22.0	46.25	-0.87
44	43	1404	1834	2225	8.0	46.25	-0.49
9	8	498	470	542	17.00	46.25	-0.95
13	11	414	494	691	28.00	46.25	-0.44
13	8	434	435	708	39.00	46.25	-0.29
14	13	469	522	742	13.00	46.25	-0.40
19	18	544	818	984	8.00	46.25	-0.91
27	26	791	1126	1422	0.50	46.25	-0.75
31	30	878	1127	1535	0.01	46.25	-0.84
44	36	1433	1229	2122	27.00	46.25	-0.34
45	36	1222	1016	1904	36.00	46.25	-0.29
54	41	1341	1127	2267	38.00	46.25	-0.26
62	58	1270	1162	2238	32.00	46.25	-0.31
40	33	1029	995	1836	27.00	46.25	-0.32
37	33	847	845	1697	19.00	46.25	-0.29
36	30	840	845	1690	23.00	46.25	-0.30
41	40	1082	1132	1913	5.00	46.25	-0.40
43	42	1448	1474	1983	0.01	46.25	-0.90
43	41	1337	1363	2103	5.00	46.25	-0.51
43	42	1297	1238	1965	5.00	46.25	-0.61
37	36	1505	1404	1747	8.00	46.25	-0.79
74	72	2045	1905	3229	12.00	46.25	-0.38
						Mean	-0.5950

Table.12.

t	=	Travelling Allowance	(£/week)
t^1	=	Tool Money Allowance	(£/week)
n'	=	National Insurance Allowance	(£/week)
h	=	H.W.P. Allowance	(£/week)
p'	=	P.H.W.P. Allowance	(£/week)
w^1	=	Wet Time Addition	(%)
c^1	=	Adjustments	
c^{11}	=	Operatives Class Increase	(%)
pb	=	Total Productive Bonus	
fb	=	Total Fall Back Bonus	
gb	=	Total Guaranteed Bonus	
z^1	=	Actual Attendance	(hrs.)

from equation (17)

$$z^1 = Ap + Tfw + pu$$

For 100% incentive scheme

$$pb = b.c^{11}.Ap. \left\{ \frac{\emptyset}{75.0} - 1.0 \right\} \qquad \text{............(23)}$$

$$\text{and} \quad fb = f.(Tfw + pu) \qquad \text{............(24)}$$

$$\text{and} \quad gb = \frac{g.z^1}{z} \qquad \text{............(25)}$$

Therefore, the total Bonus Paid 'Tb' is given by the greater of

$$Tb = \frac{pb + fb}{(z^1 - w)} \text{ or } \frac{gb + fb}{(z^1 - w)} \text{ ---- p/hr.} \qquad \text{.......(26)}$$

The total wage is made up broadly of five segments:-

(1) Overtime

(2) Bonus and Basic

(3) Allowances

(4) Wet Time Addition

(5) Adjustment

Hence, the total labour cost T_C is given by:-

$$Tc = \left[\frac{1.5\ w\ b}{100.0}\right] + \left[\frac{(b + p + Tb)\ (z^1 - w)}{100.0}\right] + \left[c + s + t + tm + n' + h + p'\right]$$

$$+ \left[\frac{wt}{100.0}\left\{\frac{1.5.wb}{100} + \frac{(b + p + Tb)\ (z^1 - w)}{100}\right\}\right] + \left[c^1\right] \quad \ldots (27)$$

Hence the total labour cost (L) for a given period containing '<u>n</u>' activities and '<u>m</u>' categories of labour is:-

$$L = \sum_{j=1}^{j=n} \left\{ \left\{ \sum_{i=1}^{i=m} Cij.Tci \right\} - (nj - naj).\overline{\overline{Cij}}.Tc\bar{i} \right\} \quad .. (28)$$

where '$\bar{i}$' in the latter part of equation 28 is chosen at random from the gang and '$\overline{\overline{Ci}}$' takes the value of zero if there are no operatives of type 'i' present and unity if there are.

5.4 <u>Weekly Summaries (WEEKSUM),(WEEKADD) Programme</u>

These programmes perform two ancillary functions. Firstly WEEKSUM (Figure.55.) sorts the daily performance, production and labour cost data into weekly and activity categories. Secondly WEEKADD (Figure.54.) calculates and outputs to the line-printer the anticipated production information which is summarised in period totals, accumulative period totals, activity totals and accumulative period totals (a typical output produced by WEEKADD is given in

Appendix 4).

5.5 Plant Cost Addition (PLANT1) Programme

A maximum of ten types of plant per activity are analysed by this programme (Figure.55.), the plant cost for a single activity 'j' occurring in a single weekly period being given by:-

$$Cpj = \sum_{i=1}^{i=10} . (cpi + bpi).Npij \quad ....(29)$$

where

Cpj = Total plant cost for a single weekly period

cpi = Unit cost of plant type 'i'

bpi = Unit bonus for plant type 'i'

Npij = Number of plant type 'i' in activity 'j'

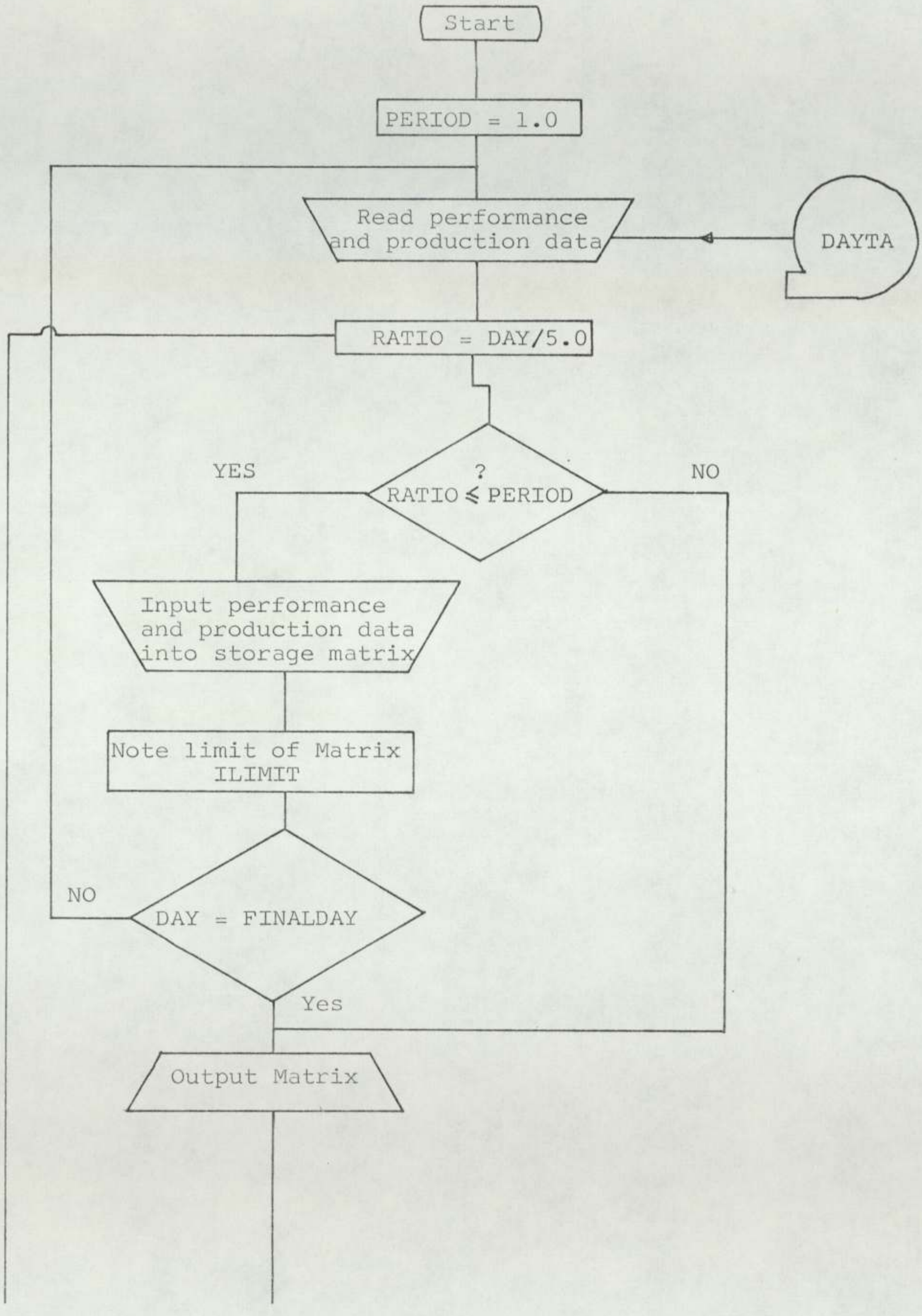
Activity and week number information is used from files LCOSTA and COUNT to produce a new file LPCOSTA. Plant hire rates per week or per hour are accepted by the programme. The labour cost file LCOSTA is retained so that amendments can be made to the plant data without having to re-run the whole of the simulation programme.

5.6 Material Cost Addition (MATERIAL) Programme

This programme (Figure.56.) calculates and adds the anticipated material costs to the previously created LPCOSTA file to create LMPCOSTA.

Material and transport costs per specified quantity are required by the programme, the material cost for 'm' types of material per activity being calculated in the following way:-

WEEKSUM


Start
PERIOD = 1.0
Read performance and production data
DAYTA
RATIO = DAY/5.0
?
RATIO ≤ PERIOD
YES
NO
Input performance and production data into storage matrix
Note limit of Matrix ILIMIT
DAY = FINALDAY
NO
Yes
Output Matrix

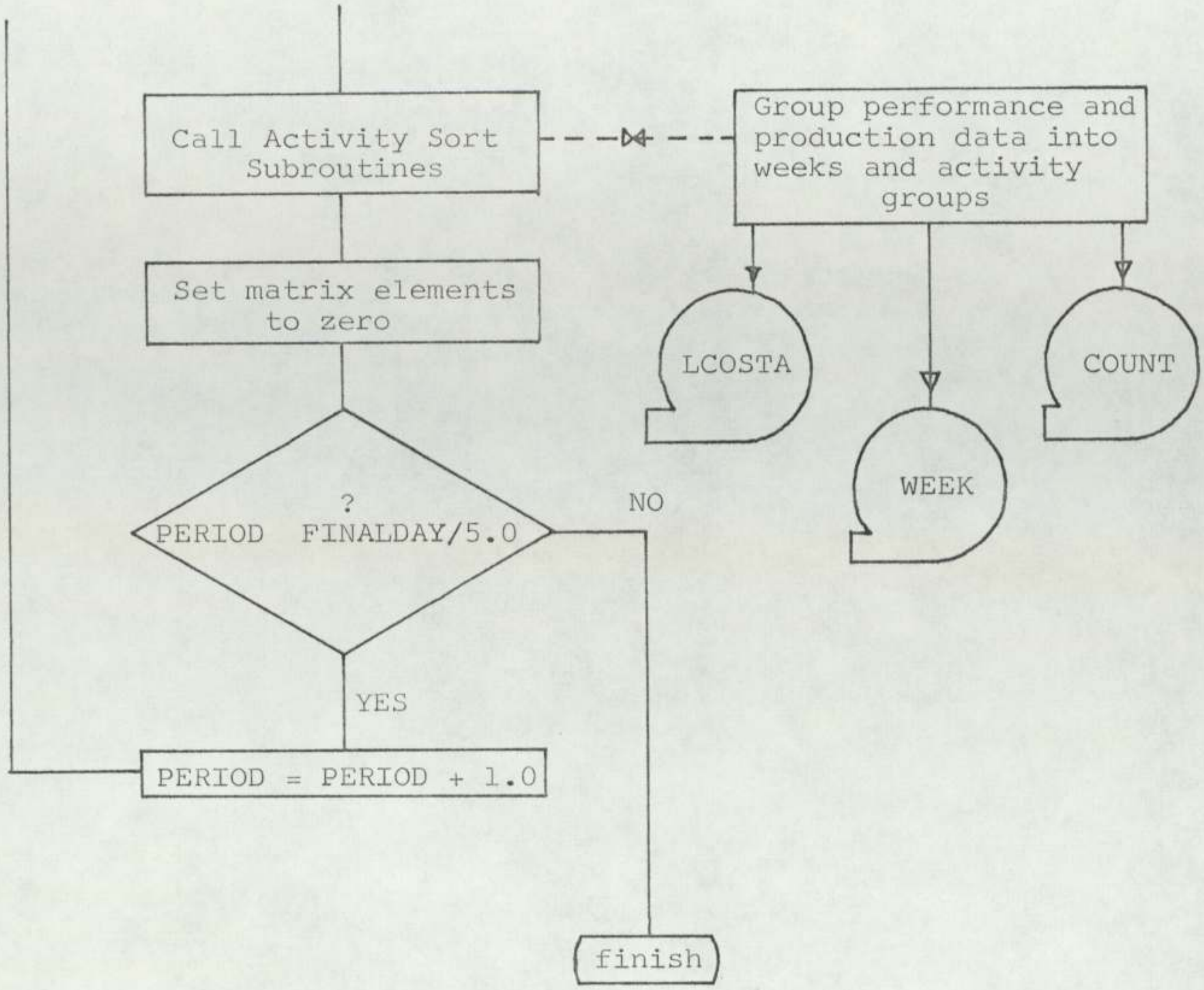

Call Activity Sort Subroutines
Group performance and production data into weeks and activity groups
Set matrix elements to zero
LCOSTA
WEEK
COUNT
?
PERIOD FINALDAY/5.0
NO
YES
PERIOD = PERIOD + 1.0
finish

Figure.53.

WEEKADD

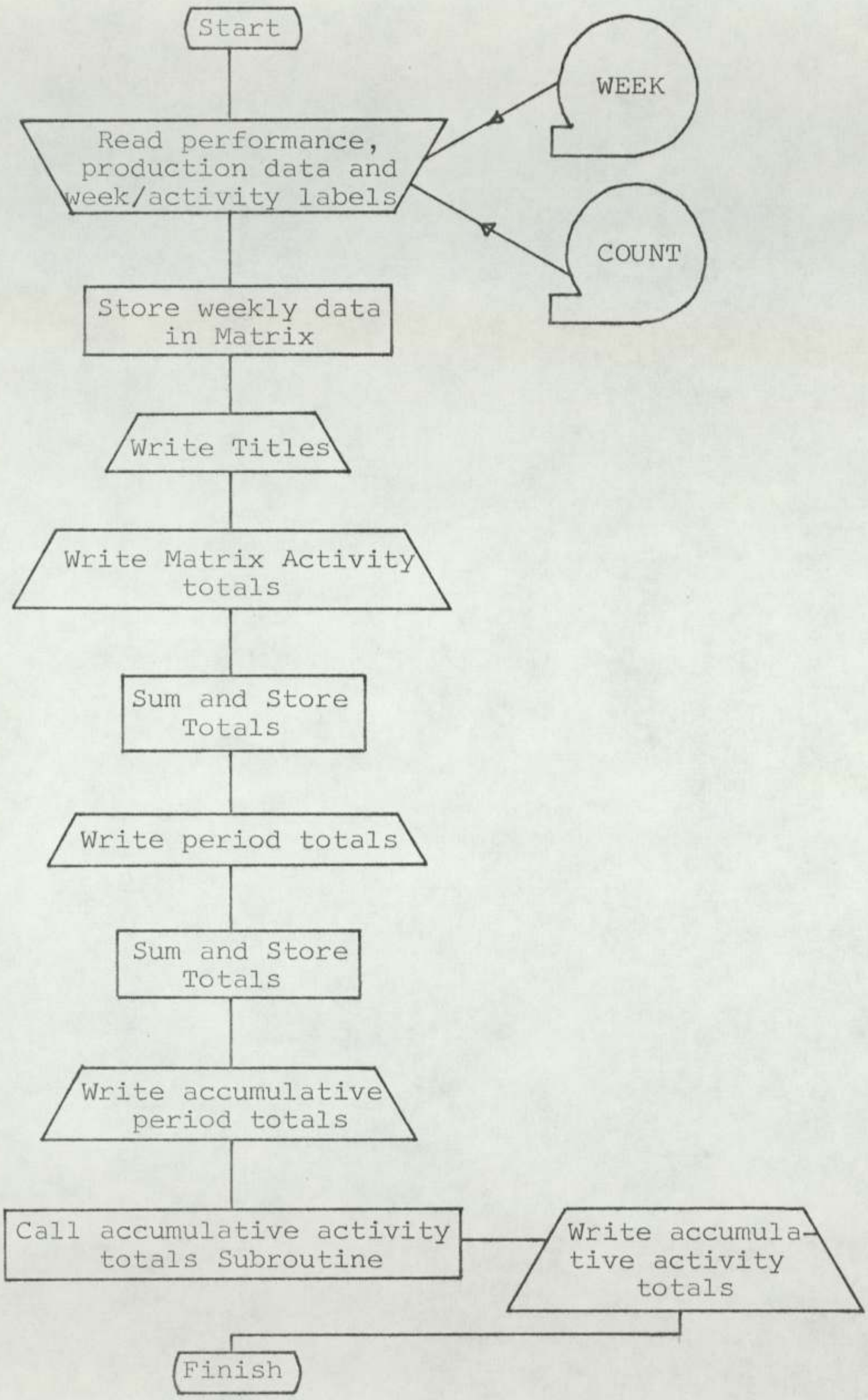


Figure.54.

