ASPECTS OF PLANNING CIVIL ENGINEERING CONSTRUCTION

A Thesis presented to the

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*This candidate has successfully completed 7 postgraduate courses (24 credit points) in partial fulfilment of the requirements for the M.Sc.Eng. degree, and therefore this thesis represents approximately one half of the value of an M.Sc. thesis submitted in complete fulfilment of the requirements for the degree.

A C K N O W L E D G E M E N T S

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DECLARATION

The writer hereby declares that except where otherwise stated, the content of this thesis is substantially his own work and has not been submitted to any other university.

Signed by candidate

RONALD P. LOS

INDEX

PAGE

PAGE

CHAPTER 3 ASPECTS OF CONSTRUCTION PROJECT CONTROL

CHAPTER 4 FINANCIAL CONSIDERATIONS IN PLANNING AND CONTROLLING CONSTRUCTION CONTRACTS

CHAPTER I

ASPECTS OF PLANNING IN THE CONSTRUCTION INDUSTRY

1.1 Planning and Control in Construction Companies

The process of management is a continuous process of planning, organising, co-ordinating, motivating and controlling according to Pilcher (Ref. 5). In any competitive construction organisation the objective of the managerial staff is mainly to ensure that the firm's resources are utilised both effectively and efficiently. In this thesis certain aspects relating to the planning and control of a contractor's resources on a Civil Engineering contract are considered.

1.1.1 The Contractor's Resources

The resources of a contractor which require to be planned and controlled at the various management levels of a construction organisation can be grouped into:-

(a) Time

(b) Labour

(c) Materials

(d) Plant and equipment

(e) Capital

(f) Managerial and Technical staff

(g) Subcontractor's services

The importance of these resources within a construction organisation are discussed briefly.

A) Time - On most construction contracts the time within which a contractor is required to complete a project is stipulated by the client in the tender documents. A common procedure on Civil Engineering contracts is also for the client to impose a penalty clause which legally forces the contractor to pay a certain sum of money to the client for every day of late completion (i.e. beyond the stipulated date). In practice clients frequently find it difficult to actually enforce this penalty clause, since it obviously requires a corresponding faultless behaviour from the client (or his representative), with regard to the timely delivery of plans, design changes, accuracy of plans, etc. Another effect of time, which affects a contractor's financial resources, is cost escalation (i.e. inflation). The estimator must make adequate allowance for increasing costs when preparing a tender for a contract which has no cost escalation clause.

B) Labour - This includes all weekly paid artisans (e.g. carpenters), semi-skilled artisans (e.g. handy-men), labourers, operators and drivers who are normally found in a construction company. A particular problem in South Africa is the high rate of turnover of artisans on construction sites. Only in rare cases does a particular artisan stay on a contract during its full duration. Because of the present contract system by which african labour is usually only employed by a particular company for one year at a time, most contractors do not consider it worth the effort to train unskilled labourers for skilled tasks. Persons receiving monthly salary payments (e.g. foremen, engineers, typists) are included under the heading H for managerial and technical staff.

C) Materials - This refers mainly to the permanent materials such as concrete, steel, bricks and earthworks which actually form part of the permanent work of a structure. Semi-permanent materials (such as timber formwork) which are usually consumed completely on a particular site are often also classed as materials although strictly speaking formwork is usually an expendable item of equipment. The requirements and sources of supply of certain materials often require careful preplanning since general shortages in the industry are known to occur (e.g. steel, cement, bricks). On country contracts the inadequate capacity of the batching plant can sometimes be a serious restriction on the site progress, but in urban areas premixed concrete can be purchased to cope with extra peak demands for concrete.

D) Plant and Equipment - The term plant is generally used to describe all items of major construction machinery such as bulldozers, graders, drilling rigs, cranes, site mixers and dredgers, while equipment often refers to scaffolding, formwork supportwork, purpose-made formwork, etc. However, American textbooks often use the term "equipment" to refer to "plant". Both plant and equipment are major investments by a contractor who recovers the purchase cost through the depreciation charges which the estimator includes within various tender Bill items. The hourly "depreciation" charge of a bulldozer for example, might be obtained by dividing the total expected cost of operating and owning this machine during its lifetime by its total expected working hours. When estimating the expected cost of a particular Bill item on which this machine will be used, the estimator includes a bulldozer plant charge by multiplying the expected number of bulldozer working hours for this Bill item with the hourly charge rate of the machine. Plant overheads such as the costs of transportation to site, insurance, maintenance and spare parts are also regarded as resources spent on plant and equipment. The operators of plant and equipment are regarded as a labour resource.

E) <u>Managerial and Technical Staff</u> - These include contract managers, site engineers, site foremen and general technicians which the contractor allocates to the various contracts on which his organisation is engaged. The managerial resource does not generally vary rapidly, and the skills and interests of managers largely determines the type of contract for which a particular contractor will tender (e.g. certain firms specialise in road contracts).

F) <u>Subcontractors</u> - These include all outside firms which the main contractor engages on a particular contract (e.g. steelfixers, ready mixed concrete suppliers, electricians, painters, etc.). Subcontractors are considered to be a resource to a contractor in that their availability enables him firstly to tender for contracts which he might not otherwise have considered, and secondly permits him to accommodate peak demands on his own resources (e.g. concrete, steelfixing). In the experience of the writer it is occasionally cheaper for the main contractor to use subcontractors on certain portions of work which he normally performs himself. This particularly applies when the main contractor is working in a geographical area which is far from his normal working environment.

G) Capital - This refers to the financial assets of the contractor which are temporarily tied-up (on site and in the head office) for the purpose of completing the contract. This investment (most of which is temporary) consists firstly of the amount of the contractor's capital tied-up in plant and equipment on site and the head office (fixed capital), and secondly, the capital tied-up as a result of the lag between the time the contractor pays his interim costs for plant, labour and materials and the time when payment is received from the client. The capital tied-up as a result of the difference in timing of payments and receipts is generally referred to as working capital, and includes the amount of retention money retained by the client during construction and the maintenance period (see Section 4.3).

1.1.2 Top Management in a Construction Firm

Senior management in a construction firm performs the task of control which is necessary to ensure that the company operates successfully as a commercial undertaking. Hence, management must carefully allocate the financial, mechanical and managerial resources of the firm to the various construction contracts. Obviously, only men with the necessary experience and knowledge can be entrusted with such decisions.

1.1.3 Site Management of a Construction Firm

The site managers of a particular construction contract are required to ensure the smooth running of a contract and are directly concerned with the efficient utilisation of the site resources (i.e. time, plant, labour and materials).

1.1.4 The use of Planning Models to Aid Construction Management

Managerial planning in a construction company generally requires members of staff to make decisions having long term effects. For example, a contract manager might be required to decide on the best end from which to start the construction of a bridge, the amount of plant and labour required to complete a contract within a given time, or to determine the effect of delaying a certain section of a contract until after the rainy season.

This type of decision might be resolved completely subjectively by sound judgement which takes into account past experience. In addition the manager might use a model to estimate the possible outcome of a particular decision.

A model can be described as "an attempt to imitate a real situation". A typical example of a model might be a scale-model concrete beam which is loaded in an attempt to predict the cracking pattern of a similar full-size beam. Similarly, an equation (which might be found as a result of the above physical experiment), for calculating the particular load causing cracking in the beam is a model which imitates a real-life situation (i.e. the cracking of the full-size beam).

In this thesis a number of models are discussed for planning certain aspects relating to Civil Engineering construction; e.g. these are models for the utilisation of resources on site, models for cash flow during construction, etc.

An important point concerning the use of models by management is firstly that a model is there only to aid a manager in assessing and manipulating the data at his disposal, and secondly the model should never remove from a manager the option to use his sound judgement in decision making. If a model is used, the management must firstly recognise the limitations of the model. Secondly, management interprets the output from the model, and then the management must make its decisions. Lastly management must also assess the long term consequences of these decisions.

1.2 Problems Particular to Planning in the Construction Industry

A number of general planning problems, some of which are unique to the construction industry, are briefly examined. These problems illustrate the type of environment within which plans are made for construction contracts.

A) Non-repetitive Nature of Construction Contracts - A typical characteristic of construction projects is the fact that the conditions on site, the design approach, and the available resources of the contractor, usually require that a unique work programme be compiled for each contract. Although there are often many activities on site which are highly repetitive during construction, the learning processes (whereby artisans, labourers or operators improve their work outputs without greater mental or physical exertions) must usually start anew once a contract has been completed.

B) Type of Contract - Construction contracts in South Africa are usually awarded to contractors either through competitive tendering or direct negotiation between the contractor and the client (or his representative). In certain instances where there is urgency (on the part of the client) for early completion of construction, the contractor is often required to submit a construction price long before the final design is completed. On this type of contract the planner is thus required to compile a construction programme with incomplete knowledge concerning certain parts of the structure. "Design-and-construct" contracts are usually considered to be very satisfactory from the contractor's point of view of construction planning. On such contracts the contractor can match the design approach with his available resources (i.e. plant, labour, managerial skills, etc.).

C) The Nature of the Project - The method which is used to prepare a construction programme generally depends on the type of contract under consideration. The work activities of a bridge contract for example, are usually highly interdependent and hence this interdependency is a dominating factor in determining a construction schedule. Techniques which take into account only the time and geographical interdependencies between activities are therefore often suitable for planning bridge contracts (see Section 2.3). A roadworks contract on the other hand usually has fewer constraints since work can be started at various geographical positions along the length of a road. A technique for controlling many simultaneous activities which are not critically constrained by geographical concentrations along the length of a road, would then be more suitable (Ref. 27, Chapter 2).

D) Unforeseen Circumstances on Construction Contracts - This includes weather, subsoil conditions and other natural factors about which there is a reasonable amount of uncertainty before the start of construction. On contracts involving large quantities of earthworks unforeseen subsoil conditions and adverse weather conditions often force the contractor to frequently review his construction schedule. On such contracts a large provisional item of money is usually provided by the client in the Bill of Quantities against which the contractor can claim when certain unforeseen circumstances occur.

E) Variations and late Information - According to a project manager (Oppenheim Ref. 4) a survey of a number of large construction projects showed that approximately 30% of all construction time delays were due to design changes by the clients, while 60% of all delays were due to late delivery of plans from the designer, and only 10% of all delays were due to bad performance by the contractor. Design changes which are made by the client during construction often cause an upheaval to the contractor's original construction plans. Similarly the late delivery of drawings from the designer to the contractor usually means that the contractor might be forced to make unscheduled re-allocations of resources (e.g. plant, labour and materials) to new parts of the construction project.

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CHAPTER 2

MODELS FOR PLANNING CONSTRUCTION PROJECTS - A REVIEW

2.1 Introduction

A) Relation between this chapter and Chapter 5

A review is provided in this chapter of a number of techniques which can be used to model certain of the characteristics of a construction project, such as the utilisation of a contractor's resources* on site. The aim in this chapter is to provide an introduction and background to the planning aspect of the model proposed in Chapter 5. Most contractors find it necessary to use a simplified version of the larger model proposed in Chapter 5 in order to suit their own input and output system. But it has been thought advisable in this thesis to first develop or describe a general idealised model which has as much useful output data as possible. Further investigation might then show the need to simplify the model to suit practical limitations due to slow or inadequate feedback of input information from the site or planning staff.

It is assumed that the reader is familiar with basic network theory. Hence the subject is only introduced briefly.

B) Bar charts

The bar or Gantt chart is presently one of the most commonly used methods for communicating construction programmes to site staff. Henry Gantt apparently first used these charts in the early 1900's for scheduling and controlling the operations of machine shops, clothing manufacturers and other

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*Refer Section 1.1.1.

production processes (Wallace Clark, Ref. 8).

Examples of Gantt charts are shown in Figure 2.6(d) and Figure 3.1.

The procedure for constructing a bar chart manually is relatively straightforward: The planner starts by identifying the project operations and estimating their durations. Knowing the construction approach he schedules the operations to a calender time scale taking note of their natural sequences (e.g. bases must be constructed before columns), resource constraints such as shortages in labour or plant, other sequences (e.g. abutment A before abutment B) and the estimated duration of all operations. The final schedule is therefore considerably influenced by the judgement, past experience and expertise of the planner who is involved in the planning process from start to finish.

The main shortcomings of this approach to planning are:-

(i) The planner is required to manipulate mentally a large amount of relatively fixed information (e.g. the interdependancies between operations); various effects caused by the limited availability of plant and labour are therefore easily overlooked and errors are frequent.

(ii) The planner is prevented, by the unscientific nature of the technique, from fully taking into consideration all the information at his disposal and is thus forced to rely mainly on his judgement; for example, it is particularly difficult to take into mental account all the complex interactions of operations on an involved bridge contract.

(iii) The process must be carried out by a responsible and experienced person throughout and cannot at any stage be delegated to a junior member of staff. This can quite easily lead to a hastily prepared programme within which some of the pitfalls might have been overlooked.

C) Network-based techniques

The use of networks to represent the interdependancies between the operations of a project was one of the first steps towards the development of a scientific planning model.

During 1958 both the United States Navy and E.I. du Pont de Nemours, a large chemical engineering firm, published details of a planning technique involving the use of networks (Lockyer, Ref. 26). These were known as PERT (Project Evaluation and Review Technique) and CPM (Critical Path Method) respectively. Both methods which are extensively described in literature (Ref. 3, 26, 28) are briefly discussed in various parts of this chapter.

D) Present developments

A number of models have since been proposed which are generally more tailor-made for the construction industry*. Unlike the early CPM and PERT models which establish a work programme simply from the durations of the operations and the interdependancies between them, these also take into account the

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*These are described in Section 2.3.

availability of plant and labour on site. Although often referred to as "network techniques" the influence of the network is considerably reduced and simply serves to describe one of a number of restraints on the construction programme, namely the natural sequence of the operations. Resource allocations on a time basis have become a major factor in these new methods.

2.2 Constructing a Network - basic theory

A) Networks

The planning network is generally defined as being a logical flowchart of the project activities which can express some or all of the following:

(1) The natural interdependancies between the project operations (e.g. a footing constructed before a column),

(2) External influences (e.g. the delivery of plans, safety restrictions which prevent two operations from occurring simultaneously, etc.),

(3) A particular construction approach (e.g. a road construction starting from a specific point).

Because the network is an important statement of construction policy, particular care should be taken in its preparation.

B) Network methods

The two most common techniques presently in use are:

(i) The Arrow or activity-on-arrow method,

(ii) The Precedence or activity-on-node method.

Table 2.1 compares their basic elements.

The arrow diagram originated from the early CPM model of Kelley and Walker (1958, Ref. 21); the Precedence method being an adaptation of a later development by Roy (1961, Ref. 31). This is extensively described in literature (e.g. Refs. 28, 29). An example is shown in Figure 2.1 to illustrate the application of both techniques to a small bridge contract.

There is often controversy among planners as to the choice of method. Although the Arrow method is used extensively in literature a number of authors have in the last two years shown strong support for the Precedence method. The main advantages of the Precedence method appear to be:

(a) Overlapping operations can be portrayed more easily.

Figure 2.2 illustrates a case where considerably less items are required to show the overlap of two activities. The "p" link indicates that operation 2 can only start after 50% of 1 has been completed. Similarly the "f" link shows that the second half of operation 2 can start only when 1 has been completed (i.e. one can do 50% of 2 before 1 is finished).

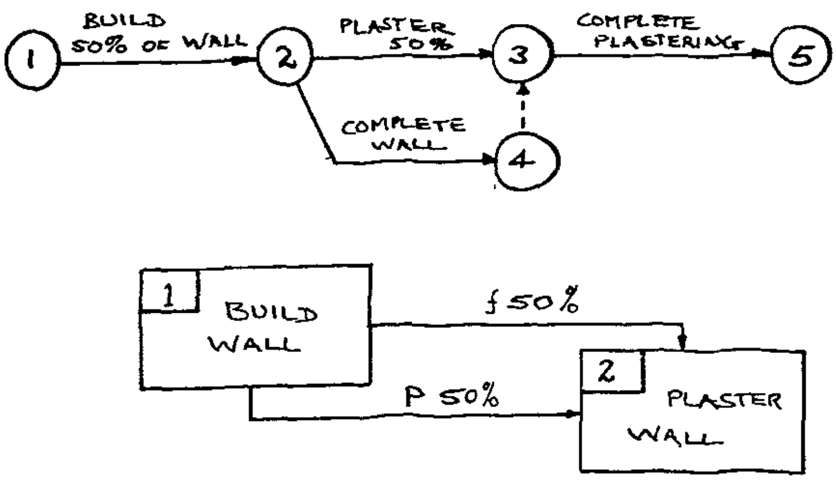

Figure 2.2 Equivalent Arrow and Precedence networks.

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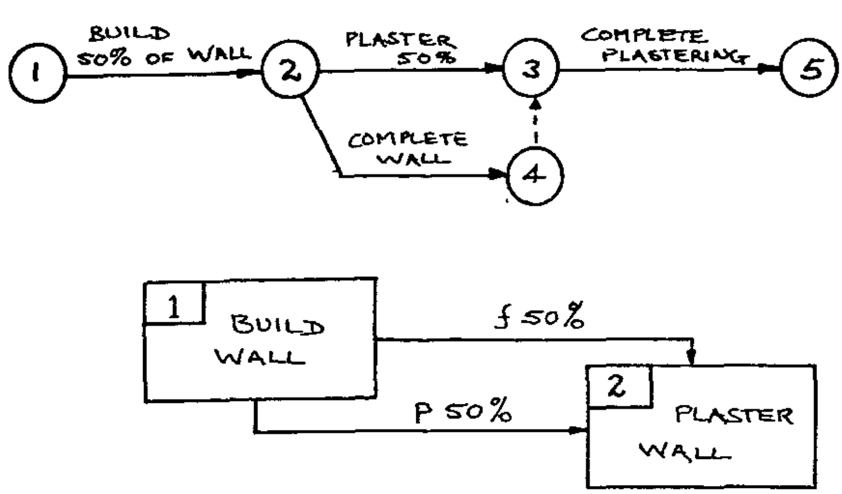
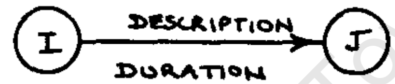
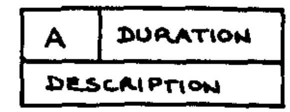
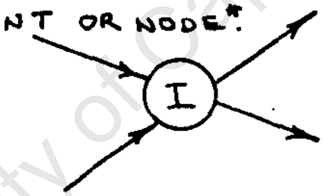
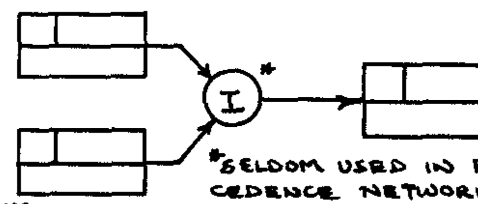
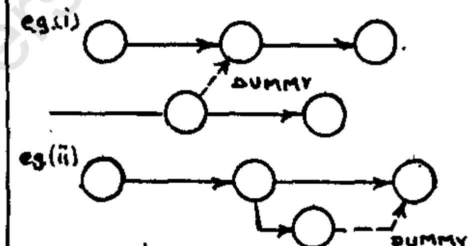
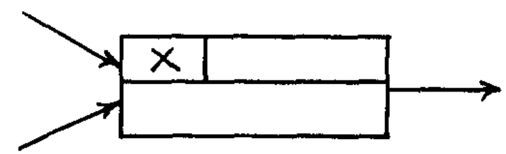
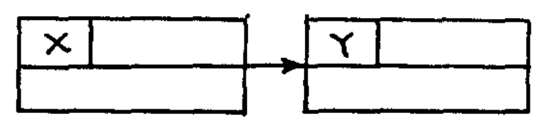


Figure 2.2: Equivalent Arrow and Precedence networks.

TABLE 2.1: Basic Elements of the Arrow and Precedence Networks

ELEMENT	DESCRIPTION	ARROW NETWORK	PRECEDENCE NETWORK
ACTIVITY OR OPERATION	DENOTES AN OPERATION WHICH HAS TO BE CARRIED OUT AND WHICH REQUIRES RESOURCE EG. TIME, LABOUR, ETC.	THE ARROW INDICATES THE ACTIVITY.  ACTIVITY NUMBER : I, J	THE BLOCK INDICATES THE ACTIVITY.  ACTIVITY NUMBER : A
EVENT OR NODE	AN OCCURRENCE AT A POINT IN TIME MARKING THE BEGINNING OR END OF ONE OR MORE ACTIVITIES.	THE CIRCLE INDICATES THE EVENT OR NODE*.  (THE NODE IS AN INSTANT IN TIME)	 *SELDOM USED IN PRECEDENCE NETWORKS BECAUSE THE LINKS SPECIFY THE CONNECTIONS.
DUMMY	ACTIVITIES WHICH DO NOT REPRESENT WORK BUT WHICH ARE USED TO INDICATE THAT ONE EVENT CANNOT START BEFORE ANOTHER EVENT IS COMPLETED.	 	 DURATION ≥ 0
LINK	DESCRIBES THE INTERDEPENDENDENCIES BETWEEN OPERATIONS (EG. IN PRECEDENCE NETWORKS.	THE LINK PATTERN IS IMPLIED BY THE ACTIVITY NUMBERING SYSTEM. THE LINKING OF ACTIVITIES OCCURS AT THE NUMBERED NODES OR EVENTS.	 THE "LINK" = X, Y

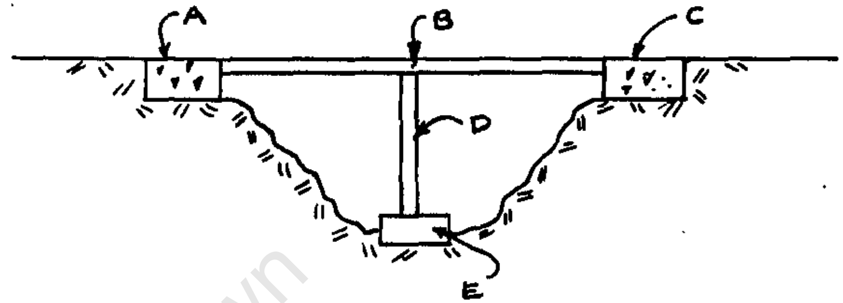


FIGURE 2.1(a): Small Bridge Structure

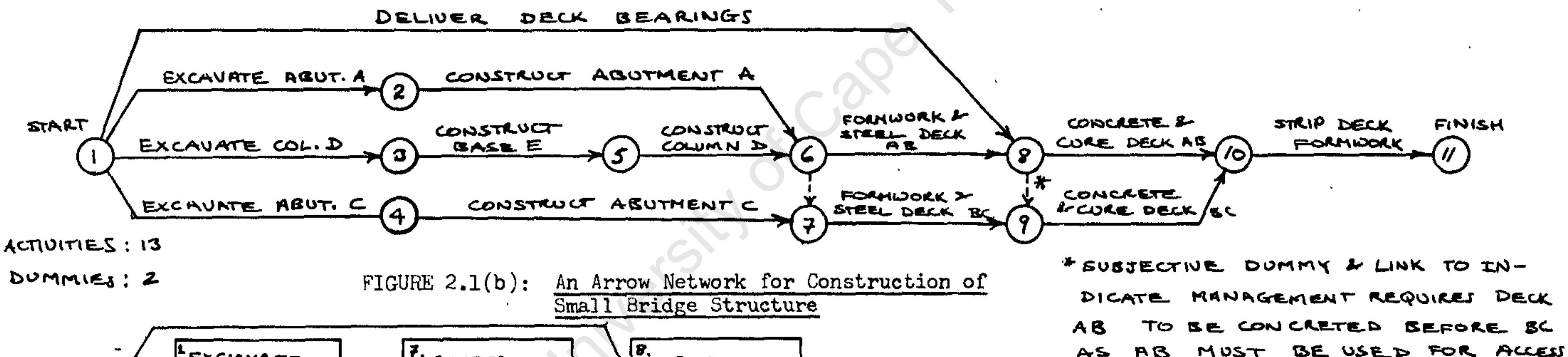


FIGURE 2.1(b): An Arrow Network for Construction of Small Bridge Structure

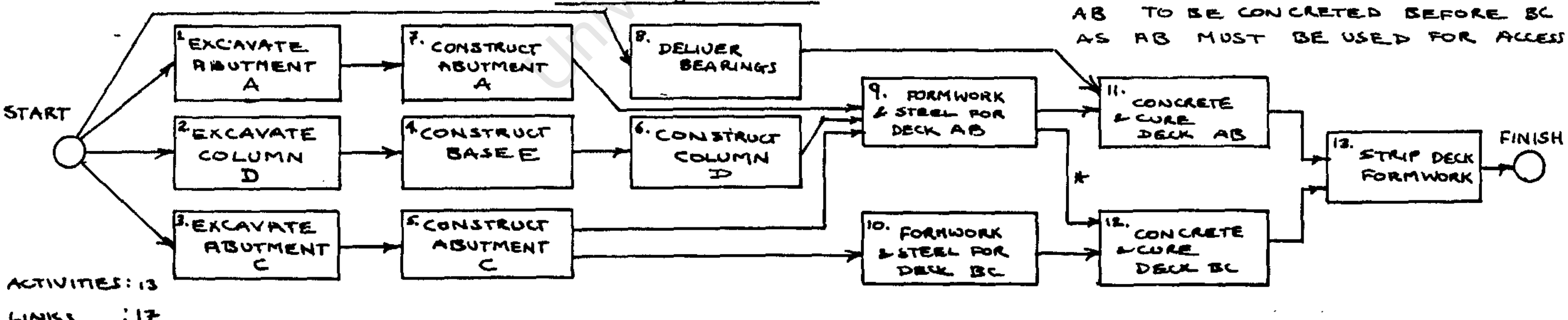


FIGURE 2.1(c): A Precedence Diagram for Construction of Small Bridge Structure

(b) Since each operation on the precedence network is only given one number it is claimed to be much easier to add or remove an activity. This is particularly useful when a computer is used to analyse the network as fewer input cards might be affected by the removal of an activity.

(c) It has been found by some engineers that the Precedence method is easier to teach. This is probably because it is basically a descriptive flow chart which is easier to read than the line diagram of a network.

(d) The final diagram is more presentable and it is easier for a second party to extract information. In the experience of the writer this is particularly true when the project is complex with many interdependancies and overlapping operations which require activities to be split into a number of parts.

It is also often stated that because the Precedence method uses fewer items to depict the same project there will be a reduction in computer calculation time (and hence cost). The writer has, however, found no experiments in the literature substantiating this claim. It will be seen from Figure 2.1 that the Precedence method does not necessarily always use fewer elements than the Arrow network.

The writer considers the choice of technique largely personal but various authors have expressed the opinion that because of the advantages discussed above, the Precedence method will gradually supersede the Arrow network in the construction industry.

An example solved by both methods is described later and shown in Figure 2.6.

2.3 Models which consider Time as the Prime Resource

The schedules derived in this section are based solely on the durations of the project activities and the interdependancies between them. No consideration is given to the availability of plant, labour and temporary materials.

2.3.1 The Critical Path Method time analysis

A) The CPM model

The network time analysis forms the basis of both the early CPM and PERT* models and is presently still found in most network-based planning methods.

Referring to Figure 2.3, it is seen that although the basic input for the CPM model is the same as that for drawing an ordinary bar chart more details relating to activity times are derived, and the critical paths within the networks are easily identified.

B) Time estimates

There are a number of sources from which the planner prepared in conjunction with the members of staff who will be responsible for carrying out the work and the original estimator and planner.

C) Calculations

The basic network calculations are described briefly to point out the main problems. For a more complete

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*The PERT model is described in Section 2.3.2.

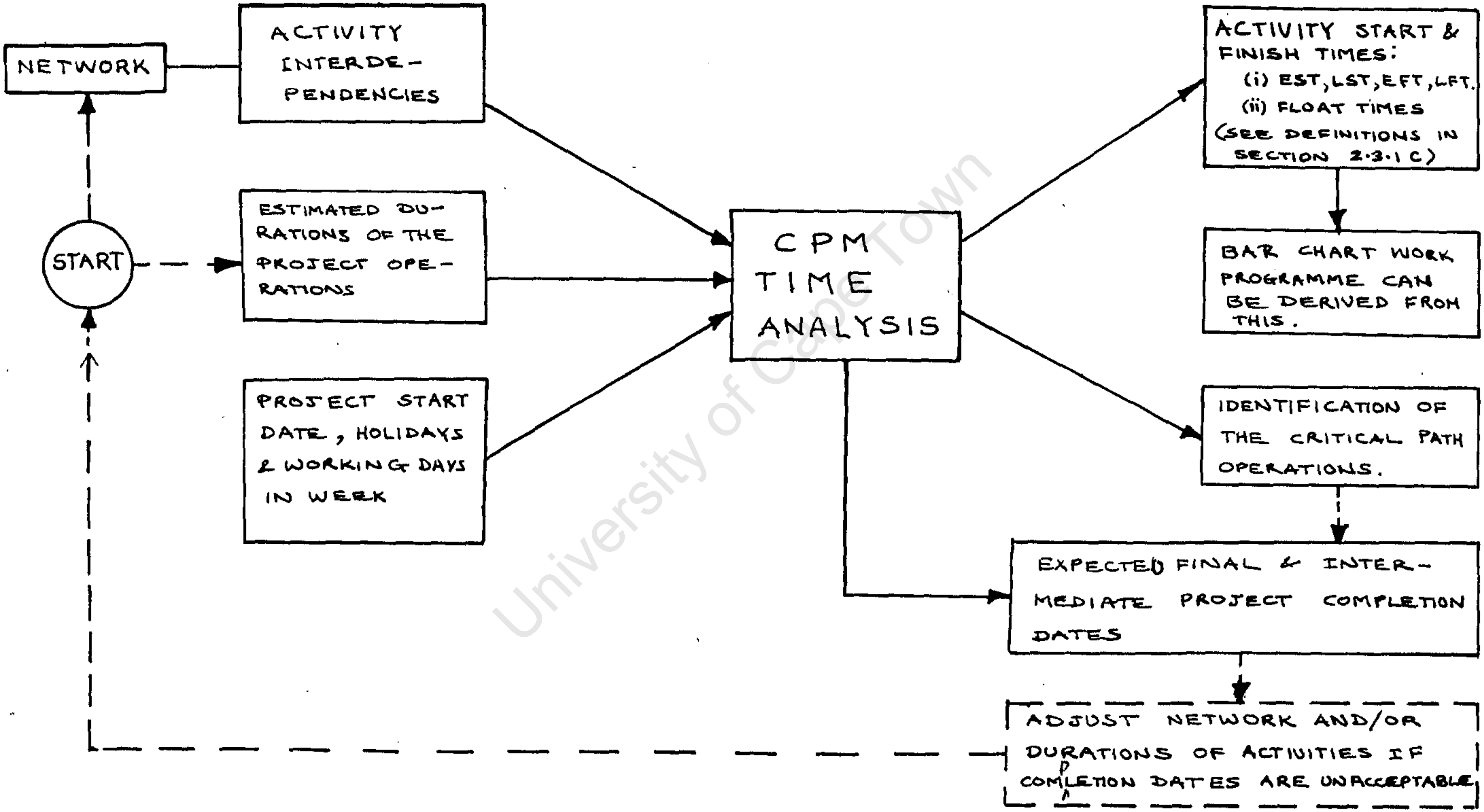

FIGURE 2.3: Inputs and Outputs of the Network Time Analysis

exposition of the procedure the reader is referred to the various introductory texts by Lockyer (Ref. 26), Battersby (Ref. 3) and others (Ref. 28, 30).

After the network and the activity durations have been estimated the next step is the calculation of the activity boundary times (see equation 2.1 to 2.4):

(i) Earliest starting time (EST): This denotes the earliest time by which an activity can start, within the constraints imposed by interdependancies between the project activities and their estimated durations.

(ii) Earliest finish time (EFT): This is the earliest time by which an operation can be completed within the constraints described for (i).

(iii) Latest start time (LST): This is the latest time at which an activity can start without extending the required completion date of the project.

(iv) Latest finish time (LFT): This indicates the latest time by which an activity can be completed before extending the project duration beyond its allowable limit.

The important assumption in definitions (i) to (iv) is that the duration times of all the activities remain constant at their estimated durations.

For the Arrow diagram the calculation of the activity boundary times starts by finding the earliest time (T_e)

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For the Arrow diagram the calculation of the activity boundary times starts by finding the earliest time (T_e)

and the latest time (T_l) for each node or event.

The T_e and T_l values for a node indicate the earliest and latest boundary times between which the event may occur. Although the node times correspond to certain of the activity boundary times (see equations 2.1 to 2.4) the calculation of these times is an intermediate step which has in the past been solved by three methods:

(i) The manual matrix method (Ref. 29),

(ii) Intuitive manual calculation,

(iii) Computer techniques (which might include the manipulation of matrix arrays).

The manual matrix solution which is particularly lengthy and performed after the network is defined, is described in literature till about 1961, after which it appears to have been superseded by the manual procedure shown in flow chart form in Figure 2.4.

The computer solution has been used since network techniques were first proposed. Early programmes were hampered by the fact that nodes had to be pre-numbered in such a way that the number of the completion node for an activity could never be less than the number of the initial node for the same activity (e.g. in Figure 2.5, I must be less than J). Programmes which accept random numbering have since been developed (e.g. ICL 1900 PERT, Ref. 17).