PLANT 1

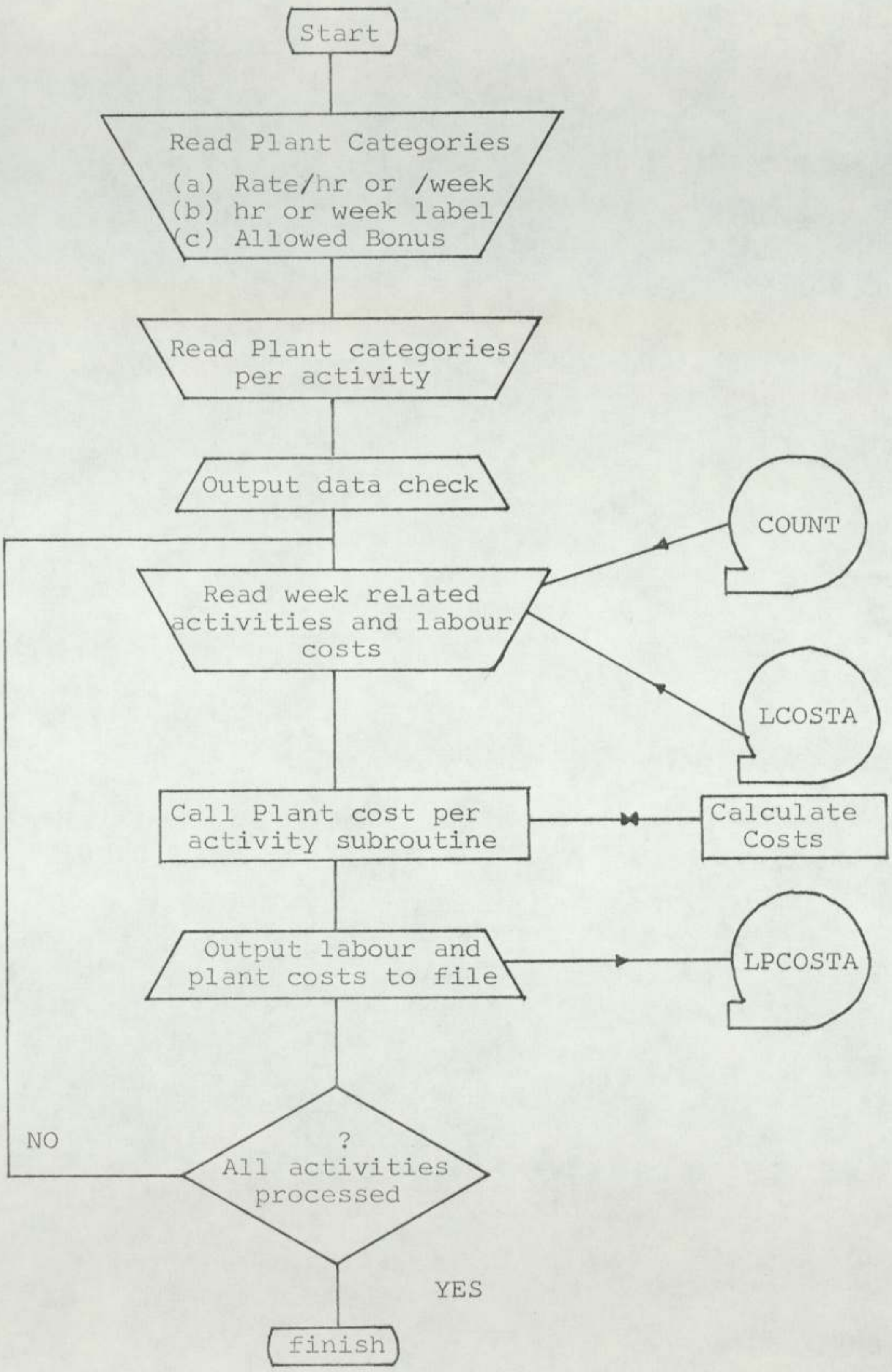


Figure.55.

$$Cmj = \frac{q}{Q} \cdot \sum_{i=1}^{i=m} \cdot xij.(cmi + Tmi) \quad \ldots\ldots\ldots\ldots (30)$$

where

xij = Quantity of material type 'i' in activity 'j'

cmi = Unit cost of material type 'i'

Tmi = Unit cost of transport for material type 'i'

Cmj = Total material cost for a single weekly period for activity 'j'

If required, the programme calculates material cost increases from anticipated percentage increases. The increases may be applied to all or some of the material types in any predetermined period range, a linear increase being assumed between the period range limits. If the period in which the material is used is underestimated, then the material is assumed to increase in cost at a rate given by the previous cost increase period used by the programme.

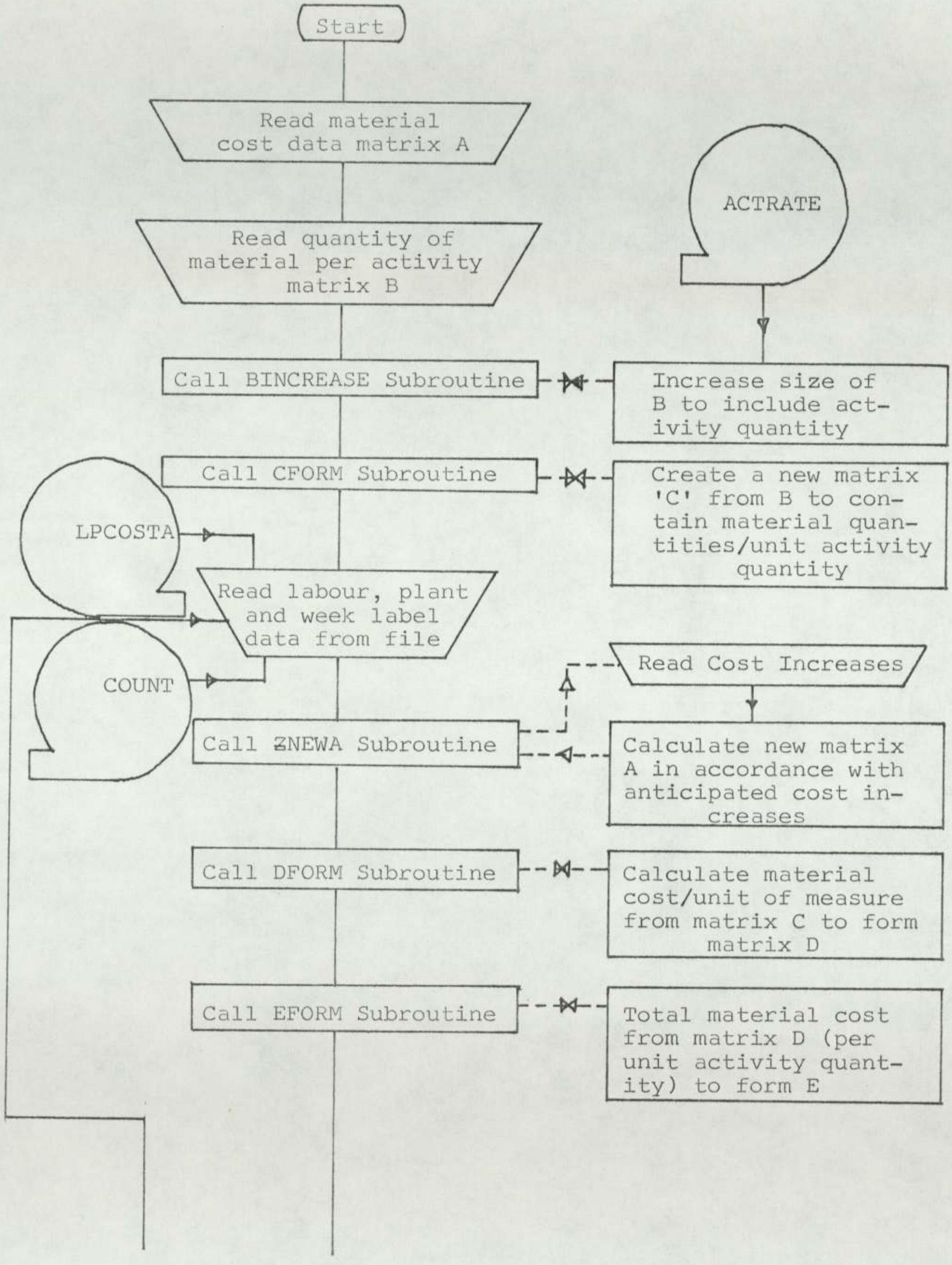
5.7 Sub-Contractor Cost Addition (SUBCONTRACTORS) Programme

Sub-contractor costs are calculated using a similar programme structure to that used for material cost addition. However, increased sub-contractor costs are not included at this stage.

The programme reads from files LMPCOSTA and COUNT to form LMPSCOSTA, LMPCOSTA being retained for possible future use.

Refer to Figure.56. and section 5.6 for the programme's flow diagram and theory.

MATERIAL/SUBCONTRACTORS



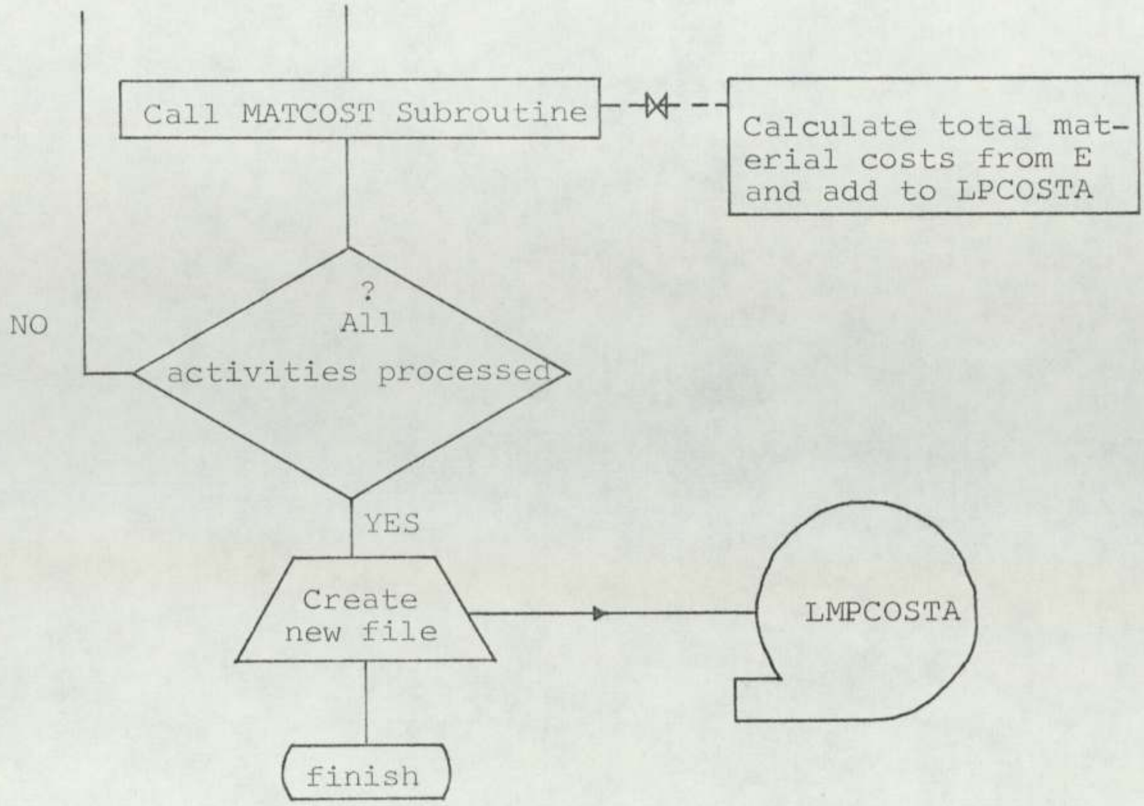

Call MATCOST Subroutine
Calculate total material costs from E and add to LPCOSTA
NO
?
All
activities processed
YES
Create
new file
LMPCOSTA
finish

Figure.56.

5.8 Preliminaries Cost Addition (PRELIMS) Programme

Preliminaries costs, which are time bases costs (Supervision, Multi-purpose Plant etc.), are calculated and stored on file LMPSPCOSTA.

The programme (Figure.57 .) apportions preliminaries costs over specified activities and period ranges. An unlimited number of preliminaries may be processed. On completion of the simulation, this programme can be used to re-arrange the amount of money applied to any activity at any time period.

5.9 SUMMARY Programme

This programme (Figure.58.) uses the information stored on file LMPSPCOSTA. The information is stored and anticipated labour, plant, sub-contractor and preliminaries cost increases are applied and the results re-stored and output to the line-printer. The summary produced contains activity totals, accumulative activity totals, period totals and accumulative period totals. Subsequently, two tables are produced which give the total net cost and net cost rate for each activity. A typical output summary is given in Appendix 4.

5.10 The Influence of Varying Performance on Activity Duration

Two groups of tests were carried out using the simulation programme. In each, a single activity is considered in preference to a set of interdependent activities which would occur in reality. The object of the first group of

PRELIMINARIES

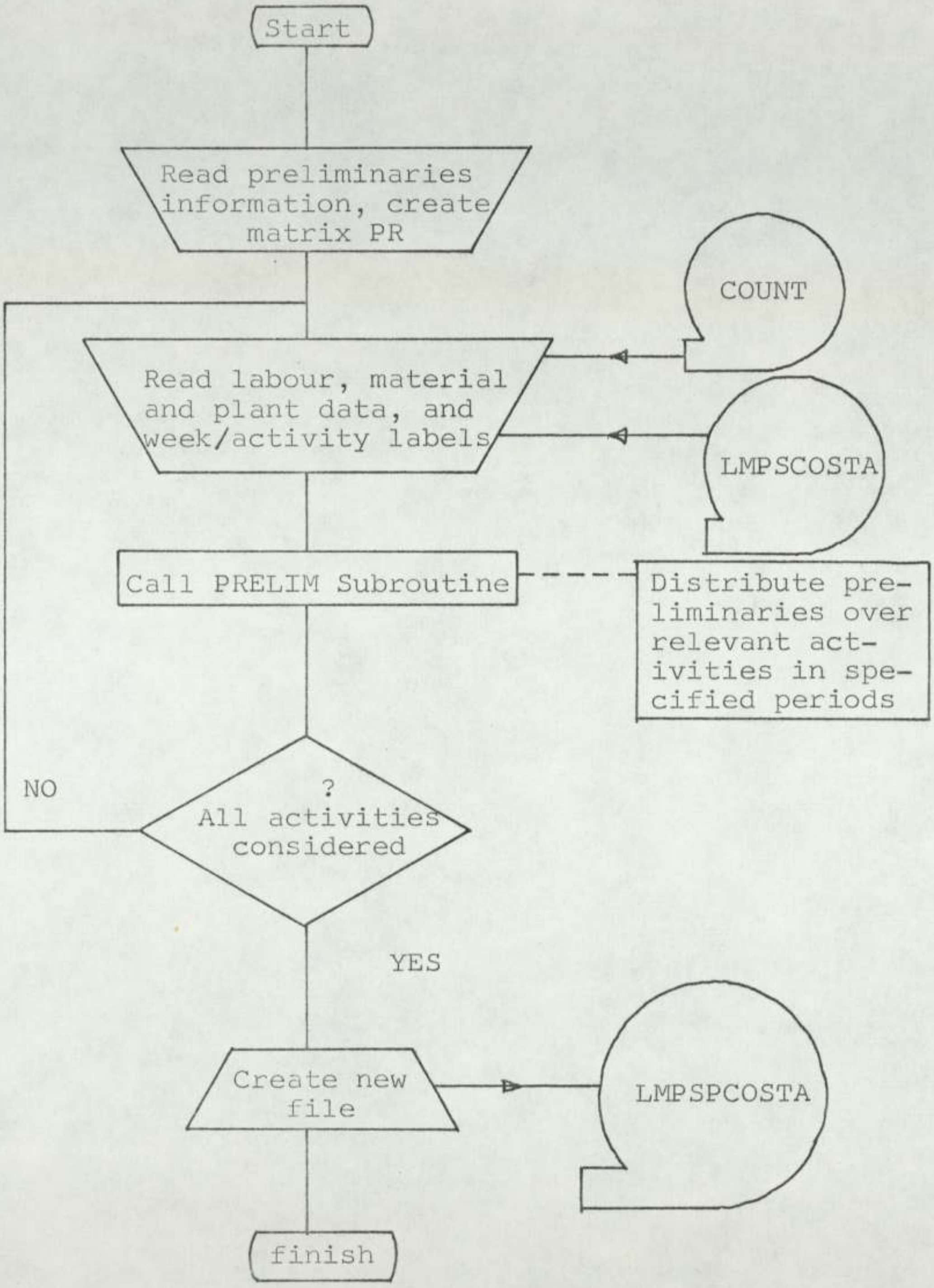
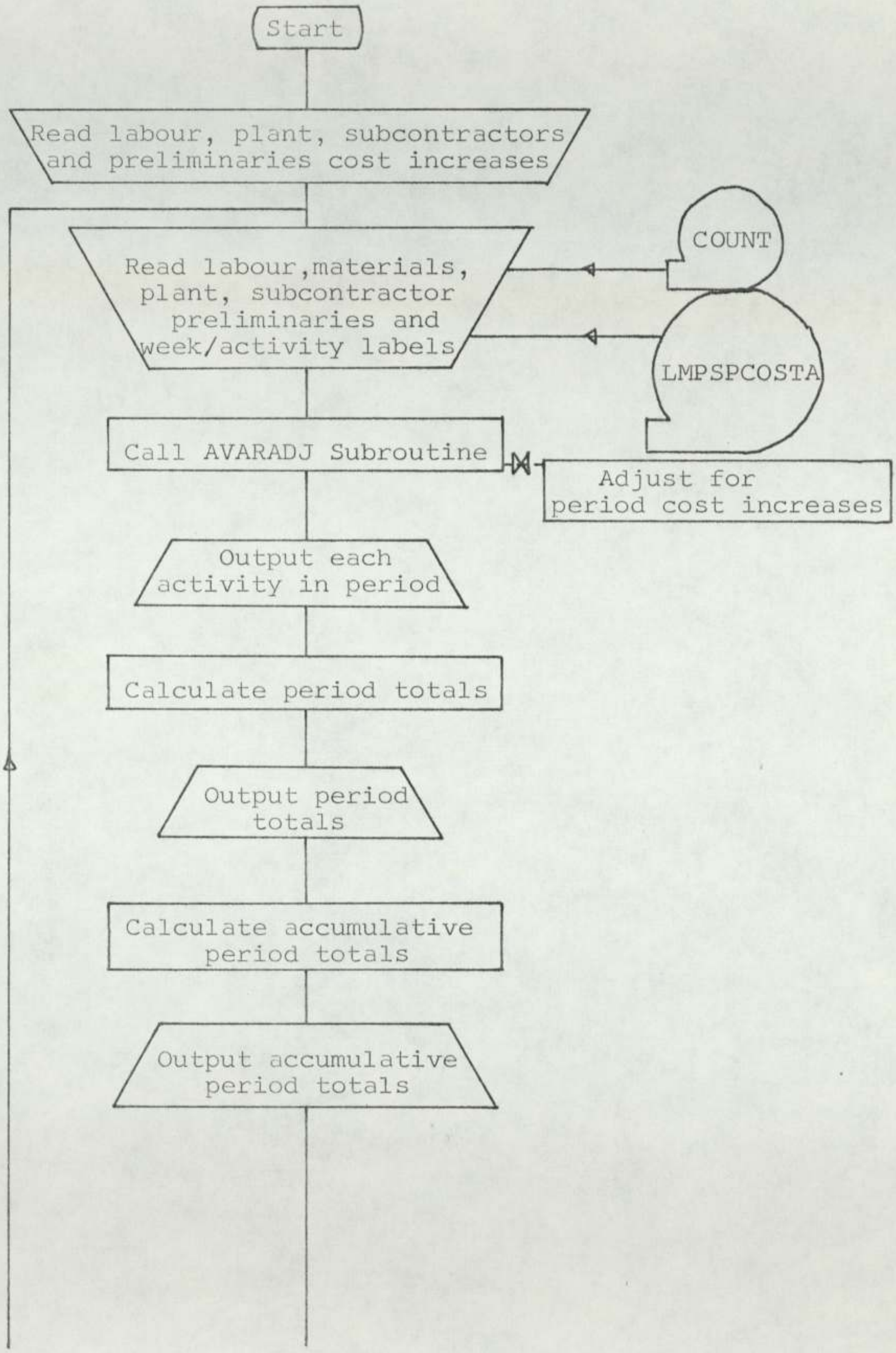


Figure.57.

SUMMARY


Start
Read labour, plant, subcontractors and preliminaries cost increases
Read labour,materials, plant, subcontractor preliminaries and week/activity labels
COUNT
LMPSPCOSTA
Call AVARADJ Subroutine
Adjust for period cost increases
Output each activity in period
Calculate period totals
Output period totals
Calculate accumulative period totals
Output accumulative period totals

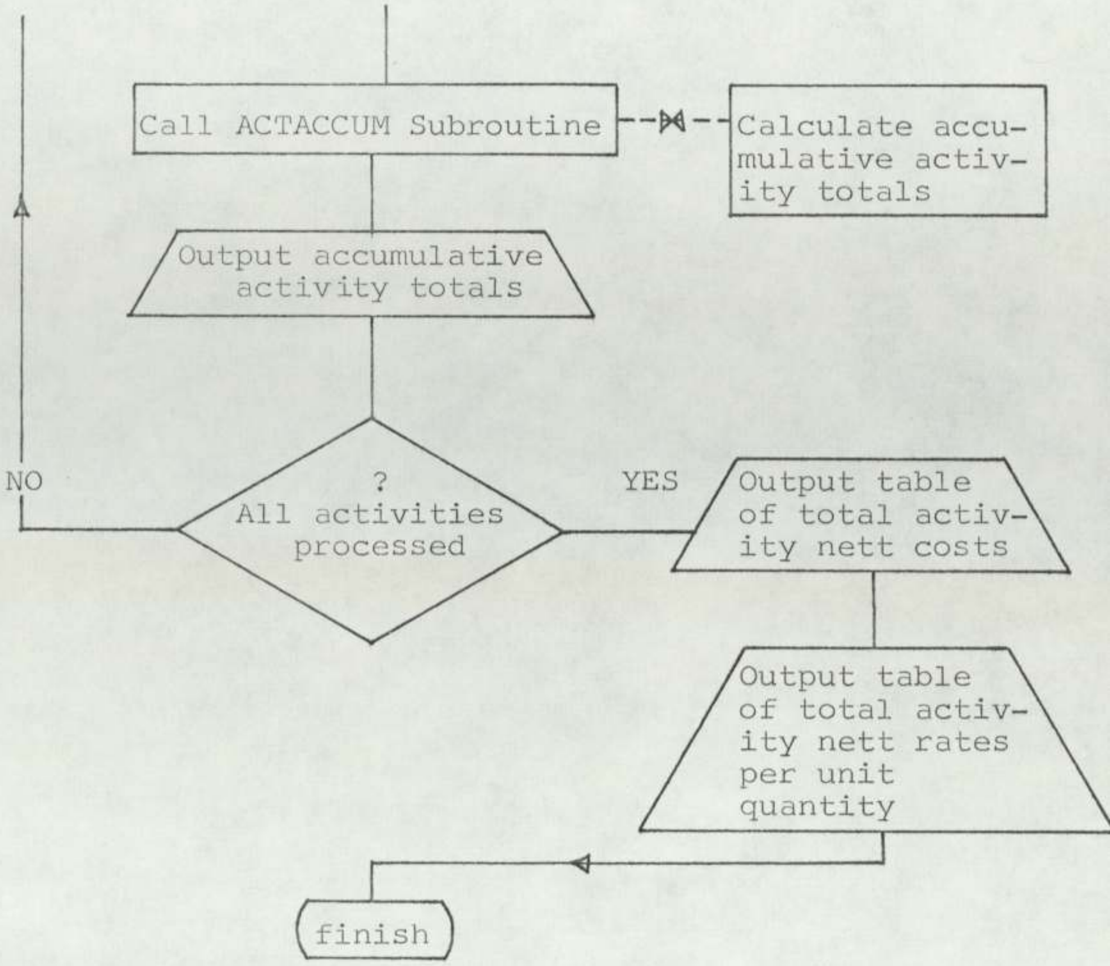

Call ACTACCUM Subroutine
Calculate accumulative activity totals
Output accumulative activity totals
NO
?
All activities processed
YES
Output table of total activity nett costs
Output table of total activity nett rates per unit quantity
finish

Figure.58.

tests is to show the relationship between the standard deviation of both the operative and site performance indices (which are assumed equal for simplicity), and the percentage addition necessary to convert standard duration into actual anticipated duration. The second group of tests are designed to show the effect of absenteeism and gang overloading on the percentage addition to standard duration.

5.10.1 Percentage Addition to Standard Duration for Varying OPI and SPI only

The mean operative performance index (OPI) is set to 100 and 90 for mean site performance indices of 70, 75, 80 and 85. In these tests, the mean productive unmeasured time and mean absenteeism are assumed to be zero with zero standard deviations. Both the standard deviations of the OPI and SPI distributions are assumed equal, the assumption being justified by the performance data distribution given earlier in Chapter three.

Currently, Estimators and Planners use an OPI of 100, an SPI of 75, with a 60% addition to standard duration to determine the anticipated duration. They do not consider the standard deviations of the distribution, neither do they consider the effect of productive unmeasured time and absenteeism. It can be seen from Figure.59. that an error of 5 in the standard deviation of the OPI and SPI distribution can lead to a ± 9.5% difference in activity duration, when considering a mean SPI of 70. However, if a mean SPI of 85 is attained, the error is reduced to approximately 5% (a decrease of 4.5%). As one would expect, the error

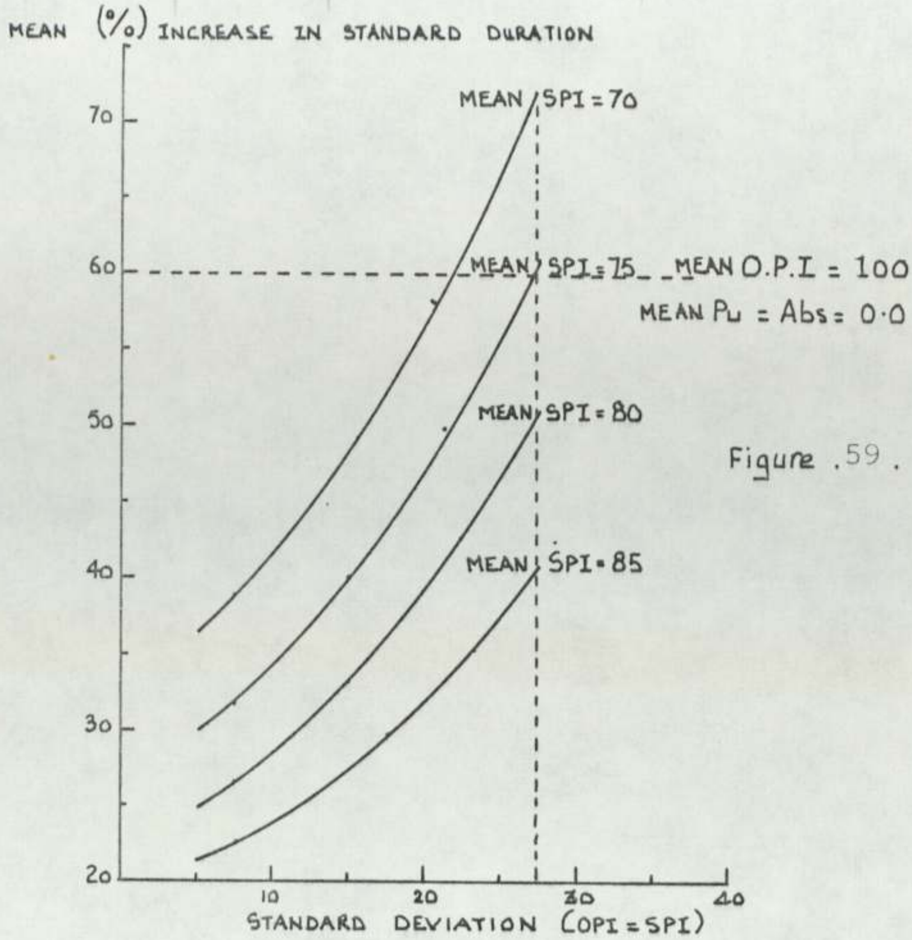


Figure .59 .

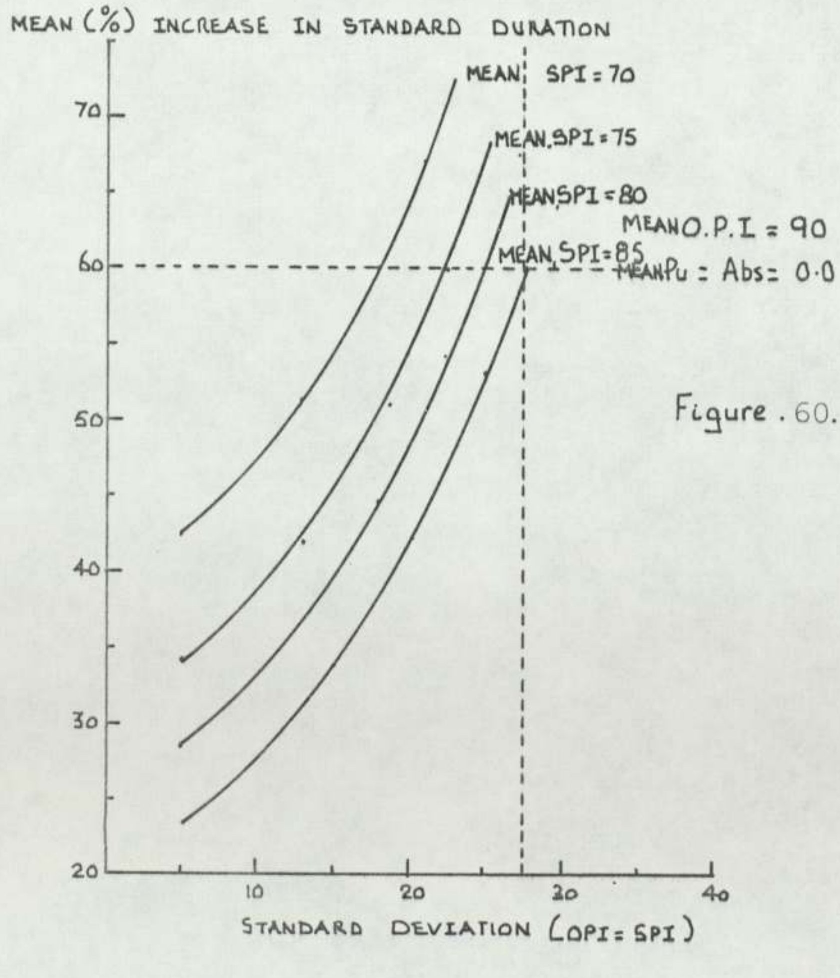


Figure . 60.

is increased even further as the mean OPI is reduced from 100 to 90 (Figure.60.). The gradients of the curves are also increased and above a standard deviation of 10, an error of 5 in the standard deviation results in an error of approximately ± 10% in duration, an error which is fairly constant no matter what the value of SPI.

The performance data presented in Chapter three indicates that both the SPI and OPI distributions for tradesmen and labourers have standard deviations in excess of 20 and mean values of OPI scattered around 90. Hence, Figure.60. represents the overall divisional performance more closely than Figure.59. The percentage addition of 60% used by Estimators and Planners is shown dotted. The mean standard deviation observed for the Division is 27.5 (Chapter 3) at an OPI of 90 and an SPI of 75, indicates (Figure.60.) that the mean percentage adjustment currently used is inadequate and should be increased to at least 76%. It should be remembered that in this series of tests, the mean productive unmeasured time and the mean absenteeism is assumed to be zero (so too are their respective standard deviations), hence the mean percentage addition of 76% is an underestimate of the true addition necessary.

5.10.2 Percentage Addition to Standard Duration for Varying OPI, SPI, Productive Unmeasured time and Absenteeism

This second group of tests assumes a mean OPI of 90 with a standard deviation of 29 (divisional values), and SPI's of 80 and 70 with standard deviations of 26. Productive unmeasured time is included but assumed constant at a mean of 10% and a standard deviation of 3% (the divisional mean being 9.55%). However, mean absenteeism is varied from +10% through zero to -10%, the standard deviation remaining constant at 3% for simplicity (Figures.61. and .62.). As one would expect, as the mean SPI decreases from 80 to 70, the effect of absenteeism increases - the whole management situation is deteriorating. At zero absenteeism, the mean percentage addition required increases from 76% to 87%, the increase of 11% being caused by the 10% productive unmeasured time now included. The mean percentage addition is increased still further to 91% if a mean absenteeism of 1% - the mean value for the Division, is included.