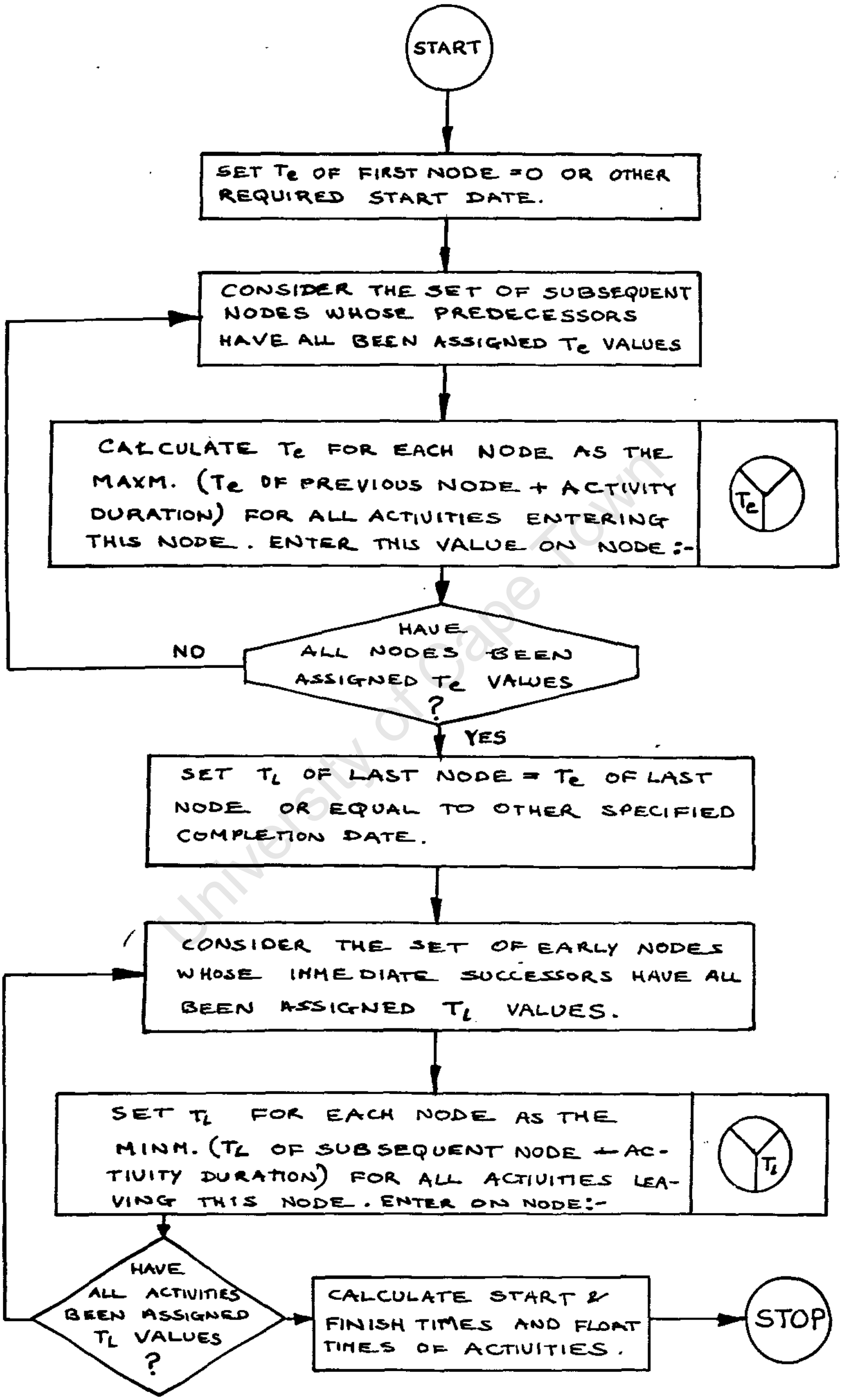

FIGURE 2.4: The Manual Time Analysis (e.g. for Arrow Diagram)

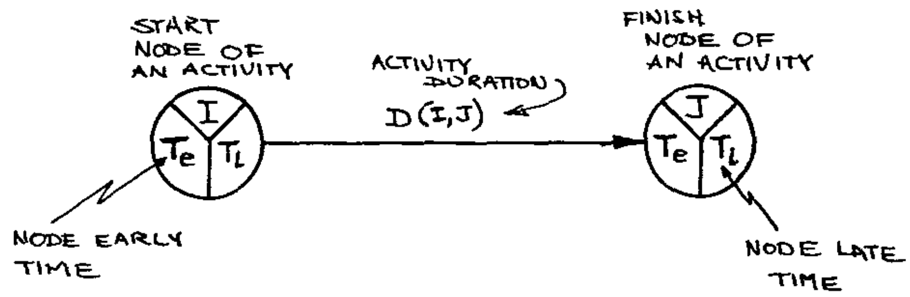

Figure 2.5: Typical notation (in arrow networks)
(Notations for precedence networks are shown in Figure 2.6)

In Appendix C a computer programme is proposed which uses an iterative routine and operates independantly of the node numbers. As far as the writer is aware this approach has not been used before. The usual procedure by other workers is to use a renumbering routine to achieve the I greater than J requirement described above. This is not necessary in the new method (see Appendix C).

From the event times T_e and T_l, which represent the earliest and latest times for a node, the activity boundary times are calculated as;

EST (I,J) = T_e(I) .... (2.1)

EFT (I,J) = T_e(I) + D(I,J) .... (2.2)

LST (I,J) = T_l(J) - D(I,J) .... (2.3)

LFT (I,J) = T_l(J) .... (2.4)

(See definitions in this section).

Where I and J are the start and finish node numbers of the activity I,J as shown in Figure 2.5.

The Precedence diagram is generally analysed either manually or by computer. Although the programme presented in Appendix C is suited to the Arrow network a similar approach might also be used for the Precedence network.

In Figure 2.6 an example of the manual calculation for both techniques is shown. These are performed on the network by partitioning the nodes and operations to allow the various times to be written directly on the diagram. For the Arrow network the early start and late finish times for the various nodes are calculated first as described in Figure 2.4. From this the activity boundary times are determined using equations 2.1 to 2.4.

One advantage of the Precedence network format is that within each activity block the activity boundary times LST and EFT can be seen at a glance for each activity. In the Arrow network these times are not usually shown on the network, but might be shown in a separate table. Obviously in the Arrow network LST and EFT can be calculated for an activity I,J by using equations 2.3 and 2.2 respectively.

For the Precedence network the time analysis procedure described by Figure 2.4 can be used if one bears in mind that the T_e and T_l event times now correspond to the EST (early start time) and LFT (late finish time) of each activity. When operations overlap the writer has

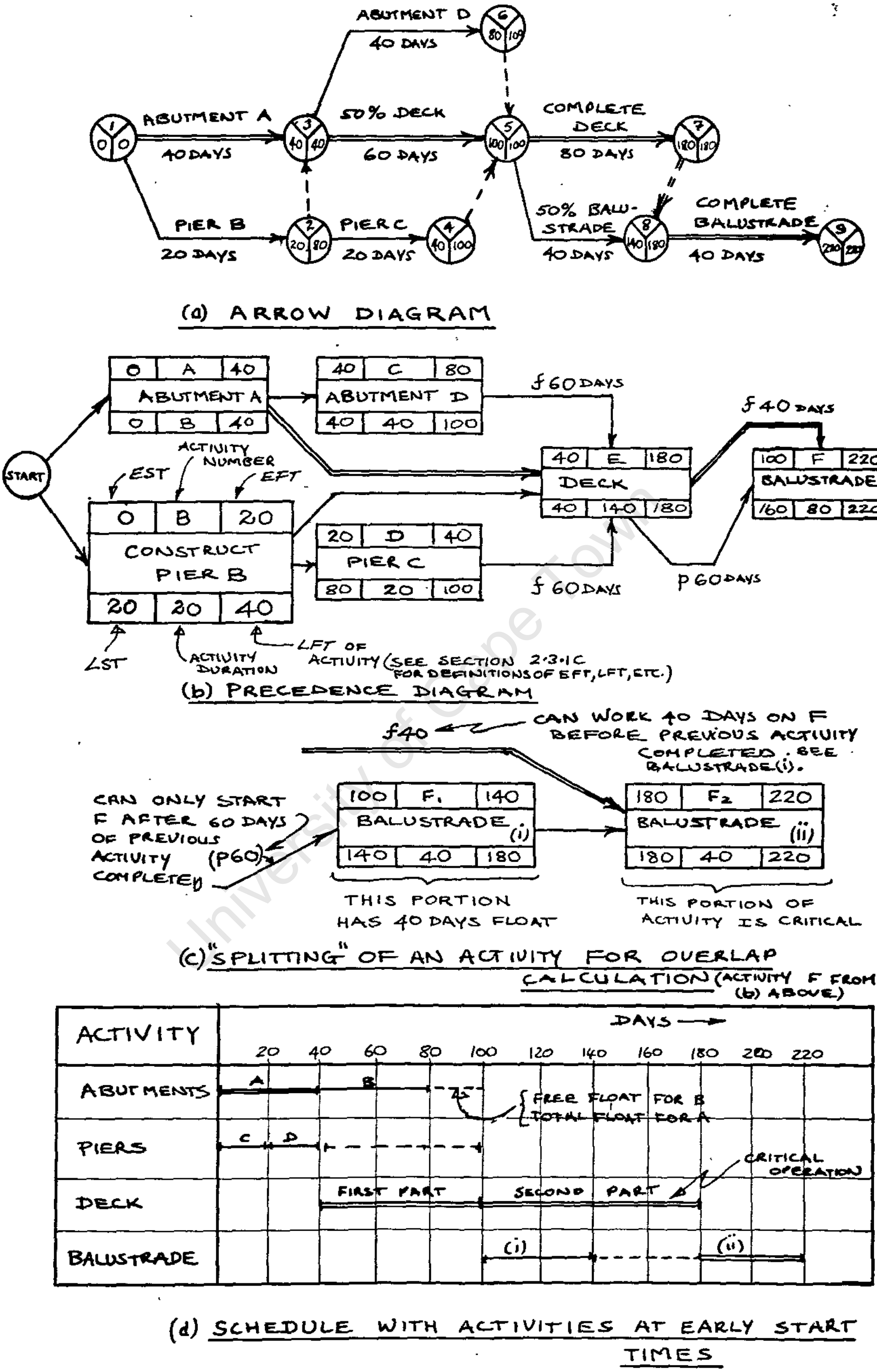

FIGURE 2.6: Example of a Manual Time Analysis

found from experience that it is best to consider these as two separate operations until one is familiar with the calculation procedure. Figure 2.6 (C) shows an example to illustrate this.

The "p" overlap indicates the amount of time for the preceding activity must have been in progress before the succeeding activity can start. The "f" overlap shows how much may be done on the following activity before the preceding one has been completed. When an activity has been suitably split (see Figure 2.6 (C)) these f and p time values are treated simply as delay values which provide built-in time constraints within the network links (see Section 2.2 B (a)).

The shortest duration for the whole project, taking only time and the interdependancies into consideration, is found from the EFT (early finish time) of the last activity.

Float is the amount of time by which an activity can be delayed without extending the project duration beyond its required completion. This might be the shortest duration (described above) or other suitable time. (Referring to Figure 2.4 it is seen that the value of T_1 for the last node is equated to the required project duration.) Two types of float are generally defined for each operation:-

Total float, which is the amount of time the actual completion date of an activity can be extended without affecting the required duration of the whole project, and is defined as LST minus EST or LFT minus EFT (see Figure 2.6 (d)).

Free float is the delay possible within the boundary times of an activity calculated so that there is no effect on the boundary times for any other activity. This is determined as the difference between the EFT (early finish time) and the EST (early start time) of a succeeding operation or where there is more than one succeeding operation, the minimum of these.

The critical path is the unbroken sequence of operations from the beginning to the end of a project which has no float. A delay in any of these activities will therefore mean an extension of the project duration.

A network may have more than one critical path exhibiting the same total duration time.

More complex concepts of floats. If a client specifies a completion date which is earlier than the estimated T_1 for the final event, it is possible to assume that negative float values exist along the critical path. In this case the critical path would be defined as the path along which the float values have the lowest algebraic value. Obviously in such a network efforts must be made to speed up the activities on the critical path.

The float values along a critical path can become more negative if the construction work lags behind schedule.

D) Conclusions

The writer draws the following conclusions concerning the application of the Critical Path time analysis technique to a construction project:

1. The ability of the network time analysis to predict the construction work programme is based on the assumption that:

   (a) the estimates of the durations for the individual activities can be assessed with sufficient accuracy without taking detailed account of the availability of plant and labour on site,

   (b) the interdependancies between the activities, as shown on the network, are representative of those which will occur on site taking into account both the natural sequences of work and any restraints imposed by the limited availability of plant, labour and materials. This point is illustrated by Figure 2.6 where subjective sequence constraints were used to show the piers and abutments in series. The piers and abutments could have been constructed in parallel, in which case a different network would have been analysed.

2. The operations forming the critical path have a special significance in that they represent a sequence to which the contractor should direct particular attention; for example, an unreliable

subcontractor should never be engaged on these critical activities. Any delays might mean that the main contractor will be forced to bear increased indirect costs due to an extended project duration or increased direct costs in trying to recover lost time. A typical example here is the steelfixing subcontractor on a reinforced concrete bridge contract who is nearly always on the critical path.

3. The advantage of the CPM network technique is its relative simplicity and the rigorous manner in which the project can be analysed. Furthermore, there are the additional benefits in that the drawing of the network firstly, leads to a better understanding of the work and secondly, it is a convenient method for communicating and recording the construction procedure and assumptions on which a work programme is based. When the network has been drawn and the durations estimated the time analysis can be delagated to a junior member of staff.

4. The main disadvantage is the fact that it does not directly take into account the actual availability of plant, labour and materials on site (e.g. bulldozers, carpenters, output capacity of the concrete batching plant, etc.). This error is probably small on a bridge contract where the time and geographical interdependancies between the operations is a dominating factor.

A roadworks contract at the other extreme usually has less constraints and the work might be started at several different geographical positions. In the latter case the main restriction would be the plant and labour on site. The Line-of-Balance method is a suitable planning technique for controlling different simultaneous activities for road pavement construction at different geographical positions along the length of the road. (This method is described in reference 27).

2.3.2 The PERT probabilistic model

The PERT (Project Evaluation and Review Technique) approach, introduced by the United States Navy about the same time as the CPM (Critical Path Method), was first used to programme and co-ordinate the development of the Polaris missile (Ref. 28).

The technique, which is in many ways similar to the network time analysis (see Section 2.3.1), attempts to take into account the uncertainty which exists in the estimated duration of each operation and hence that of the work programme as a whole.

The basic procedure of the PERT model, which is shown in flow chart form in Figure 2.7, is based on two assumptions:-

(a) If it were possible to repeat any activity of a project a large number of times under similar conditions, the frequency of occurrence of the recorded durations if plotted to a time scale (as shown in Figure 2.8) would follow a Beta statistical distribution.

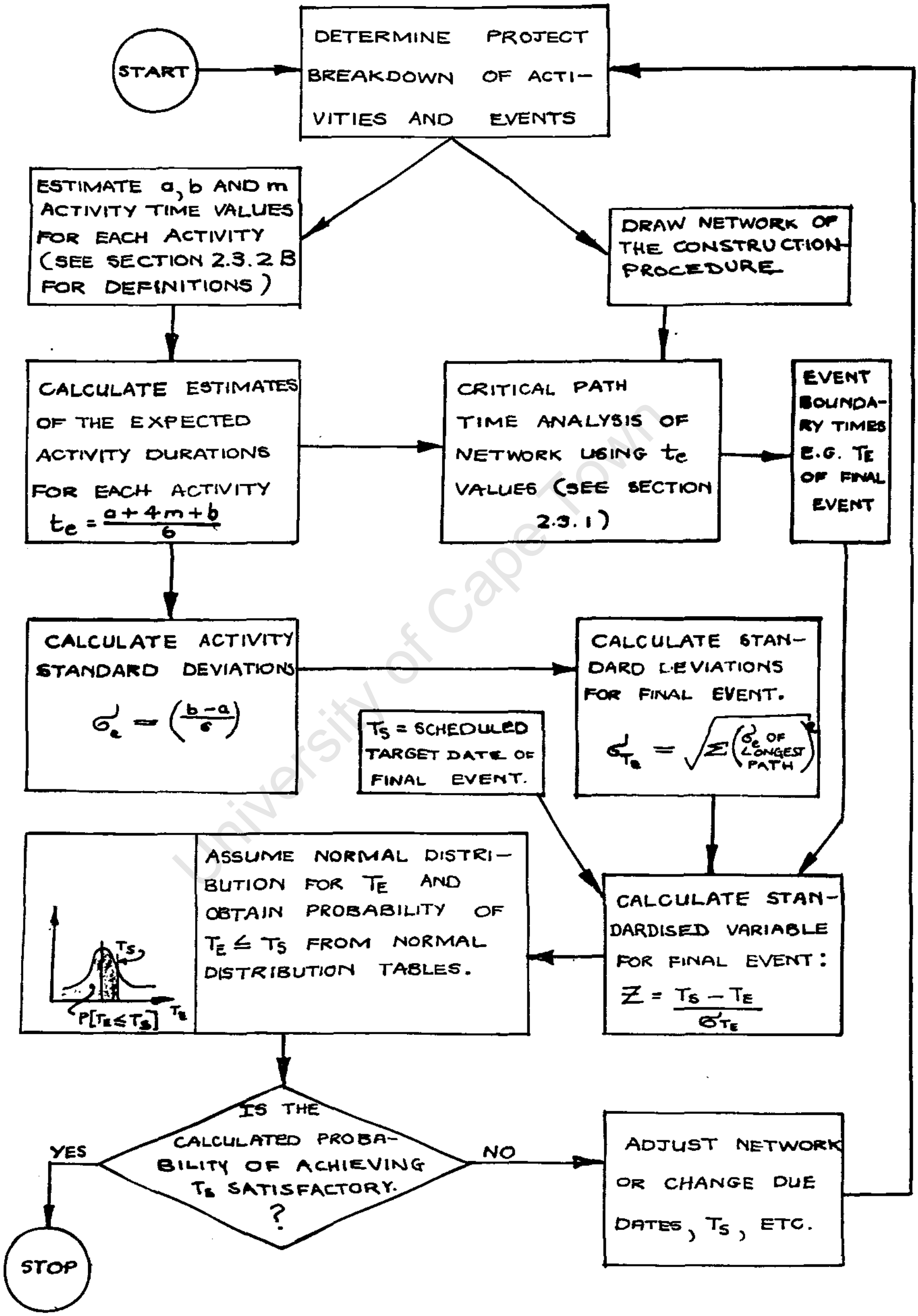

FIGURE 2.7: The Basic PERT Procedure

(b) The probability distribution of the completion time of a network event follows the normal distribution curve if the network event has been reached after a series of activities (for each of which the Beta distribution applies). This assumption permits the use of tables for normal distribution curves when estimating the probability of completing the whole network by a certain date.

The justification for (b) is the central limit theorem which states that, "the statistical distribution of the sum of a large number of random variables will approach the normal distribution" (Ref. 4, page 251). Therefore, whatever the statistical distribution of the individual network activities, the distribution of the project completion date (which is the sum of the distributions of the critical path operations) will tend to the normal distribution.

As far as the present writer is aware there is no experimental justification for assuming that the Beta statistical distribution applies to the duration of an operation (see point (a) above). Various authors (Ref. 3, 24) have expressed the opinion that the choice of the Beta distribution was based mainly on the flexible nature of distribution, which according to Benjamin and Cornell (Ref. 4) can be used to model the observed frequency of occurrence of virtually any type of experimental data.

A) The Beta statistical distribution

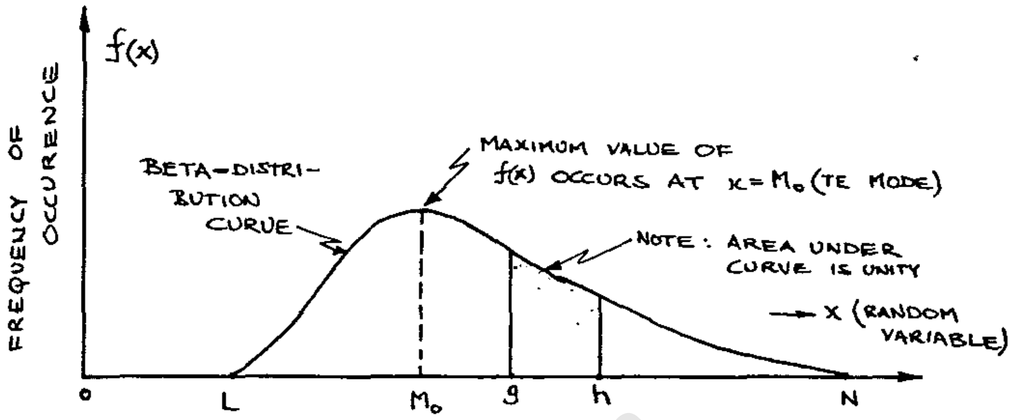

Figure 2.8: The general Beta distribution.

In the range L,N of possible values of x (e.g. activity durations) the equation of the Beta distribution is:-

$$f(x) = \frac{1}{K}(x - L)^p(N - x)^q \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.5\ a)$$

Where $K = \frac{p!\ q!}{(p + q + 1)}(N - L)^{p + q + 1}$ ...... (2.5 b)

p and q are factors which determine the shape of the Beta distribution curve (see Figure 2.9), L and N are the extreme limits of the distribution, x is a variable which is free to take on any value in the interval L,N.

Assuming that the value of f(x) is such that the area under the curve in Figure 2.8 is unity, then the probability that x lies in an interval g, h (see Figure 2.8) is the area under the curve between these limits, and is given by the equation:-

$$F[g \leq x \leq h] = \int_g^h \frac{1}{K}(x-L)^p\ (N-x)^q dx \quad \ldots\ldots\ (2.6)$$

Where L, N, K, p and q are defined as for equation 2.5a; g and h are two values which lie within the extremes L, N of the Beta distribution.

Note: When the value of g equals L and h equals N, the probability of x being within these limits will be unity (i.e. 100%) according to equation 2.6.

In addition, the mode of x (i.e. the value of x corresponding to the peak of the Beta distribution curve) is given by the equation:-

$$M_o = \frac{Lq + Np}{p + q} \quad \text{.........................} \quad (2.7a)$$

Where p and q are the shape factors of the Beta distribution curve, L and N are the extremes of the Beta distribution curve, M_o is the mode.

Also, the mean of the Beta distribution (or the expected value of x whose vertical ordinate divides the area under the Beta distribution into two equal parts) is:

$$M_x = \frac{qL + pN + L + N}{q + p + 2} \quad \text{..................} \quad (2.7b)$$

By substituting equation 2.7a into equation 2.7b the value of the mean becomes:

$$M_x = \frac{L + (p+q)M_o + N}{(p + q + 2)} \quad \text{.................} \quad (2.8)$$

The standard deviation of the Beta distribution, which is a measure of the spread of the distribution is given by:-

$$\sigma_x = (N - L)\sqrt{\frac{(p + 1)(q + 1)}{(p + q + 2)^2 (p + q + 3)}} \quad \text{..} \quad (2.9)$$

For example, a very flat distribution curve (i.e. a large spread) will have a high value of σ_x while a more peaked curve will have a correspondingly reduced standard deviation.

In Figure 2.9 various shapes of Beta distribution curves corresponding to different values of the shape factors p and q are shown. For simplicity the extremes of x were assumed to be zero and unity (i.e. L = 0 and N = 1 in Figure 2.9).

An important observation which is of relevance to the next section is

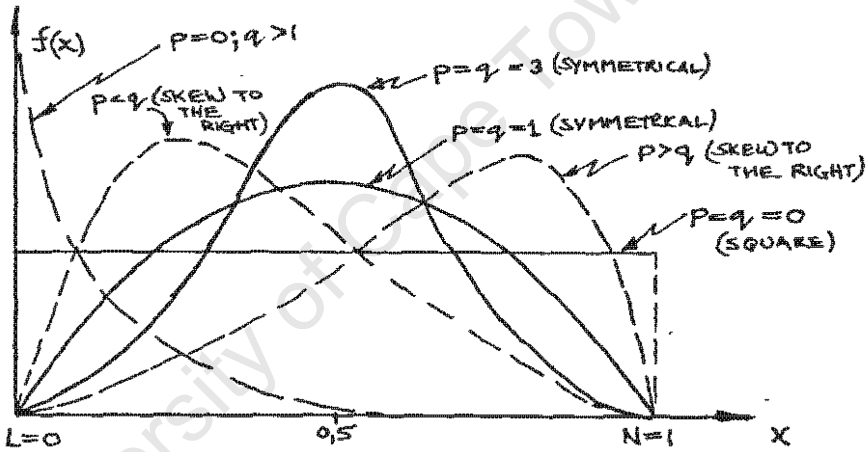

Figure 2.9: Beta - distribution shapes for different values of p and q (Ref. 4).

that for given values of the extremes L, N and given shape factors p and q the position of the mode M_o (i.e. the value of x corresponding to the peak of the curve can be fixed; see equation 2.7a).

B) The PERT assumptions concerning the probability distribution of an activity duration

As described in the introduction to Section 2.3.2 one of the main assumptions of the PERT probabilistic model is that the probability distribution of a project activity can be approximated by a Beta distribution. In order to use this assumption practically as part of a network analysis two additional assumptions are made:-

(1) It is assumed that three parameters a, b and m can be subjectively estimated, where:-

a is an estimate of L, the lower limit of the Beta distribution, and is defined to be an estimate of the most optimistic duration of an activity corresponding to a one in one hundred chance of occurring,

b is an estimate of N, the upper limit of the Beta distribution curve, and is an estimate of the most pessimistic duration of an activity with a possibility of occurring once in a hundred times,

and m is an estimate of the mode M_o of the Beta distribution and is defined to be the estimated most likely duration of an operation (i.e. if it were possible to repeat the same operation a large number of times under the same conditions this duration would occur most often).

It must be noted that although a and b are normally defined as having a probability of occurrence of 1 in 100 in the PERT model (i.e. a 1% probability) they are in fact estimates of the extreme points L and N of the Beta distribution (see Figure 2.8) which theoretically have zero probability of occurring.

(2) In addition, the PERT model assumes that the shape factors p and q of equations 2.5 a to 2.9 take on the values:-

(a) $p = 2 + \sqrt{2}; \quad q = 2 - \sqrt{2}$

or (b) $p = 2 - \sqrt{2}; \quad q = 2 + \sqrt{2}$

By substituting either of the above sets of values for p and q into equations 2.8 and 2.9 and by assuming that a, b and m are suitable estimates of L, N and M_o respectively the following two equations, which are used in the PERT model to estimate the mean M_x and standard deviation σ_x of an activity duration, are found:-

$$t_e = \frac{a + 4m + b}{6} \quad \text{.......................} \quad (2.10)$$

$$\sigma_e = \frac{(a - b)}{6} \quad \text{.......................} \quad (2.11)$$

Where t_e is the estimated mean value of the duration of an activity,

σ_e is the estimated standard deviation or measure of spread of the distribution for which t_e is the estimated mean,

a and b are estimates of the extreme values of the Beta distributions L and N and are defined in point (1) above,

and m is an estimate of the mode M of the Beta distribution as defined in point (1) above.

It is seen in Figure 2.7 that the value of t_e is calculated for each activity and then used in the network time analysis to determine the expected project completion date (T_E) and the project work programme. The value of σ_e is used to determine the probability that T_E (the calculated expected project completion date) will not exceed a target required completion date T_s.

C) <u>A discussion of the PERT statistical assumptions concerning the activity durations</u>

To review briefly, the PERT model assumes that the probability distribution of an activity duration can be modelled with a Beta statistical function with fixed shape factors p and q (i.e. p = 3,414 and q = 0,586 or p = 0,586 and q = 3,414). Also it is assumed to be possible to subjectively estimate three points on the Beta distribution curve from which an estimate of the mean (t_e) and standard deviation σ_e of an activity duration can be calculated.

Since it is particularly difficult to determine experimentally the actual probability distribution of an activity the writer considers that the choice of the Beta distribution is probably as reasonable as using a Triangular or other suitable distribution.

Assuming therefore that a Beta distribution is an acceptable choice, the accuracy in estimating the mean and standard deviation from equations 2.10 and 2.11 is briefly investigated.

Referring to the previous section, it will be seen that the values of L, N and M_o were approximated by the subjectively estimated values a, b and m, thus giving three known points on the Beta curve. In order to uniquely fix the shape of this curve all that is then still required is the value of one of the shape factors (i.e. p or q), since there is a relationship between p, q, L, M_o and N (see equation 2.7 a). In the PERT model, however, fixed values are assumed for both p and q (i.e. p = 3,414 and q = 0,586 or p = 0,586 and q = 3,414) for all calculations. Obviously, this assumption will not always be compatible with equation 2.7 a and could lead to errors when using equations 2.10 and 2.11 to estimate the mean (M_x) and standard deviation σ_x. In addition, as far as the present writer is aware the originators of the PERT model made no attempt to justify the choice of the above particular values for p and q. A possible explanation might be that the assumed difference between a and b (according to equation 2.11) is always equal to six standard deviations. In many statistical distributions almost the whole area of the distribution curve lies between six standard deviations (e.g. in the normal distribution this is 99.7%.)

To determine the possible error in the estimated mean (t_e) and estimated standard deviation (σ_e) for an activity MacCrimmon and Ryavec (see Kransdorf, Ref. 24) determined the value of M_x (the true value of the mean of the Beta distribution; see equation 2.8), and σ_x (the true value of the standard deviation; see equation 2.9) for various values of p and q. The authors assumed that a, b and m were suitable estimates of L, N and M (i.e. a = L, b = N, m = N in equations 2.8 and 2.9) and varied p and q according to the relationship between these parameters given by equation 2.7 a. The values calculated for M_x and σ_x were compared with the PERT estimates t_e and σ_e from equations 2.10 and 2.11. The authors found differences of up to 33 percent between M_x and t_e and 17 percent between σ_x and σ_e. A range of 0,1 was used (i.e. a = L = 0, b = N = 1).

Similar calculations were performed by the present writer for the following values:-

a = 2 weeks

b = 6 weeks

m = 2, 4 and 5 weeks

and various positive values of p and q were used.

For example, by substituting a equals 2, b equals 6 and m equals 4 into equation 2.7 a (i.e. a = L, b = N, $m = M_o$) the relationship between p and q is:-

$$4 = \frac{2q + 6p}{p + q}$$

i.e. $p = q$ for the chosen values of L, N and M_o.

In Table 2.2 the values M_x and σ_x (from equations 2.8 and 2.9) for different values of p, q and M_o, and t_e and σ_e from equations 2.10 and 2.11 for different values of m are compared (M_o was assumed equal to m).

It will be seen in Table 2.2 that when the mode is at the extreme of the distribution (i.e. $m = M_o = 2$) the error in t_e (expressed as a percentage of M_x) is at its

m & M_o	SHAPE FACTORS		M_x (Eqn. 2.8)	t_e PERT	% ERROR	σ_x (EQN. 2.9)	σ_e PERT	% ERROR
	p	q						
2	0	0,5	3,60	2,67	26%	1,06	0,67	37%
2	0	1	3,33	2,67	20%	0,94	0,67	29%
2	0	10	2,33	2,67	15%	0,31	0,67	86%
2	0	20	2,18	2,67	22,5%	0,17	0,67	300%
4	1	1	4,00	4,00	0	0,90	0,67	25%
4	3	3	4,00	4,00	0	0,66	0,67	0
4	10	10	4,00	4,00	0	0,40	0,67	93%
5	1,5	0,5	4,5	4,65	3%	0,86	0,67	22%
5	3	1	4,60	4,65	0	0,71	0,67	5%
5	6	2	4,80	4.65	3%	0,66	0,67	2%
5	30	10	4,95	4,65	6%	0,27	0,67	150%

Table 2.2: Errors possible in the PERT estimated activity mean and standard deviation; assuming $a = L$ and $b = N$.

maximum. When the mode is located more centrally (i.e. $m = M_o = 4$ or 5) the error is very small.

The error in σ_e was found to be much higher than that calculated by MacCrimmon and Ryavec (Ref. 24) who reported variations of 17 percent between σ_x and σ_e. In Table 2.2 the standard deviations (σ_x and σ_e) correspond only when the values for p and q are close to those assumed in the PERT model (i.e. $p = 3{,}414$ and $q = 0{,}586$ or $p = 0{,}586$ and $q = 3{,}414$).

Although the errors found by MacCrimmon and Ryavec (Ref. 24) and in Table 2.2 above are significantly large it must be noted that the values of a and b were assumed to be the extreme points L and N of the Beta distribution (see curve A in Figure 2.10). The values a and b are actually defined as points on the x-axis for which the vertical ordinates enclose 98 percent of the total area under the Beta distribution (see curve B in Figure 2.10), although for calculation purposes they are equated to L and N respectively.

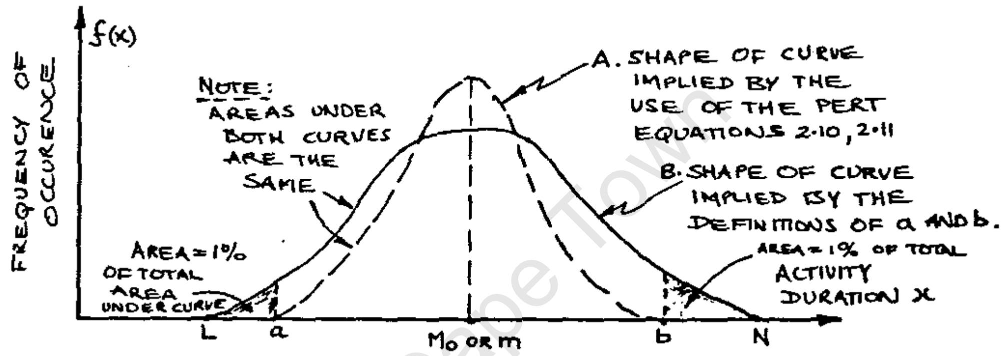

Figure 2.10: <u>Beta distributions for the PERT model.</u>

However, it is expected that if one assumes that the end areas of the Beta distribution between points a and L and points b and N are each always equal to 1 percent of the total area under the whole curve, the number of possible values for p and q (and hence possible shapes of curves) will be reduced (see conclusions in Section 2.3.2 D). Obviously, a and b are now no longer equal to L and N whose values are variable and depend on the shape of the Beta curve used.