The curves obtained indicated that absenteeism affects production at a greater rate than gang overloading (from Figure.62. 10% absenteeism would increase the standard duration by 158% whilst a similar gang overloading would increase the standard duration by 141%). This occurs because absenteeism affects the available productive time immediately it occurs. However, gang overloading affets production indirectly through the SPI.

It is clear that the current mean percentage addition of 60% used by Estimators and Planners is an under-estimate of what occurs on most sites. It is also clear that a mean percentage addition of 91% derived in this Chapter would over-estimate what actually occurs on some sites. Therefore, in order to reach a solution nearer reality, each project

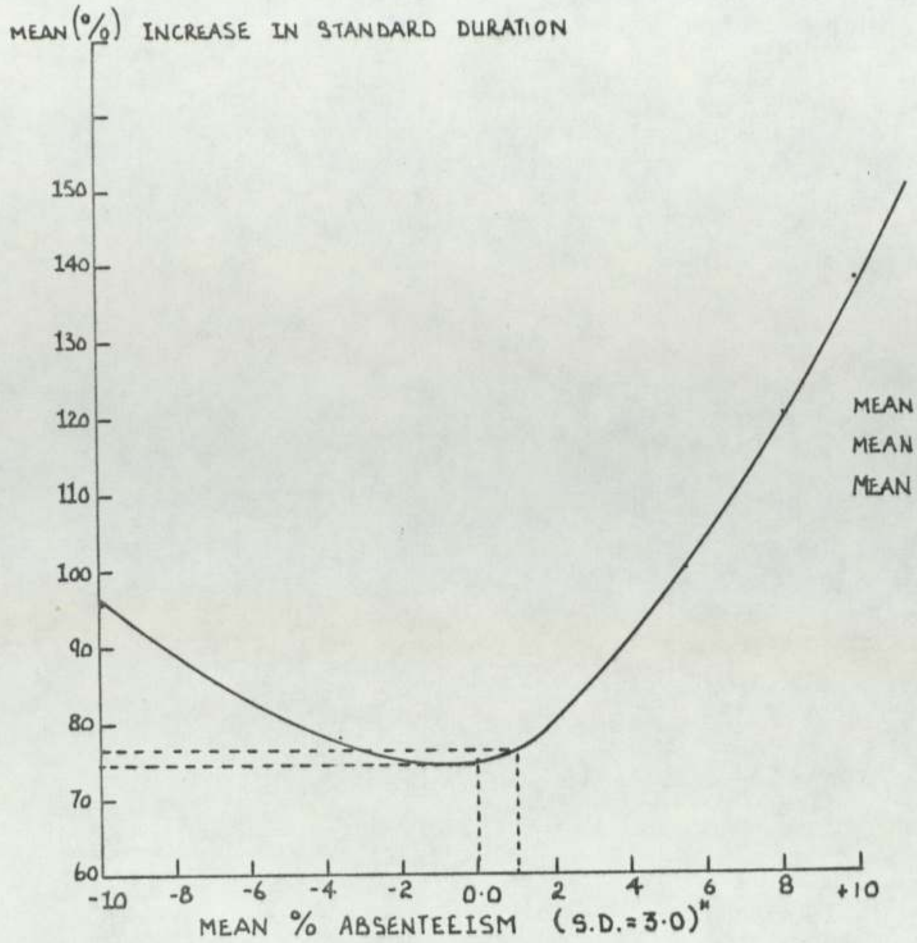


Figure . 61.

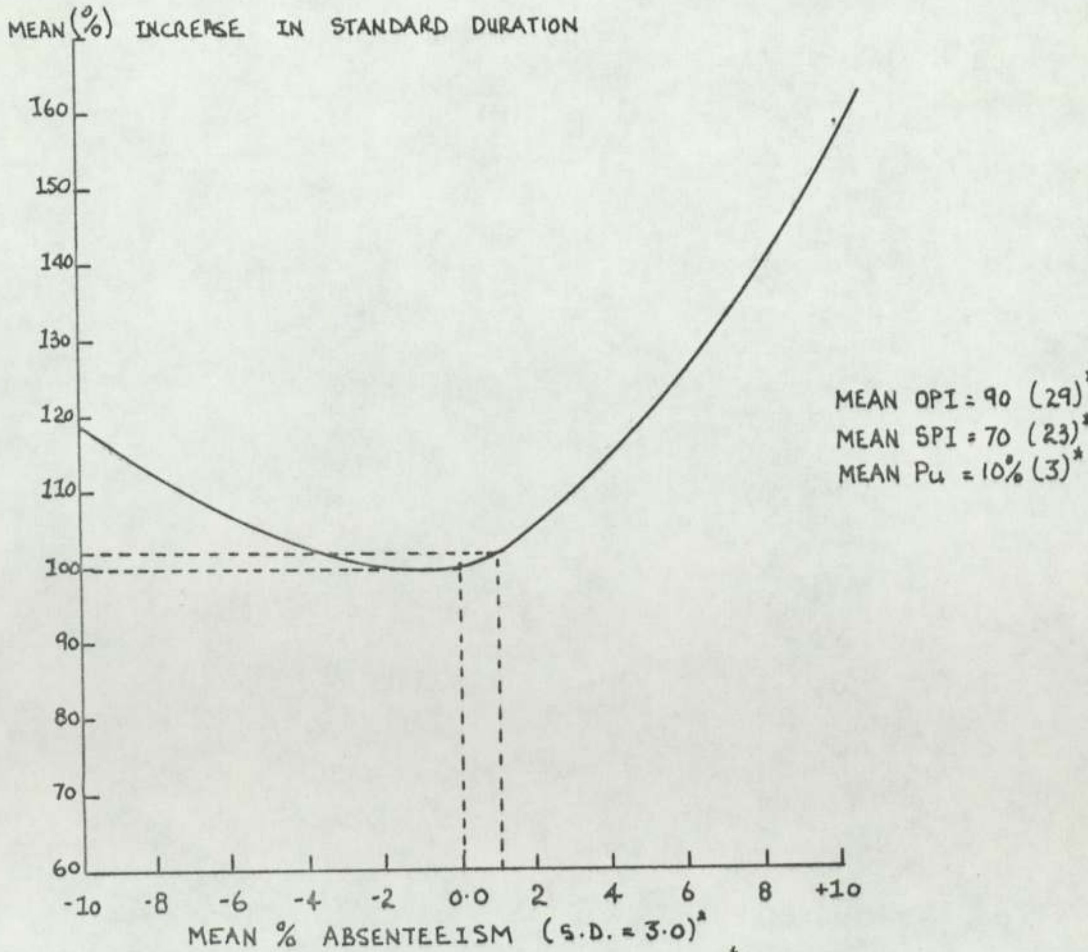


Figure . 62.

* STANDARD DEVIATION.

must be treated separately, using the simulation programme and utilising several previous sites' data as a guide to the anticipated variations in performance.

5.11 River Bridge Simulation

The following study is an analysis of a small river bridge using the computer simulation suite. The bridge forms part of a large roadworks scheme currently being constructed by the Division.

The bridge has a single span deck 8 m in length constructed from pre-cast concrete beams which are simply supported on cast insitu reinforced concrete abutments.

Three studies were carried out using selected items of the performance data given in Chapter three (Tables.3., .4.,.7.) to produce a mean, pessimistic and an optimistic value for the river bridge.

The results of the simulation are given in Tables.13., .14. and .15.

It can be seen from Table.13. that the gross mean value produced by the simulation is only £210 less than that calculated manually by the Estimator. However, this is due to the increased labour value produced by the simulation being compensated for by the decrease in value of the preliminaries produced by the decrease in the construction time. The value of material and sub-contractors' work produced by both the simulation and the Estimator are similar as they are independent of construction duration given a constant price.

At optimistic and pessimistic levels of performance

(Tables.14,.15.), the gross mean value of the work produced by the simulation indicates a possible 9% decrease and 20% increase in value respectively, a population range of 29% of the gross mean value. Individual samples of the population exhibit an average range of 4.5% of their respective gross mean values.

The amount of performance information obtained during the research is insufficient to permit the degree of risk associated with an estimate to be established. However, the results produced do show that changes in performance level significantly affect the estimate, irrespective of the possible additional affect of such unpredictable uncertainties as material shortages, labour shortages and strikes.

As explained earlier, the computer simulation suite follows the estimating procedures used in the Division. The simulated estimate is arrived at using the anticipated sequence of work. In so doing, it formally links the planning and estimating functions, thereby ensuring that the Planner and Estimator use the same work outputs and material and plant rates.

Estimating by computer simulation does not increase the accuracy of an estimate, nor does it increase the probability of obtaining an individual contract. However, its speed and flexibility enables the Planner and Estimator to concentrate on the overall construction strategy, to process several possible schemes quickly and to assess the financial implications of different levels of performance and changes in labour, material and plant rates. Once the contract is obtained, the simulation suite is capable of helping management to assess and predict the financial outcome of the scheme using actual performance distributions obtained from site, hence formally connecting pre-contract appraisal and post-contract production.

DESCRIPTION	SIMULATION				MANUAL	PROJECTED	UNIT
	MEAN VALUE	MINIMUM VALUE	MAXIMUM VALUE	STANDARD DEVIATION	ESTIMATE	ACTUAL	
Duration	27.46	26.00	29.00	0.82	30	26 to 30	weeks
Labour	5949.71	5801.70	6223.50	121.99	5016.39	5500	£
Unit Labour	1.20	1.17	1.26	0.03	1.18	1-20	£/hr.
Material	8265.78	8224.34	8307.79	31.94	8089.77	8150	£
Plant	1459.47	1307.65	1750.95	139.98	1127.20	800	£
Subcontractors	6281.54	6262.06	6297.97	12.45	6399.13	)	£
Preliminaries	6459.42	6115.98	6821.67	318.39	7997.74	)Unknown	£
Net	21956.50	21784.20	22398.40	196.08	20632.49	)	£
Gross	28415.92	27900.18	29220.07	422.14	28625.23	)	£

OPI = 101(19), SPI = 90(17.5), PU = 10(3), A/O = 1.0(3.0)

MEAN PERFORMANCE

TABLE.13.

DESCRIPTION	SIMULATION				MANUAL	PROJECTED	UNIT
	MEAN VALUE	MINIMUM VALUE	MAXIMUM VALUE	STANDARD DEVIATION	ESTIMATE	ACTUAL	
Duration	21.20	21.00	22.00	0.45	30	26 to 30	weeks
Labour	5159.92	5007.98	5316.20	131.84	5016.39	5500	£
Unit Labour	1.27	1.24	1.28	0.02	1.18	1.20	£/hr.
Material	8266.01	8225.02	8307.05	29.00	8089.77	8150	£
Plant	1290.42	1141.50	1388.65	91.56	1127.20	800	£
Subcontractors	6280.04	6265.13	6295.07	10.61	6399.13	) Unknown	£
Preliminaries	4986.88	4939.83	5175.06	172.57	7997.74	) Unknown	£
Net	20996.38	20880.31	21306.96	177.62	20632.49	) Unknown	£
Gross	25983.26	25820.14	26482.02	197.30	28625.23	) Unknown	£

OPI = 115(5), SPI = 95(5), PU = 1.0(0.3), A/O = 0.1(0.03)

<u>OPTIMISTIC PERFORMANCE</u>

TABLE.14.

DESCTIPTION	SIMULATION				MANUAL	PROJECTED	UNIT
	MEAN VALUE	MINIMUM VALUE	MAXIMUM VALUE	STANDARD DEVIATION	ESTIMATE	ACTUAL	
Duration	37.43	36.00	40.00	1.40	30	26 to 30	weeks
Labour	7377.30	7096.33	7626.46	205.64	5016.39	5500	£
Unit Labour	1.14	1.11	1.19	0.03	1.18	1.20	£/hr.
Material	8293.22	8257.23	8307.09	22.04	8089.77	8150	£
Plant	2036.85	1810.72	2569.55	249.66	1127.20	800	£
Subcontractors	6289.34	6277.00	6294.29	7.47	6399.13	Unknown	£
Preliminaries	8804.66	8468.28	9409.2	539.14	7997.74		£
Net	23997.29	23649.55	24795.20	404.34	20632.49		£
Gross	32801.95	32117.83	34204.4	837.76	28625.23		£

OPI = 91.76(28.83), SPI = 76.30(26.34), PU = 10(3), A/O = 1(3)

PESSIMISTIC PERFORMANCE

TABLE.15.

CHAPTER 6

VALUE-COST MONITORING AND FEEDBACK

Summary

An analysis of the existing Post-Contract Financial Monitoring System to produce a computer aided Value-Cost Monitoring and Feedback System to be adopted by the Company

CHAPTER 6

VALUE-COST MONITORING AND FEEDBACK

6.1 Introduction

During the past decade, the size and complexity of civil engineering projects has dramatically increased. This, coupled with unparalleled increases in the cost of resources, has highlighted the inadequacies which exist in current manual value-cost monitoring systems.

The current post-contract financial monitoring system used by the company is manual and capable of producing global value-cost analyses for individual projects and company divisions. However, they are produced at erratic intervals throughout the year and the results are often criticised by management for being inaccurate, out of date and incapable of allowing them to isolate specific operations which are not profitable.

Although computer facilities (in the form of standard pre-written bureau packages) for value-cost monitoring have been available for several years, their successful introduction into the civil engineering industry has been limited. The writer considers that this is due, in the first instance, to management's lack of detailed knowledge about the system which they are attempting to computerise and hence they expect too much from the system. It is also due to Computer Bureaus over-selling standard computer packages, giving management the impression that they will fit any company and cure all systems' shortcomings.

This chapter examines the current manual post-contract financial monitoring system and establishes the existing methods of information, presentation and transfer. A new computer aided system is then proposed and its introduction into the company discussed.

6.2 The Current Post-Contract Financial Monitoring System

Broadly, this may be split into four sub-systems, the first dealing with value monitoring and the remainder, cost monitoring. They are:-

(1) The Value Monitoring Sub-System

(2) The Labour Cost Monitoring Sub-System

(3) The Material Cost Monitoring Sub-System

(4) The Plant Cost Monitoring Sub-System

6.2.1 The Value Monitoring Sub-System (Figure.63.)

This is the sole responsibility of the Quantity Surveying Department and is known as interim valuation and certification. The quantity of completed work, materials on site and the pertinent preliminary items are periodically assessed in a standard way (laid down by the standard method of measurement stipulated by the client or client's representatives). The value is then determined (from the rates given in the Bills of Quantity) and the results sub-

Value Monitoring Sub-system

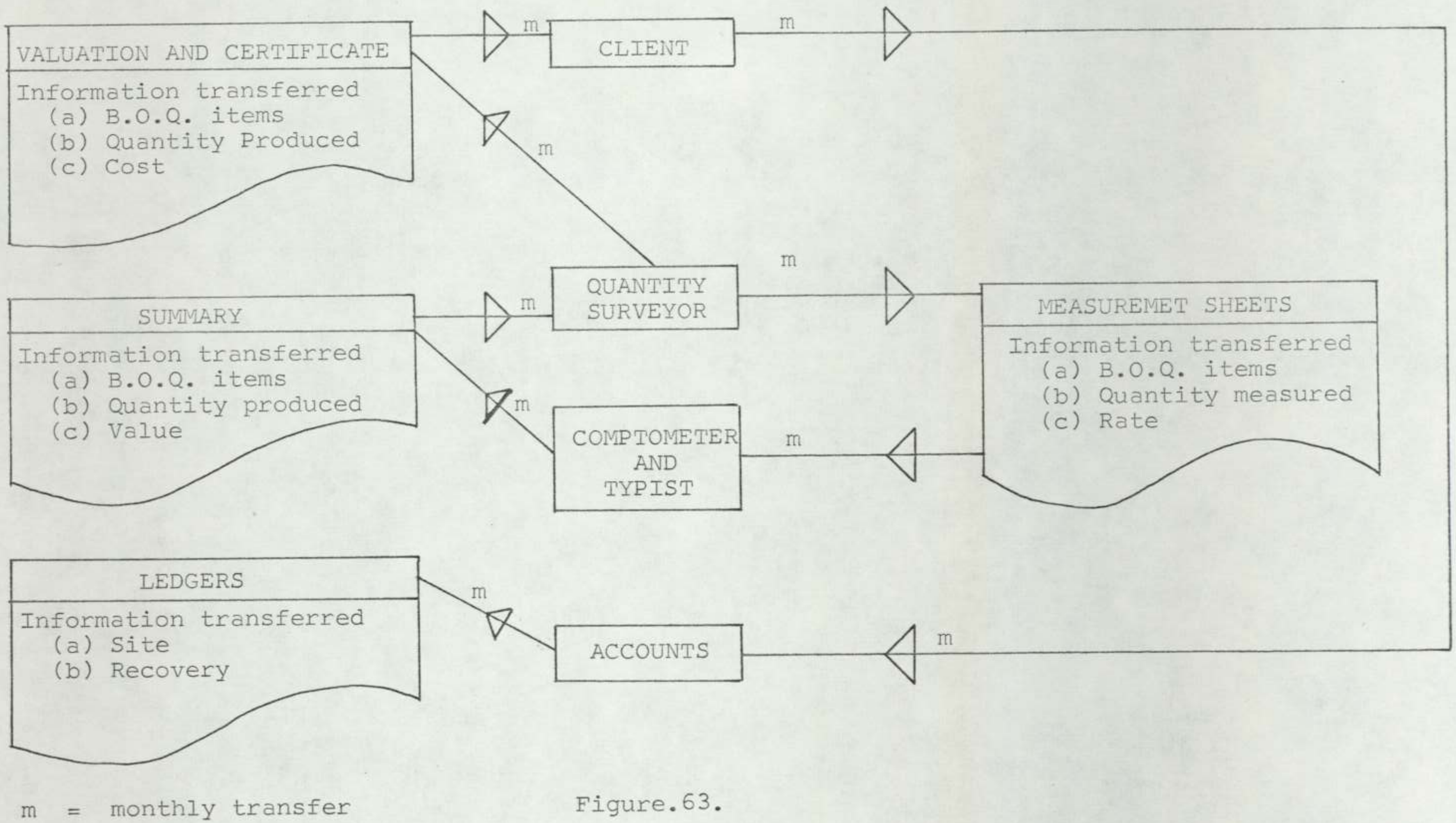


Figure.63.

mitted to the client for payment, who deducts retention and any money he feels the contractor has not earned. The resultant money (usually termed Recovery by contractors) is then paid to the contractor.

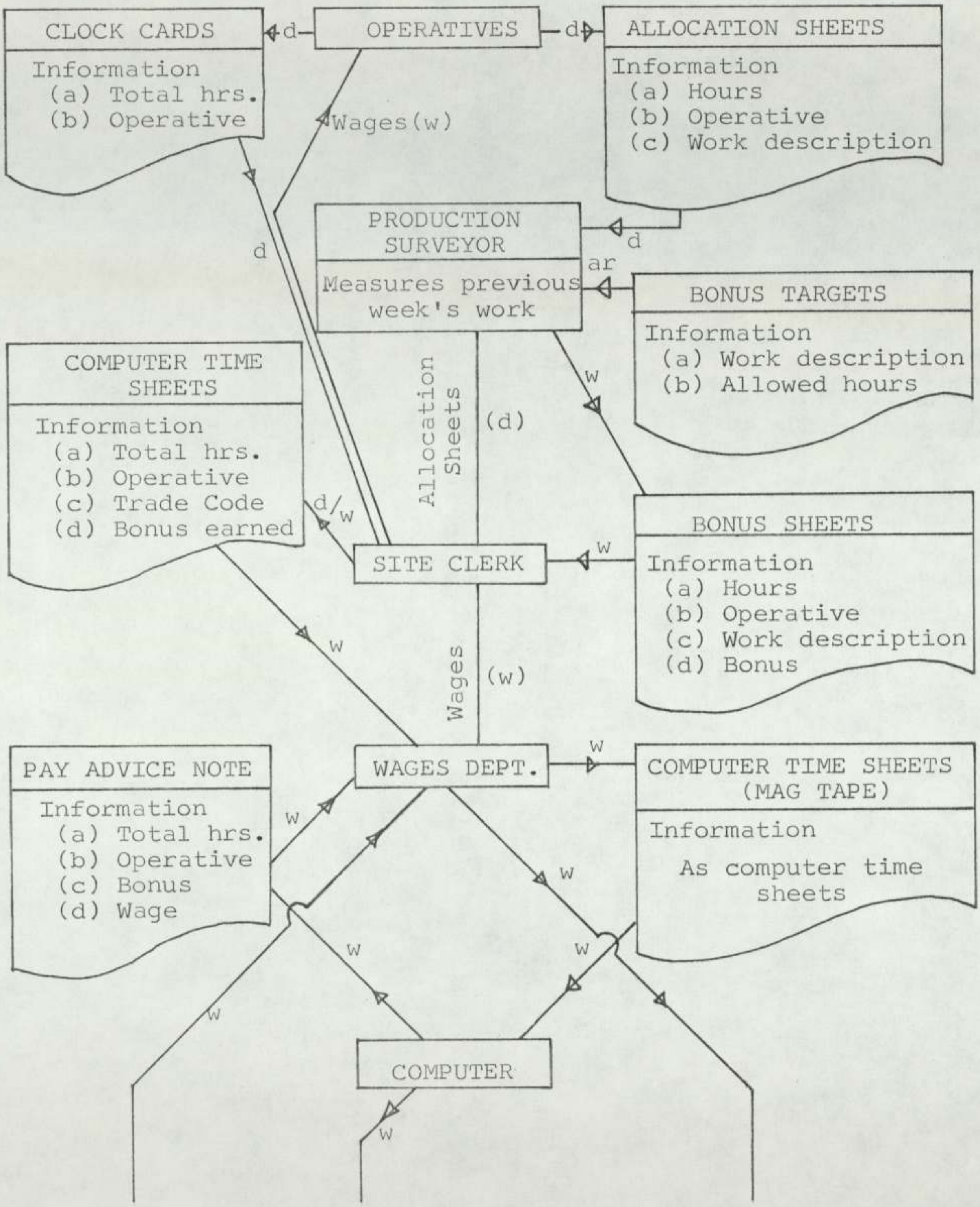
The process of interim valuation and certification (Figure.63.) is repetitive and usually takes three to four weeks, 75% of which is devoted to value calculation and re-typing the relevant Bill sections. In addition, the client may take a similar period of time to pay. A period of 1½ to 2 months between the end of the valuation period and receipt of the recovery from the client is common and there are obvious benefits to the contractor if the period can be reduced.

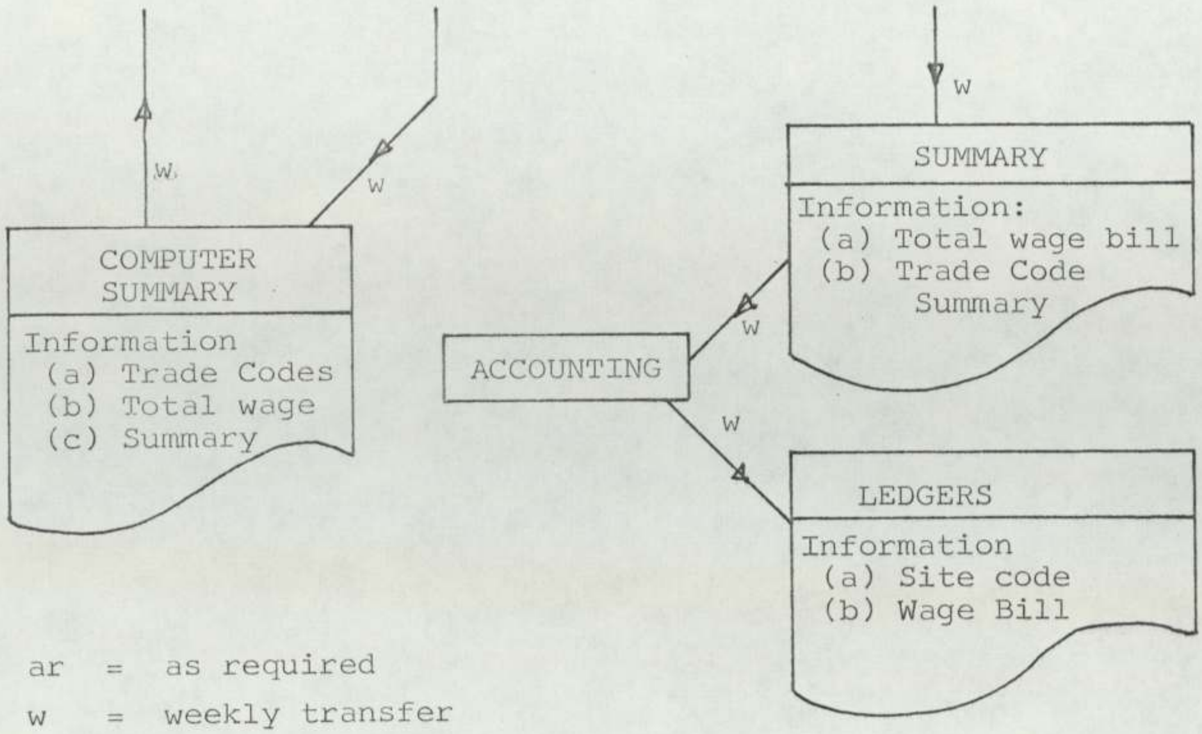
6.2.2 <u>The Labour Cost Monitoring Sub-System</u> (Figure.64.)

The wage payroll is currently calculated by computer. The programme used is one of a suite produced by BARIC Computing Services Limited.

The programme calculates the weekly wage bill and produces the necessary pay advice slips and a labour cost summary which shows total labour costs grouped into trade categories. The bonus earned is calculated on site by Production Surveyors the week after the work is completed. This means that the basic wage (the wage independent of production rate) earned by the operative is contained on a summary with his previous week's earned bonus. The error created by this procedure can be as large as ± 33% when analysing weekly figures, but gradually reduces when accumulative labour costs are analysed.

Labour Cost Monitoring Sub-System





ar = as required

w = weekly transfer

d = daily transfer

Figure.64.

Allocation of the type of work completed is solely dependent upon the operative's willingness to describe the work adequately and allocate the correct time taken. Random checks indicated that most operatives allocate work taking longer than 15 minutes to complete and combine smaller work elements into broad categories. The errors associated with this method of allocation can be substantial if the Allocation Sheets are not constantly checked by the production staff. However, more sophisticated methods of allocation, such as Job Card Allocation, require additional supervisory staff, hence savings would probably be negligible.

6.2.3 <u>The Material Cost Monitoring Sub-System</u> (Figure. 65.)

Materials delivered to the site are received and documented by the Site Clerk. The details given on the delivery note, together with the anticipated cost (supplied by the Buying Department) are entered on Daily Return of Material Forms (D.R.M's). This procedure takes no account of where the material is to go on site or for which operation it is required. The D.R.M's are periodically sent to the Invoice Department where they are checked against the invoices sent by the suppliers. A summary of invoices containing the project and the supplier's name is then sent to the Accounts Department for payment and documentation.

6.2.4 <u>The Plant Cost Monitoring Sub-System</u> (Figure.66.)

This sub-system relies on the participation of the driver. He is required to allocate the work completed. Plant which is hired without a driver is allocated by the Production Surveyors.

Although the work undertaken by the plant is usually adequately described on the Allocation Sheets, it is not transferred onto the Plant Record sheets, which are sent to the Plant Accounts Department for checking against the invoices received. A summary of the invoices, containing the project and suppliers' names are then sent to the Accounts Department.

6.3 Sub-System Shortcomings

The shortcomings inherent in each sub-system were grouped into two broad categories. (1) Intrinsic shortcomings, created by the individual sub-systems as a direct result of their method of working or information transfer procedures; and (2) Extrinsic shortcomings which are imposed on the sub-systems from outside the company. Perhaps the best example of this is the time taken by suppliers to send invoices for payment, thus impeding cost collection.

One of the most important functions of a value-cost monitoring system is to produce accurate results qucikly. The extrinsic shortcomings (Table.16.) imposed on the sub-systems show that,even with the best computer aided system, accurate results cannot be produced for at least 40 days after the end of the measurement period. This is a reduction of about 33% on the current time taken. It is also clear that computer aided value-cost monitoring will neither increase the accuracy of allocation nor reduce the amount

Material Cost Monitoring Sub-System

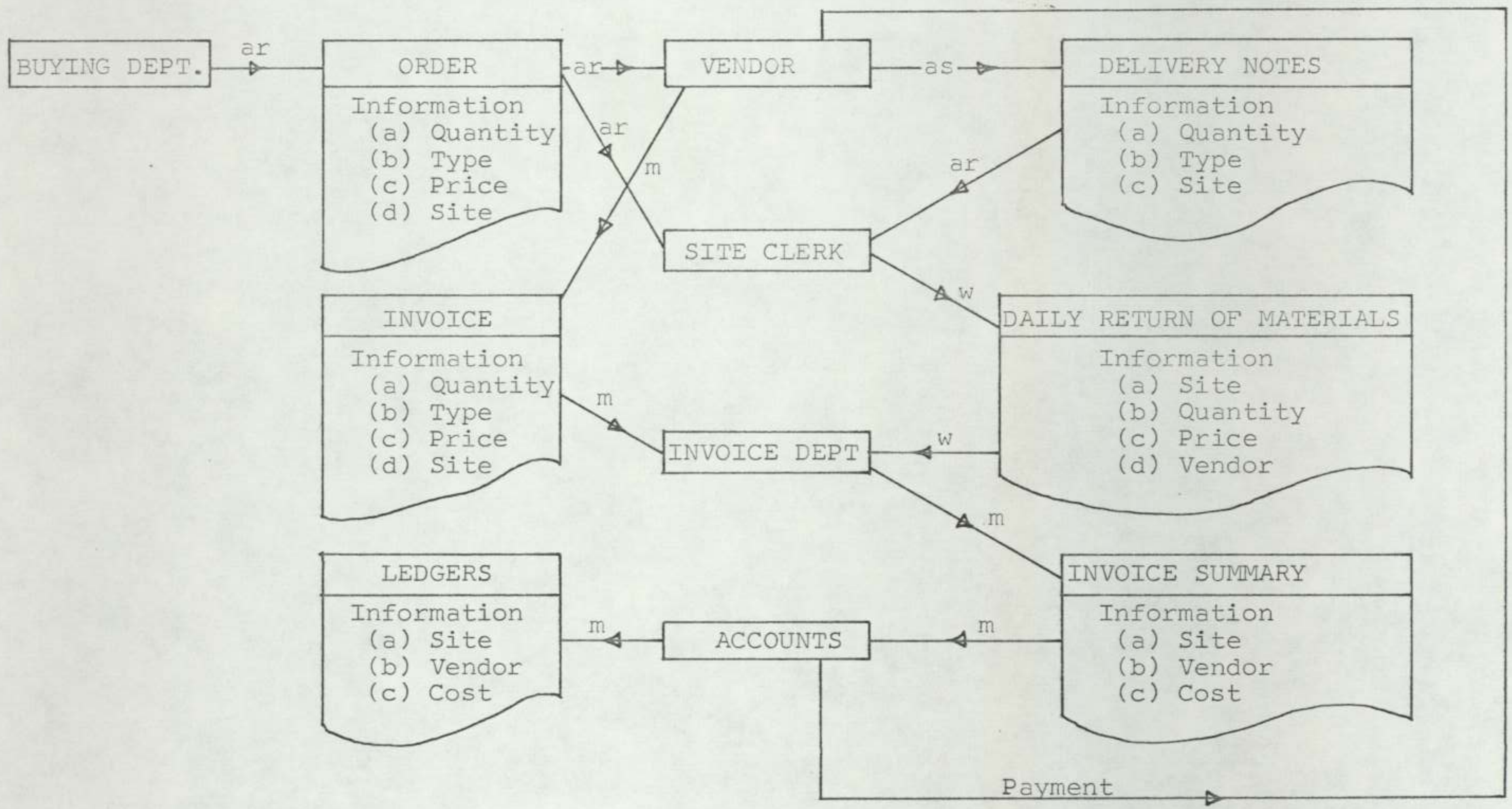


Figure.65.