To determine whether the above assumption significantly affects the errors in Table 2.2 the writer calculated the values of L and N from standard statistical tables for the Beta distribution and substituted these into equations 2.7 a, 2.8 and 2.9.

For example:-

$a = 2$ weeks $\quad p = 0, 2$

$b = 6$ weeks $\quad q = 1, 4$

From statistical tables for the Beta distribution (Ref. 4) it is found that for a 99% probability x occurring in the interval L to b and the above values p and q:-

$$\frac{b - L}{N - L} = \frac{6 - L}{N - L} = 0,90 \quad \ldots\ldots\ldots\ldots \quad (2.12\ a)$$

Similarly for a 1% probability of x occurring in the interval L to a and the above values of p and q:-

$$\frac{a - L}{N - L} = \frac{6 - L}{N - L} = 0,019 \quad \ldots\ldots\ldots\ldots \quad (2.12\ b)$$

From equations 2.12 a and 2.12 b it was found that L = 0,94 and N = 6,66. Substituting these values into equation 2.7 a:

$$M_o = \frac{0,94 \times 1,4 + 6,66 \times 0,6}{1,5 + 0,5} = 2,66 \text{ weeks}$$

The values of M_x and σ_x were determined from equations 2.8 and 2.9 using calculated values of L, N and M_o, and the values of t_e and σ_e were calculated from equations 2.10 and 2.11 using the given values for a and b and the calculated value of M_o.

$M_x = 3,24$ weeks $\quad t_e = 3,21$ weeks

$\sigma_x = 1,25$ weeks $\quad \sigma_e = 0,67$ weeks

If one assumes that a equals L and b equals N as in Table 2.2, it is found that $M_x = 3,34$ and $\sigma_x = 0,875$.

There is thus a reduction in the difference between t_e and M_x and an increase in the difference between σ_e and σ_x when a and b are considered as points on the x-axis (see Figure 2.10) which correspond to a 1 percent probability of occurring (rather than by equating these to the extreme limits L and N as in Table 2.2).

Furthermore, the writer found that when the mode M_o is close to a or b (i.e. $M_o \simeq$ a or b) there is no difference in the calculated value of M_x and σ_x whether one assumes a equal to L and b equal to N, or if one assumes a and b to correspond to the one percent end areas of the Beta curve (see curve B in Figure 2.10). The errors in both case were then as shown in Table 2.2 for m equals a.

It was also found that since the value of M_o in the above approach is a function of N and L (which were calculated from a, b, p and q) it was possible to determine only one Beta distribution curve (i.e. one set of p and q) for a particular combination of a, b and m. (M_o was assumed to be equal to m.) Since only a limited range of p and q values were investigated more extensive experimentation would be required to verify this conclusion.

D) Conclusions by the present writer

The main controversies concerning the application of the PERT model approach to the planning of a project seem to concern accuracy of assuming the Beta distribution to describe the probability distribution of an activity, the accuracy of the simplified equations used by the PERT model to estimate the mean M_x and standard deviation σ_x of an activity and the accuracy possible in estimating the three subjective values a, b and m.

As stated previously no experimental data seems to exist to determine the actual probability distribution of an activity duration. The choice of the Beta distribution thus appears to be based amongst others on the fact that even if the mode and the extreme limits of this curve on the x-axis are estimated independantly of each other the shape of the whole curve can be determined.

From experimentation with various shapes of Beta curves (as described in Section 2.3.2 C) MacCrimmon and Ryavec (Kransdorf, Ref. 24) concluded that the knowledge of the three points N, M_o and L on the Beta distribution curve (i.e. a = L, b = N and m = M_o) is not sufficient to uniquely establish the shape of this curve. Also the authors found that large errors were possible if one compared the PERT estimated activity mean and standard deviations (equations 2.10 and 2.11) with the same values obtained from the exact Beta distribution equations (2.8 and 2.9) for various different shapes of curves. (Note: the PERT model assumes that only one shape of curve and hence only one set of shape factors p and q applies for all activities.)

Investigations by the present writer, however, tend to indicate that if one treated the subjectively estimated values a and b according to their definition (i.e.

optimistic and pessimistic activity durations with a 1 percent probability of occurring) an additional constraint is imposed for which only <u>one</u> Beta distribution exists (see Section C above).

Furthermore, the writer also found that even if the above assumption is made for a and b large errors can still result when using the PERT equations 2.10 and 2.11 to estimate the true mean M_x and standard deviation σ_x of an activity.

The writer therefore suggests that a possible extension to the PERT model might be the development of a simplified procedure to determine the parameters p and q (and hence the values M_x and σ_x) for a particular set of a, b and m; where a and b are defined to be the values on the x-axis of the Beta function as shown for curve B in Figure 2.10. The method described in Section 2.3.2 C could be used by varying the parameters p and q (for given values of a and b) to find different sets of values for N and L (see equations 2.12 a and 2.12 b). These could then be substituted into equation 2.7 a to find the values of p and q for which M_o equals the given value of m. However, unless a computer is used this calculation would be completely impractical;as can be seen from the example calculation.

It is expected that many of the errors in estimating the activity times a, b and m will cancel out over the whole project unless the estimator is consistently over- or under-estimating.

The writer is of the opinion that if more accurate but still practical methods can be devised to estimate the mean M_x and standard deviation σ_x of an activity (or if it can be verified experimentally that the errors caused by the approximate PERT equations 2.10 and 2.11 cancel out over the whole project) the PERT model can be used to derive useful additional information from the network time analysis.

For example, if a large standard deviation value σ_{T_E} for the final completion date of the whole project is calculated (see Figure 2.7), this indicates that a large uncertainty exists with respect to the probable completion date of the project. (Extra plant and labour will be required to shorten the activity durations if the scheduled target completion date T_S is not considerably greater than the estimated value of T_E for the completion event.) A small value for σ_{T_E} indicates greater certainty with regard to completion date estimates. Under these circumstances over-confidence can result and problems can arise if the scheduled target date T_S is too close to the calculated expected date T_E even when the value of σ_{T_E} is small.

The need to consider resources other than time is discussed in the next section; and the inadequacies of plain network time analysis are described in Section 2.4 C.

2.4 Models for Planning the Allocation of Plant, Labour and Materials

A) Introduction

Two factors which usually impose an important restriction on the construction programme of a civil engineering project are:

(a) The availability of plant (including equipment) and labour on site,

and (b) The supply of materials required for the permanent work of the structure (e.g. concrete).

The relative importance of these depends on the type of contract, i.e. roadworks, pipeline, bridge construction, etc. and external influences such as temporary shortages in cement, the distance from a city and the availability of labour in the industry.

Heavy plant (e.g. drill rigs, bulldozers, excavators) are a major investment for the contractor whose purchase must be carefully planned to ensure that enough work will be available to warrant the expenditure. It is not uncommon for contractors in large cities to hire plant during short-term peak periods or when special items are required (e.g. a 60 tonne crane). Country contracts are usually planned in much greater detail to avoid being delayed by a critical item of machinery which must come from elsewhere.

Bridges, retaining walls and other concrete constructions are highly dependant on the amount of equipment in staging and formwork available. In the writer's experience the construction time for a prestressed concrete bridge of 6 independant cast in-situ spans has been reduced by up to 30% using two (instead of one) spans of shuttering and support. Very little increase in the actual number of carpenters was necessary as these could now start on a new span while steelfixing and cable draping was taking place on the previous one.

The shortage of skilled artisans is a particular problem of the South African industry. The rate of absenteeism and turnover of labour on a construction project is high. Trained or skilled supervisory staff is also in great demand and the amount of work which can be tackled on a job often depends on the capability of the foremen on site.

The capacity of the concrete mixer or the batching plant is a common restriction on construction sites. As the size of "concrete pours" on most Civil Engineering contracts are large but infrequent it is usually more economical to use ready mixed concrete. On country sites mixing facilities are often small and structures (e.g. bridge decks) are therefore divided into a number of sections of say 100 cubic metre batches which can be handled in one day.

B) The basic resource-duration equation

For a single operation where only one type of labour or plant is required the relationship between resource and duration can generally be expressed as:

$$T = \frac{Q}{WN} \qquad (2.13)$$

Where T is the expected duration of the operation (e.g. days),

Q is the quantity of work involved (e.g. m^2 formwork, m^3 excavation),

N is the amount (or teams) of plant or labour applied (e.g. 2 carpenters),

and W is the average rate of working of one unit of the resource team (e.g. m^2 per carpenter-day); neglecting possible effects of overcrowding, understaffing, etc. It is generally assumed that W is constant between certain limits x and y as shown by Figure 2.11 a.

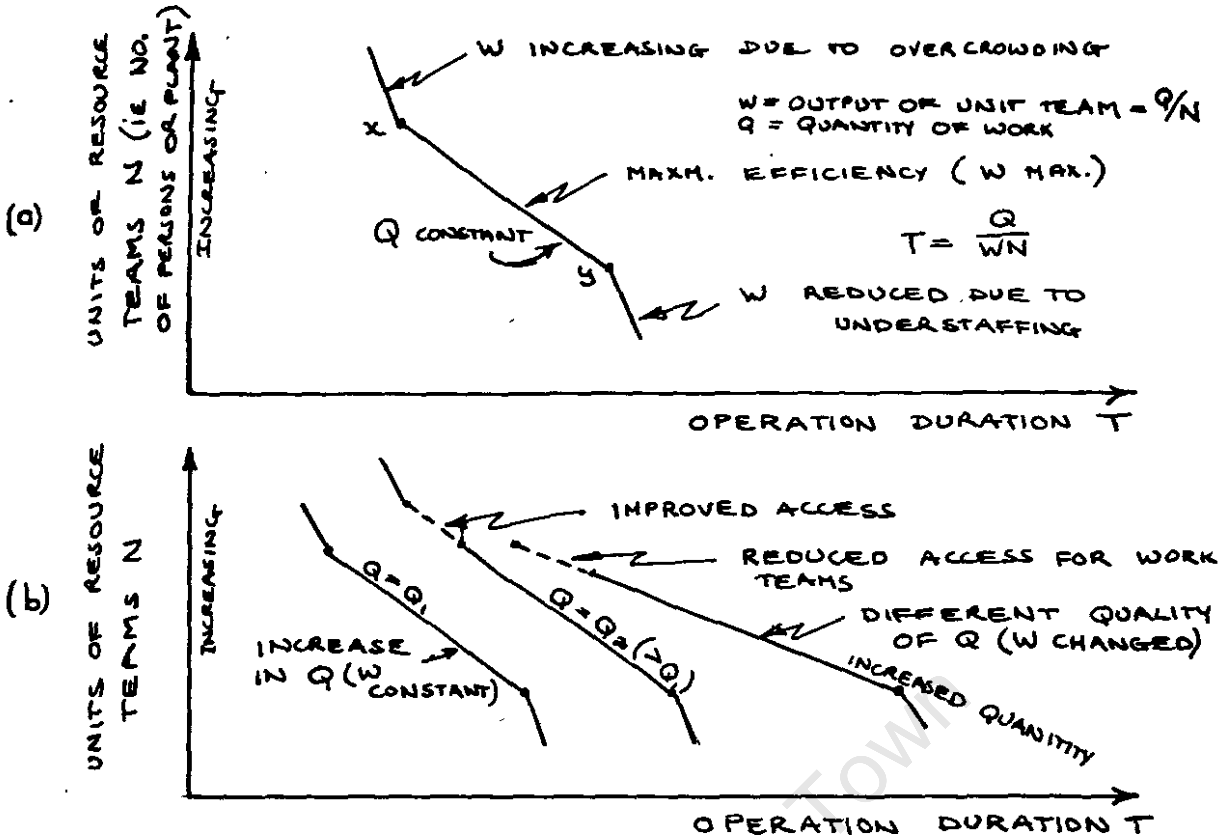

FIGURE 2.11: The Relationship between Time and Work for an Operation

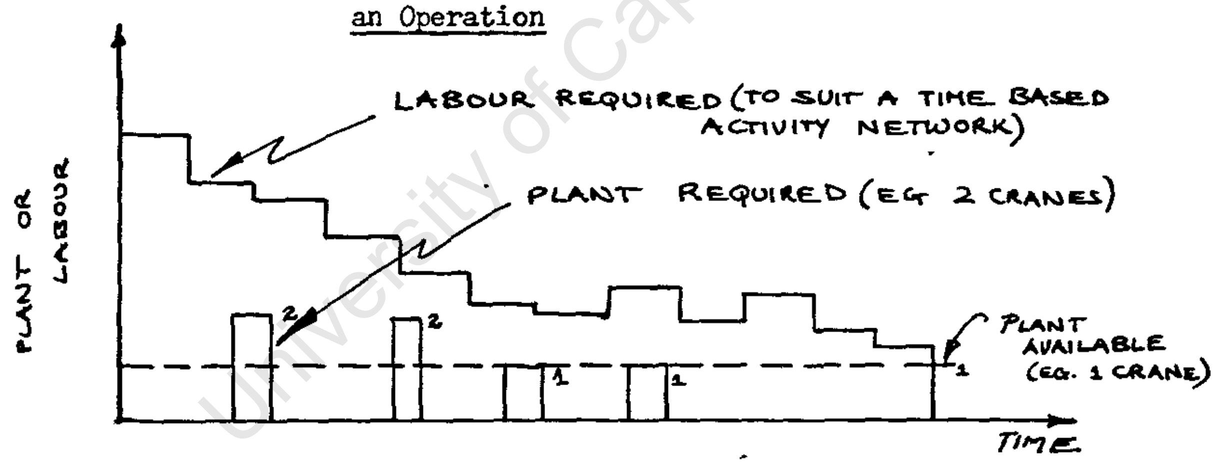

FIGURE 2.12: Typical Time Analysis Plant and Labour Demand Prediction

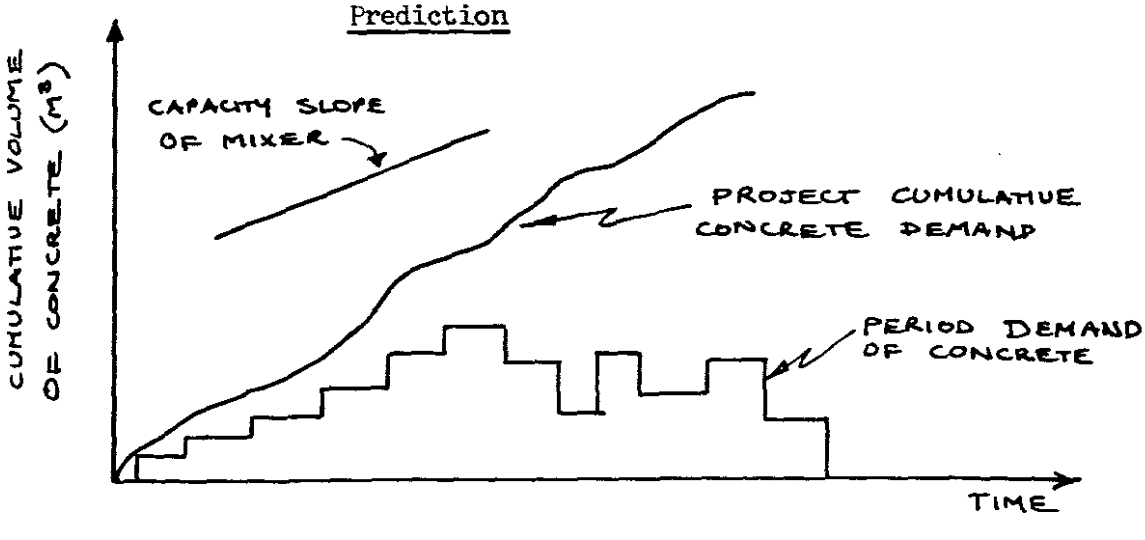

FIGURE 2.13: Project Cumulative Material Demand

This equation is sometimes used by construction managers to assess roughly the duration of a whole project (e.g. earthworks) or set of operations by assuming an expected working rate (W) under the conditions prevailing and the type of plant or labour available.

For example, a common assumption made in tendering is that a carpenter should be able to erect 1 square metre of formwork per hour at ground level. Assuming that no loss of efficiency is caused by overcrowding the duration for shuttering a 5,000 m^2 reservoir wall should therefore take 8 carpenters approximately;

$$\frac{5,000}{1 \times 8} = 625 \text{ hours}$$

or about 73 eight-hour days.

Figure 2.11 b shows various factors which might influence the duration of an operation. When plant is involved the output W will be decided by the type of machine, access, slope of the ground, type of material, etc. For operations involving mainly labour one must consider the type of material (e.g. column formwork, beam formwork), the height from the ground, complexity of the operation, etc. before estimating the value of W.

C) Inadequacy of the network time analysis

Figure 2.12 shows a typical labour demand* predicted by a normal critical path time analysis with all operations starting at their earliest duration. Should this be unacceptable to

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*This is often referred to as resource aggregation in literature and is found by cumulatively summing the resource requirements (e.g. labour) of all the operations at each point in time over the contract duration.

the contractor, certain of the operations will have to be delayed to reduce this early peak. Similar conflicts can also occur for plant and must similarly be corrected by shifting operations.

With regard to materials, it is often found on bridge projects that the size of certain "concrete pours" (e.g. for the deck) exceeds the capacity of the site mixer for a normal working day. As these pours are infrequent they can simply be completed during overtime hours. When concrete is, however, placed continuously such as for dams, reservoirs and similar contracts this would be an uneconomical proposition. The capacity of the batching plant will then have a significant influence on the work programme. Figure 2.13 shows a typical cumulative concrete requirement curve which is found in the same way as that for labour and plant; the maximum slope of the curve determines the maximum quantity rate required (e.g. 100 m^3/day) and must be checked against the capacity of the site mixer.

For small projects it is usually possible to adjust the critical path time analysis manually to take into account the effects of any limitations on the amount of plant, labour or materials available on site. Various models have, however, been developed which allow the construction manager to perform these calculations for almost any size of project using data processing facilities. The operation of these models and their limitations are discussed in the remainder of this section.

2.4.1 Resource scheduling models

A) The two basic types of models for resource scheduling

The models which have been applied with the most success to the project resource allocation problem are those which were originally developed as an extension to the network time analysis*. This is probably because the network was the first adequate method for describing graphically the interrelationships between the various operations.

The structure of the early models was determined largely by two schools of thought who formulated the problem in different ways:

(1) Galbreath (Ref. 14), de Witte (Ref. 11) and other authors considered the problem to be one of levelling the resource demand of the schedule determined by the network time analysis*; without extending the project duration. This was achieved by shifting the network activities within their total float to reduce fluctuations in the plant, labour and materials demand over the project duration. Other terms used to describe this technique are resource smoothing and time-limited scheduling.

(2) Kelley (Ref. 22), Wiest (Ref. 35) and others (e.g. Ref. 5) assumed that the project manager would be more interested in determining the effect of a particular resource application to a project (e.g. 2 carpenters, 6 bulldozers, etc.) This is generally referred to as resource allocation or resource-limited scheduling in literature. In this latter approach the total project duration would not necessarily be constrained to a fixed value. The basic

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*Described in Section 2.3.1 which deals with the C.P.M. method.

inputs and outputs of the two approaches are summarised in Figures 2.14 and 2.15.

B) Examples

To illustrate the techniques of resource aggregation, levelling and allocation a number of simple examples are shown in Figure 2.16. In the resource allocation model the project duration is invariably extended when the resource availability is low. An important point here also is that the critical path as defined in Section 2.3.1 (i.e. the path along which no delays are permitted) now loses its meaning as the operations no longer form an unbroken chain because the start of a "critical" activity might have to be delayed until the necessary resources become available. The term "critical sequence" which refers to the sequence (or sequences) of operations with zero float is sometimes used.

On its own the resource allocation model is generally favoured by contractors. This is probably more easily understood if one considers that the contractor's resource constraints are not only a limited supply of plant, labour and materials but also that of having to meet a certain project completion date. Referring to Figure 2.14 it will be seen that in the case of the levelling model one can only do this by manually adjusting the network until the project duration is acceptable. The same effect (i.e. acceptable project duration) is achieved in the allocation model by simply varying the resource levels.

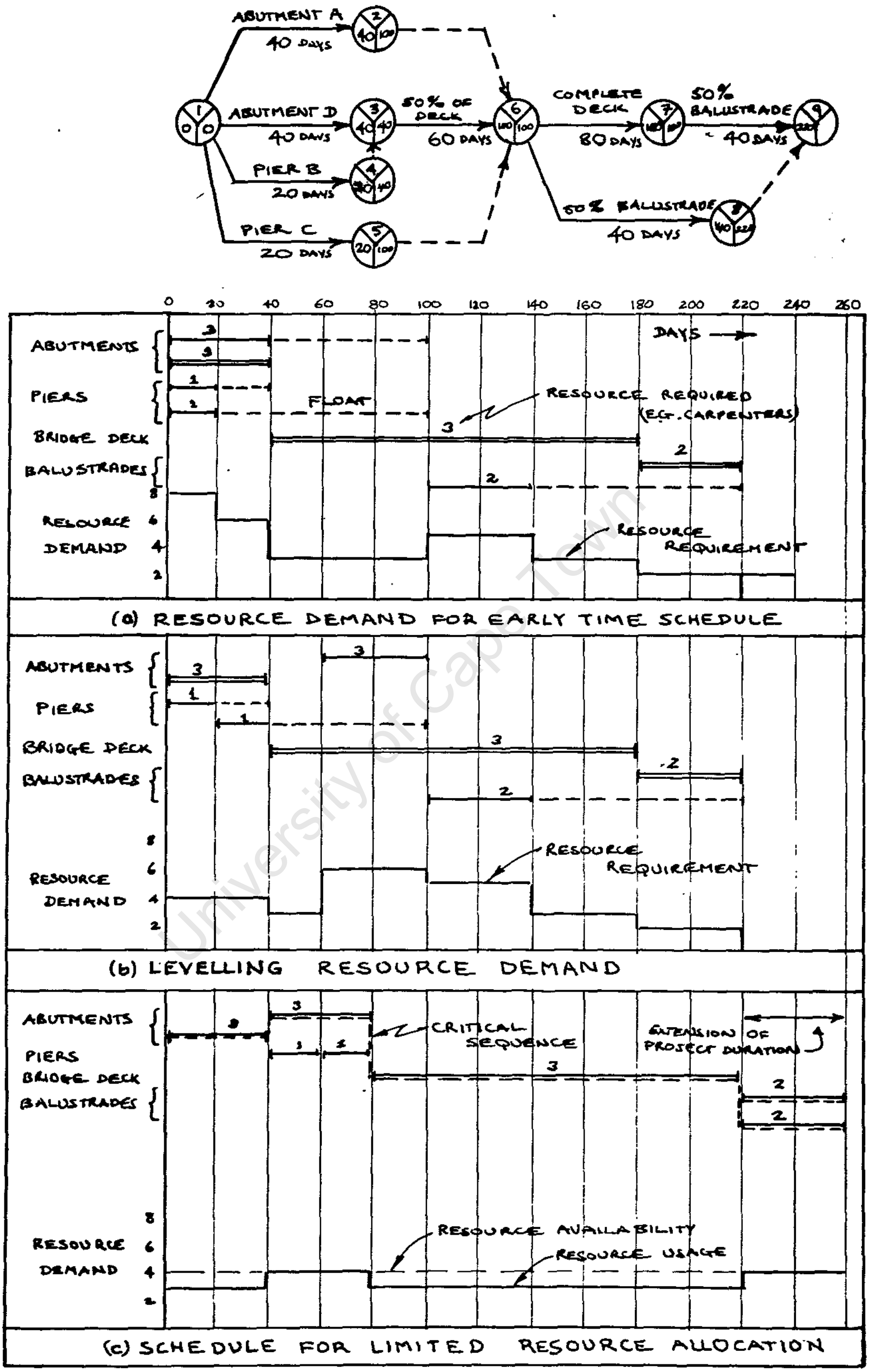

FIGURE 2.16: An Illustration of Resource Scheduling
(e.g. Scheduling of Carpenters)

A more recent development is a combined allocation and levelling model (e.g. Ref. 17) which allows the planner to set limits to both the project duration and project resource levels (see Section 2.4.3). In this case the resource allocation process operates until the project duration has been extended to its permitted limit. After this the levelling model continues and attempts to flatten the high resource demand peaks in the project without necessarily lowering the peaks below the specified resource level.

For the remainder of this section the writer will concentrate mainly on the resource allocation model as this appears to be more suited to the problems of the contractor. It will then be shown how the resource levelling approach can be included as a useful extension to this technique.

2.4.2 Solution techniques of resource allocation models

A) Introduction

As stated previously a manual solution of the resource scheduling problem is possible when the project is small or when only one or two resources are available. For more complex projects it has, however, become generally accepted that some form of electronic data-processing facility is required to perform the large number of calculations involved. Some consideration is given in this section to the type of solution techniques which have been developed for this purpose.

B) <u>Linear Programming and other mathematical solutions</u>

It has been shown by various authors (e.g. Wiest and Levy; Ref. 34, Conguet; Ref. 15) that the interrelationships between the project operations, their resource requirements, the resource availability and the objective of completing the project as soon as possible can be expressed in linear programming form*. This can be solved by computer to yield an <u>optimal</u> answer to the above resource allocation problem. Various other mathematical programming techniques such as branch and bound methods and dynamic programming have also been used in attempts to find exact solutions.

The development and progress of these techniques, up to about the middle of 1972, has been extensively investigated by Herroelen (Ref. 16). The author was, however, forced to conclude that because of certain computational problems no mathematically exact solution techniques suited to present commercial requirements were available. Investigations by the present writer tend to confirm that

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*Linear programming methods are used to solve sets of linear equations with constraints in the form of equalities and inequalities (e.g. a job may not start before its logical predecessor is completed) and an objective function which must be optimised (e.g. minimise project duration).

this is still the case. Personal discussions with Dr. Barnes* have shown that he is presently using linear programming techniques to solve certain practical problems, but because of the expertise required to set up the input data and the computational costs the programme is limited in its application.

Excessive computation time (and hence cost) appears to be mainly due to the large number of variables required to express the problem and the large number of possible combinations of activity positions, which the programme must investigate.

Most research is presently concentrated in using operations research techniques to estimate a speedy solution.

C) Heuristic programmes

As far as the writer is aware all present commercially available computer programmes which can be used to plan the allocation of plant, labour and material resources to construction projects are of this type.

According to the World Book dictionary the term heuristic has been derived from "heuriskein", the Greek word meaning "to discover". It is used extensively in literature to describe solution techniques which can lead to approximate or suboptimal answers. These range from completely mathematical calculations to methods which are simply based on a number of skillful guesses. Feldman (Ref. 13) for example, uses the term "heuristic"

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*Of Martin Barnes and Partners, London.

to describe a solution found by the simplex algorithm, which because of certain assumptions made for the input data, will not always provide an exact answer. Wiest (Ref. 35) on the other hand points out that the rule: "When the sky is clouded, take an umbrella" is a perfectly good example of a heuristic solution. In other words this is a rule of thumb method which displaces the impossible direct method of contacting the creator of the weather.

In its present sense a heuristic programme incorporates a set of decision rules which operate in a manner very similar to the procedure followed by a site foreman when he decides each day to which operations he should allocate his limited supply of plant, labour and materials. Although these rules are known to provide reasonable answers no guarantee can be given that these rules will provide the optimum answer.

From an examination of six* different heuristic resource allocation programmes, of which details have been published, the writer found the following points of similarity between the solution techniques.

Three main types of decision rules could be identified as follows:-

(i) The scheduling heuristic rules; These rules determine that a computer programme uses either a parallel or serial activity scheduling procedure. The concepts of parallel and serial scheduling are

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*See Table 2.3

described below and in Figures 2.17 and 2.18.

(ii) The priority heuristic rule; This rule decides which operations should receive priority in being allocated resources.

(iii) A subroutine of "schedule- or-delay" heuristic rules; These become operative only when an operation is eligible to start on a particular day but insufficient resources are available to achieve this.

The basic procedures of serial and parallel programmes are summarised in Figures 2.17 and 2.18 for a project with only one resource. The writer found that once the workings of these simplified diagrams were understood it was relatively easy to predict the workings of commercial computer programmes, simply from the description of the input and output data in the users' manual.

Both the serial and parallel approaches were proposed by Kelley (Ref. 22, 1961) in what appears to be the first paper on network-based resource allocation.

D) The serial and parallel methods

The serial method (Figure 2.17) focuses on the activity. These are arranged in a certain order of priority and schedules one by one at their EST (early start time) if sufficient resources are available over their complete duration. Otherwise these activities are delayed to a later date.