Plant Cost Monitoring Sub-System

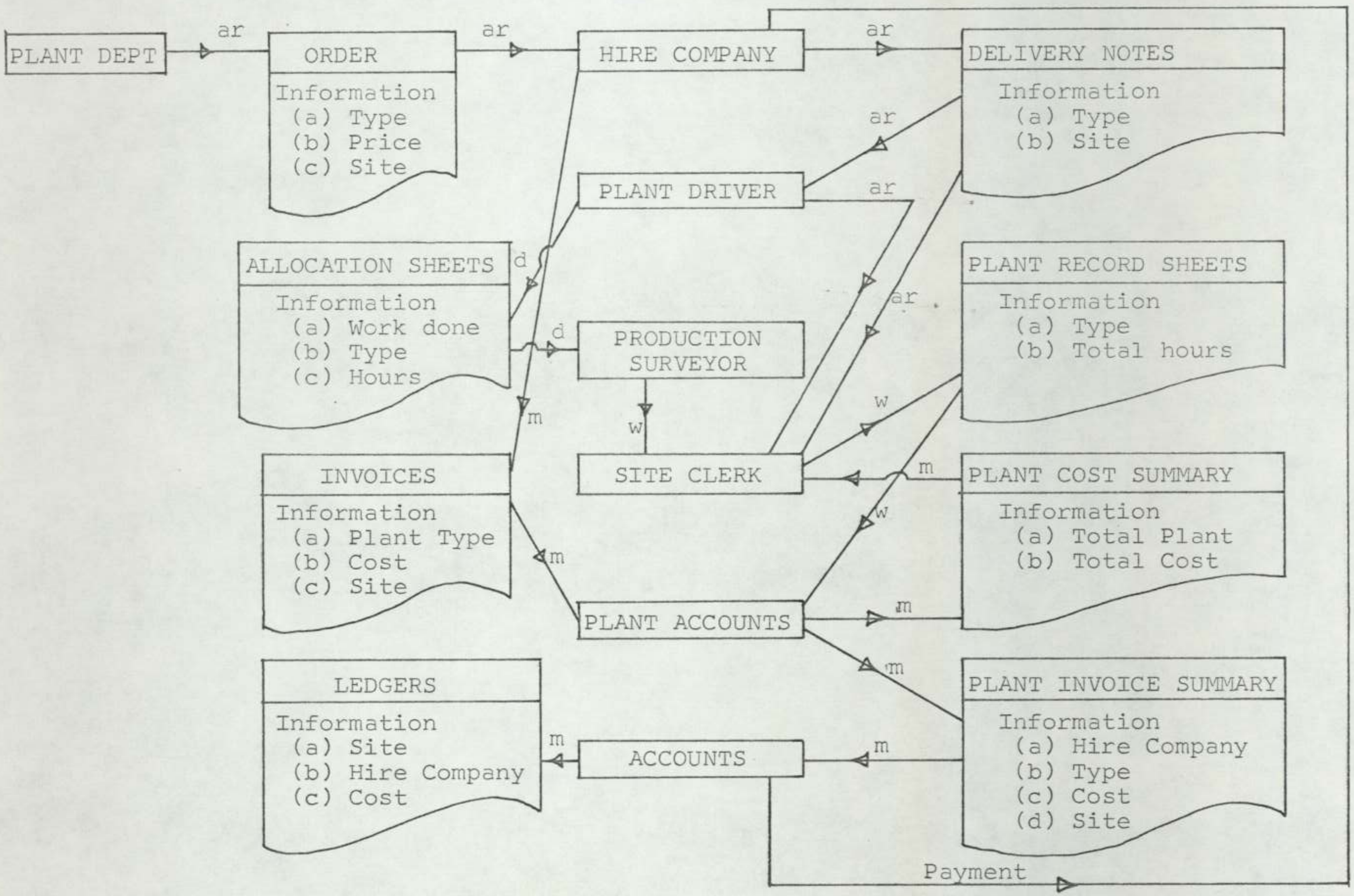


Figure.66.

of data to be processed. However, re-design of the individual sub-systems will eradicate the over production of unused information which is common to all three cost sub-systems and the introduction of computer facilities will make the comparison of values and costs easier, reduce the "in company" processing time and is capable of producing the type of useful value-cost summaries required.

6.4 <u>Value-Cost Monitoring v Bills of Quantity</u>

The Bills of Quantity are prepared by the client or client's representative. It is primarily intended for the preparation of tenders and subsequently for allowing periodic valuations to be produced. Practical site production often clashes with the quantity oriented Bills of Quantity structure. A typical example of this conflict often occurs in drainage construction.

A gang of operatives, together with the required plant and material are instructed to construct a pipeline. Site management want to know both the cost and value of the operation so that they can assess the construction method adopted. The Quantity Surveyors are capable of determining the value of the individual elements of the operation. However, the cost of the work depends on the willingness and ability of the operatives to allocate their time to the individual elements of the operation based on the same method of measurement adopted by the Quantity Surveyors. The implication of this is that in order to retrieve costs based on the unaltered structure of the Bills of Quantity, the operatives used must be conversant with the Bill and the standard method of measurement used or alternatively, the Quantity Surveyors must be prepared to transpose the cost information so that it can be directly compared with the value.

If one accepts the hypothesis that neither educating the site operatives in the use of the method of measurement nor increasing the staff complement to transpose the allocated work would solve the apparent conflict between the Bill structure and monitoring costs, then altering the Bill structure to accommodate cost retrieval (remembering that it must also perform its present function), is the only remaining alternative. This can be done in one of two ways. Firstly, splitting Bill items into their component parts and then grouping the parts into basic operations (bedding, pipelaying, backfill etc.). Secondly, combining Bill items into groups which attempt to represent actual site operations. The groups would, in effect, become psuedo operations. As an example, all Bill items describing a given pipe diameter may be grouped.

Both methods were tried in practice. The first method (splitting Bill items) tends to increase the number of Bill items, and in doing so increases the amount of documentation required at site level, it demands greater alloaction accuracy, both of which are difficult to achieve. Grouping Bill items proved to be the most effective way of restructuring the Bills of Quantity. It effectively reduces the number of Bill items, hence documentation of data is easier and the results tend to be no less accurate. By far the greatest advantage produced by grouping Bill items is

TABLE.16.

	Description of Shortcomings	Value	Labour	Material	Plant
		Sub-Systems			
	INTRINSIC				
1	Allocation of worked hours depends on operatives' participation.		●		●
2	Allocated description not passed on.		●	●	●
3	Only total cost summaries available		●	●	●
4	Completed work measurement depends on; construction method, work records, complexity of construction.	●	●		
5	Slow data preparation due to manual procedures	●	●	●	●
6	Comparison of similar value/ cost element not possible	●	●	●	●
	EXTRINSIC				
7	Bonus earned one week in arrears of basic wage		●		●
8	Plant and material invoice not received until the 10th and 18th day of the following month respectively.			●	●
9	Recovery not received from client for 30 to 50 days after measurement period	●			
10	Initial costs supplied by vendors at ordering stage change due to additional transport, fuel cost etc.			●	●

that the method merely summarises the Bill into workable groups as opposed to splitting it into what is, in effect, a new document.

Ultimately, the interface between value and cost monitoring can only be bridged by a change in the structure of the Bills of Quantity before they are received by the contractor. This means that they must be accepted as documents for cost control (as well as one for tender and valuation preparation) by clients. However, until such time, value-cost monitoring must rely on grouping Bill items to form psuedo operations and coding each to create operation value-cost centres which form part of the total value-cost coding structure.

6.5 Value-Cost Coding Structure

The structure of a coding system primarily depends on the requirements of the various management functions, whether they be company management, divisional or contracts management, each management function requiring a different degree of value-cost analysis. Company management, whether one person or a Board of Directors, are generally concerned with the profitability of each Division. Divisional Management are concerned with the profitability of each project and the contract or site management are interested in the profitability of the individual operations on site.

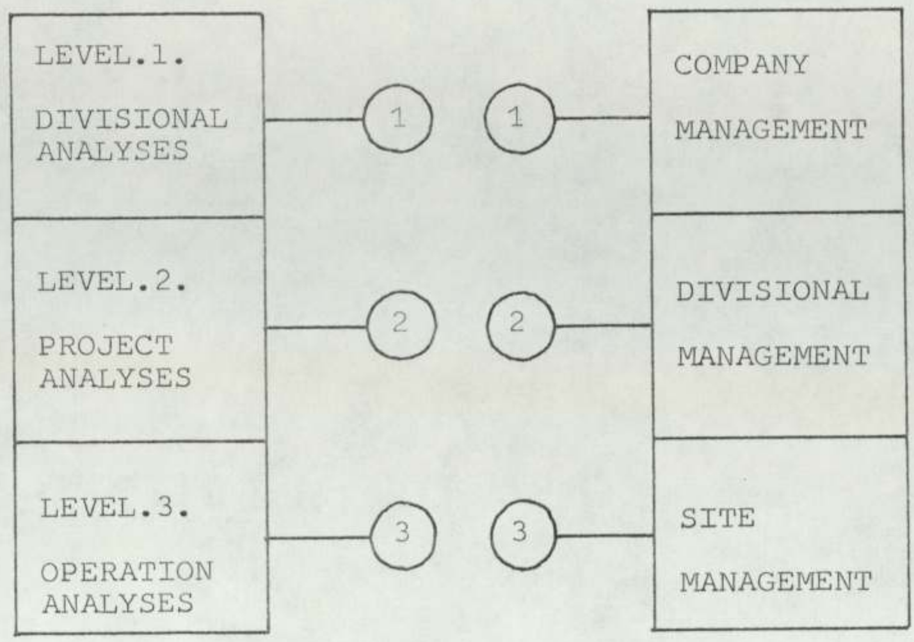
If the value-cost analysis results are not compatible with the objectives of the management functions for which they are produced, over or under communication occurs. That is to say, either company management is inundated with value-cost analyses of site operations (over communication) from which they must extract the information required, or site management receive value-cost analyses for the division (under communication) from which they must try to extract the information relevant to their project. Hence the value-cost coding structure must be compatible with the hierachy of the organisation structure (Figures .67. and .68.) and, therefore, possess its own sub-structure to meet the requirements of each level of management.

6.6 Value-Cost Coding Sub-Structure

The composition of each coding sub-structure is dependent upon the amount and complexity of the information to be analysed.

There are four individual construction divisions within the company, each serviced by several smaller divisions providing ancillary services (plumbing, joinery etc.) making ten in all. Divisional analyses would, therefore, contain a small amount of global information, hence sophisticated computer sorting and collating techniques are not required. Each division controls several sites, the number of which fluctuate, but generally do not exceed twelve. Because of the small amount of information produced by the project analyses sub-structure, manual sorting and collating of the final results is adequate. However, site management require value-cost information on many separate operations occurring on site. (One project of estimated value £2 million contained approximately 600 Bill items which were reduced to 170 psuedo operations for value-cost coding, of which

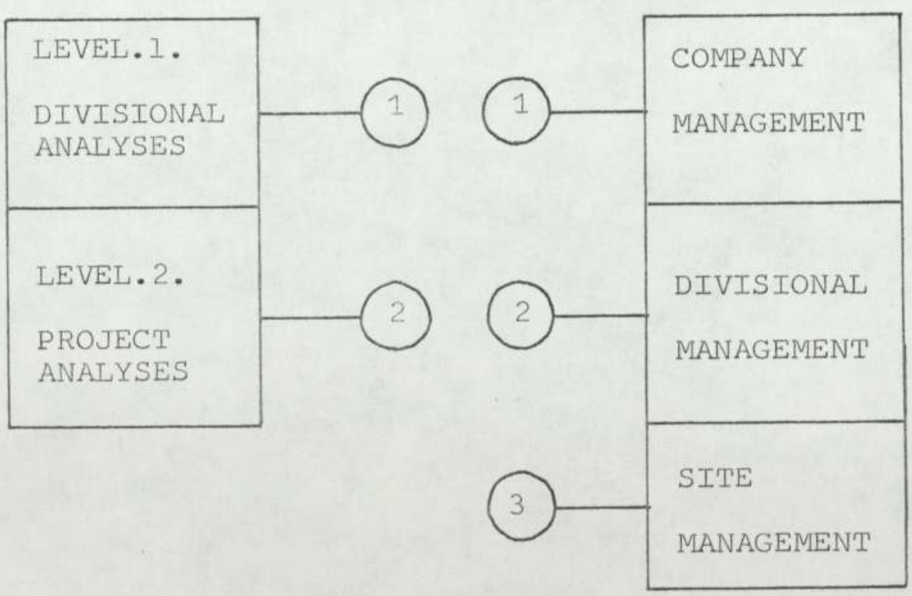
Figure.67.



COMPATIBLE STRUCTURES

The value-cost coding structure produces the information required by each management function.

Figure.68.



INCOMPATIBLE STRUCTURES

The value-cost coding structure is incapable of producing information required by site management, therefore, preventing a complete problem solving system.

20-30 were used in a single period of analysis). Consequently, flexible computer sorting and collating facilities are required.

Division and project value-cost analyses are produced by the current manual value-cost monitoring system. To do this, each division is given a 2 digit numeric code and projects are allocated a 4 digit code. However, the manual procedures fail to produce accurate results at regular intervals throughout the financial year. The value-cost codes used have proved successful over the years (although the method of manipulating them has not) and most of the management and office personnel are familiar with them. Consequently, they are retained in the proposed value-cost monitoring system.

The current coding structure under communicates with the organisation structure, (Figure. 68 .). Consequently, decisions which are made by company management (and transmitted via the organisation structure) cannot be quantatively assessed. To remedy this, operation coding is required.

6.7 Operation Code Field Width and Composition

Several site studies were carried out using 2 and 4 digit code field widths, the individual digits being numeric, alphabetic or a combination of both (alphanumeric). A summary of the results is given in Table.17 .

TABLE.17.

Code Field Width	Code Composition	General Remarks
2	Numeric	Limited flexibility and descriptive powers.
2	Alphanumeric	Limited flexibility, users disliked mixture. Descriptive powers criticised.
2	Alphabetic	Limited flexibility but worked well on projects up to £750,000.
4	Numeric	Limited flexibility and descriptive powers.
4	Alphanumeric	Limited flexibility and descriptive powers.
4	Alphabetic	Worked well on projects up to £3 million. Spare characters available for further system development.

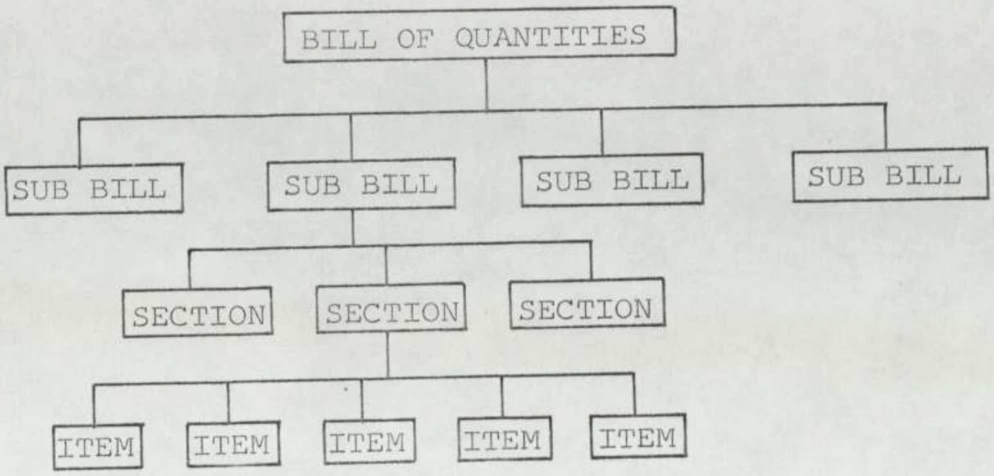
Most users (Site Clerks, Production Surveyors, Junior Engineers) felt that as they were attempting to describe an actual site operation, alphabetic codes were easier to use. They also preferred to use codes with 2 digit field widths but this severely limited the flexibility of the system on large projects. Four digit alphabetic codes worked well throughout but it was found that describing psuedo operation using the initial letter as a code digit (Formwork, Code F) somewhat confused the system, particularly when similar initial letters occurred for different operations, i.e. Formwork and Fencing).

6.8 Operation Code Format

Retrieval of value and costs of completed operations is dependent upon the effective use of the Bills of Quantities. Both line and division management use the Bill as a vehicle for communication both with each other and with the client or client's representative.

Most Bills of Quantity commonly used in the civil engineering industry have a common structure (Figure.69.). Firstly, they are divided into sub-Bills which generally categorise the work to be completed (roadworks, each structure etc.), each sub-Bill containing sections which further describe the work (drainage, earthworks etc.). At this stage, the sub-Bill and section headings are operationally oriented and hence closely allied to the broad operations which will occur on site. Finally, each section comprises of bill items, each briefly describing different quantities of material to be placed or removed. It is this latter subdivision of the Bill which impedes cost monitoring. As the items are now quantity oriented and do not relate directly to site operations, they must be grouped into psuedo operations.

FIGURE.69 .



As can be seen from Table.18., the Bills of Quantity code description occupies three field positions within the proposed four field codes. The remaining field position is intended for distinguishing between the different categories of labour and plant used on site.

The value-cost codes do not in themselves distinguish between labour, plant, material and sub-contractor costs. This is done at the input stage, that is to say, the data sheets contain different data columns but the same value-cost code.