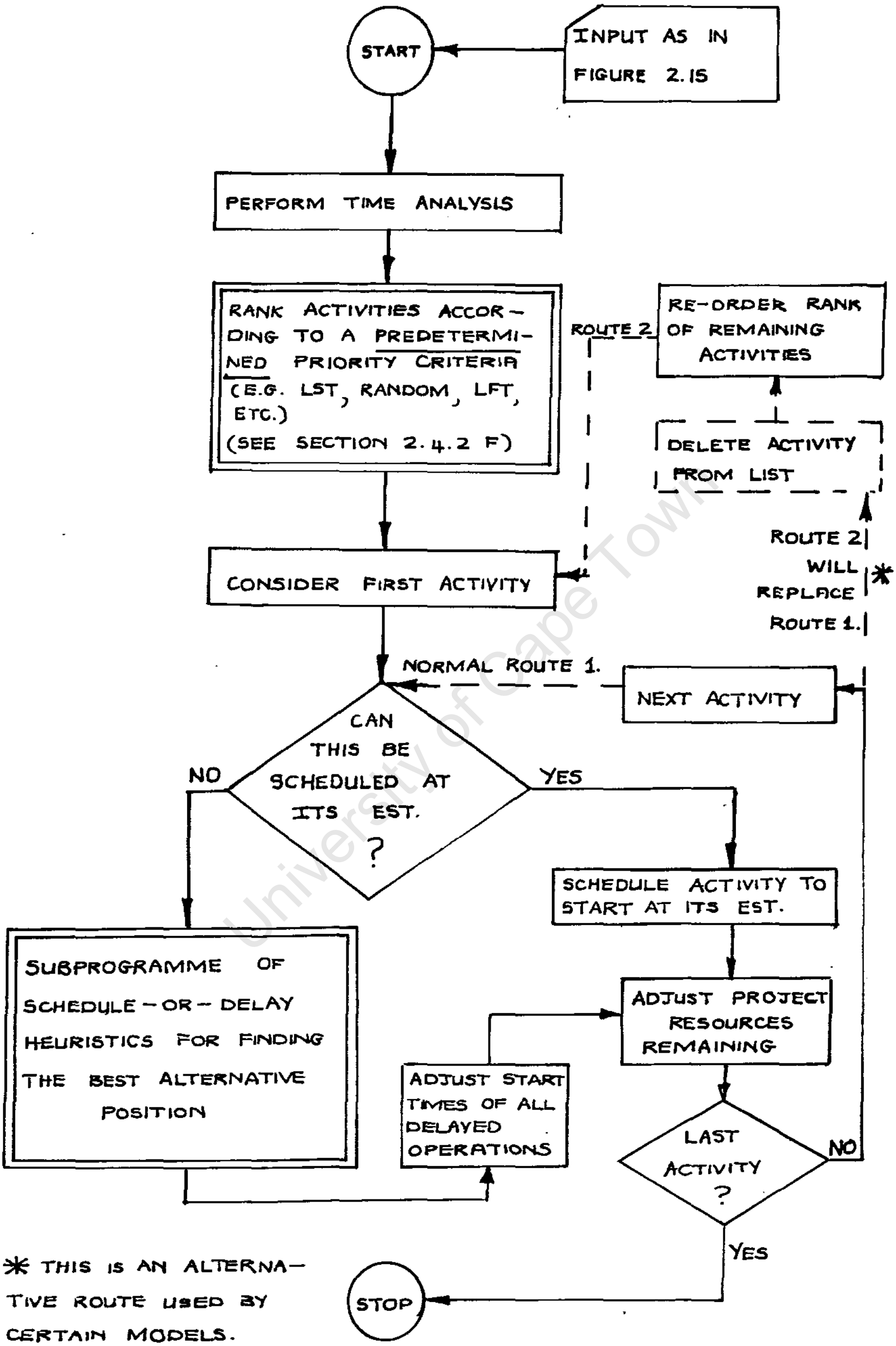
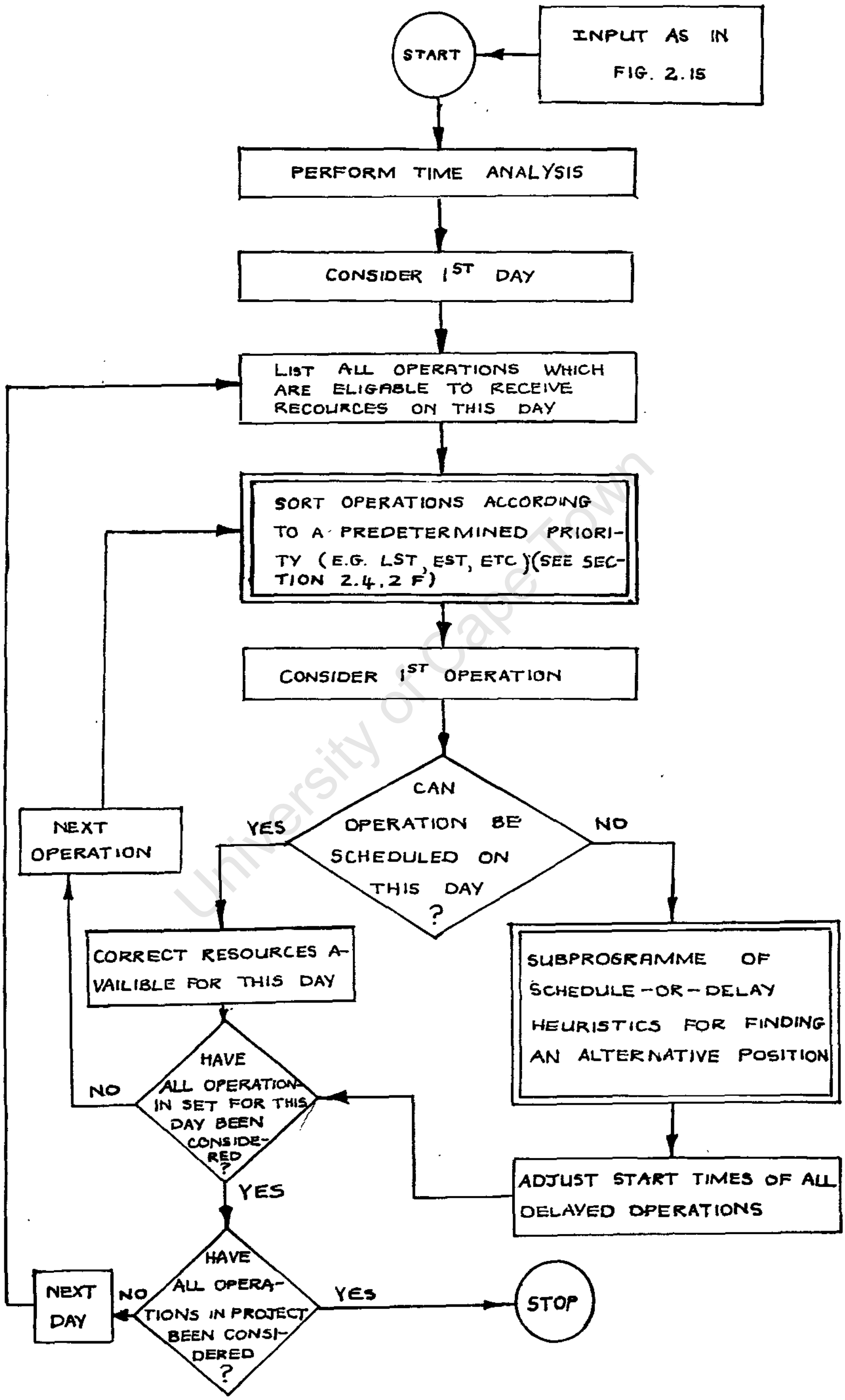


FIGURE 2.17: The Basic "Serial" Resource Allocation Procedure



START
INPUT AS IN FIG. 2.15
PERFORM TIME ANALYSIS
CONSIDER 1ST DAY
LIST ALL OPERATIONS WHICH ARE ELIGABLE TO RECEIVE RECOURCES ON THIS DAY
SORT OPERATIONS ACCORDING TO A PREDETERMINED PRIORITY (E.G. LST, EST, ETC.)(SEE SECTION 2.4.2 F)
CONSIDER 1ST OPERATION
CAN OPERATION BE SCHEDULED ON THIS DAY ?
YES
NO
NEXT OPERATION
CORRECT RESOURCES AVAILIBLE FOR THIS DAY
SUBPROGRAMME OF SCHEDULE-OR-DELAY HEURISTICS FOR FINDING AN ALTERNATIVE POSITION
HAVE ALL OPERATIONS IN SET FOR THIS DAY BEEN CONSIDERED ?
NO
YES
ADJUST START TIMES OF ALL DELAYED OPERATIONS
HAVE ALL OPERATIONS IN PROJECT BEEN CONSIDERED ?
NEXT DAY
NO
YES
STOP

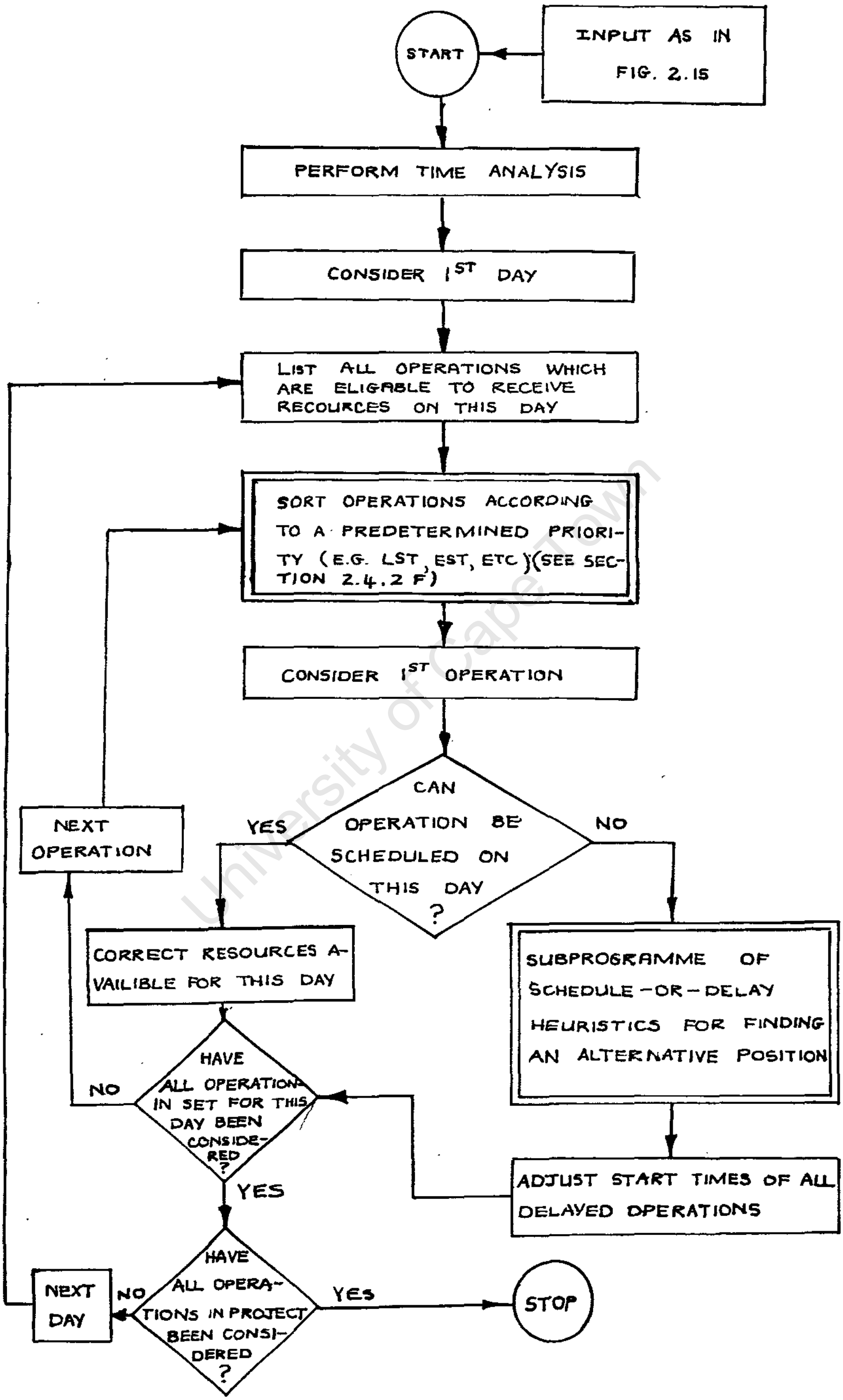


FIGURE 2.18: The Basic "Parallel" Resource Allocation Procedure

In the parallel approach (Figure 2.18) the allocation is performed day by day over the project duration. For each day those operations which are eligible to start, or which are already in progress, are listed in a given order of priority. The programme then attempts to schedule as many of these operations with their resource requirements for the day under consideration and delays the rest of the activities for consideration for the next day.

E) The serial-parallel model

It is generally regarded that the parallel procedure will result in a more precise allocation of resources. For example, at the time of planning the model examines the operations on a daily basis and it can, if necessary more easily allocate resources to the operations such that these resources vary over the activity duration (e.g. 2 carpenters on first day building up to 4 as they are freed from other operations which have been completed). This type of solution is also possible with the serial method, but it is more difficult to program for this facility.

Pascoe (Ref. 30) statistically compared the schedules and durations of 32 different projects by each method and found the parallel method to be better ninety nine out of a hundred times. It must, however, be noted here that the author used the original Kelley serial model shown in Figure 2.17. It is the opinion of the writer that had the modification of re-ordering the data after each allocation been used in the serial model, the difference might not have been so great. It is interesting to note that this modification (shown dotted in Figure 2.17) in fact almost makes the serial method equivalent to the parallel method and is sometimes referred to as the serial-parallel model.

F) Priority heuristic rules

The priority heuristic rules decide to which of the operations resources should be allocated first.

As the objective* of the allocation model has generally been to complete the project as soon** as possible with the resources available, it was often argued that critical operations should receive priority. Verhines (Ref. 33) and Kochanski (Ref. 23) both proved mathematically for a small project that this does not always lead to the shortest project duration and suggest that priority be determined by the minimum LFT (late finish time). After extensive experimentation, in which 32 different projects were each evaluated by 10 different sorting

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*The thinking behind this objective and other possible approaches are discussed in a later part of this section.

**Resource allocation generally starts with a time analysis; one exception is the model by Bennet (Ref. 4, Chapter 5).

criteria*, Pascoe concluded that on average both LFT (late finish time) and EST (late start time) would give the best result; i.e. the shortest project duration. From the results of these tests it was, however, clear that one could not state categorically which priority would give the best solution for <u>every</u> type of project.

An interesting finding by Campbell (Ref. 7) who compared the schedules of 5 commercial resource allocation models for the same project, was that the resulting project durations differed by about 15 - 20%. This could probably be attributed partly to different priorities used and the basic differences in the structures of their solution routines.

Table 2.3 shows some of the priority rules which have been suggested by various authors. A further conclusion drawn by Pascoe (Ref. 30) was that if activities have been sorted according to EST values, then there is no advantage in further ordering those activities with identical EST values.

G) Schedule-or-delay subroutines

The subprogramme of schedule-or-delay heuristics differs from programme to programme and only comes into working when an activity cannot be scheduled at its early start time (or revised start time if it has been delayed)

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*This included minimum EST, LST, EFT, LFT, TF, FF, Random sorting and three based on the amount of resource remaining in an operation.

TABLE 2.3: A Comparison of Six Heuristic Resource Allocation Programmes

PROGRAM	RPSM**	—	—	—	SPAR I**	ICL 1900 PERT**
AUTHOR	KELLEY	VERHINES	BROOKS	PIKE	WIEST	—
REFERENCE	22; 1961	33; 1963	5; 1963	12; 1964	35; 1966	17; —
SERIAL / PARALLEL	SERIAL	SERIAL	PARALLEL	PARALLEL	PARALLEL	PARALLEL
	(SEE DEFINITIONS IN SECTION 2.4.2D AND FIGS. 2.17 AND 2.18)					
SCHEDULING PRIORITY RANKING OF ACTIVITIES (1ST / 2ND)	MINM. J-NODE NO (FIG. 2.5) THEN IF NECESSARY LEAST TOTAL FLOAT.	LEAST LFT (SEE SECN. 2.4) THEN IF NECESSARY LEAST DURATION	LEAST LST (SEE SECN. 2.4)	LEAST EST THEN IF NECESSARY LEAST LST	LEAST TOTAL FLOAT	?
INPUT: PROJECT RESOURCE LEVEL	NORMAL & OVERTIME LEVELS, BOTH CAN VARY WITH TIME THROUGH CONTRACT FOR EACH RESOURCE.	ONE CONSTANT RESOURCE LEVEL FOR EACH RESOURCE THROUGH CONTRACT.	ONE CONSTANT RESOURCE LEVEL	ONE CONSTANT RESOURCE LEVEL	ONE VARIABLE RESOURCE LEVEL	THREE VARIABLE RESOURCE LEVELS (i) NORMAL (ii) OVERTIME (iii) SUPER O/TIME
INPUT: ACTIVITY RESOURCE LEVEL	(i) NORMAL LEVEL (ii) MINM. START VALUE (PER RESOURCE	ONE LEVEL (E.G. 6 CARPENTERS/DAY)	ONE LEVEL	ONE LEVEL	THREE LEVELS (i) MAXIMUM (ii) NORMAL (iii) MINIMUM	ONE LEVEL
INPUT: ACTIVITY DURATION	ONE DURATION CORRESPONDING TO EACH RESOURCE LEVEL OF ACTIVITY	ONE DURATION	ONE	ONE	ONE CORRESPONDING TO NORMAL RESOURCE LEVEL (ii)	ONE ONLY
NO. OF RESOURCES *	26 × 9	—	1 × 1	>1	12 × 2	250 × 60
COMPUTER OUTPUT ALLOCATED ACTIVITY RESOURCE-TIME PATTERN	CONSTANT RESOURCE USAGE OVER ACTIVITY DURATION	—	CONSTANT OVER ACTIVITY DURATION	CONSTANT	VARIABLE OVER ACTIVITY DURATION	VARIABLE OVER ACTIVITY DURATION

* NO. OF RESOURCES PER PROJECT × NO. OF RESOURCES PER ACTIVITY

** COMMERCIAL PROGRAMMES

(Ref. Figures 2.17 and 2.18). The programme then attempts to find an alternative start time for the activity rather than extend the project duration, which is the last resort.

Typical alternatives are:-

(i) Delaying an operation within its free or total float,

(ii) splitting an operation and scheduling a portion at a later date (it is usually specified in the input data whether this is allowed),

(iii) some programmes accept various resource levels for each operation (as shown in Table 2.3). This takes into account cases where an activity can also be equally started with a lower resource allocation: the duration being adjusted proportionately,

(iv) in Table 2.3 it is also seen that some models allow one to specify a project "overtime" resource level which can be used before the project duration time is extended.

In Figure 2.19 an example of a parallel resource allocation model for projects with more than one resource type is shown. This has been adapted from the model described by Dike (Ref. 12) to illustrate the operation of a number of schedule-or-delay heuristic rules.

An interesting approach is used in this regard by the ICL

1900 PERT system* (Ref. 17), a commercially available planning and control programme containing a resource allocation model. From the description provided in the user's manual it is clear that this has a parallel routine of the type shown in Figure 2.18. No indication is given of the initial sorting routine but the schedule-or-delay heuristics are described in detail. These have been arranged in the form of a decision matrix, which rates each operation according to whether resources are available, its criticality** (i.e. how much total float remaining), whether it may be split and what its criticality would be if it were delayed. From this rating the model decides whether to schedule, delay or split an operation. Although the approach is basically similar to the questioning routine shown in Figure 2.19 it is expected that it will lead to a somewhat quicker answer due to the apparent simplification of the calculation procedure. Tests would, however, have to be performed to substantiate this conclusion.

H) Objective functions of resource allocation models

The structures of the resource-limited scheduling models described up to now in this section are all centred around the objective of minimising project duration; (i.e. each decision rule is designed to schedule an

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*The main features of this system are summarised in Appendix A.

**As determined by the time analysis (Section 2.3.1) and any delays imposed during resource allocation.

operation within a given resource availability with if possible, no extension of the project duration).

There appear to be various reasons for this. By minimising the project duration one is probably also maximising the resource utilisation (i.e. minimusing "idle" time or dips in the resource demand curve). This would then in turn minimise the direct cost of the scheduled project which could be evaluated from the total area under the required and idle resource curves. The third argument here might be that since a large portion of project indirect costs are related to the project duration (Figure 2.21) these will also be minimised. Another advantage is the relative ease with which the minimisation of contract duration can be built into a model since it does not require an additional calculation routine as would for example, the objective of minimising fluctuations in resource utilisation.

Under certain conditions the above time based objective might not lead to the cheapest schedule*. For example, when a project overtime resource level is specified the model might use this to avoid extending the project duration. A project scheduled for a longer period at the lower normal resource levels might provide a cheaper alternative.

Various extensions related to cost have been proposed. In the ICL 1900 PERT system (Ref. 17) for example, the

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*Neglecting the fact that there will almost always be some form of error in a schedule because of the approximate nature of the solution procedure.

onus is placed on the planner who may specify whether overtime resources should be used first or the project duration extended. In Section 2.5.2 the technique by Wiest (Ref. 35) is described which does not use overtime resources in the scheduling procedure but attempts to find a cheaper solution by successively lowering the resource availability line on the final schedule.

With reference to Figure 2.25, it can be seen that if the normal resource level (plant or labour) is reduced from R_1 to R_2 (while the project completion time remains constant) then the peaks above level R_2 can be considered as overtime peaks, and the unused troughs below level R_2 are considered as paid idle time. The total productive and idle cost is now equivalent to the total area below R_2 (using normal rates) plus the peak areas above R_2 (using overtime rates). This total cost might be less than the total cost using the resource level R_1. The latter cost is equivalent to the total area below level R_1 (using normal rates).

In Section 2.5.2 the resource allocation models by Wiest (Ref. 35) and Barnes (Ref. 2) which attempt to simulate the relationship between total cost and project duration are also discussed.

2.4.3 Combined allocation and levelling models

Although the resource allocation model is generally regarded as being more suited to the requirements of the contractor one disadvantage is the lack of control which one has over the project duration chosen by the model. The planner is sometimes required to try a number of project resource levels before the project duration is considered acceptable.

A possible solution here would be to use a model which can perform both a time-limited and resource-limited analysis. For a purely mathematical solution procedure (e.g. linear programme) the required project duration would simply be another constraint in the form of an inequality. In a heuristic programme this requires a complete redesign of the solution procedure.

Figure 2.20 illustrates a similar feature of the ICL 1900 PERT model (Ref. 17). Here the planner can first specify whether he prefers the model to exceed the available resource level (4) or the stipulated project duration (2). When during the course of the normal resource-limited scheduling (allocation) procedure the project duration as determined by the time analysis (1) has been extended to the allowable duration (2) the planner can programme the model to now either exceed this time duration (2) to point (3) or to start to use overtime resources to level (5) to avoid having to extend the project duration any further than point (2). In other words the planner at this stage indicates his priorities by specifying instructions in the following priority form A-B-C or A-C-B (see Figure 2.20). When necessary, areas such as D,E and F will be subsequently used in the order specified. If portions of the allocation diagram are permitted to move into zone E, there is no resource limit to these peaks in zone E.

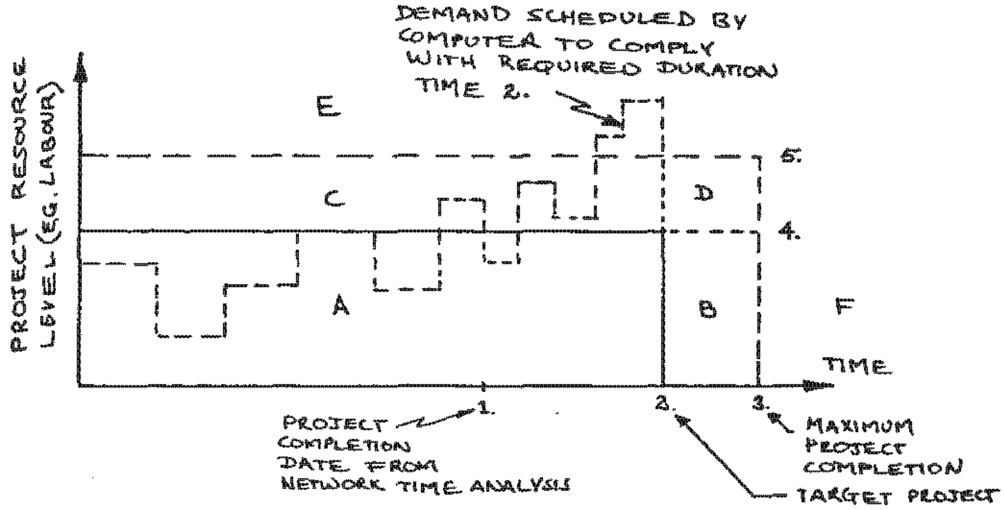

Figure 2.20: A feature of the ICL 1900 PERT model

It is clear that the procedure above is not a true "levelling" technique in the sense that most levelling techniques reduce fluctuations in the resource demand and they do not necessarily limit the height of the maximum peak. The method in Figure 2.20 is simply another "schedule-or-delay" decision rule of a resource allocation model and the corresponding heuristic rules can be specified by the planner (see also Figures 2.18 and 2.19). It is therefore expected that once the required project duration has been reached the resource demand schedule will start to increase from left to right as shown in Figure 2.20. From this the planner can then simply deduce new resource levels for those resources where this excessive late demand occurs, and he can re-analyse the project to try to obtain a smoother demand pattern; For example if the required duration must remain constant one divides the project duration into the approximate area of the excessive peaks and increases the resource level by this value. Using a normal resource allocation model one would have to try successive resource levels until the project duration is acceptable.

It is the opinion of the writer that this will help to considerably reduce computation time.

2.5 Models for Planning Reductions in Construction Costs

The total cost to the contractor of a construction project can be divided into:

(a) Direct costs,

(b) Indirect costs or overheads.

Literature is often vague on how to distinguish between the two; for example, the ICWA* (Ref. 19) define indirect costs to be expenditures not easily related to a cost centre (such as an activity, a person, a machine or item against which costs can be collected).

For the purpose of this thesis the writer prefers the definition by Barnes (Ref. 1), that indirect costs include all costs not directly proportional to the amount of permanent and semi-permanent work produced during construction (e.g. the costs of salaries of site staff, transportation of plant, contract insurance, site and head office buildings, plant maintenance, etc.). Direct costs then comprise only of labour wages, plant charges and material costs which can be directly related to the quantity of work performed on site.

A more detailed classified description of construction costs is given in Section 3.3 (A) (Table 3.2 A). The important point is that site overheads are generally either proportional to time (e.g. foreman's salary) or occur as lump sums during construction (e.g. site establishment costs).

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*Institute of Cost and Works Accountants, London.

The typical relationship commonly assumed to exist between the various types of construction costs and the project duration is shown in Figure 2.21.

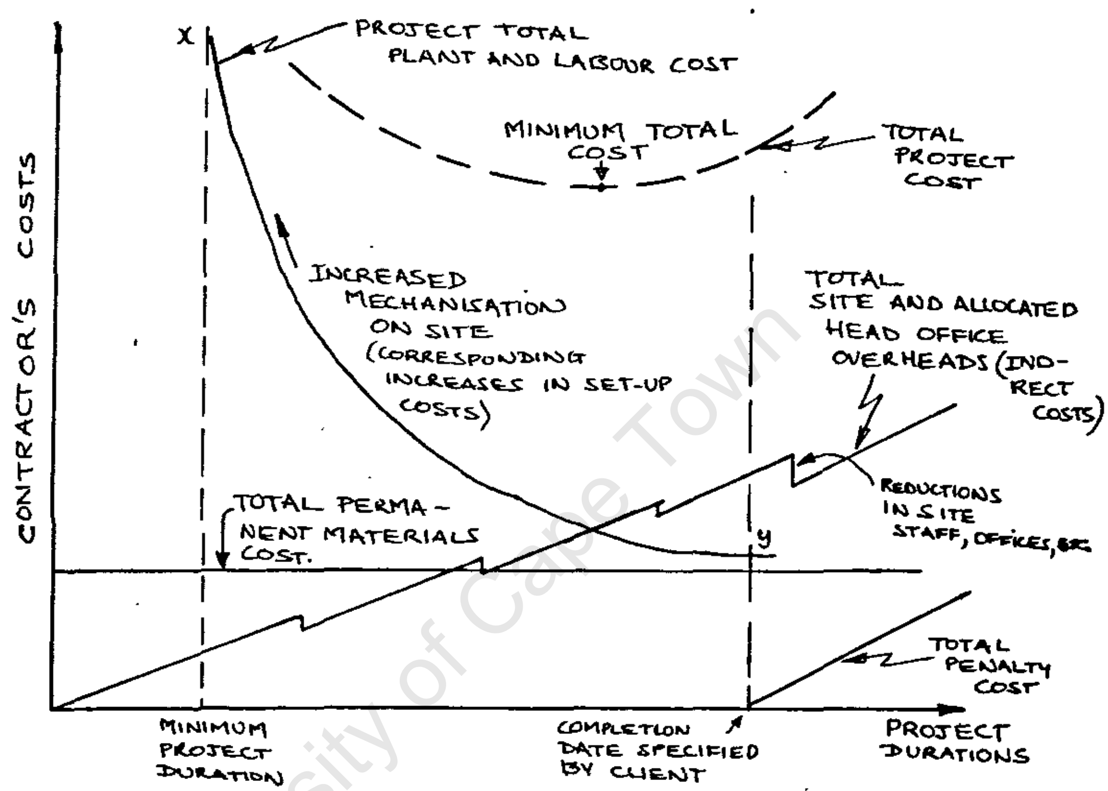

Figure 2.21: <u>Construction costs and project duration (Creasy, Ref. 9)</u>.

The materials cost element is expected to be reasonably constant at different durations although a contractor might for example, use a higher strength (and thus more expensive) concrete to reduce curing time. Plant cost will be progressively higher as the site becomes more mechanised to reduce construction time and additional transportation overheads will occur. Also shown are the penalty costs which the contractor will theoretically incur should the project duration stretch beyond that specified in the tender documents (plus any extensions); clients invariably make changes during construction for which the contractor can claim additional time. The project duration corresponding to the minimum total cost is then the construction time for which the contractor should aim; assuming that he has the resources available to do so.

It is important also to note that the costs in Figure 2.21 are based on current costs at the time when the evaluation is made. In Chapter 4 the effect of time on the costs of the contractor will be examined, namely the effects of the earning power of money (Section 4.4) and the effects of inflation (Section 4.5).

In the remainder of this section two models are described which attempt to simulate the cost characteristics shown in Figure 2.20; the objective in both cases being to find the minimum time-related cost of a construction contract.

2.5.1 The time-cost optimisation model

This technique which is also known by other names such as "minimum cost expediting" and "time-cost trade-off procedures" was originally developed by Kelley (Ref. 21) in 1958 as an extension to the Critical Path Method* The author assumed that for most of the project operations there exists a relationship between time and direct cost as shown in Figure 2.22. It was then argued that by starting with a time analysis of all operations at their maximum duration (minimum cost) one can find the project direct cost versus

*The other part of this model which was developed by the same author is the network time analysis described in Section 2.3.1.

project duration curve (Figure 2.19) by systematically shortening those operations for which the reduction per unit time is the cheapest. The complete procedure is shown in flowchart form in Figure 2.23.

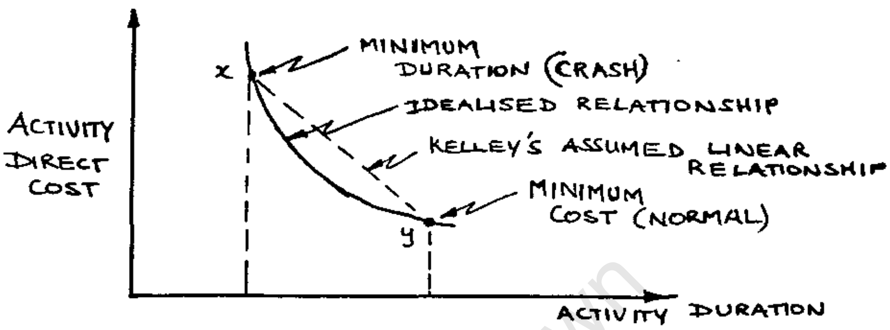

Figure 2.22: Kelley's assumed relationship between activity time and cost

In the original model by Kelley (Ref. 21) the activity cost curve was approximated by a straight line (x - y, Figure 2.22). The overall problem of time analysis and cost optimisation was then expressed in linear programming form and solved by computer. Various extensions have since been proposed for taking into consideration other shapes of curves. Feldman (Ref. 13), for example, has developed a computer programme which can handle any shape of activity time-cost curve consisting of up to four continuous straight-line segments.

The approach appears to have found very little successful application in the construction industry. In a survey by Campbell (Ref. 7) of eleven commercially-available computer programmes using the critical path technique only one was able to perform this calculation. The writer has also noticed that the method is appearing less frequently in later publications on this subject.

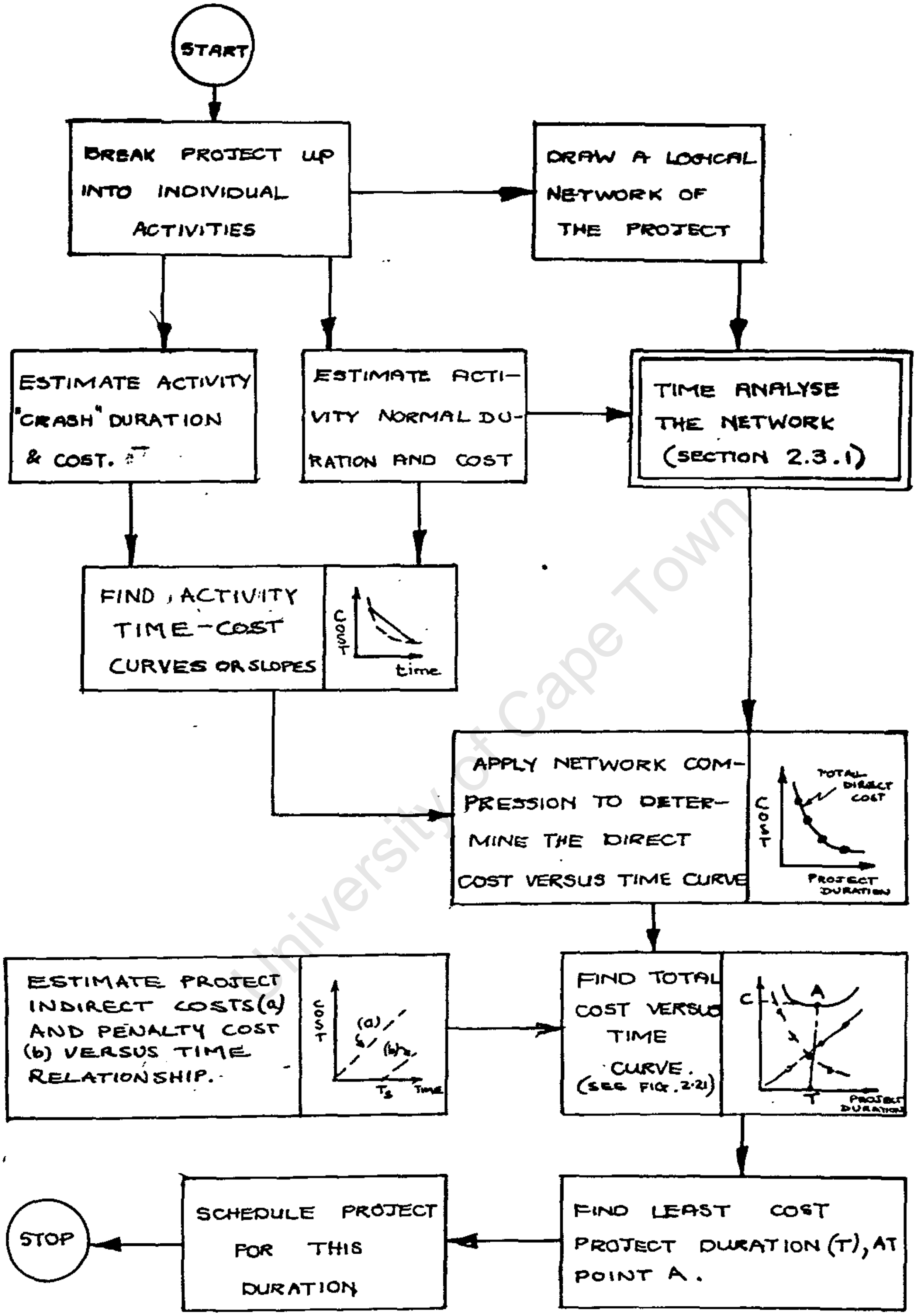

FIGURE 2.23: Flow Chart of the Original CPM Model (After Kelley, Ref. 21)

The main shortcomings of this method are briefly;

(1) Since the model will independently choose points on each activity time-cost diagram corresponding to either plant, labour, subcontractors or combinations of these, the resulting utilisation might be too erratic for effective site control (e.g. the model might suggest that trench A might be excavated by machine, B by hand, C by subcontractor, etc.).

(2) The assumption that the total direct cost equals the sum of the activity direct costs is not generally correct. Kochanski (Ref. 23) has proved this inequality mathematically for a small project; i.e. that the idle cost of plant or labour (i.e. valleys in the resource demand curve) should also be taken into consideration (see Figure 2.24). This should not impose too serious an error as this is the assumption generally made for compiling a tender.

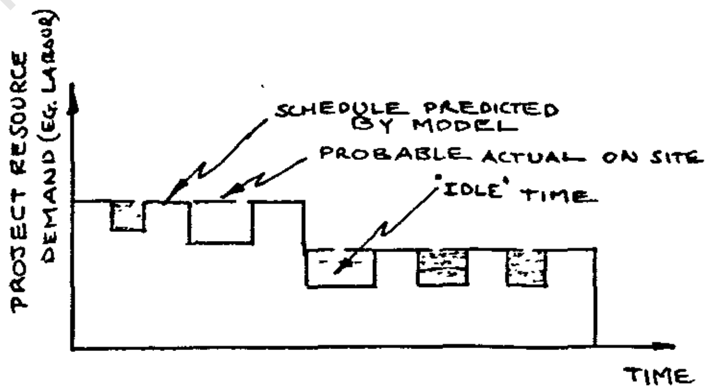

Figure 2.24: Idle time in a resource schedule.

(3) Contractors generally find it difficult to estimate the two extremes of "crash" and "normal" and are therefore often reluctant to perform these calculations.

A possible solution to point (1) would be to use only one type of resource team for each type of operation (e.g. labour gangs for hand excavation). The "normal" and "crash" points would then correspond to different sizes of this team and any peaks in the resource demand schedule could be reduced either by manual calculations or by using a resource allocation model. It is expected, however, that this levelling will in many cases increase the project duration and cancel out any reductions made by using the time-cost model.

It is the opinion of the writer that this technique will not yield significant benefits for a construction contract. Here savings are more readily made when the contract is considered as a whole rather than by finding only local economies for the individual operations.

The whole contract is considered in the next model.

2.5.2 Resource cost models

Wiest (Ref. 35, 1966) who appears to be one of the first authors to make this proposal, suggested that the total direct cost of a project should not be evaluated as the sum of the individual activity costs but rather as the total cost of all resources employed used or left idle over the project duration.

According to Wiest these should include:-

(1) normal costs (e.g. normal wages),

(2) overtime costs,

(3) idle time costs (e.g. plant standing),

and (4) set-up costs (e.g. transporting plant to site).

Figure 2.25 illustrates Wiest's (Ref. 35) approach to evaluating this cost for plant and labour. From the resource demand curve predicted by the resource allocation programme (see Section 2.4.1) the total cost of each type of plant or labour was calculated as being either:

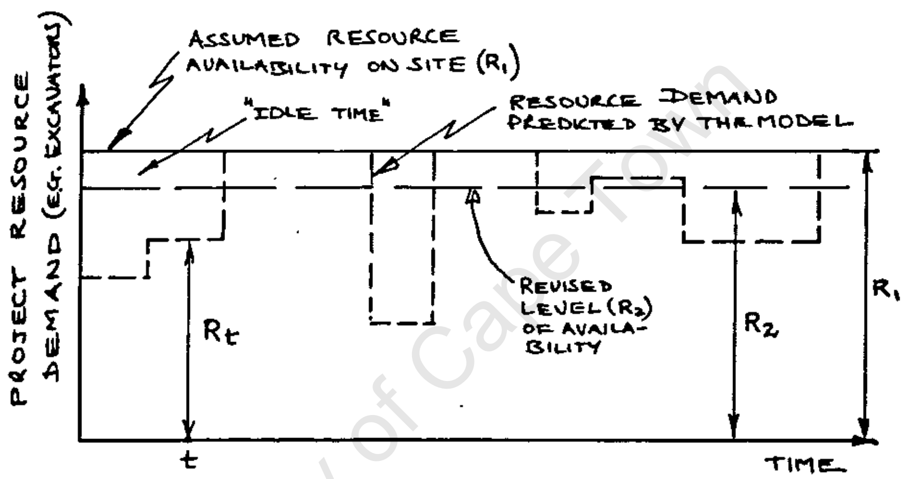

Figure 2.25: Estimated project plant or labour demand.

(i) $R_1.T.C.$ .... (2.14)

or (ii) a new level R_2 is found and any peaks above this evaluated as overtime,

i.e. $R_2.T.C + \sum_{t=1}^{T} (R_t - R_2)\ C.W.K.$ .... (2.15)

where $K = 0$ when $R_t - R_2 \leq 0$

$K = 1$ when $R_t - R_2 > 0$

R_1 is the amount of plant or labour allocated to the project,

T is the project duration,

W is the ratio of overtime to normal unit cost

C is the normal unit cost,

R_2 is the improved resource level which minimises equation 2.15 ($R_2 < R_1$),

R_t is the original resource demand curve predicted by the resource allocation model.

Equation 2.14 and 2.15 both assume that "idle" time is paid for while 2.15 also attempts to find out whether a small reduction in R_1 (to R_2) will not be cheaper when any peaks above R_2 are evaluated at overtime cost. It is important, however, that when contractors charge plant costs according to operating hours, only the area under the resource demand curve must be considered; i.e.

$$\text{Plant direct cost} = h.\sum_{t=1}^{T} R_t \text{ .... } (2.16)$$

Where h is the plant hourly cost,

R_t the daily plant requirements in hours,

and T is the project duration.

It might be interesting to note that the ICL 1900 PERT programme (Ref. 17) does not take into account idle time but does include overtime costs; i.e.,

$$\text{Resource cost} = C.R_1.T - C.\sum_{t=1}^{T} (R_1 - R_t)$$
$$+ (W - 1)\ C.K.\sum_{t=1}^{T} (R_t - R_2) \text{ .. } (2.17)$$

where $K = 0$ when $R_t - R_2 \leq 0$

$K = 1$ when $R_t - R_2 > 0$

and all other variables are as for equation 2.15.

Wiest's model (Ref. 35) also finds the plant and labour direct cost curve (of Figure 2.21) by the procedure shown in Figure 2.26. Starting with an unlimited availability of plant and labour resources for the project these levels are progressively reduced to find for each resource level a new resource total direct cost and project duration. The cost of each set of schedules is evaluated by using equations 2.14 or 2.15 to find a new point on the direct cost versus project duration curve. (Curve x - y in Figure 2.21.)

The author also suggested that start-up costs (e.g. transportation of plant) be added but the author does not show how this is done. It is expected that this will have to be done manually by examining the predicted resource demand curve to determine when plant is to be moved on and off the site and the amount to be moved. Other indirect costs might be added by using cost-only activities as described in Section 3.3.3, or determined separately for each schedule and plotted as a curve (see Figure 2.21).

Although the resource-cost approach is more realistic than the time-cost model, in the form above it will only be able to simulate a limited portion of the total direct cost curve (e.g. curve a - b; Figure 2.27). This is because only one method of working is assumed for each operation and no consideration is given to increased mechanisation, other construction methods, etc. (e.g. curve c - d; Figure 2.27). These will have to be investigated separately to find the complete curve.

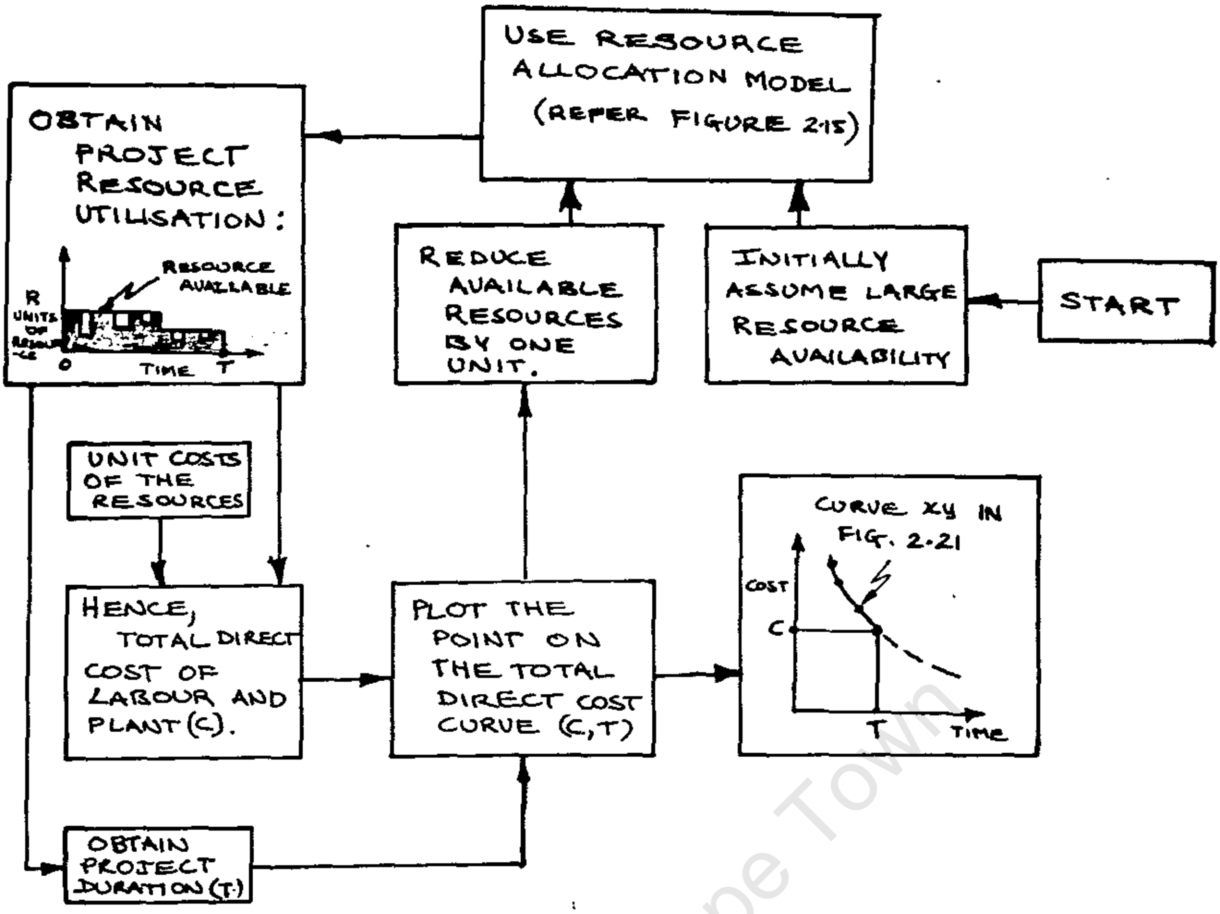

FIGURE 2.26: Project Total Direct Costs from Resource Schedule

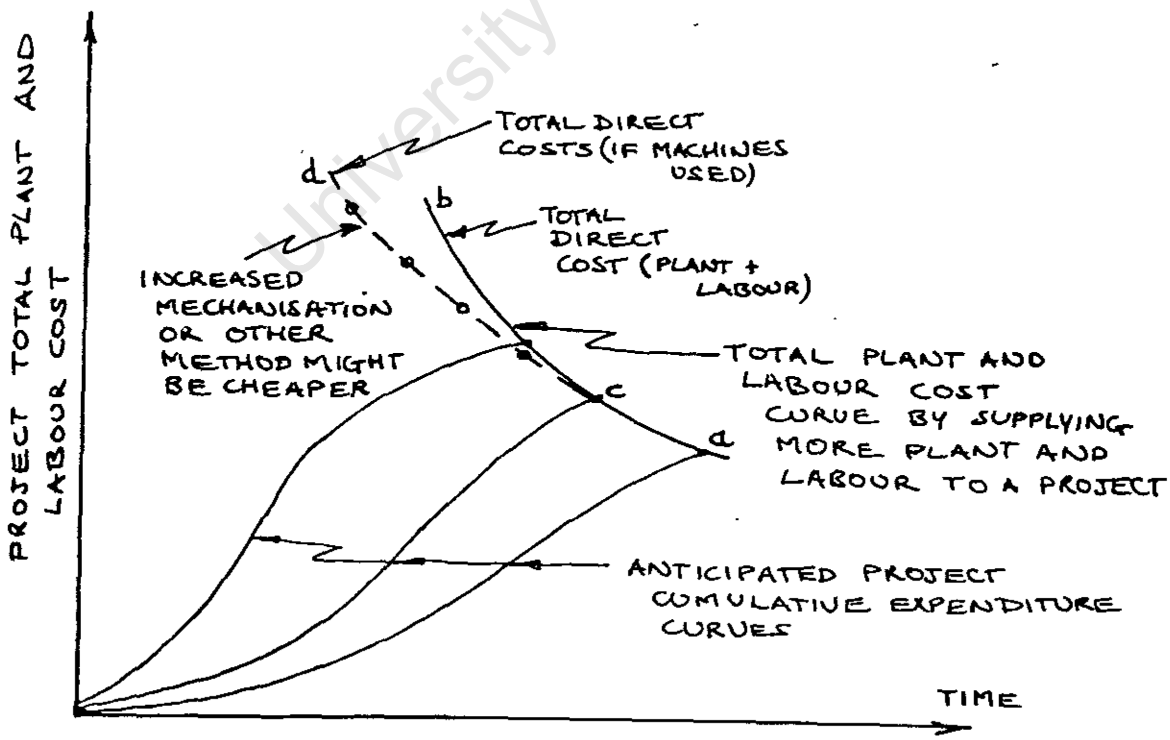

FIGURE 2.27: Project Direct Costs (Total indirect costs and fixed costs must be added to above direct costs as in Figure 2.21)

It is interesting to note the model by Barnes and Gillespie (Ref. 2) also finds a total cost versus project duration curve apparently without using either of the simulation techniques described in this section (e.g. in Figures 2.25 and 2.26). No description is provided by the authors but the writer suspects that the model in fact performs the same resource allocation procedure using different sorting priorities. Since this is known to often produce widely differing schedules (see Section 2.4.2 F) and different project durations it is expected that a fair portion of a project total cost versus time curve may be obtained in this manner.
This is then also a convenient method for improving the schedule found from the resource allocation model providing the resource level remains the same for all schedules.

By evaluating the cost of a particular schedule over the project duration a labour and plant expenditure (incurred cost) curve can be obtain (see Figure 2.27) which can be used for control purposes as described in Section 3.3.3.

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CHAPTER 3

ASPECTS OF CONSTRUCTION PROJECT CONTROL

3.1 The Management Control function

Anthony (Ref. 1) defines management control to be "the process by which managers ensure that resources are obtained and used efficiently in the accomplishment of an organisation's objectives".

Once construction has started, the emphasis changes from planning to control and any changes to the original or recently revised construction programme are made in the light of what has happened to date.

In most construction firms management can be separated into two levels - by virtue of their geographical differences and the type of resources on which they focus their attention:

(a) Site Management - Which is concerned with the efficient utilisation of site resources (plant, labour, time and material) and hence the performance (e.g. profitability, progress, etc.) of the site as a whole.

(b) Top Management - Which must ensure that their allocations of company, financial, mechanical and managerial resources on several sites and contracts are yielding the required returns (profit).

Although it is beyond the scope of this thesis to deal with point (b) in any great detail, a number of financial factors which could influence the choice of a particular course of action are discussed in Chapter 4.

3.1.1 The Human Aspect of Control

As the manager does not perform the work himself, control becomes largely the control of people - who are doing the work and incurring the cost. For this reason the principles of management were derived from studies in human behaviour rather than science or economics.

Site management* in South Africa in particular must be versatile to deal with the various ethnic groups found on construction sites. The success of a project often depends on the ability of site staff in motivating workers to produce the necessary service within suitable time limits.

Study programmes into these problems have been initiated by the CSIR and other bodies but, as far as the writer is aware, very little has been published on the motivation and production of Coloured and Bantu labour on Civil Engineering contracts.

3.1.2 The Need for Information

The information which signals the need for managerial intervention reaches the construction manager in a number of ways. He might make the observation personally; for example, he might notice trucks using an access road when they could be helping to compact earthworks. At the other extreme he might receive information via a formal control system operated within a company (e.g. cost information to the effect that earthwork costs are exceeding the allowable estimates).

3.1.3 The Accounting Department

The main control system of most firms is centred here.

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*This includes site engineers, site agents and foremen.

The accounting function can be divided into two parts:

(a) Financial Accounting - This is required by law and is responsible for providing shareholders, the Receiver of Revenue, bankers and other outside parties with financial information about a firm. This information is summarised on the balance sheet and income statement.

(b) Management Accounting - Which provides information useful to management for planning and control (e.g. cost data, estimated profits). As this is not a compulsory record system it is quite possible for a firm to survive with only a rudimentary management accounting system.

Although management accounting information is generally reported in monetary terms, it is often first collected in terms of manpower hours, operating hours and quantities. This is then converted into costs (e.g. average cost per cubic metre of excavation).

The remainder of this chapter will be concerned with various techniques for collecting and manipulating control information during construction, to aid management decision-making and construction planning.

3.2 Control Techniques for Site Management

In this section a number of parameters are investigated through which management can exercise control over the various operations of a construction contract. The techniques described might be used both manually or as part of a more formal control system described in Section 5.2.

3.2.1 Control of Time Progress

A) Bar charts

This is one of the most commonly used methods for controlling progress on a construction site. For each operation on the work programme bar chart, an estimate is made of the completed proportion of the operation and this is coloured in to show actual progress. A vertical line at the review date indicates the expected progress.

Figure 3.1 shows a conventional bar chart which has been updated in this fashion. One disadvantage here is that unless the critical path has been identified it is difficult to tell whether progress is actually ahead or behind schedule. A better method would be to draw the network to a time scale and then update it as shown in Figure 3.2. Frequent updating in this fashion (e.g. weekly) will ensure a permanent record of the project progress and might be used to substantiate claims for extensions of time when critical operations are held up by design changes. Since the above technique can only be used with the Arrow network an alternative diagram known as the cascade chart has been developed for use with the overlapping activities shown in Precedence networks (see Figure 5.3). To show the critical path one could simply emphasise the critical

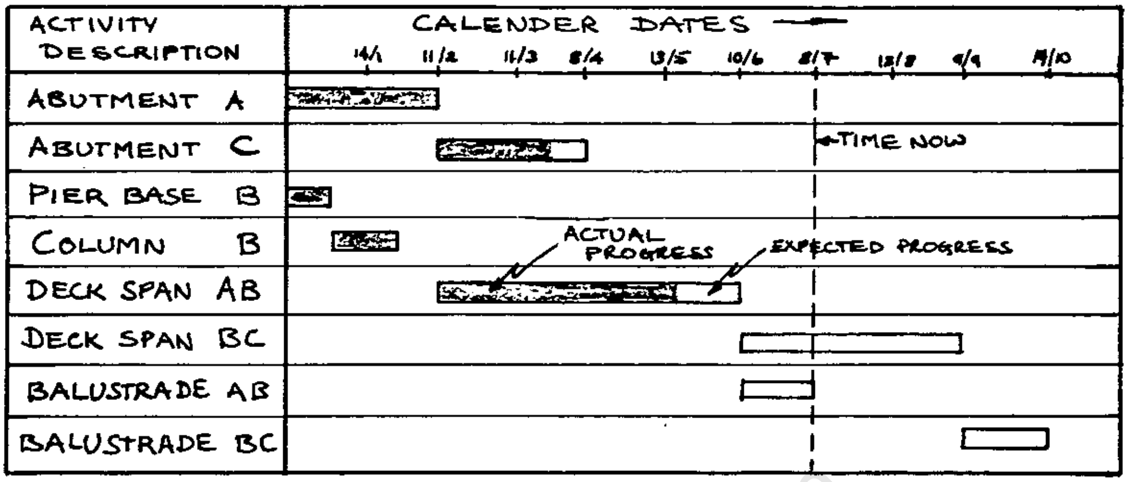

FIGURE 3.1: Updating of a Conventional bar chart

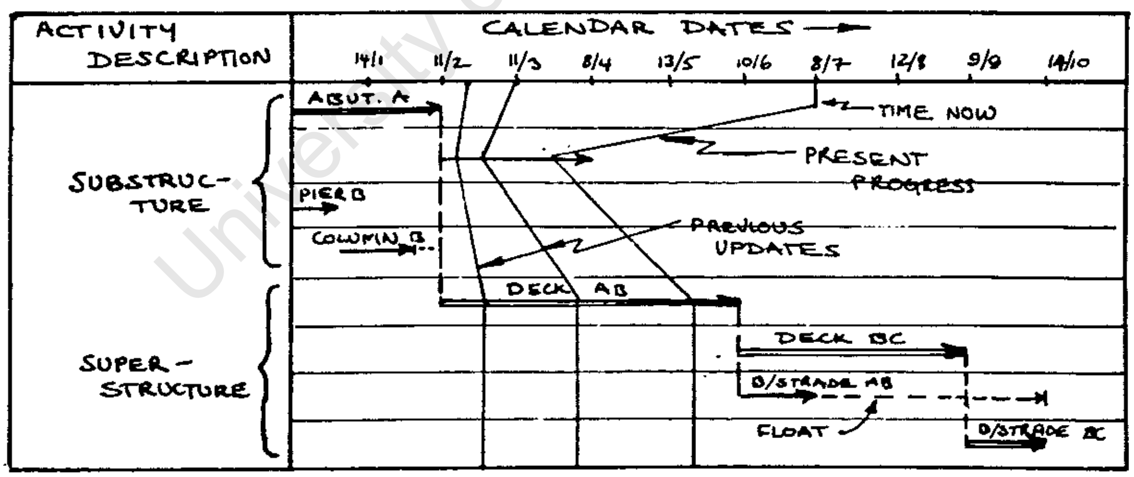

FIGURE 3.2: Updating of a time-scaled Arrow bar chart

operations on the conventional bar chart (see Figure 5.3).

B) <u>Care in interpreting bar charts</u>

In a resource allocated schedule the critical operations will not necessarily form an unbroken sequence of operations. Care must therefore be taken that gaps in the critical path are not mistaken for float.

When reviewing progress the critical operations should be examined first. Since these can directly affect the completion date of a contract every effort must be made to catch up on lost time (e.g. by working overtime, by moving additional plant or labour from non-critical activities, etc.).

One must also consider operations whose total float has been exceeded. As these are now in effect critical they also warrant the same treatment (i.e. additional resources). Other non-critical operations are simply examined to ensure that no serious delays are occurring which might affect the project at a later stage, and if progress is ahead then plant or labour resources might be diverted to more critical operations.

When using this approach the contractor can tell which part of the contract is behind schedule. This was not always possible with the conventional bar chart (Figure 3.1) and unnecessary overtime (e.g. Saturdays) was frequently worked on activities even where this was unnecessary.

C) <u>A record progress for top management</u>

A technique which is sometimes used to review and record progress for top management (Ref. 8) is shown in Figure 3.3. The duration of every operation is ex-

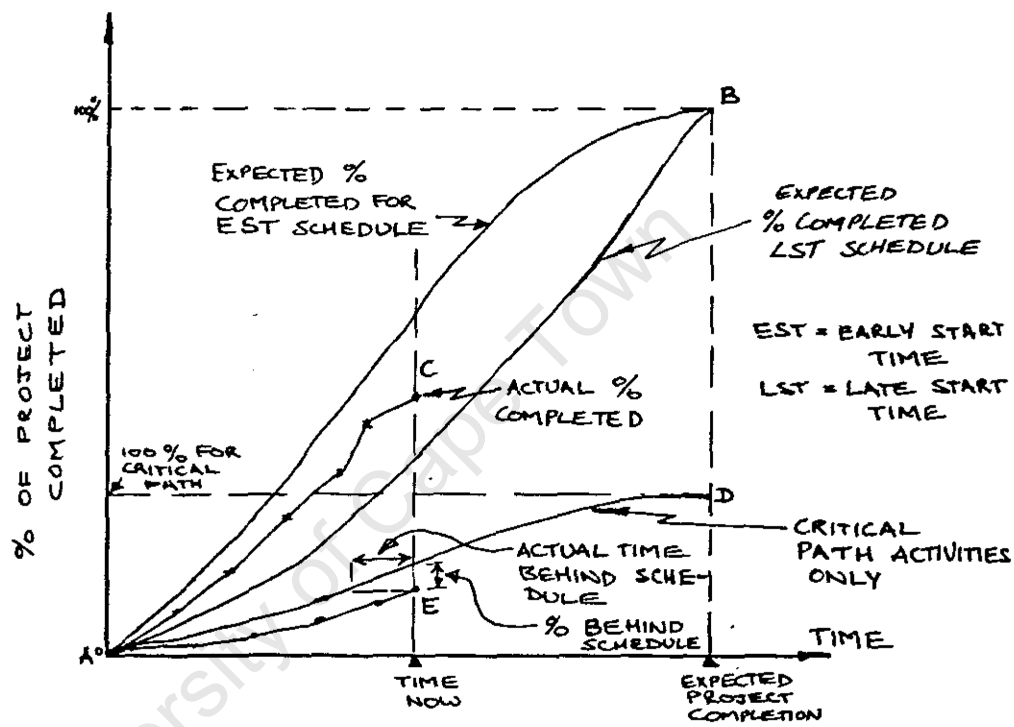

Figure 3.3: <u>Project "percentage progress" chart</u>

pressed as a percentage of the sum of the durations of <u>all</u> the operations (including those which do not lie on the critical path). Assuming this percentage to be uniformly spread over the operation a project "percentage progress" chart can be drawn, by summing the above percentages or proportional part of these percentages for all the operations completed or partially completed at various points over the construction period. In Figure 3.3 two curves A3 are shown corresponding to all operations either at their early or late start times.

During construction, progress is evaluated by multiplying the actual proportion of each operation completed by the percentage the operation represents of the project as a whole. The sum of these is then the project percentage completed (point C in Figure 3.3) which is compared with the expected progress.

It is generally assumed that as long as point C (Figure 3.3) falls within the vertical intercept between the two curves, the average progress is satisfactory. This is, however, not always so, particularly if there is a serious delay of a critical path operation even though other work is ahead of schedule.

The writer considers it better in this case to plot a separate diagram for the critical operations (see curve AD in Figure 3.3). This should be drawn as the percentage of the total of all the critical activities' durations (i.e. point D in Figure 3.3 corresponds to 100% for the critical operations).

From the progress evaluated for the critical operations (point E, Figure 3.3) it will be easy to determine both the percentage and actual time by which the project is ahead or behind schedule (from the horizontal and vertical intercepts between curves AE and AD); irrespective of how many critical paths are present.

3.2.2 Control of Construction Costs

Through cost control the construction manager attempts to keep in touch with the actual expenditure of a contract, the objective being to identify areas where costs might be reduced in order to improve the eventual profits. Top management is similarly interested in the profitability of the various contracts on which the firm is engaged.

Ideally, the functions of a complete cost control system which satisfies both these levels of management would be:

(1) To draw attention during construction to any operation or section of work which could be performed more economically; i.e. a detailed cost analysis for part or all of a contract (e.g. weekly),

(2) A regular evaluation of the interim total allowable cost of a project and a comparison with the actual,

(3) Regular forecasts (e.g. monthly) of a contract's expected final cost and a comparison with the final allowable cost,

(4) An evaluation of the contract interim profit (expected revenue less incurred cost to date) and a forecast of the expected profit (or loss) at completion,

(5) In addition, to supply the estimator with data concerning the actual performance during construction; either in the form of costs (e.g. cost per square metre of formwork) or output (e.g. square metres of formwork per carpenter-hour).

It is unfortunately not always economically feasible to derive such detailed information in practice. A particular handicap in South Africa for example, appears to be the shortage of trained clerical staff for collecting the necessary data on the site.

In Section 3.3 the workings and merits of three cost control systems applicable to construction sites are discussed; i.e.,

(a) The Unit Cost Control System,

(b) The Standard Costing System,

(c) The Combined Time and Cost Control System.

With regard to point (5) Civil Engineering contractors, as opposed to Building Contractors, generally regard historical costs to be relatively valueless for estimating purposes because of the tremendous variations which can occur from one site to the next. One exception here might be when tendering for a project which is adjacent to one under construction. The supplying of the estimator with production figures (e.g. cubic metres of excavation per loader-hours) is usually preferred, but has the disadvantage that information must be collected with particular care. For example, whereas the unit cost of excavated fill for a D4 bulldozer might be almost the same as that for the larger but much more expensive D7, their actual output will be vastly different. Other factors such as the type of material, the slope of the ground, access, etc., will all affect the figures and must be recorded. In Section 3.2.5 a practical example is described where the productive output of labour was recorded during construction. Besides shortage of trained clerical staff for collecting the necessary data on the site.

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3.2.3 Control of Site Earnings*

On certain contracts, e.g. those with relatively few interdependancies between the operations but involving large quantities of work such as a roadworks contract, it is often difficult to evaluate progress from the time schedule alone. In such cases the contractor might draw a curve showing the expected earnings plotted cumulatively over the project duration. This he obtains by summing cumulatively the money due from the client for the various operations of the construction work programme, according to the Bill of Quantity items contained in each operation.

In Figure 3.4 an example of a hypothetical earnings curve AB for the "measured" work of a project is shown. In this

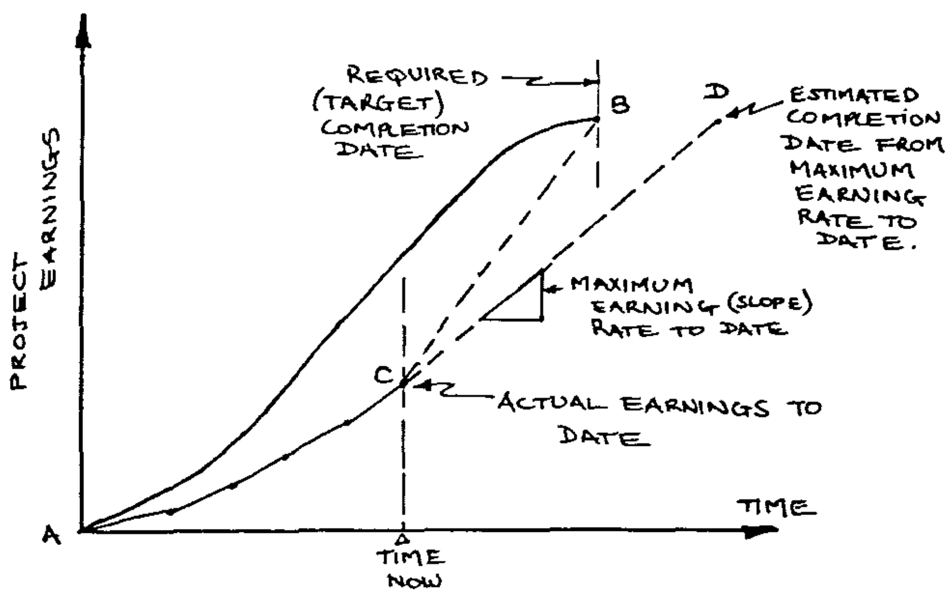

Figure 3.4: Contract expected earnings curve

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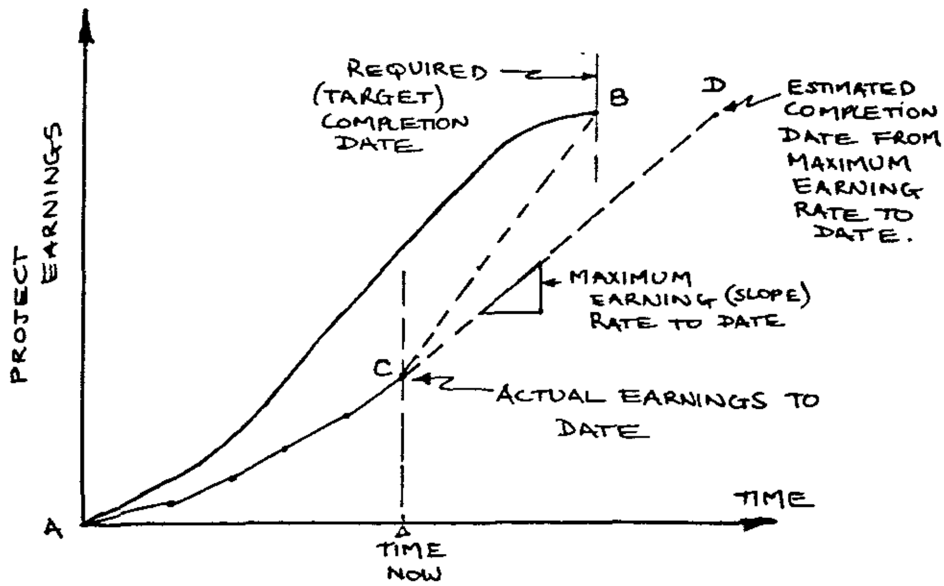

Figure 3.4: Contract expected earnings curve

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*Defined as money due to the contractor (refer Section 3.3 B).

case the actual* earnings are less than expected. To achieve the completion date (point B) the actual curve must at least attain the slope CB, which is greater than anything achieved to date. From the performance to date, it could be concluded that project will finish late (e.g. point D if the steepest slope to date is drawn from point C).

When the above occurs the contractor must conclude that either one or more of the following are true:

(i) his present method of working is inefficient or ineffective,

(ii) his present plant and labour on site are insufficient to maintain the required rate of progress,

(iii) he is behind schedule because of bad weather and other delays (plant breakdown, delivery delays, etc.)

The shortcoming of this approach is therefore that it does not localise the exact area where progress is behind. One possibility for a large contract might be to divide the earnings curve into smaller curves representing different sections of a contract which could be updated separately to pinpoint the exact area where progress is behind schedule.

An alternative procedure is to determine curves as above

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*Actual earnings are defined as the total money due from the monthly certificate (including retention) less payments for materials on site. In this example only the measured word is considered.

for the cumulative productive output of those quantities which are on the critical path or known to be critical to the completion of a contract (e.g. cubic metre concrete, excavation, kilogram of steel, square metre formwork, etc.). From this one might then be able to pinpoint more exactly the region where progress is behind schedule (i.e. by comparing the actual and expected quantities completed at a particular point in time).

It must, however, be remembered that the progress of certain quantities is dependant on others. For example, if the area (m^2) of formwork already placed in position is behind schedule, then there will also be a delay in the tonnes of steel fixed and the volume (m^3) of concrete placed.

3.2.4 Control of Wastage on Site

Wastage manifests itself in a number of ways on a construction site. Material wastage is the form most commonly thought of, but possibly more important is that of plant and labour. While it is easy, for example, to recognise careless handling which reduces the expected life of formwork, the underutilisation of labour and plant is not so easily identified.

Although the cost control system is useful in identifying cost overruns, the information is often not specific enough to pinpoint the actual cause. It is then still up to the manager to decide whether this is due to actual inefficiency, bad weather, under-estimated cost or other causes.

A number of techniques are examined which could assist the site manager in making such decisions.