6.9 Proposed Operation Coding

The four digit alphabetic code, based on the most commonly used method of measurement[61], is given in Table .18. It utilises 17 of the 26 alphabetic characters available, the remainder being omitted because they were often mistaken either for numbers or for other letters by the computer punch operators.

Alphabetic Characters Omitted	Mistaken For
D	P
G	C
I	1
J	I or 1
O	ZerO or Q
Q	ZerO or O
R	K
U	V
Z	2

The consistency of the Bills of Quantity structure and the commonly used labour and plant categories made it possible to fix the first, second and fourth digit of the operation code. However, it was decided to leave the third digit floating.

Estimators, Planners, Quantity Surveyors and line management approach each project in different ways. Often they find that an operation occurring on one project requires more detailed analysis than a similar operation on another, either because the operation is critical or they anticipate changes in the type of plant or cost of materials to be used. On one project, excavation may be important because a new type of plant is used, therefore, excavation items would be grouped irrespective of, say, pipe diameter. On another, the cost of the type of pipe laid may be significant.

1	2	3	4

Code	Sub-Bill Description	Code	Section Description	Code	Item Group Desctiption	Code	Resource Description
A	Accommodation Works	A	Testing	A		A	Direct Ganger Chargehands
B	Works for Statutory Bodies	B	Sub-base and Road-base	B		B	Direct Craftsmen
C	Each Bridge or Structure	C	Concrete Carriage-way	C	Floating digit	C	Direct Skilled labourers
E		E	Earthworks	E	Description deter-mined	E	Direct Labourers
F		F	Flexible Surfacing	F	By Management	F	•
H		H	Hedges	H		H	Hired Plant
K		K	Kerbs,footway,track	K		K	•
L		L	Super structure	L		L	•
M		M	Structure	M		M	•
N		N	Drainage	N		N	•
P	General Prelims.	P	Special Prelims.	P		P	Owned Plant
S	•	S	Site Clearance	S		S	•
T	•	T	Traffic sign and Road mark	T		T	•
V	•	V	Finishings	V		V	S/E Gangers
W	Road Works	W	Fencing and Walls	W		W	S/E Craftsmen
X	•	X	Substructure end Supports	X		X	S/E Skilled la-bourers
Y	Day Works	Y	Substructure Inter-mediate supports	Y		Y	S/E Labourers

TABLE.18.

therefore, items of similar pipe diameter would be grouped irrespective of the depth of excavation. Although this method of coding is inconsistent and prevents direct comparison of similar operations on different projects, the management felt that to maintain a coding system of not more than four characters which is consistent with the accuracy of allocation expected, is a greater advantage, particularly at such an early stage in the development of the computer aided system.

6.10 The Computer Value-Cost Monitoring System

The proposed computer aided value-cost monitoring system (Figure.70.) is made up of three sub-systems, each fulfilling separate objectives but which are interdependent. They are:-

(1) Interim Valuation and Certification

(2) Value-Cost Evaluation and Analysis

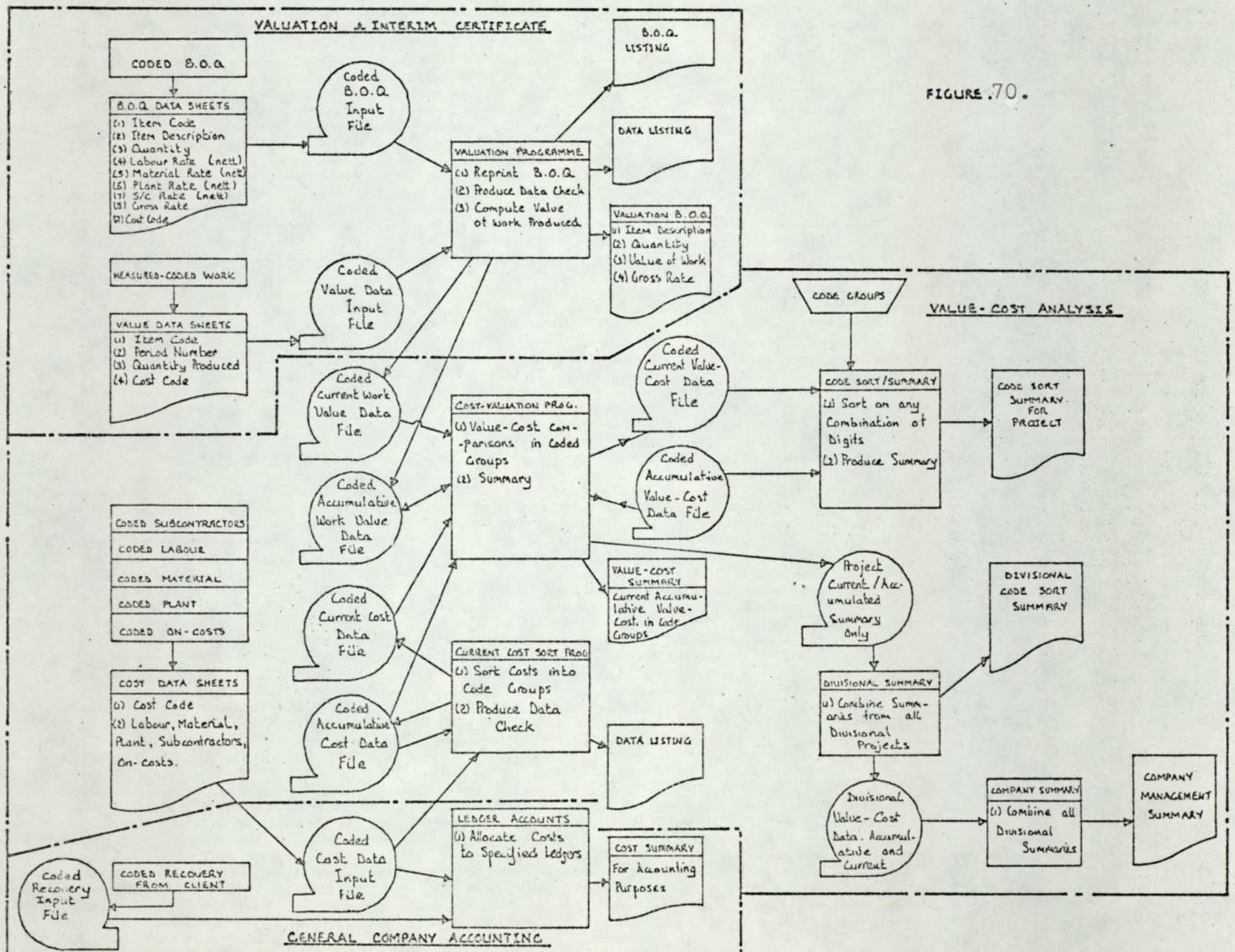
(3) General Company Accounting

Computer packages produced by several Computer Bureaus were examined (Table.19.), their usefulness being assessed by studying their ability to satisfy the following objectives:-

(a) Input requirements must be flexible enough to allow the company to design their own input forms.

(b) The type and amount of data input must be stipulated by the company and not by the computer system.

FIGURE .70.


VALUATION & INTERIM CERTIFICATE
CODED B.O.Q
B.O.Q DATA SHEETS
(1) Item Code
(2) Item Description
(3) Quantity
(4) Labour Rate (nett)
(5) Material Rate (nett)
(6) Plant Rate (nett)
(7) S/C Rate (nett)
(8) Gross Rate
(9) Cost Code
Coded B.O.Q Input File
VALUATION PROGRAMME
(1) Reprint B.O.Q
(2) Produce Data Check
(3) Compute Value of Work Produced
B.O.Q. LISTING
DATA LISTING
VALUATION B.O.Q.
(1) Item Description
(2) Quantity
(3) Value of Work
(4) Gross Rate
MEASURED-CODED WORK
VALUE DATA SHEETS
(1) Item Code
(2) Period Number
(3) Quantity Produced
(4) Cost Code
Coded Value Data Input File
Coded Current Work Value Data File
Coded Accumulative Work Value Data File
COST-VALUATION PROG.
(1) Value-Cost Com-parisons in Coded Groups
(2) Summary
VALUE-COST SUMMARY
Current Accumulative Value-Cost. in Code Groups
Coded Current Value-Cost Data File
Coded Accumulative Value-Cost Data File
CODE GROUPS
VALUE-COST ANALYSIS
CODE SORT/SUMMARY
(1) Sort on any Combination of Digits
(2) Produce Summary
CODE SORT SUMMARY FOR PROJECT
Project Current/Accumulated Summary Only
DIVISIONAL SUMMARY
(1) Combine Summaries from all Divisional Projects
DIVISIONAL CODE SORT SUMMARY
Divisional Value-Cost Data. Accumulative and Current
COMPANY SUMMARY
(1) Combine all Divisional Summaries
COMPANY MANAGEMENT SUMMARY
CODED SUBCONTRACTORS
CODED LABOUR
CODED MATERIAL
CODED PLANT
CODED ON-COSTS
COST DATA SHEETS
(1) Cost Code
(2) Labour, Material, Plant, Subcontractors, On-costs.
Coded Current Cost Data File
Coded Accumulative Cost Data File
CURRENT COST SORT PROG
(1) Sort Costs into Code Groups
(2) Produce Data Check
DATA LISTING
Coded Cost Data Input File
LEDGER ACCOUNTS
(1) Allocate Costs to Specified Ledgers
COST SUMMARY
For Accounting Purposes
CODED RECOVERY FROM CLIENT
Coded Recovery Input File
GENERAL COMPANY ACCOUNTING

BUREAU	PACKAGES AVAILABLE		
	INTERIM VALUATION AND CERTIFICATION	VALUE-COST ANALYSIS & EVALUATION	GENERAL COMPANY ACCOUNTING
Centre File Ltd.	•	•	
C.R.D. Computing Services	•	•	•
I.B.M.	•	•	•
B.A.R.I.C.	•	•	•
LAING	•	•	
COMPUTEL	•	•	
ATKINS	•	•	•
WATES	•	•	
K. & H. Business Consultants	•	•	
London University	•	•	

Table.19.

(c) The layout of the analysis results must be designed by the company management.

(d) The system must be capable of sorting and collating the value-cost codes, by groups, individual digits and groups of digits.

(e) The computer system as a whole must be flexible enough to fit the company system during the phasing out of the old and introducing the new.

The facilities provided by BARIC Computing Services Limited was chosen primarily because they already had a computer package (CIVACA) which would fulfill the interim valuation and certification and partially satisfy the value-cost analysis requirements. They were also prepared to amend existing programmes and write new ones to fit the company's requirements.

6.11 Introduction of the Computer Sub-Systems

Studies of the current manual sub-systems through to the proposed computer sub-systems yield the boundary constraints (accuracy of data, speed of processing etc.) of the problem and isolate the objectives which must be achieved (regular value-cost analyses, compatibility of both analysis structure and organisation structure, etc.). Knowledge of the current lines of communication and the interdependence between Departments indicate the need for a gradual systematic approach which is capable of predicting the effect of a change before it is actually brought about. Although three different computer sub-systems are proposed, it is clear that one cannot be introduced without the others in mind,(Figure.70., one computer sub-system's storage and output is another's input).

The computer aided interim valuation and certification sub-system was introduced into the company system in less than two months. It is clear from Figure.63. that the manual sub-system was dominated by the Quantity Surveying Department and that inter-departmental participation on a large scale was, and still is, unnecessary. The manual valuation and certification procedures were repetitive, consistant and common to most construction companies, consequently an existing computer package easily fulfilled the requirements. Broadly, success in such a short period of time seemed to be due to the fact that the procedure was already mechanical and processed in a single, somewhat independent, department.

The problem of value-cost monitoring and feedback is not one of data creation, but one of data preparation, transfer and manipulation as all organisations must document the cost incurred and value of work done in order to function, all of which rely on a high degree of inter-departmental participation. The phasing in of the computer aided value-cost evaluation and analysis sub-system was started in October, 1973. New forms of information transfer were introduced, together with slightly amended communications system (Figure.71.). A Data Preparation Department was introduced to collect cost information from the Labour, Materials and Plant Cost Monitoring sub-systems. The sub-system was introduced onto new projects only. Currently, all civil engineering projects within the company are using the system, the same ones (up to £1 million) are having more success than multi-million pound projects on which allocation and coding accuracies are extremely difficult to control.

Phasing in of the General Accounting sub-system was started in January of 1974 and is still in progress. The computer facilities are being developed using several standard sort packages controlled from a master programme written by Bureau programmers for the company. Although the manual and computer sub-systems are similar, the need to maintain the manual sub-system whilst simultaneously phasing in the computer aided sub-system is proving difficult.

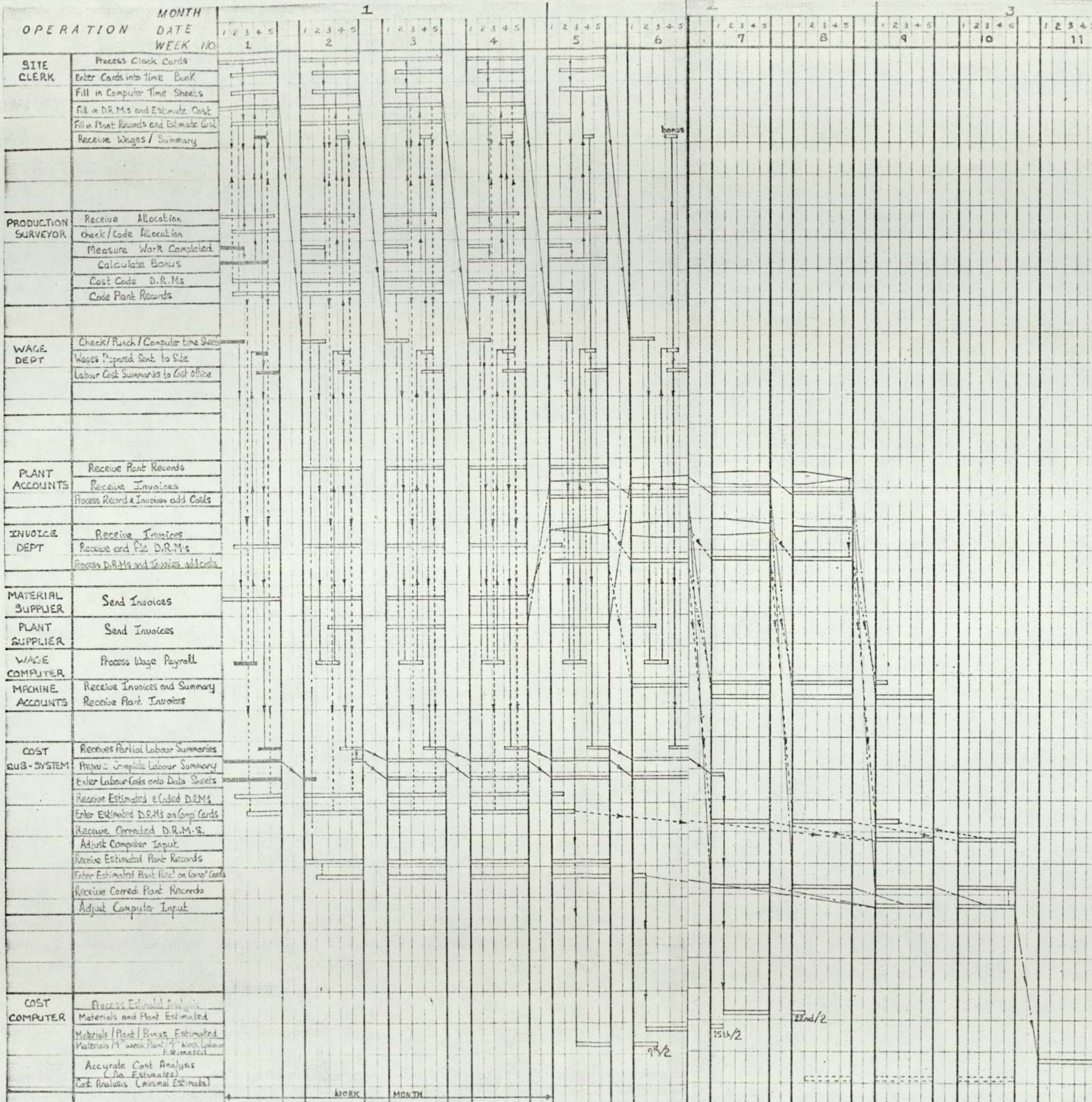

OPERATION
MONTH
DATE
WEEK NO.
1
2
3
SITE CLERK
Process Clock Cards
Enter Cards into Time Book
Fill in Computer Time Sheets
Fill in D.R.M.s and Estimate Cost
Fill in Plant Records and Estimate Cost
Receive Wages / Summary
PRODUCTION SURVEYOR
Receive Allocation
Check / Code Allocation
Measure Work Completed
Calculate Bonus
Cost Code D.R.M.s
Code Plant Records
WAGE DEPT
Check / Punch / Computer time Sheets
Wages Prepared Sent to Site
Labour Cost Summaries to Cost office
PLANT ACCOUNTS
Receive Plant Records
Receive Invoices
Process Record & Invoices add Costs
INVOICE DEPT
Receive Invoices
Receive and file D.R.M.s
Process D.R.M.s and Invoices add costs
MATERIAL SUPPLIER
Send Invoices
PLANT SUPPLIER
Send Invoices
WAGE COMPUTER
Process Wage Payroll
MACHINE ACCOUNTS
Receive Invoices and Summary
Receive Plant Invoices
COST SUB-SYSTEM
Receives Partial Labour Summaries
Prepare Complete Labour Summary
Enter Labour Costs onto Data Sheets
Receive Estimated & Coded D.R.M.S
Enter Estimated D.R.M.S on Comp' Cards
Receive Corrected D.R.M.S.
Adjust Computer Input
Receive Estimated Plant Records
Enter Estimated Plant Rec' on Comp' Cards
Receive Corrected Plant Records
Adjust Computer Input
COST COMPUTER
Materials and Plant Estimated
Materials / Plant / Bonus Estimated
Materials 4th week Plant 4th week Labour Estimated
Accurate Cost Analysis (No Estimates)
Cost Analysis (minimal Estimates)
bonus
9th/2
15th/2
22nd/2
WORK MONTH

Figure.71.