A) Wastage of material

Contractors generally consider that precise control over material cost is not warranted because of the large amount of paperwork involved. This may be a valid conclusion on some contracts but on other contracts precise controls may save extra costs. The issue is also complicated by general rises in the prices of materials and the contractor might regard savings due to minimizing wastage as being small compared with the general rise in prices. The main areas of interest are to control wastage, to ensure that quotes on which the tender prices were based are not exceeded, and to determine the effect of actual material cost on the project total cost. (The latter aspect will be enlarged on in Section 3.3.2).

Figure 3.6 shows a method which might be used to control the wastage of certain bulk materials delivered to site in identifiable quantities and which are easily related to the amount required in the structure (e.g. cement, bricks, aggregate, etc.).

At the end of each control period (e.g. weekly) the allowable amount in the structure and the quantity on site are subtracted from the total delivered to determine the wastage; (obviously corrections due to bulking of aggregates must be made) see Figure 3.6.

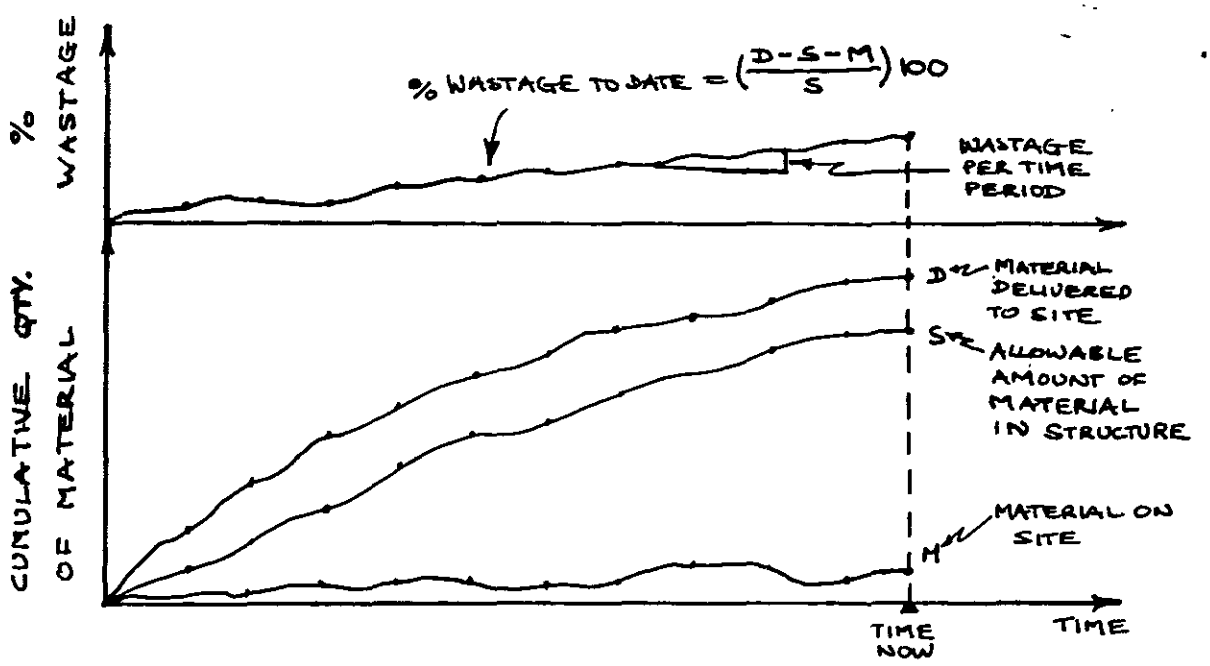

FIGURE 3.6: Control Graph of Material Consumption (e.g. Cement)

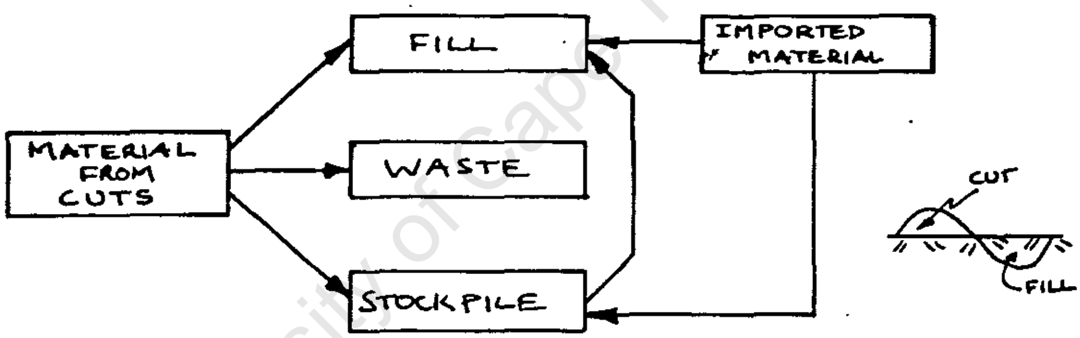

FIGURE 3.7(a): Destination of Cut and Sources of Fill on Site

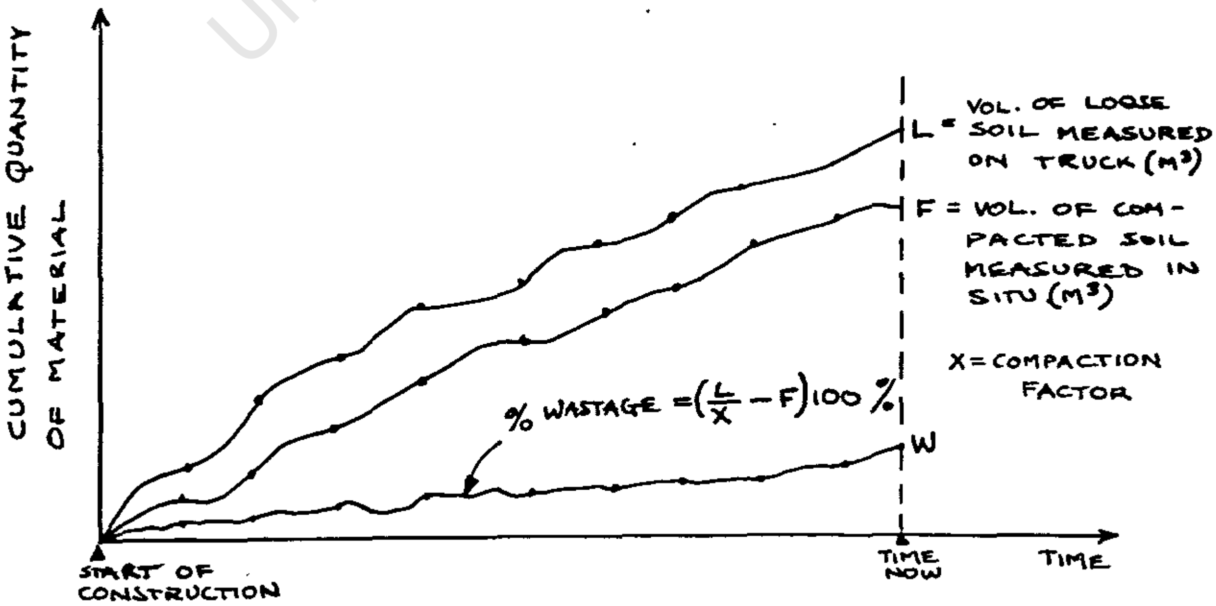

FIGURE 3.7(b): Control of Fill Wastage

When wastage exceeds a certain level it might be necessary to investigate the reason for this wastage.

The writer is aware that contractors engaged on earthworks contracts often operate a system of carting-tickets on which the truck drivers state the source, size and destination of each load.

Figure 3.7(a) shows a schematic representation of the possible movements of cut and fill on site. On a contract where virtually all the fill material is brought by trucks, and only a negligible volume is bulldozed directly from cut to fill regions the contractor might determine the fill wastage as shown in Figure 3.7(b). Curve L is found from the total number of loads carted for fill, while curve B (Figure 3.7(b)) is the fill determined from cross-sections and for which the contractor is paid. Material wastage is then calculated as;

$$\% \text{ Wastage} \quad W = \left(\frac{L}{X} - F\right) \frac{100}{F} \quad \ldots\ldots\ldots\ldots\ldots \quad (3.1)$$

Where L is the volume of fill carted by truck (quantity is measured on the truck),

F is the measured fill in the monthly certificate for which payment is received,

and X is the soil bulk factor which is the average ratio of the volume of uncompacted (i.e. as measured on the truck) to compacted soil, for the material under consideration.

A similar procedure could be applied to soil volumes from cuts (X is now equal to one) but since material is here very often bulldozed to one side it is doubtfull whether the above technique will find application here.

It is expected that equation 3.1 will be more suited to the construction of subbases and basecourses of roads where the material is almost always imported from outside and brought to site by truck. In this case L will be the volume of material delivered (as measured on the truck), less the volume of material stockpiled, and F the quantity for which payment is claimed.

Information concerning the wastage of material will also be useful for future estimating purposes.

B) Plant idle time

It is equally important that plant is operated at a reasonable level of its capacity. In Figure 3.8 the operating, waiting*, breakdown and service time of a certain plant item (e.g. trucks, graders, bulldozers) has been plotted as a percentage of the total operating hours available (e.g. weekly, monthly, etc.). The available operating hours include the normal working hours of each day plus any additional scheduled overtime. From this the contractor might be able to deduce the inefficiency of his workshop (high breakdown time),

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*According to a local contractor this type of information to the detail of waiting time is only accurate when recorded by a built-in tachometer.

excessive carting plant (excessive waiting time) and the general under-utilisation of certain machines. This type of graph is naturally influenced by various factors and simply indicates to the site manager that further investigation is required. For example, excessive waiting time for carting plant might be due to the unavoidable breakdown of certain important items of loading plant.

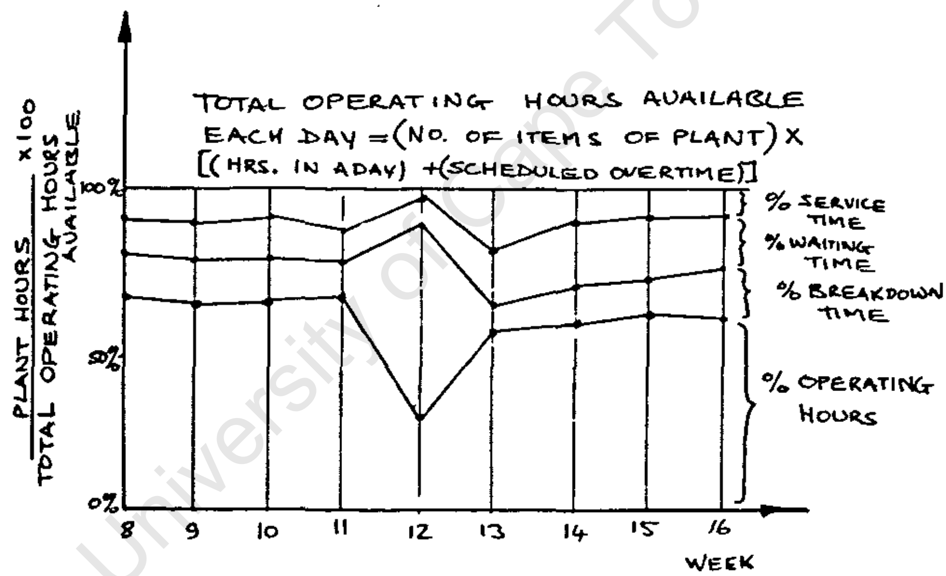

Figure 3.8: Analysis of plant operating hours

3.2.5 Control of Unit Output

Figure 3.9(a) shows a number of observations recorded by the writer, of a team of carpenters, apprentice carpenters and labourers erecting formwork and staging* for the

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*Staging denotes the supportwork on which the soffit formwork rests. The average height above ground level for the above structure was approximately 8 metres.

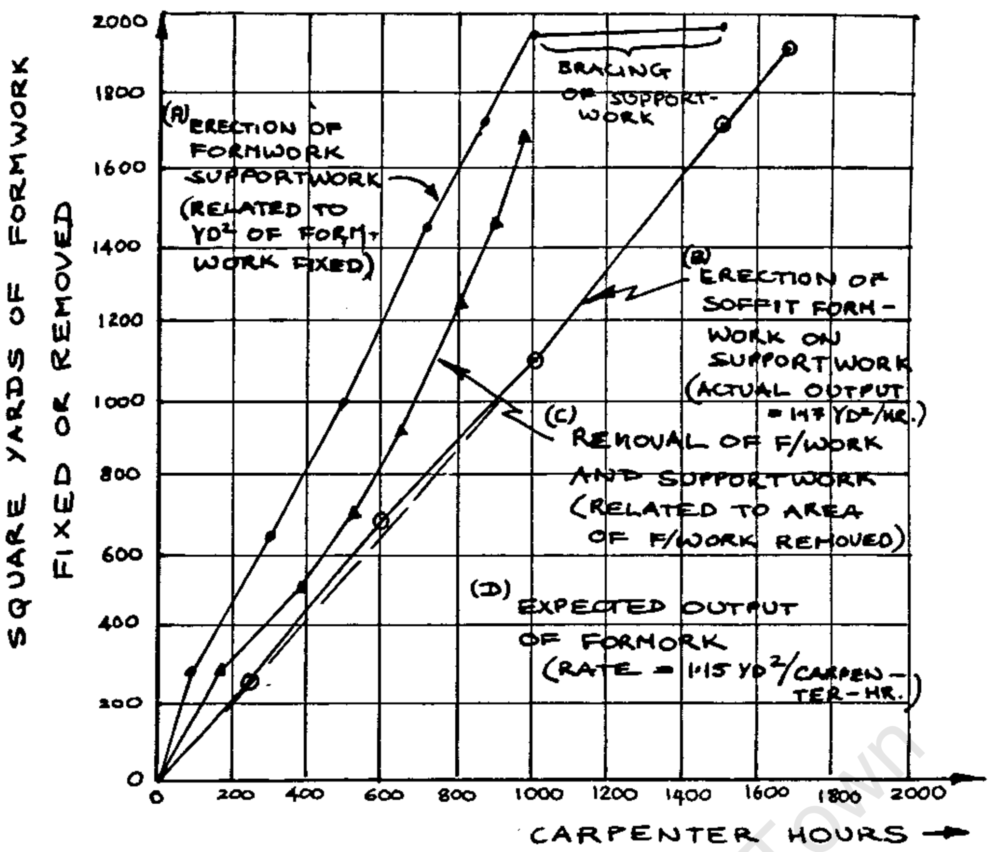

FIGURE 3.9(a): <u>Erection of Bridge Soffit Formwork and Formwork Supportwork</u>

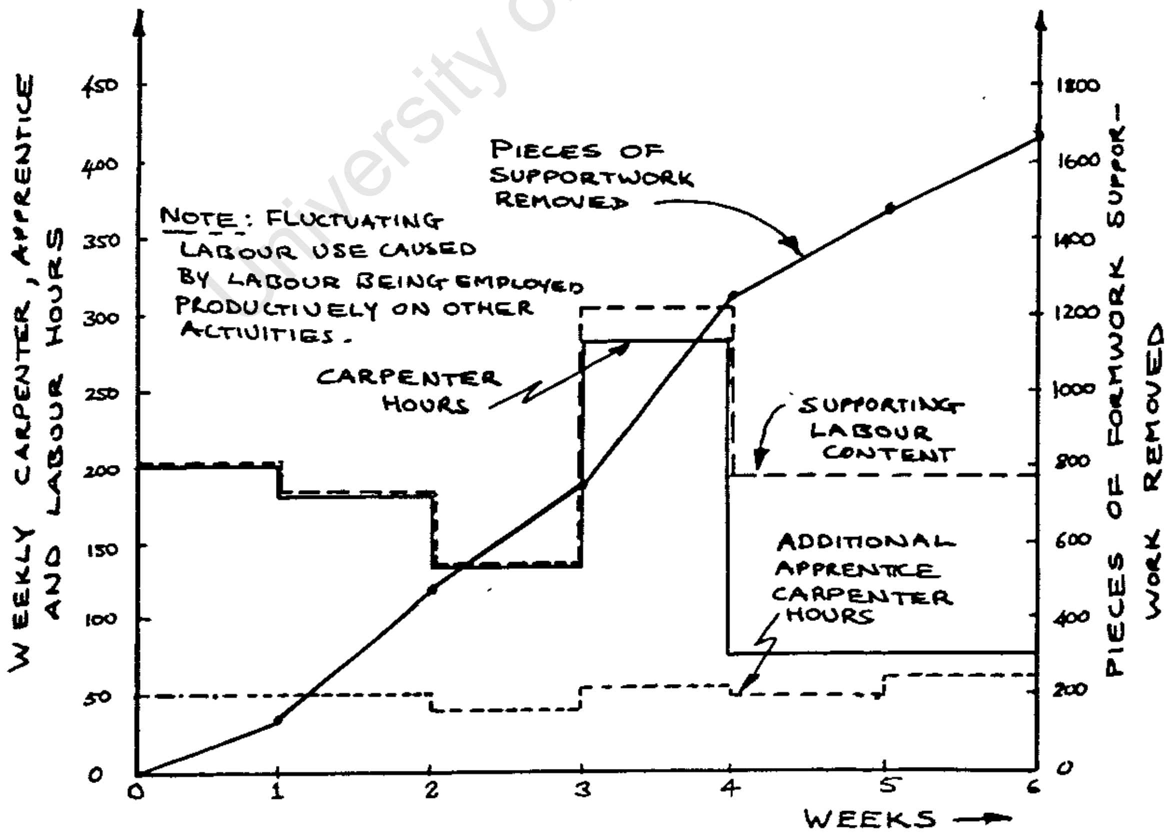

FIGURE 3.9(b): <u>The Weekly Application of Labour to the Removal of Formwork and Supportwork</u>

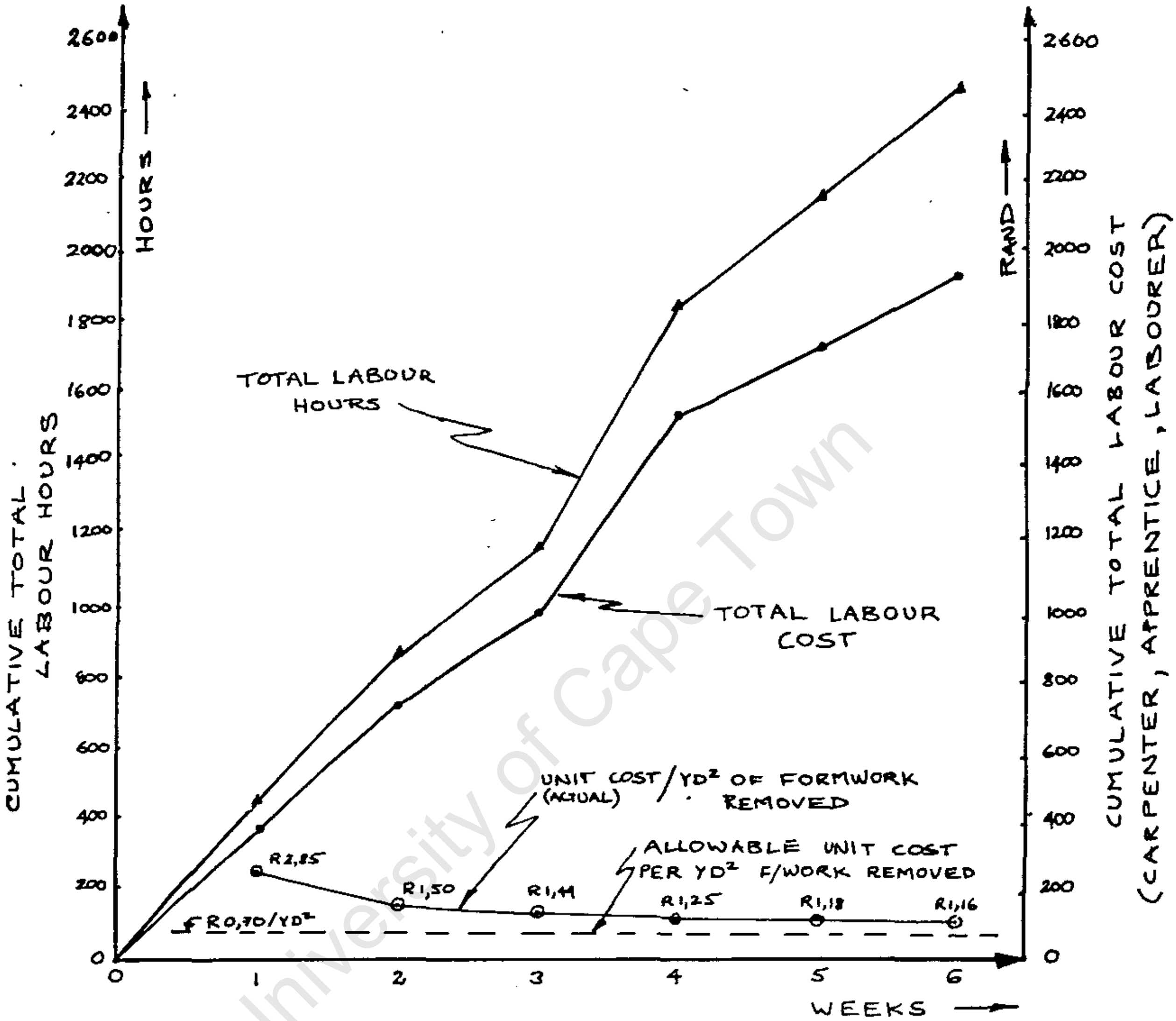

FIGURE 3.9(c): Labour hours and Costs for the Removal of Formwork and Supportwork

soffit of a pre-stressed concrete bridge deck, in the Cape Town region. The deck formwork had been tendered for at a particularly keen price and since this Bill item accounted for a large portion of the contract cost it was decided that the actual production output should be regularly checked against the allowable production rate.

The Bill item representing the above work was divided into the three operations of erecting the supportwork, fixing the formwork and the dismantling of both, after the stressing of the concrete deck.

During construction the actual number of hours worked by each of the three labour trade groups were recorded daily and the actual number of formwork and staging units processed were plotted at the end of each week against the number of carpenter-hours. The resulting curves could then be compared with the required output which was plotted as a straight line on the same diagram (Figure 3.9(a), curve D, for formwork). Since the estimator's assumed output was in two cases based on different combinations of the three labour groups new target output rates had to be calculated for these. For example, in case of the removal of formwork and staging the allowable cost* of R0,70 per square yard of formwork removed was based on the following data;

1 handyman @ R1,20 per hour, assisted by
4 labourers @ R1,20 per hour (total)
combined output: 3.50 square yards per hour.

---

*See also definition of allowable cost given as footnote in Section 3.3.1.

From this the allowable cost of removing the formwork and staging was calculated as $\frac{R2.40}{3.50} = R0.70$ in terms of the number of square yards of formwork removed.

Since it was found on site that labourers were incapable of removing the intricate formwork system under the bridge deck, the actual team was altered to one labourer for each carpenter. A new target output was then calculated as;

$$\frac{R1.45 + R0.30}{R0.70} = 2.50 \text{ square yards of formwork removed per hour.}$$

Where $R0.70/yd^2$ is the allowable formwork removal cost according to the tender, and R1.45 and R0.30 is the hourly wage rate for carpenters and labourers respectively.

Table 3.1 shows a summary of the final outcome. It is seen that all three operations exceeded their allowable unit cost. From a closer examination of the data collected on site the writer suggests the following reasons for these discrepancies.

In the case of the erection of the supportwork excessive costs might have been due to the time taken to fix the cross-bracing of the staging (shown as a flat portion at the end of curve A, Figure 3.9(a)). Fixing cross-bracing, for which no additional allowance was made in the tender estimate, accounted for about 30% of the cost of operation A and should be taken into consideration for future estimates.

The difference between the actual and the allowable cost of fixing the formwork (approximately 3%) is considered to be negligible and is probably within the average range of variations normally found in cost estimates.

OPERATION	ACTUAL HOURS CARPENTERS	APPRENTICES	LABOURERS	UNITS PRODUCED	OUTPUT PER CARPENTER HOUR	ACTUAL COST PER UNIT	TENDER COST PER UNIT
A	1381 (1,00)*	908 (0,65)	2468 (1,80)	SEE FORMWORK	1,37 PER YD^2 FORMWORK	R1.74 PER YD^2 FORMWORK	R1.40 PER YD^2 FORMWORK
B	1631 (1,00)	367 (0,25)	1679 (1,00)	1906 YD^2	1,17 YD^2	R1.60 PER YD^2 FORMWORK	R1.55 PER YD^2 FORMWORK
C	959 (1,00)	313 (0,32)	1208 (1,26)	1666 YD^2	1,73 YD^2	R1.16 PER YD^2 FORMWORK	R0.70 PER YD^2 FORMWORK
COST RATE	R1.45	R0.60	R0.30	TOTAL UNIT COST		R4.50	R3.65

Operation A: Erect deck formwork support

Operation B: Fix deck soffit formwork

Operation C: Strip formwork and support

*The figures in brackets are the average proportions of the three trade groups as calculated from the actual working hours of each trade group.

Table 3.1: Summary of unit outputs and costs achieved during construction

As described above the labourer content of the third operation (C in Table 3.1) was almost equal to that of carpenters because of certain difficulties in dismantling the timber formwork system used. Figure 3.9(b) shows that the number of carpenters were reduced (and the labourers increased) near the end of the operation. Once the timber soffit panels had been removed from under the bridge deck, only labourers were then required to dismantle the steel supportwork. This problem probably accounted for the increase in cost (see Table 3.1) for which an allowance should be made in the tenders for future contracts of a similar nature.

It is the opinion of the writer that this is a useful control technique for construction sites. It is, however, clear that the target output depends on the cost of the team allocated to an operation (i.e. if one wants to stay within the cost allowed for in the tender). When there is the possibility that the ratio between the various trade groups will vary over the duration of an operation (as was the case in Figure 3.9(b)) a better approach might be to calculate the unit cost in addition to the output each week (see Figure 3.9(c) and Section 3.3.1).

3.3 Cost Control Systems for Construction Contracts

From literature and discussions with various local contractors the main factors which contribute to the success of a cost control system appear to be:

(i) Simplicity - A problem particular to the construction industry is the lack of educated site staff. Foremen and charge hands are generally shy of paperwork and the collection of labour and plant working hours on site is usually left to semi-trained

Bantu or Coloured staff. This is then converted to cost at the contractors head office and compiled into reports. The system should therefore be relatively simple, and clear pre-printed forms, preferably in different colours for plant and labour should be used to collect cost information on site. An explanatory site office manual will ensure that a standard procedure is followed on all contracts.

(ii) Timing of information - Historical cost information is usually of little value for site control. A certain amount of accuracy (e.g. ± 3%) might have to be sacrificed if it means that reports will be timely. This is also part of the reason why material costs are not subject to regular cost control as invoices are often received long after the costs are incurred.

(iii) Management support - Unless those members of staff who are in a position to affect construction costs, actively make use of cost information the system will simply become a "paper-shuffling routine" which provides work for a large number of clerks.

(iv) Flexibility - Small contracts usually do not require the same detailed cost control as a large contract. It will therefore be a serious handicap if the cost control system cannot be adjusted to suit the size and type of contract. A particular example here is the use of a company-wide cost collection sheet with fixed cost headings which have to be used regardless of the type of job; this approach is common to the unit-cost control approach (Section 3.3.1).

A) Construction Costs

Costs are traditionally divided into direct and indirect costs. As mentioned in Section 2.5 indirect costs or overheads are defined as being all expenditures not directly proportional to the amount of permanent or temporary material required in a structure (e.g. The site engineer's salary, transportation costs, insurance). Direct costs are then directly proportional to the quantity of work (e.g. the volume of concrete on site, labour wages and the cost of materials).

Table 3.2 shows a classified breakdown of the various types of costs which the contractor might incur during construction. It will be seen from column four that for the purpose of cost control these can be grouped into:

(1) Direct labour costs (e.g. hourly wages),

(2) Direct plant costs (e.g. internal plant charges or outside hire costs),

(3) Direct cost of material (e.g. for cement),

(4) Site overheads; these usually occur either as lump sums (e.g. plant set-up) or as time related costs such as the salaries of professional site staff,

(5) Subcontractor payments,

(6) A proportion of the head office costs (e.g. design office costs).

Of these only direct labour, direct plant and site overhead costs are generally subject to frequent review by management as most cost overruns occur in these items. Contractors

TABLE 3.2 A: Characteristics of Construction Project Costs

ITEM	TYPE OF COST	TYPICAL EXAMPLES	TYPICAL CHARACTERISTICS	CLASSIFICATION FOR COST CONTROL PURPOSES	OCCURENCE IN BILL OF QUANTITIES	INTERVAL FOR REVIEW BY CONTRACTOR
1a	LABOUR DIRECT	WAGES OF WORKERS, OVERTIME, ALLOWANCES	∝ QTY. OF WORK COMPLED ON SITE	IS KEPT AS A SEPARATE ITEM (SEE TABLE 3.2 B	IN RATES OF MEASURED ITEMS	REGULAR COST CONTROL (E.G. WEEKLY)
1b	LABOUR INDIRECT	PROFESSIONAL SALARIES, BONUSES, HOLIDAY PAY, TRANSPORT TO AND FROM SITE	∝ TIME, OR AS LUMP SUMS	UNDER ITEM 4a OR 4b OF THIS TABLE	PREFERABLY UNDER P&G ITEM IF THIS EXISTS	———
2a	PLANT DIRECT	AS PLANT "DEPRECIATION" CHARGES, FUEL, OIL, OPERATOR WAGES, HIRE CHARGES	∝ QTY. OF WORK COMPLETED ON SITE	KEPT AS A SEPARATE ITEM	IN RATES OF MEASURED ITEMS	REGULAR COST CONTROL
2b	PLANT PURCHASE COST	ALLOCATED TO A SITE AS AN EQUIVALENT DEPRECIATION CHARGE (SEE 2a)	AS LUMP SUM OR SERIES OF PAYMENTS.	———	———	———
2c	PLANT INDIRECT	TRANSPORTATION OF PLANT TO AND FROM SITE, ERECTION COST, INSURANCE	∝ TIME, OR AS LUMP SUMS.	UNDER 4a OR 4b	PRELIMINARY AND GENERAL OR AS MEASURED ITEMS	———
3a	MATERIAL DIRECT	PURCHASE COST, PREPARATION COST (E.G. FORMWORK)	∝ QTY. OF WORK	AS A SEPARATE ITEM.	IN MEASURED ITEMS	REGULAR QUANTITY CONTROL
3b	MATERIAL INDIRECT	TRANSPORTATION TO SITE, LOADING	LUMP SUMS	UNDER 4a OR 4b	P&G OR MEASURED ITEMS	———
4a	FIXED OVERHEADS (INCL. ITEMS FROM 1b, 2c, 3b)	STAFF SALARIES, SITE OFFICES, SMALL PLANT, SURVEY, SITE ESTABLISHMENT, ETC.	∝ TIME OR AS LUMP SUMS	AS "SITE OVERHEADS"	P&G MAINLY BUT ALSO IN RATES OF MEASURED ITEMS	NOT SO FREQUENT (E.G. MONTHLY)
4b	VARIABLE OVERHEADS (INCL. ITEMS FROM 1b, 2c, 3b)	TRANSPORTATION (1, 2 & 3), PLANT SET-UP, WORKER BONUSES	DEPEND ON WORK PROGRAMME	AS "SITE OVERHEADS"	DITTO	DITTO
5	SUBCONTRACTOR	SPECIALISED WORK (E.G. STEELFIXING).	∝ QTY. OF WORK (SOMETIMES AS LUMP SUMS)	AS A SEPARATE ITEM	USUALLY FIXED BY TENDER. MEASURED REGULARLY FOR PAYMENT BUT SELDOM FOR CONTROL	
6	HEAD OFFICE COST (ALLOCATED TO A SITE)	DIRECTOR'S FEES, TYPING, DESIGN OFFICE, ALLOCATED BUILDING DEPRECIATION COST	E.G. ALLOCATED AS PERCENTAGE OF CONTRACT VALUE	SEPARATE OR UNDER 4a.	UNDER P&G ITEM OR AS PART OF PROFIT MARK-UP	INFREQUENT (E.G. EVERY THREE MONTHS)

TABLE 3.2 B

(a) CUMULATIVE REVENUE AND EXPENDITURE STATEMENT FOR A CONTRACT (E.G. EVERY THREE MONTHS).

EXPENDITURE ON ONE CONTRACT

PLANT HIRE COSTS	3
WEEKLY WAGES	20
STAFF SALARIES	10
INTERNAL PLANT COSTS	12
INVOICES FOR MATERIAS	13
SUNDRY SITE OVERHEADS	6
SUBCONTRACTOR CLAIMS	4
HEAD OFFICE O/HEADS (ALLOCATED)	6
(1) TOTAL EXPENDITURE:	74

REVENUE DUE FOR THIS CONTRACT

MEASURED WORK	40
P & G DUE	20
DAYWORKS	8
MATERIALS ON SITE	7
FOR COST ESCALATION CLAUSE	3
(2) TOTAL REVENUE DUE:	78
"POSSIBLE PROFIT" (2)-(1):	4

NOTES:

(A): EARNINGS OF ALL CONTRACTS CONTRIBUTE TO EARNINGS OF THE FIRM

(B): ALL CONTRACT COST, EXCLUDING DEPRECIATION INTERNAL PLANT CHARGES (SEE D)

(b) INCOME STATEMENT FOR A FIRM (PREPARED FOR A WHOLE YEAR AT THE END OF A FINANCIAL YEAR)

TOTAL EARNINGS OF FIRM:	300
LESS: TOTAL COST:	200
INCOME BEFORE TAX:	100
LESS. PROV. FOR TAXES	40
NETT INCOME (PROFIT/LOSS)	60
PLUS: RETAINED EARNINGS OF PREVIOUS YEAR:	20
CUMULATIVE TOTAL:	80
LESS: DIVIDENDS (PAID OUT THIS YEAR)	40
RETAINED EARNINGS (AT END OF THIS YEAR):	40

NOTES:

1. AN INCOME STATEMENT SHOWS THE PERFORMANCE OF A FIRM OVER A PERIOD OF TIME
2. (C): RETAINED EARNINGS ARE PORTION A FIRM'S PROFIT WHICH ARE NOT PAID OUT AS DIVIDENDS BUT RETAINED TO FINANCE FUTURE GROWTH; (RET. EARN. INCREASE THE OWNER'S EQUITY)

(c) BALANCE SHEET FOR A FIRM (PREPARED AT AN INSTANT IN TIME, USUALLY AT THE END OF A FINANCIAL YEAR).

LIABILITIES (SOURCES OF A FIRM'S CAPITAL)		ASSETS (USES OF A FIRM'S CAPITAL)	
OWNER'S EQUITY		**FIXED ASSETS**	
SHARE CAPITAL	250	PLANT & EQUIPMENT (LESS: DEPRECIATION)	200
RETAINED EARNINGS	40	OFFICES AND YARD (LESS: DEPRECIATION)	80
NON-CURRENT LIABILITIES		**CURRENT ASSETS**	
LONG TERM LOANS	50	CASH	40
MORTGAGE BONDS	20	STOCK (INVENTORY)	25
CURRENT LIABILITIES		WORK IN PROGRESS	50
ACCOUNTS PAYABLE	40	ACCOUNTS RECEIVABLE	5
BANK OVERDRAFTS	—		
TOTAL LIABILITIES	400	TOTAL ASSETS	400

NOTES:

1. A BALANCE SHEET SHOWS THE FINANCIAL POSITION OF A FIRM AT AN INSTANT IN TIME.
2. (D): YEARLY DEPRECIATION OF PLANT AND EQUIPMENT IS CHARGED TO A PARTICULAR FINANCIAL YEAR TO DETERMINE TOTAL ANNUAL COST.
3. AN INCREASE IN DEPRECIATION CAUSES A DECREASE IN RETAINED EARNINGS FOR A PARTICULAR YEAR. HENCE, THERE IS A REDUCTION IN OWNER'S EQUITY.

usually do not regard it worth the effort to control material costs to the same detail as plant and labour costs and rather concentrate on ensuring that tender quotes are not exceeded, and on minimising the physical wastage on site; e.g. using a graphical technique as described in Section 3.2.4 A.

The quantity of material required for a contract is mainly specified by the designer's drawings, whereas the efficiency of plant and labour utilisation is a variable factor of major importance which is under the control of the contractor. If a delay occurs in the use of material on site, this constitutes a cost equivalent to the cost of storage and the interest of unused capital with a reduction correction if prices of material are rising. This type of cost due to the delay in the use of materials is small compared with the possible cost fluctuations due to the variation in idle time and the efficiency of use of plant and labour. In the ideal system the costs and wastages of material would also be considered.

The costs of the subcontractor (to the main contractor) are relatively fixed by the tender agreement and need less control, and need only be taken into consideration when the interim or final profit of a contract is calculated.

Head office costs are difficult to determine exactly for each contract and are therefore generally added as a percentage of the total contract value (e.g. 5%) or are allocated on a pro rata basis depending on the value of a particular contract in relation to the total value of all contracts.

An important point regarding cost control is that one usually considers a cost to have been incurred when work has been performed rather than when the actual payment is made. In other words costs are matched with work completed.

B) Construction Revenue (Earnings)

The two most common types of civil engineering contracts in South Africa are:

(a) Lump sum contracts - In these the contractor is paid a fixed sum of money for the completion of a contract according to his tender based on the original drawings and specifications. Any variations which might be made by the client during construction are valued separately. Typical examples of civil engineering contracts which have been awarded in this form include townships, basements for high rise buildings, small roadwork contracts and concrete headgears for mine shafts.

A Bill of Quantities is not usually provided and a frequently used method of paying the contractor is often according the time progress of the contract. For example, if a contract is scheduled to take ten months then the contractor will receive the total sum as ten equal payments spread evenly over this period. Other methods such as paying according to sections of completed work have also been used.

(b) Unit price contracts - In these contracts the contractor is paid a fixed tendered rate for each unit of permanent work constructed. Information concerning the breakdown of a structure into basic units of work as well as an estimate of the final* quantities of each, is contained in a "Bill of Quantities" which accompanies the tender documents. Agreement of the rates to be paid to a contractor is usually either through competitive tendering or direct negotiation with a client (or his representative). Typical examples of this type of contract include most types of road construction, harbour works and bridge contracts.

The earnings of a contractor from a unit price contract generally fall into some or all of the following categories:

(i) For measured work according to the unit rates in the "Bill" and the quantities completed,

(ii) Preliminary and General** (for site and head office overheads); usually paid as lump sums at various stages specified by the client's tender document (see Section 4.1.1),

(iii) Prime cost payments for special material, machinery, etc. specified in the tender documents (or subsequently) by the client and which the contractor must include in the structure,

---

*When a project is still in its design stage at the time of tendering very approximate "provisional" quantities are supplied.

**With reference to the "Standard Method of Measurement of Civil Engineering Contracts" (Jan. 1960) there seems to be no standard method of describing this item. In certain Bills of Quantity this item is referred to as "Establishment of plant on site" while in others the latter description appears as a sub-section of "Preliminary and General". As far as the writer is aware all Bills of Quantity presently used in South Africa include a section for overheads.

(iv) Dayworks and additional measurable works which are performed due to circumstances which are unforeseen in the tender document, or variations by the client,

(v) Time related price increases; "Rise and Fall clauses" often apply to Civil Engineering contracts which allow the contractor to adjust the unit rates of certain items according to increases or decreases in material suppliers' prices and labour wage rates. The present tendency is to use a price adjustment factor (see Section 4.5) which corrects a certain proportion (e.g. 85%) of each monthly certificate to reimburse the contractor for the effects of inflation.

Most of the above subdivisions are only permitted by virtue of the wording of the tender documents as drafted by the client's agents, or because of subsequent variations made by a client. One does not therefore automatically find that every Bill of Quantities permits the above subdivisions. In the case of (ii), for example, the writer could find no reference to a standard method of specifying this item in the "Standard Method of Measurement" for Civil Engineering contracts in South Africa (1st edition, 1960).

Contractors normally play a large role in trying to frame new forms of tender documents for acceptance by client bodies, especially in relation to time related price clauses and the new proposed method related bills (see Barnes, Ref. 4).

An important point in connection with method related Bills of Quantities is that there is often a difference between the way in which the contractor earns revenue and the manner in which it is received; for example, site overheads are continuous expenditures for which the contractor is only reimbursed at one or more stages during construction. A certain percentage of the monthly certificate is also usually withheld (e.g. 5%) till the end of the maintenance period (e.g. one year after project completion) against possible default by the contractor.

C) Profit

The interim or final profit of a contract is almost always evaluated in an accounting sense rather than in terms of actual cash payments and receipts;

i.e. Profit = Revenue - Expenditure ....(3.2)

Where Revenue describes the total money due for the measured work which has been completed (a portion of which can be claimed for in the certificate and the rest in the subsequent retention payment) plus a proportion of the money due from the Preliminary item (for overheads), plus money due for day-works earned to date and the benefits of any price increases and Expenditure is the sum of all costs incurred during the same period though they have not necessarily yet been paid by the contractor (i.e. labour wages, plant charges, material costs due, etc.).

One of the main problems in evaluating interim profit is ensuring that expenditures and revenue must both refer to the same work or time period (i.e. they are matched). For example, whereas the revenue due for the measured Bill items can easily be derived from the monthly certificates an estimate will have to be made of the corresponding proportion of Preliminary and General money due, as the latter is only paid by the client at prearranged stages during construction (e.g. half of the Preliminary and General money might be received when about 50% of the tender sum is claimed). It is similarly often difficult to evaluate certain costs accurately in a given time period. Invoices for materials and claims from subcontractors generally arrive long after work has been performed. Material costs can be assessed from delivery notes collected on site in which case the cost of unused material on site must be assessed and subtracted to find the cost of the used material to which the earned revenue refers.

Interim profits are therefore regarded as approximations and often referred to as "expected" or "possible" profits on accounting statements (see Table 3.2 B (a)).

D) <u>"Cost Centres" for cost control systems</u>

The phrase "cost centre" is analogous to the name of an accounting ledger in which costs are listed (i.e. pertaining to a certain aspect of the project).

Cost centres denote any item, activity or section of work for which costs can be collected with the object of cost control (e.g. a contract as a whole, excavation work, etc.).

To decide on the necessary cost centres for a particular contract, the contractor might use the following sources:

(a) The Bill of Quantities - The description of items in the "Bill" presently used in South Africa are usually too specific to be used for this purpose. Particular attention has been paid to this point in designing the new Bill of Quantities recently introduced in Britain (Ref. 4).

(b) Standard cost collection form - This is a preprinted daily report sheet with general cost headings; e.g. excavation, formwork, base course, etc. This is often used in unit costing (Section 3.3.1) where all costs are converted to unit costs from the quantity completed (e.g. using Rand / cubic metre of excavation). Only limited control is possible with this system. For example, in the case of formwork several rates apply to different portions of a contract and therefore the cumulative cost total is a general average and must be interpreted correctly (see Section 3.3.1). Within a certain firm the same standard form might be used on several different sites.

(c) A coded classification - In this method more subdivisions of cost details is possible than in the above standard cost collection form. A number code is used to indicate a certain item. For example, the code 2.3 might represent formwork (code 2) in columns (Code 0.3).

From a set of standard work descriptions the necessary items required for a particular contract are compiled into a cost collection form. In other words, the major cost centres used might vary from contract to contract, but the code would be standard throughout the firm. This ensures that there is sufficient cost detail for management and at the same time this provides standard descriptions and codes for electronic processing of the data. An example of this is shown in Section 3.3.2 B.

(d) Network activities - Alternatively one can use network activities as cost centres. A number of commercial computer programmes are marketed which allow the contractor to control costs by estimating and recording both this allowable and actual costs for each network activity (see Section 3.3.3).

3.3.1 The Unit Costing System (i.e. keeping retrospective records for present evaluation)

This is an approach commonly used by the smaller contractors for recording incurred costs. In this method all costs are related to certain items of permanent and temporary materials, and a cost per unit quantity is determined from the amount of work completed.

$$\text{i.e. Unit cost to date} = \frac{\text{Total expenditure to date}}{\text{Total quantity completed}} \quad \ldots\ldots(3.3)$$

(e.g. Rand/m^2 of formwork)

Because of certain difficulties associated with collecting material costs, only plant charges and labour wages are generally considered, except where material costs form a major portion of the cost centre.

A variation of unit costing is to use plant or labour working hours rather than cost. This would be more significant to the estimator, but requires accurate reporting as, for example, the performance of a front-end loader of 10 m^3 capacity will be different to one of 5 m^3 capacity.

Cost centres are generally defined to include only the large value items on a contract as these are the cause of most cost overruns; for example,

Formwork:

(a) to slabs

(b) in bases

Excavation:

(a) hard material

(b) soft material

(c) for pipes

etc.

Barnes (Ref. 6) examined a large number of Civil Engineering contracts in the United Kingdom from which it was found that on average 90% of the construction costs were contained in only 20% of the "Bill" items; also, 99% of the increases in total cost (from that estimated in the tender) were caused by those large value items which make up about 50% of all "Bill" items. The significance of this fact is that by concentrating only on these large items, a contractor can still exert a reasonable measure of cost control over a contract.

A typical example of how unit costs could be used as a control tool is shown in Figure 3.10.

A comparison between the unit cost to date and the allowable cost* derived from the tender estimates will give an indication of whether the expected profit margin for an item is being maintained. The monthly (or weekly) figure is expected to fluctuate but will show an increasing cost trend more quickly than the curve showing average unit cost to date.

In other words the monthly unit cost $\frac{C_i}{V_i}$ will show a variation more quickly than $\left(\frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} V_i}\right)$ the average unit cost to date. Where, C_i and V_i are the total costs and volume of concrete for a particular month i (n is the number of months which have elapsed since the start of construction).

The cumulative quantity produced (e.g. concrete volume in Figure 3.10) can also be drawn and might help to explain why a certain cost increase occurrs. For example, during periods where smaller batches of concrete are placed unit costs might be higher since the labour used on a 100 cubic meter "pour" will not differ significantly from that when 150 cubic meters are placed and the time involved for the larger "pour" will probably be less than 1,5 times the

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*"Allowable cost" in this sentence means portion of the tendered rate in the signed tender documents, e.g. in Table 3.1 the allowable cost for stripping formwork is R0.70 per square meter although the tendered price for erection, fixing and stripping formwork is R3.65 plus overheads plus profit plus unbalancing adjustments.

duration of the smaller "pour".

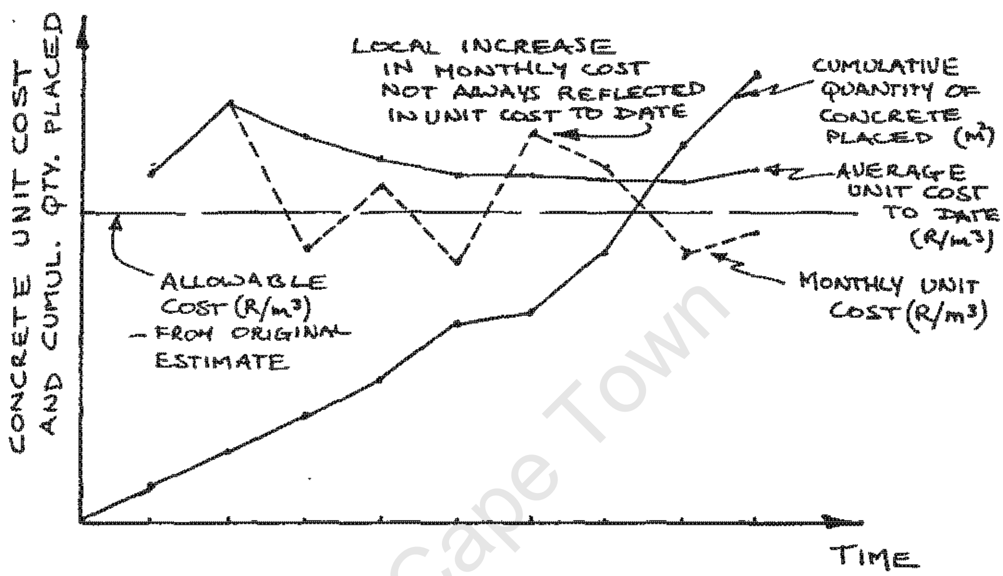

Figure 3.10: Example of cost control with unit costs

Advantages

The main advantage of the unit cost approach is its simplicity. Only operations which are known to be prone to cost overruns are considered (e.g. concrete, formwork, excavation) and usually in this control system only plant and labour costs are collected.

Disadvantages

Unit costs are particularly sensitive to weather, site conditions and accuracy in measuring quantities. When a contractor starts on a relatively easy part of a contract unit costs might be low and create the impression that efficiency is high.

When many items of a similar nature such as various types of formwork are considered as a single cost centre the actual unit cost calculated will depend very much on the part of the structure being constructed. For example the unit cost of column formwork will be considerably higher than that for a large slab.

If production figures (e.g. plant hours/m^3) are reported instead of expenditure within a certain costing period, a great deal more work will be involved to ensure that information is collected accurately (e.g. types of plant, etc.).

Furthermore, as only a part of the site costs are considered, the actual cost data is easily adjusted to the advantage of site staff by under allocating costs to the items under review. This causes false records which are useless for interpretation purposes.

Indirect costs which are often the cause of cost overruns are not considered.

3.3.2 The Standard Costing System (i.e. the use of target costs for continuous evaluations)

In a Standard Cost control system management compares actual costs with a predetermined standard target cost for the same amount of work to decide if intervention is necessary.

A) Target Costs

Gobourne (Ref. 10) lists four different standards which might be used for measurable work:

(1) Historical costs - These often vary from site to site depending on conditions such as weather, type of labour or location and are generally regarded as having more relevance to Building rather than Civil Engineering contracts.

(2) Estimator's cost - These are not always completely representative because the eventual method used for construction might be different from the method initially envisaged by the estimator.

(3) Work study standards - Unless the conditions applying during the study are recorded, the same disadvantages as in (1) apply. (i.e. They cannot be used for accurate predictions of conditions on future Civil Engineering contracts.)

(4) Estimators' handbooks - Such data would only apply to the country for which it is compiled. In South Africa, where the type of labour might differ tremendously depending on the ethnic area where a contract is located, it will be difficult to accept the general validity of a standard of this type with respect to labour output. Part of the variability of labour output may be due to difficulties in language communications or lack of education in industrialised techniques.

The present writer is of the opinion that the estimator's cost will give the best and most useful target cost for two reasons; firstly, a standard relevant to the work under consideration will always be available, and secondly, all cost comparisons particularly those for the site as a whole will show directly how a particular cost over- or underrun affects the contractor's profit.

Two problems might arise here, namely:

(a) Which portion of the estimator's cost to use,

(b) What if his cost was under-estimated.

In Figure 3.11 it will be seen that the original cost estimate passes through various stages of adjustment during the preparation of a tender and the final bill rate might be completely different from the initial estimate. It is therefore important that the cost standard used for the cost centre should usually be the original* cost estimate prepared by the estimator prior to the addition of overheads (e.g. head office costs), profit, and unbalancing adjustments (plus any subsequent reasonable corrections of estimator's error which might have been discovered by management during or after tendering).

Since the estimator must make certain assumptions as to the eventual construction method some errors might occur (e.g. a common problem is having to use plant where labour was allowed for). When costs are under-estimated the writer considers it best to leave the target costs as they are rather than to re-estimate these to suit the method of construction on site. This is partly a

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*In Section 5.3.1 B) an example is shown on how the allowable cost (i.e. target cost) of a cost centre can be determined from the estimator's calculations.

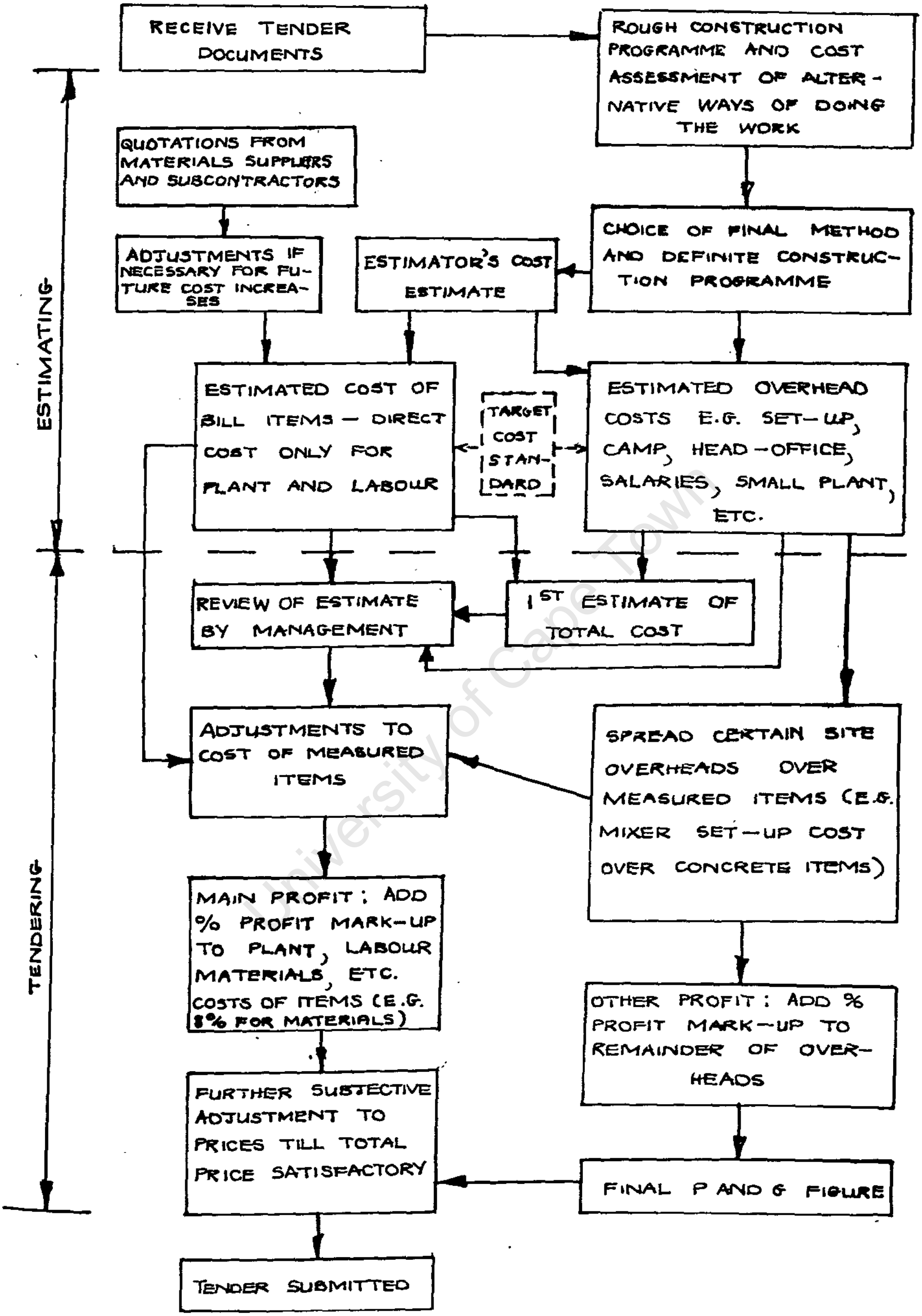

FIGURE 3.11: One Method for the Preparation of a Tender

psychological problem as site management might now tend to blame any avoidable cost overruns on under-estimating. Also if site staff see that the cost standard (i.e. target cost) can be adjusted, they might be less inclined to try and reduce costs in other ways.

B) Cost centres

As most comprehensive cost control systems are of the standard costing type (Section 3.3.2), cost centres are usually defined in such a way that all costs which are incurred on site can be allocated to them.

A typical approach might be to use a system consisting of a coded classification list* from which the necessary cost centres can be chosen (Pilcher, Ref. 17); for example,

1. Excavation	.1 bases
2. Formwork	.2 abutments
3. Steelfixing	.3 columns
4. Concrete	

The cost centres for abutments could then be taken as:

1.2 Excavation for abutments

2.2 Formwork to abutments

3.2 Steelfixing abutments

(Concrete is often usually considered as a general item for the whole contract hence the subdivision 4.2 might not be used.)

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*In Section 5.3.1 A) an alternative form of such a list is discussed.

In this way a complete list can be compiled for the whole contract. On site, cost data is collected according to the descriptions in the above list while in the office the data might be processed according to the codes which are standard throughout the firm.

C) Collection of actual costs

The flow-chart in Figure 3.12 illustrates how a typical standard costing system might operate. (This system was introduced in Section 3.3.2.)

The procedure frequently employed on South African construction sites for collecting labour costs, is to use a timekeeper who visits a contract once or twice a day and notes down a description of the activity and the corresponding labour hours for each trade. These times he must balance with the total hours entered on the wage sheets. An alternative would be to derive this information from the foreman's report which is more or less the same as that of the timekeeper. The writer prefers the use of a foreman's report which should yield a better distribution of costs, because the foreman is more knowledgeable about the history of each activity and its labour usage. Since supervisory staff are not particularly fond of paperwork the writer suggests that a small incentive bonus be paid when the foreman's report is presented on time. All labour hours listed in the report are then converted to costs by multiplying these with an hourly charge rate for each corresponding trade.

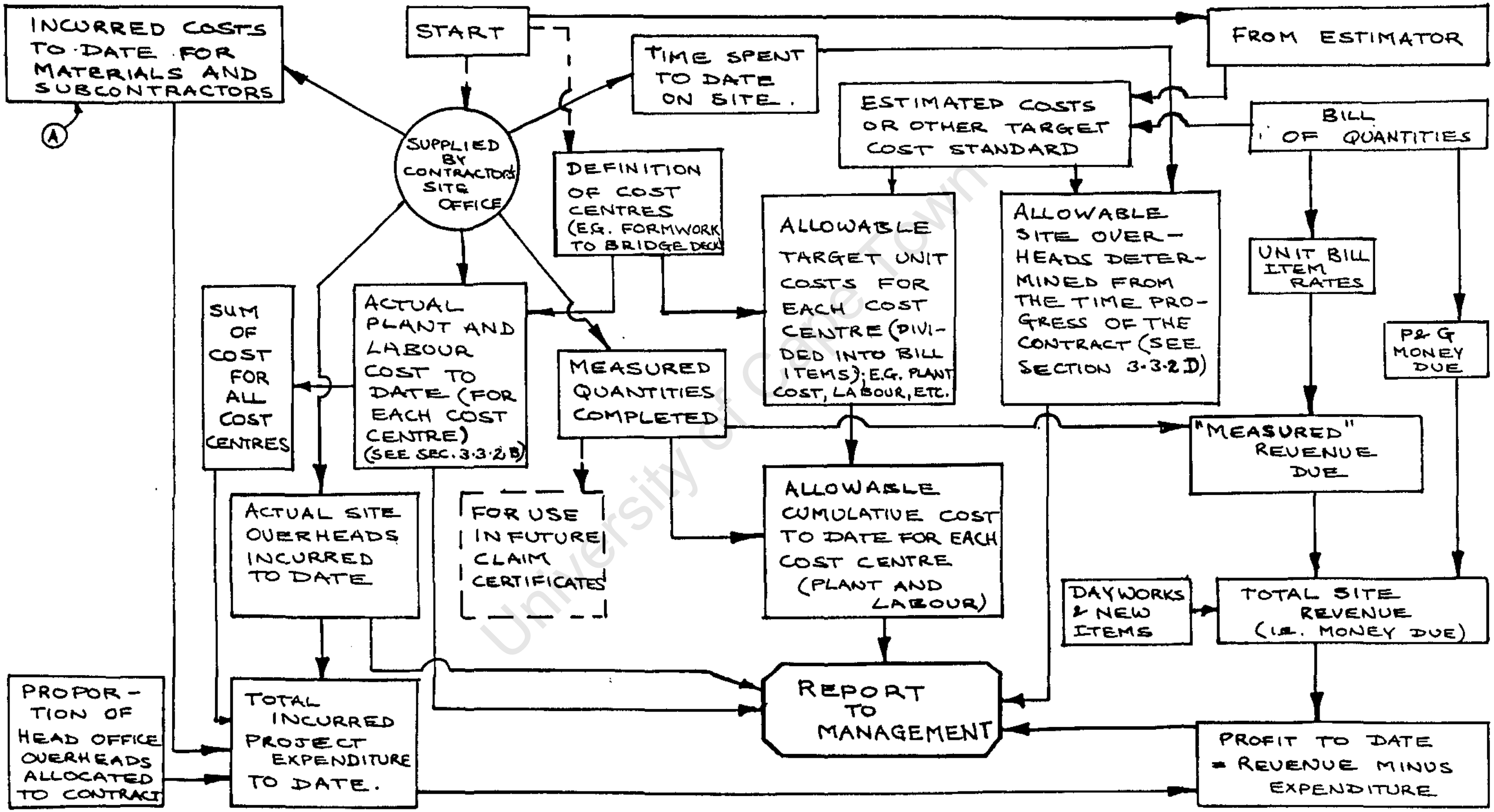

FIGURE 3.12: The Simplified Operation of a Typical Standard Costing System (see Section 3.3.2)

Plant costs are allocated to the various cost centres in a similar manner by using the descriptions of the work and the operating hours noted in the operator's machine book. An hourly operating charge rate for each type of plant converts plant and operator hours to costs.

Material costs are generally not considered in detail and are only evaluated for the site as a whole in block A in Figure 3.12 using the invoices received or the delivery notes collected on site.

D) Problems with indirect costs

With indirect costs the main problem is matching the timing of actual costs and allowable costs. It will be seen from Table 3.2 that indirect costs are either:

(i) proportional to time and incurred over all or part of the project duration (e.g. staff salaries, mixer on site, crusher, small plant, etc.),

or (ii) lump sums which occur at various times during construction (e.g. site set-up, transportations of plant to and from site, etc.).

Various approaches are possible here. Gobourne (Ref. 10), for example, suggests that an equivalent monthly allowable rate be calculated by summing (i) and (ii) and dividing by the construction period. Total allowable overheads since start of construction are then determined from the number of months construction has been in progress. The writer considers that the best results will be obtained if indirect costs are split into subheadings mentioned in the groups (i) and (ii), and standard target costs (allowables) for these subheadings are derived from the thinking behind the tender estimate; for example, transportation "allowables" (i.e. target costs) might be calculated in proportion to the construction time period, while the allowable site set-up costs are assumed to be a lump sum cost immediately erection is completed.

3.3.3 The Combined Time and Cost Control System

This approach, which is sometimes referred to as activity-costing, integrates project planning and cost control by using the network activities or groups of activities as cost centres. (See definition of cost centre in Section 3.3 D.)

A) Basic procedure

The first model of this type, known as PERT/COST was developed as an extension to the PERT probabilistic planning model described in Section 2.3.2. PERT/COST was used extensively by the National Aeronautics and Space Administration in the U.S.A. to control military development projects (Ref. 3,14). Contractors who were engaged on these contracts were often forced to use the system, but did so with reluctance because of the changes required to their existing cost accounting systems. Whereas previously costs were budgeted and collected by organisational units (e.g. mechanical engineering, assembly department, etc.) it was now necessary to do this for the various operations of every project even though several different departments were concerned with a particular activity. Despite this complication, the system has certain advantages (see Section 3.3.3 E).

A similar approach has been suggested for use on construction projects. Various commercial programmes have been developed for this purpose and are presently available to the contractor. Figure 3.13 shows diagrammatically how this model operates.