CHAPTER 7

CONCLUSIONS

CHAPTER 7

CONCLUSIONS

7.1 Introduction

From the outset, the aim of this research has been to satisfy the needs of the Civil Engineering Division of C. Bryant and Son Limited.

The management of the Division is finding that, because the construction industry is in a perpetual state of change, more 'control' is required over its activities if greater profitability, or even survival, is to be realised.

This Thesis investigates the current systems for pre-contract appraisal and post-contract production and financial monitoring in an attempt to determine where computer facilities could satisfy the needs of the management.

Research into the organisation and communication structure prevailing in the Division shows a sparse formal communications structure, heavily supplemented by an informal communications structure, independent of what should be highly interdependent management functions. This is highlighted by the isolation of the work study function from the bonusing, planning and estimating functions. Informal communication, although an integral part of an organisation can, if allowed to become too dominant, impede the development of new management systems because in an informal structure different management functions are only aware of their own needs. They therefore tend to become too independent and hence slow down the corporate growth of the organisation.

Although the type of infra-structure which exists is all important in assisting or impeding the development of new management systems, it must be remembered that the global industrial environment exerts extrinsic shortcomings on the development of new systems and these are capable of destroying the anticipated benefits of new systems. Two typical examples of extrinsic shortcomings are the influence of the Bills of Quantity structure on both estimating and cost retrieval systems and the dependence of the cost retrieval system on the regular and prompt collection of invoices supplied by vendors.

7.2 The Tools for Systems' Development

The production of the work measurement (Appendix 1) and performance data bases is designed to unify the current personal data bases used by Planners and Estimators, thereby providing all management functions with a single reference document from which everyone works. Although the work measurement data base is developed specifically for the analysis of main drainage construction, the methodology used to create it can be extended to many other aspects of civil engineering construction - formwork erection, general roadwork construction and earth moving. The work measurement data base has been used manually by

Planners and Estimators since June, 1973. Prior to the development of the pipeline and manhole analysis programmes, the data base was formed into a planning and estimating manual (Appendix 5). This was done to check the accuracy of the data and the validity of the anticipated procedures to be used by the computer programmes.

The two computer programmes use the work measurement data. They combine small elements of time to yield both the construction time at standard performance, and the required gang size in an attempt to represent the anticipated construction procedure, thereby promoting "operational pricing". Operational pricing has long been recognised as the most effective way of estimating, purely because it is sensitive to the methods of construction and to labour, material and plant price fluctuations. However, because manual operational pricing is time consuming, laborious and requires large amounts of data, the more rapid but insensitive method of estimating, "unit pricing", has prevailed. The programmes herein combine the need for rapidity with the most sensitive method of estimating in order to balance the attributes of both estimating methodology and computer capabilities.

The construction simulation programme maintains the application of operational pricing throughout pre-contract appraisal. The basic planning and estimating programmes (PIPELINE and MANHOLE) start the process by generating construction times for single activities. They do not consider the eventual interdependence which will exist on site, nor do they consider the effects of varying operative and site performances. Pre-contract appraisal is a cyclic operation in which construction methods and resource combinations are evaluated, compared and eventually accepted or rejected. The simulation programme provides the required flexibility and is accepted by Planners and Estimators because it is specifically designed to blend with the current methods of performance data retrieval and the general estimating and planning procedures adopted by the Division.

The analysis programmes and the simulation suite are tools for creating a formal feedback of work measurement and performance information from post-contract production to pre-contract appraisal. The feedback of financial information is assisted by the computer aided value-cost monitoring system. In general, the system is composed of three interlocking computer facilities. They are:-

(i) Valuation and Certification

(ii) Value-Cost Analysis (C.I.V.A.C.A.)

(iii) General Company Accounting (A.S.1.)

Because of the large number of commercially available packages, the actual "software" design is not considered in this research, the accent being placed on the overall "software" configuration required to satisfy the needs of the management. Design of the overall computer system configuration indicates that the extrinsic shortcomings created by the industrial environment as a whole are capable of reducing the system's effectiveness.

The procedures and data used by the computer programmes developed have been in use within the Division since 1973. The pipeline and manhole analysis programmes were used successfully to analyse a £1.75 million drainage scheme and, subsequently, the simulation suite was successfully used to analyse a road scheme, from which the bridge analysis in Chapter 5 is taken. However, further introduction of these facilities, together with the simultaneous introduction of the computer aided value-cost monitoring system is considered by the Divisional Management to be too great a step to be taken at once. Computer aided valuation and certification facilities have been successfully introduced into the Company (Chapter 6). The general accounting system (A.S.1.) is now fully installed and producing the required information. Vlaue-cost analysis by computer is still being introduced and is currently limited to civil engineering projects. However, extensions of the system into other sections of the company is imminent.

7.3 Formal Communication Using Computer Systems

The three computer programmes developed in the research formally connect the work study, bonusing and the planning and estimating functions. That is to say, the data generated by one function forms the data base for the next interdependent function. Although the programmes are used during pre-contract appraisal, the data they require demands formal communication with functions participating in post-contract production.

Similarly, the computer aided financial feedback system demands a high degree of formal communication in order to produce the information required by management so that they are able to exert the necessary control.

7.4 Further Development of the Research

The use of different materials and construction methods reduces the cost of main drainage construction, (Chapter 4).

Adoption of 'operational pricing'techniques by both clients and contractors, using similar programmes to those developed in this work, could lead to optimum cost design.

The computer programmes developed in this work (with the exception of the simulation suite) are created for main drainage analysis only. Further work is required to extend the application to formwork, road works and structural steel and concrete construction analysis. However, it would be impossible to successfully complete such work without the close participation of industry.

In recent years, advances have been made in optimum weight and shape design of structures and extension of this into optimum cost design is a further development required by both clients and contractors. The simulation suite will assist in such research work.

If the true potential of new materials, plant, construction methods and design techniques is to be fully realised, both clients and contractors must design, plan, estimate and control projects accordingly. This will mean processing and interpreting a greater quantity of information, hence the increasing use of computer facilities is inevitable. However, it must be remembered that the real advantages of computer aided systems cannot be realised if they are not created within the industrial environment for which they are intended.

REFERENCES

1. WIENER, N., 1948. "Cybernetics". Control and Communication in the Animal and the Machine, John Wiley and Sons, New York.

2. CHURCHMAN, C. W., 1954. "Introduction", in Proceedings of the Conference on Operations Research in Production and Inventory Control, Cose Institute of Technology, Cleveland, p.8, January 20-22.

3. CHURCHMAN, C. W., and ACKOFF, R. L., 1950. "Purposive Behavious and Cybernetics", Social Forces, 29, 32-39.

4. MORRIS, P. W. G., 1973. "Organisational Analysis of Project Management in the Building Industry", 'Build International', Vol. 6(6), pp. 595-616.

5. MARCH, J. G., and SIMON, H. A., 1958. "Organizations". Wiley, New York, pp. 158-160.

6. BURN, T., and STALKER, G. M., 1961. "The Management of Innovation", Tavistock, London.

7. THOMPSON, J. P., 1967. "Organizations in Action", Mcgraw Hill, New York, pp. 54-56.

8. WOODWARD, J., (ed.), 1970. "Industrial Organization, Behaviour and Control", Oxford University Press, London, p.5.

9. op. eit. (8), pp. 237-238.

10. ETZIONI, A., 1964. "Modern Organizations". Prentice Hall Englewood Cliffs, p.3.

11. ANSOFF, H.I., 1968. "Corporate Strategy". Penguin.

12. BENIEN, F. K., 1968. "General and Social Systems". Routgers University Press, p.21.

13. JENKINS, G. M., 1969. "The Systems Approach". Journal of Systems Engineer, Vol. 1(1): pp. 3-45.

14. CHECKLAND, P. B., 1972. "Towards a Systems Based Methodology for Real - World Problem Solving". Journal of Systems Engineering, Vol. 3 (2), pp. 87-115.

15. DEUTSCH, K. W., 1952. "On Communication Models in the Social Sciences". Publ. Opinion Quart., 16, pp. 356-380.

16. MARCOSSON, I. F., 1920. "Adventures in Interviewing". John Lane, The Bodley Head Ltd., London.

17. NEJELSKI, L., 1947. "Communication in Practical Affairs", in L. BRYSON et al. (ed.), "The Communication of Ideas", Harper and Brothers, New York.

18. BALES, R. F., 1950. "Interaction Process Analysis". Addison-Wesley Press, Cambridge, Mass.

19. BAVELAS, A., 1950. "Communication Patterns in Task Oriented Groups". J. Acoust. Soc. Amer., 22, pp. 725-730.

20. CHAPPLE, E. D., 1940. "Measuring Humal Relations: An Introduction to the Study of the Interaction of Individuals". Genent. Psychol., 22, No. 1, Feb.

21. STARK, R. M., 1971. "Information Systems for Construction Companies". Pro. A.S.C.E.

22. ACKOFF, R. L., "Management Misinformation Systems". Management Science Centre, University of Pennsylvania.

23. OXLEY, R., and POSKITT, J., 1969. "Systems Analysis and Design Applied to the Construction Industry". Building Technology and Management, pp. 332-335, Dec.

24. DUDLEY, N. A., 1968. "Work Measurement" London: Macmillan.

25. GEARY, R., 1969. "A Progress Report on Work Study in the Building Industry". Building Technology and Management, pp. 69-70, March.

26. FLAGLE, C. D., 1961. "Probability Based Tolerances in Forecasting and Planning". The Journal of Industrial Engineering, Vol. 12, No. 2, March - April, pp. 97-101.

27. "PERT Summary Repo t, Phase 1". Special Projects Office, Bureau of Naval Weapons, Department of the Navy, Washington, D.C., July, 1958.

28. MALCOLM, D. G., J. H. ROSEBOOM, C. E. CLARK, and W. FAZAR, 1959. "Applications of a Technique for R and D Program Evaluation", (PERT). Operations Research, Vol. 7, No. 5, pp. 646-669.

29. WALKER, M. R., and SAYER, J. S., 1959. "Project Planning and Scheduling". Report 6959, E. I. duPont de Nemours and Co., Wilmington, Delaware. March.

30. KELLEY, J., 1961. "Critical Path Planning and Scheduling: Mathematical Basis". Operations Research, Vol. 9, No. 3, May-June, pp. 296-321.

31. DOD and NASA Guide, PERT Cost Systems Design, by the Office of the Secretary of Defense and the National Aeronautics and Space Administration. U.S. Government Printing Office, Washington, D.C., June, 1962. Catalog Number D16/2:P94.

32 BEUTEL, M. L., 1963. "Computer Estimates Costs, Saves Time, Money". Engineering News-Record, February 28.

33. RIST, P. T., 1969. "Modern Programming Techniques". Building Technology and Management, pp. 64-66, March.

34. BAKER, F. A., 1969. "Critical Path Analysis in Construction Management". Building Technology and Management, pp. 188-190, August.

35. MACBRIDE, L. W., 1970. "Owners Return from CPM - Fact or Fiction". Journal of the Construction Division, Pro. A.S.C.E., June.

36. GAARSLEV, A., 1969. "Stochastic Models to Estimate the Production of Material Handling Systems in the Construction Industry". Technical Report No. 111, Department of Civil Engineering, Stanford University, Stanford, California, August.

37. SUSSMAN, J. M., 1970. "Simulation - A Systems Tool for Engineers". Pro. A.S.C.E.

38. FINE, B., 1970. "Simulation Technique Challenges Management". In Construction Progress, No. 14, July. A Publication of Richard Costain Limited, 111 Westmister Bridge Road, London, S.E.1.

39. WILLENBROCK, J. H., 1971. "Estimating Costs of Earthworks via Simulation". Pro. A.S.C.E.

40. PARTI, E. W., and TUNG Au, M., 1972. "Simulation Model for Building Construction Planning". Pro. A.S.C.E.

41. "Construction Cost Estimating and Control". Committee on Estimating and Cost Control, A.S.C.E. Construction Division. Pro. A.S.C.E., 1962, September.

42. BARNES, N. M. L., and THOMPSON, P. A., 1971. "Civil Engineering Bills of Quantity". C.I.R.I.A. Report No. 34, September.

43. STARK, R. M., 1972. "British Approaches to Projects Planning Uncertainties". A.S.C.E., January.

44. BOYER, L. T., and VOLKMAN, R. C., 1972. "Remote Terminal Cost Estimating". Pro. A.S.C.E., March.

45. GATES, M., 1971. "Bidding Contingencies and Probabilities". Pro. A.S.C.E., pp. 277-302, November.

46. GATES, M., 1967. "Bidding Strategies and Probabilities". Pro. A.S.C.E., pp. 75-107, March.

47. SPOONER, J. E., 1974. "Probabilistic Estimating". A.S.C.E. Construction Division, pp. 65-76, March.

48. "How Contractors Organize their Cost Estimating and Control". Progress Report of the Sub-Committee on Organization of Estimating Department, Committee on Estimating and Cost Control. A.S.C.E., Construction Division, pp. 53-74, 1966, January.

49. TORRANCE, J. S., KIRTON, F. H., ROOLEY, R. H., and BERRYMAN, A. W., 1973. "Design Costing and how Computers would help". Building Services Engineer, Vol. 41, June.

50. CUNNINGHAM, J. A., and YARMOWICH, E. P., 1973. "Rate of Work Method: Simplified Project Control". Civil Engineering - A.S.C.E., pp. 62-64, November.

51. PAULSON, B. C., 1972. "Man-Computer Concepts for Planning and Scheduling". Pro. A.S.C.E. Construction Division, pp. 275-286, September.

52. WALSH, S., 1973. "Least Cost Method for Sewer Design". A.S.C.E. Journal of the Environmental Engineering Division, pp. 333-345, June.

53. RAWLS, W. J., and KNAPP, J. W., 1972. "Methods for Predicting Urban Drainage Costs". Pro. A.S.C.E. Hydraulics Division, pp. 1575-1585, September.

54. GORCZYCA, M., 1972. "Construction Cost of Water Supply and Sewage Networks in Poland - 1961-1970". Pro. A.S.C.E. Sanitary Engineering Division, pp. 987-1003, December.

55. CHANG, S. S., 1973. "The Interdisciplinary Higher Degrees Scheme". Chartered Mechanical Engineer, pp. 78-80, June.

56. CLARKE, N. W. B., 1962. "Simplified Tables for Loads on Underground Pipelines". Nat. Bldg. Studies Special Report No. 32. H.M.S.O.

57. CLARKE, N. W. B., 1966. "Loading Charts for the Design of Buried Rigid Pipelines". Nat. Bldg. Studies Special Report No. 37. H.M.S.O.

58. GEDDES, S., 1971. "Estimating for Building and Civil Engineering Works". Newnes-Butterworths.

59. PILCHER, R., 1973. "Appraisal and Control of Project Costs". Mcgraw-Hill.

60. "Glossary of Terms used in Work Study". BS.3138: 1969, British Standard Institution.

61. "Method of Measurement for Road and Bridge Works". 1971. Department of the Environment, Scottish Development Department, Welsh Office. H.M.S.O.

62. TAUSSKY, O., and TODD, J., "Generation and Testing of Pseudo Random Numbers".

63. HULL, T. E., and DOBELL, A. R., "Random Number Generators".