If one compares this to a normal cost-only standard costing system (Section 3.3.2) the following main differences will be found;

(1) Allowable target construction costs (e.g. for plant, labour and possibly materials) are expressed in terms of the individual network operations,

(2) All actual construction costs are collected for operations or groups of operations (cost centres) for the purpose of cost control,

(3) Project progress is measured simultaneously against two standards, namely the allowable target cost and time progress which are measured together (e.g. Figure 3.15, point B),

(4) The system must be operated in conjunction with a network planning model from which the time standard is derived,

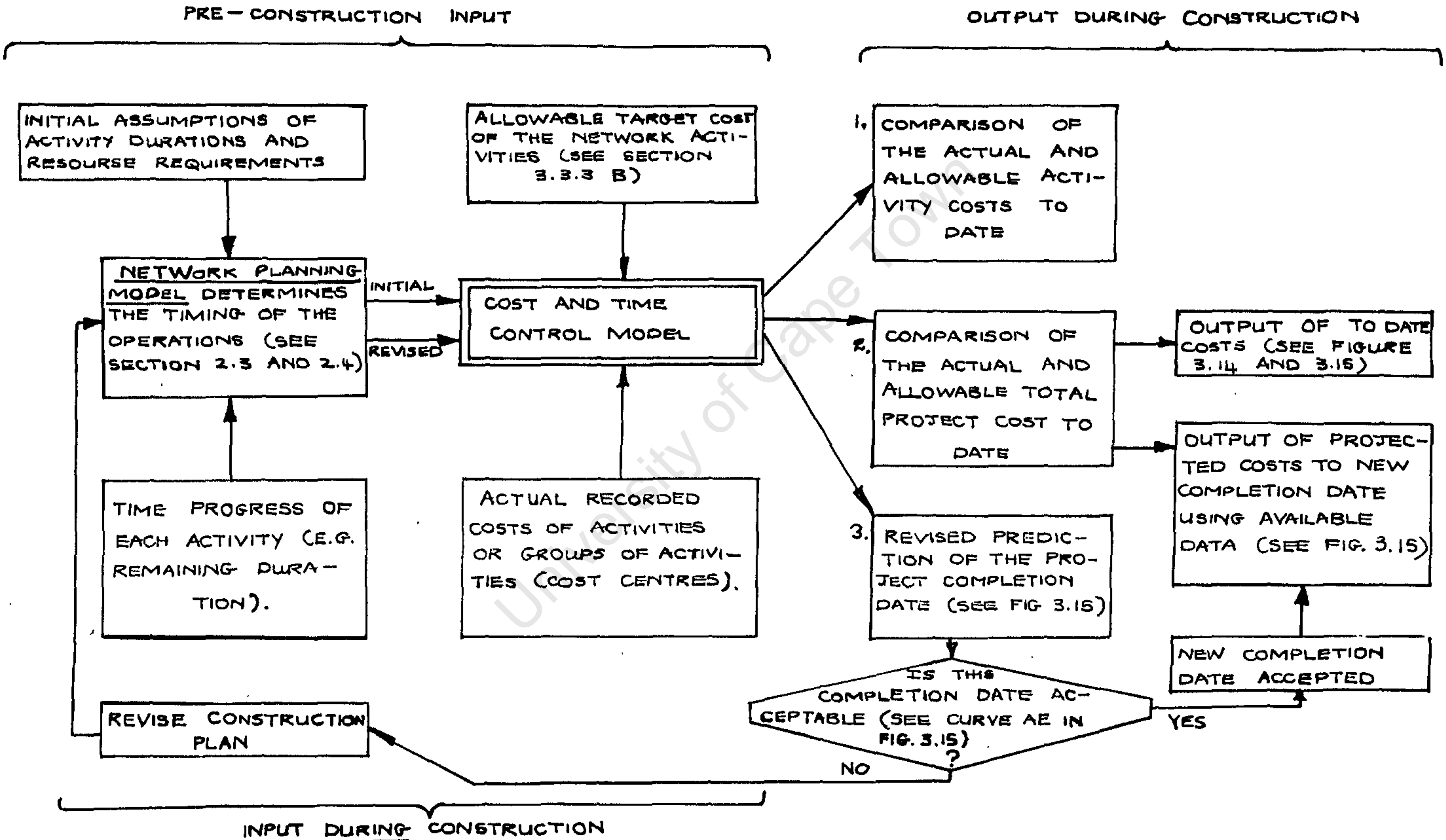

FIGURE 3.13: Typical Inputs and Outputs of a Cost and Time Control Model

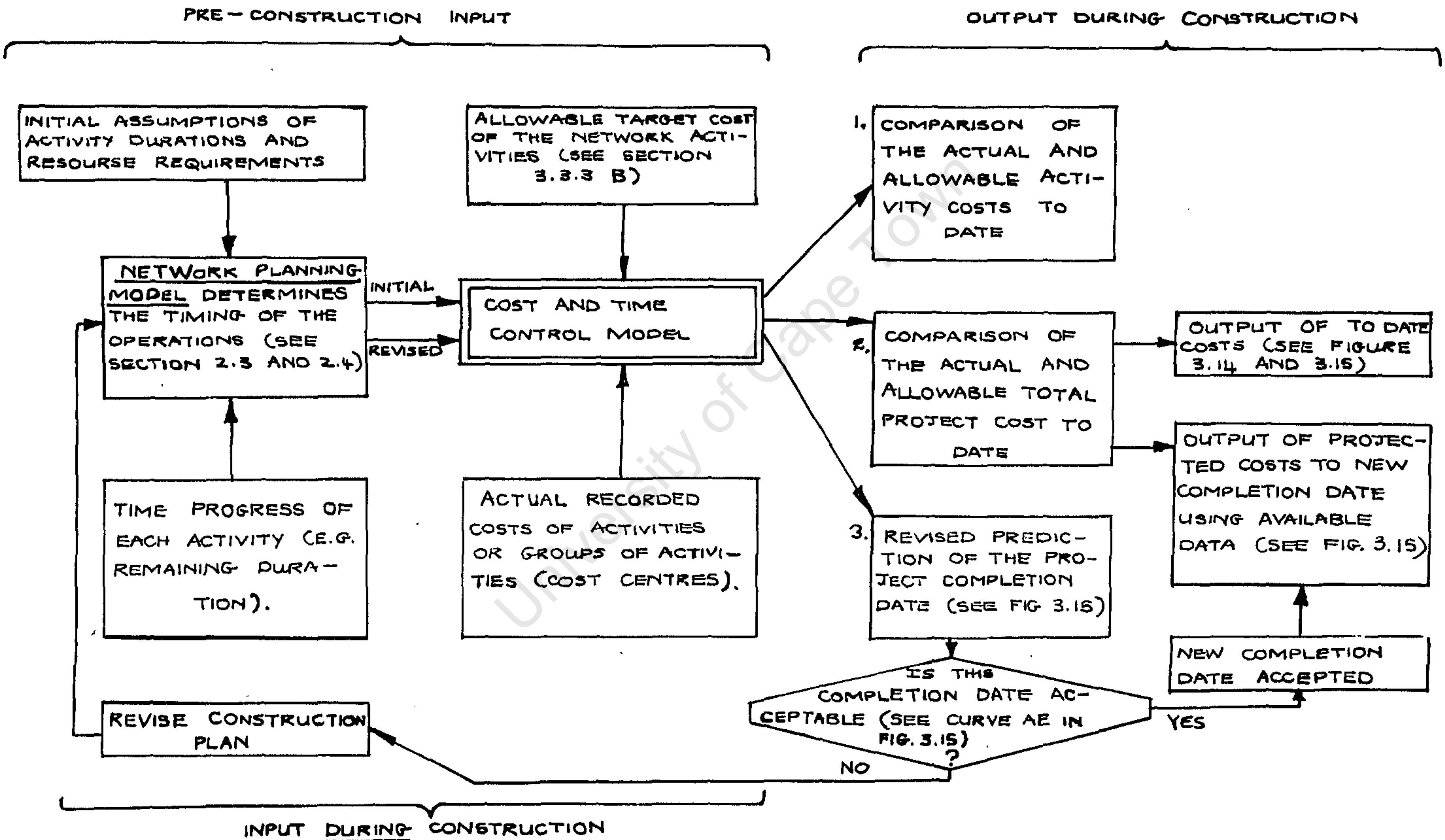

FIGURE 3.13: Typical Inputs and Outputs of a Cost and Time Control Model

(5) Also, these models must be used in conjunction with electronic data-processing facilities because of the large number of calculations involved.

Before discussing various refinements and implementation problems the general philosophy for using this model as a project cost and progress control device is described.

In Figure 3.14 the two cumulative allowable cost curves QZ corresponding to the early and late start schedules of a network time analysis are shown (Ref. Section 2.3.1). In each case the allowable target costs of the network operations (assumed to be spread over their durations) were summed cumulatively for the whole project. Various authors (e.g. Ref. 9, 17) have used this graph in the sense that as long as the project actual cost (i.e. point Y) stays within these limits the project is on schedule, both with respect to time and cost. The present writer is not entirely in agreement with this approach which will hold only if the costs of the various operations are directly proportional to their durations. For example, if all activities were performed at their expected durations and completed at the latest finish times but at excessive cost, then the total actual cost (point Y in Figure 3.14) would still fall within the envelope. It would therefore seem better to evaluate periodically an updated allowable target cost curve QX from the operations completed and partially completed to date. In this case the curve QX could be calculated

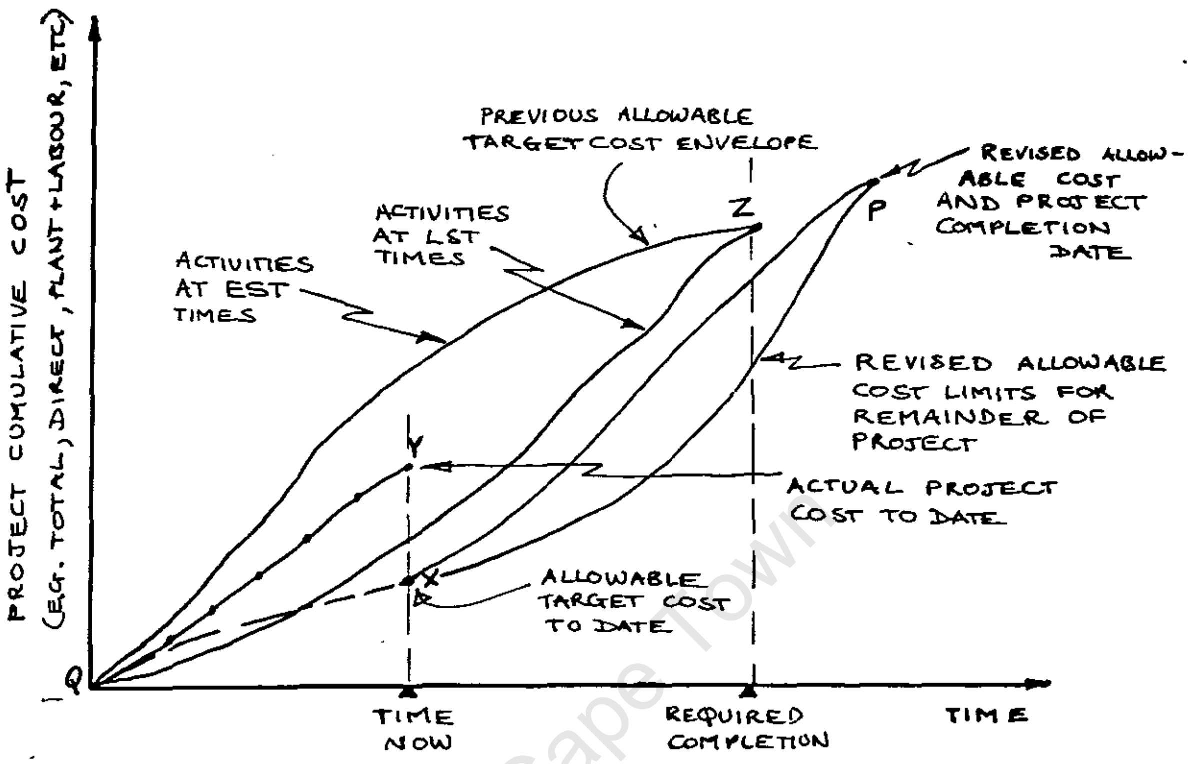

FIGURE 3.14: Cost Control with Time Analysis Model Cost Curves
(Using boundary times a double curve OZ is obtained)

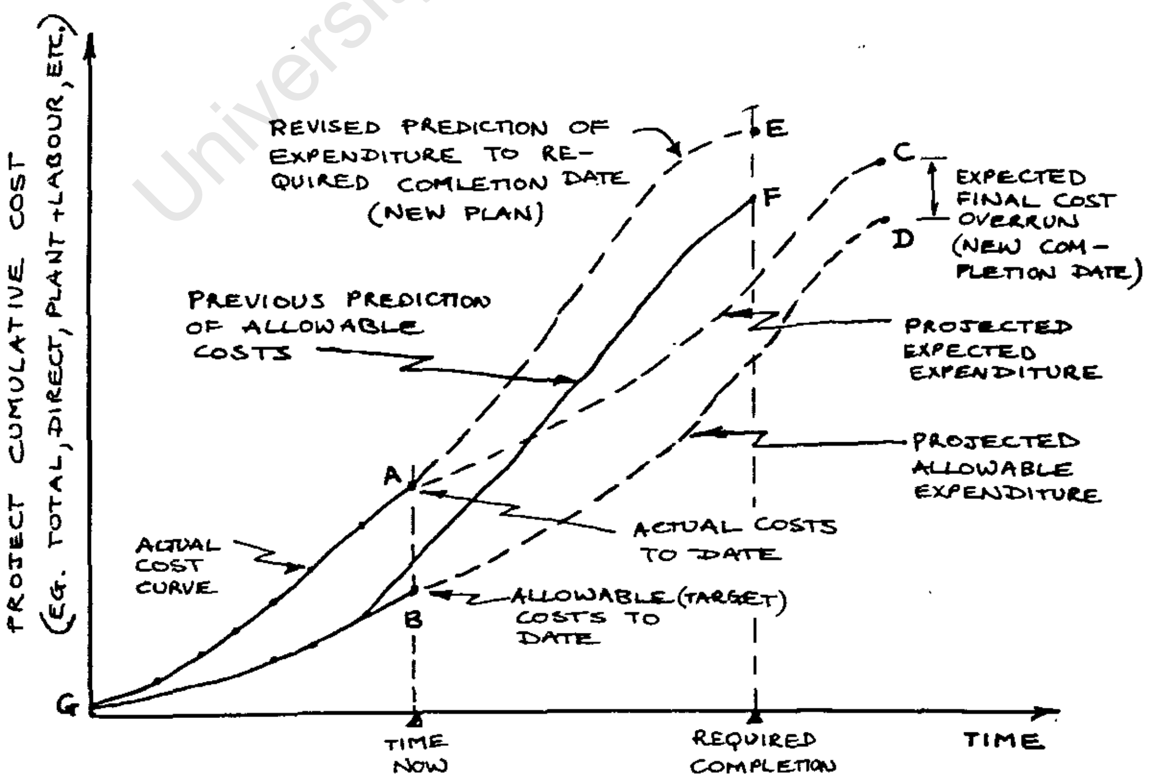

FIGURE 3.15: Cost Control using Simplified Single Curves

by assuming the allowable cost to date of each operation to be incurred in relation to the proportion by which it has been completed.

Figure 3.15 shows a more extensive application of the same principle. Here a single curve GF from one particular time-activity schedule is used. At each control date the actual and target project costs (points A and B) are plotted as shown in Figure 3.15. Allowable costs are calculated as above, from the progress to date (point B). For the uncompleted work the model can now prepare a forecast of both the actual and allowable cost to completion of the project (segments AC and BD) to show the expected final cost overrun. Actual costs might have been revised to take into account expected increases in cost due to a revised activity network, increases in unit cost, etc. Allowable target costs might similarly be periodically revised to take into account increased quantities for the various activities. Should the new project duration be unacceptable this duration might have to be corrected by revising the previous plan (see curve AE in Figure 3.15).

For more precise cost control the actual and allowable target costs of the individual operations or groups of operations might be examined.

From an examination of a number of models based on the activity costing approach the writer identifies the following three aspects where problems are expected to occur in applying this technique to a contractor's organisation:

(1) The allowable target cost to be used for the activities, and the detail to which this is specified,

(2) The manner in which indirect costs are treated,

(3) The method of cost allocation and the preparation of reports.

These aspects are discussed in the next section.

B) Allowable activity target costs

It seems that the allowable costs for the network activities have been modelled in two ways;

(a) Expected costs - These are the costs required for the completion of an activity and depend upon the actual construction method used (i.e. they are estimated according to the resources which will be used, and these costs may be altered during construction because the method of construction is changed or the quantity of work is changed).

(b) Estimated costs - These are determined by the estimator at the time of tendering and are assumed to be constant allowable target costs which will vary only if the actual measured quantities are different from the stipulated quantities in the Bill of Quantities (i.e. these estimated costs are regarded as allowable target costs which do not vary with the type of plant or labour used to complete the activity).

Expected costs

For type (a) the typical procedure is to determine the plant and labour costs for the activity from the required units of resource specified for each operation (e.g. carpenter-days, loader-hours) and their corresponding unit costs. Material and other items for example subcontractor might be allocated as lump sums which are spread over the activity duration or treated separately for the project as a whole. An example is shown in Figure 3.16 of the procedure followed by the ICL-1900 PERT programme to determine the activity allowable target cost. This uses a particularly sophisticated resource allocation programme which can amongst other things evaluate the overtime required to complete a project within a given time. The important point about the approach is that should conditions change during construction (e.g. should the unit cost of labour rise, or the plant is changed) then alterations are made to take this into account.

For example;

Activity: Excavate basement 800 m^3

Expected labour 60 hours @ 50c/hr.	= R 30
Expected Excavator 20 hours @ R5/hr.	= R100
Expected cost for activity	= R130

If instead an RB 22 dragline is to be used on its own for 30 hours @ R6,00 per hour then the new total expected cost for the activity will be R180,00.

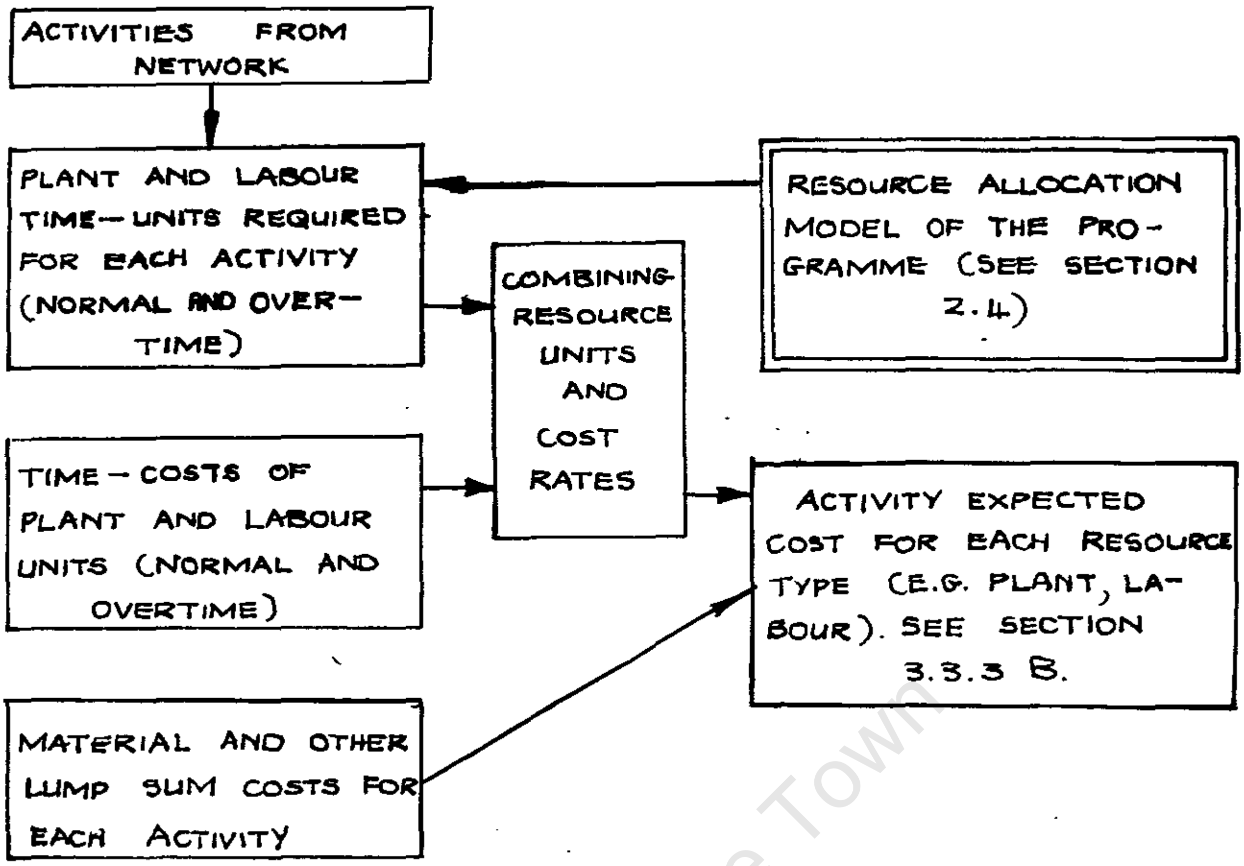

FIGURE 3.16: Activity Allowable Target Cost (i.e. expected cost) from the Expected Resource Utilisation (Ref. 13)

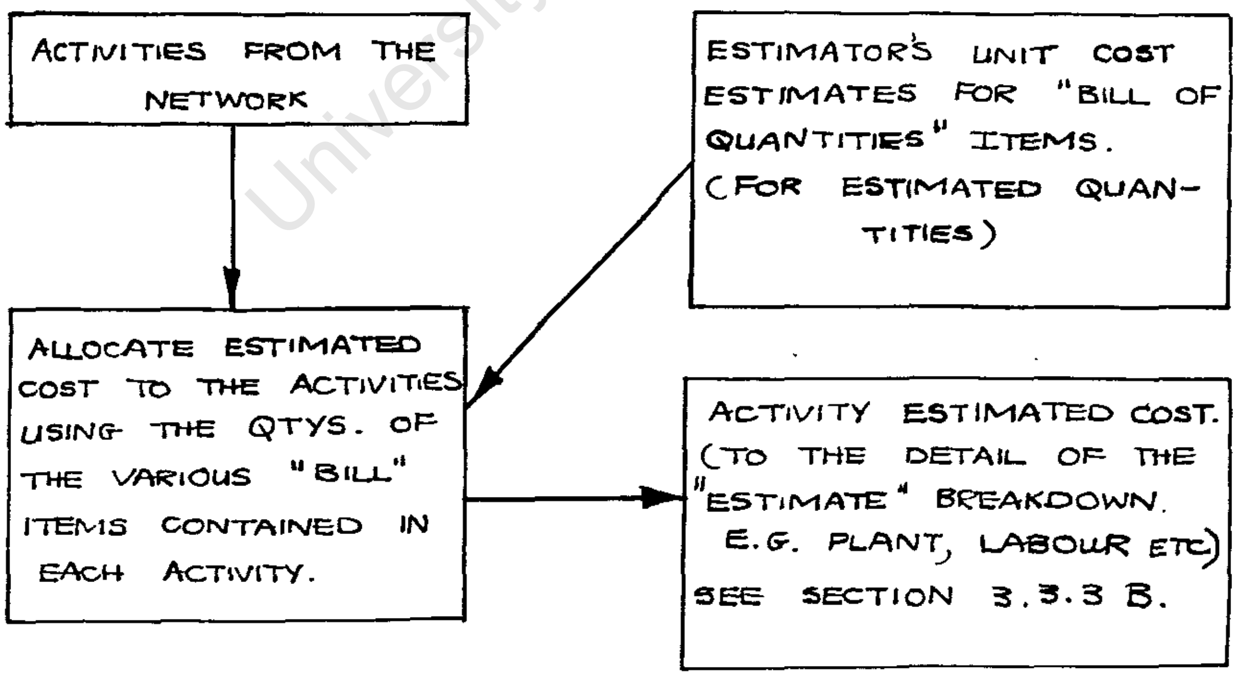

FIGURE 3.17: Activity Allowable Cost from Tender Estimate (i.e. estimated cost) (Ref. 11, 18)

<u>Estimated costs</u>

When estimated costs (type (b)) are used the activity allowable target costs will change only when there is an increase or decrease in one of the measured quantities of the Bill items contained in each activity.

For example;

<u>Activity</u>:	Concrete column base 50 m^3	
From Bill:	Estimated labour cost	R3/m^3
From Bill:	Estimated material cost	<u>R7/m^3</u>
	Total unit cost	R10/m^3

Estimated cost = R500 total cost for the activity

Should the quantity have to be increased to 60 m^3 to deepen the foundation then the new allowable cost will be R600. Any other change such as an increase in duration will simply result in the allowable total target cost being spread proportionately over the new time.

As a cost control tool the estimated cost approach (Ref. 11, 18), shown diagramatically in Figure 3.17, has certain advantages. Firstly, a target cost standard is always available and cannot be manipulated to suit management, and secondly, any cost overruns show the effect on the final profit. This will have an additional benefit in that the estimator will be made aware of the items which he might be consistently over- or under-estimating.

The advantage of the previous expected cost approach (a), however is that a construction manager can at any stage investigate the cost outcome of various construction methods, numbers of plant, the effect of delays, etc. before deciding on the best course of further action, since all expected costs are now representative of an actual situation. As in the case of the standard costing system (see Section 3.3.2) an allowable target cost which is open to adjustment will never have the same effect of motivating site staff to reduce costs as a target cost which remains fixed.

C) Network indirect costs

It will be seen from Table 3.2 that indirect costs or overheads are generally of two types:

(i) proportional to time; e.g. staff salaries, insurance, survey,

(ii) as lump sums, e.g. transportation of plant, site establishment, close-down costs, etc.

In activity costing the method for treating indirect costs is through "hammocks" or "cost-only operations". Figure 3.18 shows a cost hammock for a workshop which is on site

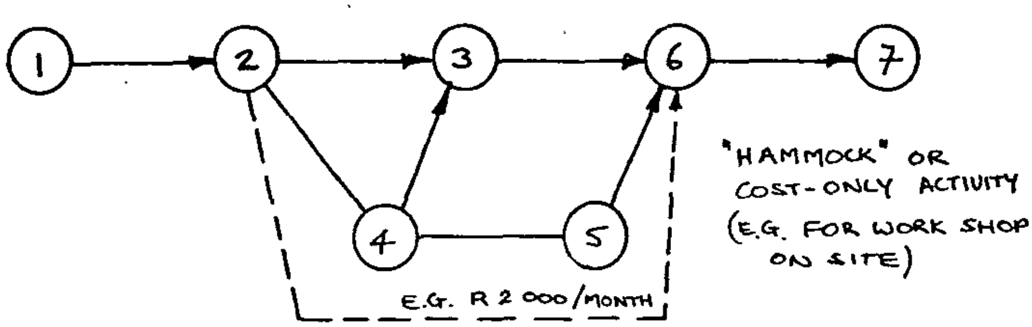

Figure 3.18: Example of an indirect cost activity

between the events (or nodes) 2 and 6. The "hammock" is never actually drawn in practice but only the nodes between which it occurs and the charge rate for the particular indirect cost (e.g. Rand/week) are specified.

The indirect cost of the cost hammock at some stage between the events 2 and 6 is calculated from the time which has elapsed between these events and the hammock cost rate per period of time.

Barnes (Ref. 5) has included an additional extension in his programme which allows a lump sum to be attached to the beginning and end of a hammock to take into account the set-up and dismantling cost of the workshop in the above example.

As in the case of the direct costs (see Section 3.3.3 A) there is again the choice of whether to use expected cost (i.e. according to the eventual construction method) or estimated cost (i.e. from the tender estimate) as the standard against which to measure actual indirect costs.

If estimated costs are used for direct costs, then one is obviously forced to use the estimated cost approach for indirect costs. The advantages and disadvantages of using estimated costs instead of expected costs have been discussed in the previous section of this thesis.

D) <u>Allocation of activity actual costs</u>

Since the detail of the network operations often exceeds the detail in which costs can be collected on site, the network activities can be grouped to form more manageable cost centres (e.g. all formwork activities). Target and actual costs for the activity can then be compared on the same basis as for the project as a whole (i.e. allowable costs to date are evaluated from the operations completed and partially completed for each cost centre. See Section 3.3.3 A.)

A particular problem in South Africa is the lack of suitably educated clerks for collecting costs on site. It is therefore expected that fewer and larger cost centres (each involving many network operations) will have to be used where there is a shortage of clerks. This then partly opposes the objective of this system which is to obtain more detailed information to increase the sensitivity of the system for managerial analysis.

E) Conclusions

One of the main advantages of the combined time and cost control approach is the relative ease with which allowable target costs can be evaluated for a cost centre (i.e. one or more activities) or the project as a whole. All that is required is information concerning the proportions of the various operations completed (see Section 3.3.3 A). Although the allowable target cost is based on the assumption that the cost of an operation is incurred uniformly over its duration it is expected that many of the errors will cancel out when a group of operations are considered together.

Forecasts of estimated allowable or expected allowable costs for the remainder of the project (or cost centre) can be easily determined (see Section 3.3.3 A).

The main disadvantage is the fact that the activity-time progress of the plan must be constantly updated and the network must be revised when there are changes in the method of construction. This should be done by the construction manager who does not always have the necessary time at his disposal to make these alterations. The preparation of a standard cost report (see Section 3.3.2) on the other hand is not activity related and can be left to an office clerk who simply evaluates the cost of each cost centre from the quantity of work completed and the unit cost standard; for example as described in Section 5.3.3 A.

In addition to this both the determination of the activity allowable target costs and the preparation of activity cost reports are lengthy procedures to perform manually and ideally require the aid of a computer.

The writer is of the opinion that for a small or medium size Civil Engineering contract the benefits to be derived from the activity costing technique will not warrant the additional clerical effort by site managers and the probable increased cost required to implement it. It is, however, expected that on a very large contract the reverse will be true and definite advantages exist in the activity costing technique. Since data processing for any costing system will in any case be by computer on a large contract, the activity costing technique will probably prepare cost control reports and cost forecasts more rapidly than by the standard costing approach in which the quantities of work completed must first be collected. Activity costing does not require this type of input since allowable target costs are evaluated from the elapsed times of the activities. Activity costing might be used for making weekly cost checks while more accurate monthly reports are prepared from the actual units completed, as described in Section 5.3.3 A.

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CHAPTER 4

FINANCIAL CONSIDERATIONS IN PLANNING AND CONTROLLING CONSTRUCTION PROJECTS

Introduction

Contractors, whether large or small, are required to devote a "working portion" of their capital to a contract during its construction period. This takes the form of cash locked-up because cost payments must be made before receipts are received from the client, and also consists of the value of plant and equipment tied-up on the site.

Besides planning and controlling his application of plant and labour on site as described in the previous chapters, a contractor is equally concerned with making an adequate return (profit) on this temporary investment. To do this he must ensure that a contract fits into an overall financial plan, at all stages during its execution.

In this chapter the writer discusses a number of models for evaluating and forecasting the effect which a decision taken with regard to a particular contract might have on the financial resources of a contractor.

4.1 Cash Flow Forecasts for Construction Contracts

The importance of cash in a firm is very effectively pointed out by Jones (Ref. 7) who states that "a business can survive in the short term without profit, but not without cash".

In most firms (i.e. including Civil Engineering contractors) possible periods of cash shortage (or cash surplus) are pre-examined by making a forecast of the expected payments and receipts of the whole business for a certain period in the future (e.g. one year). This enables a firm's financial manager to estimate the amount of free cash which a business will need at different times. The difference between the cumulative expected cash payments and cash receipts is the nett cash balance from which management must decide the amount and timing of any additional financing which might be required.

Contractors generally prepare separate cash flow analysis for their various contracts and then sum these to determine the expected overall cash position of the whole firm for some period in the future.

4.1.1 Cash flows of construction contracts

In Figure 4.1 the types of payments (cash outflows) and receipts (cash inflows) which might contribute to the flow of cash on a construction contract are shown. It is seen that the receipts from the client consist of payments for "Measured" work, for "Preliminary and General", "Retention" money and possible additional payments to reimburse the contractor for the effects of cost escalation to his plant, labour and materials costs (not all clients make a provision for the latter). For those items of work which are measurable on a contract the usual procedure in South Africa is for the contractor to claim monthly payments from the client according to the units of work which have been completed. A minimum time within which the client is required to pay for such claims is generally agreed in the tender documents. This delay is usually about one month from the time the contractor submits his certificate.

The payment of Preliminary and General* money in South Africa

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*Which the contractor includes in his tender bid to cover his head office and site overhead costs.

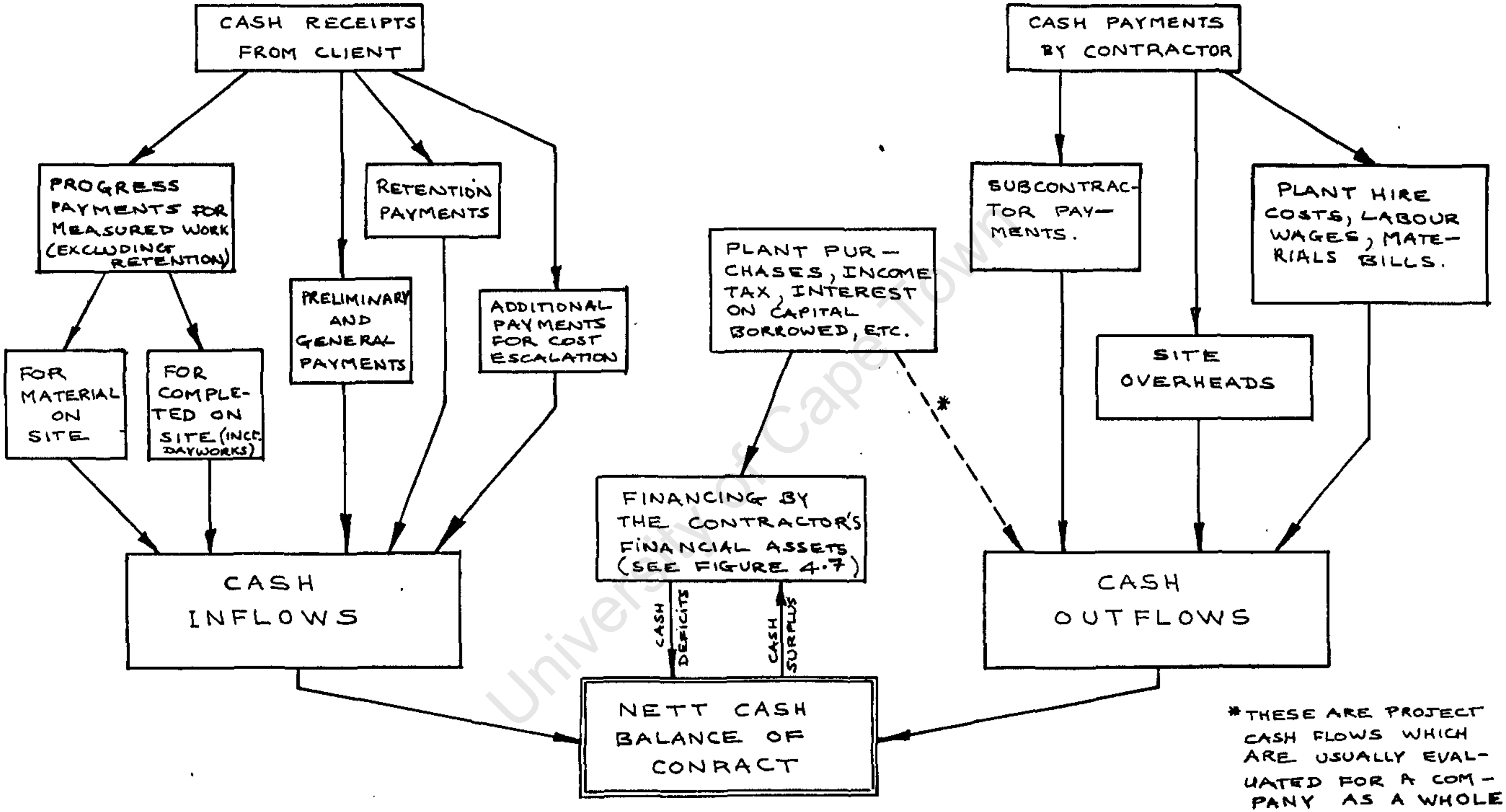

FIGURE 4.1: The Main elements contributing to project cash flow during construction

at present depends completely on the procedure of payment set out by the client in the "Conditions of Contract" which accompany the tender documents. The present writer could find no officially suggested procedure for making these Preliminary and General payments. A typical procedure on contracts with the Cape Provincial Administration is to pay Preliminary and General sums in four equal payments, each one quarter of the total lump sum tendered by the contractor for the Preliminary and General item. By pre-arrangement the first payment is made with the first certificate, the next two when the contractor has successfully claimed one third and two thirds respectively of the total original tender value, and the fourth with the certificate paid at the completion of construction (see Figure 4.2). The Cape Town City Council on the other hand do not have a fixed time schedule for paying Preliminary and General sums and usually leave this to the discretion of the contractor who is expected to make reasonable monthly claims against his tendered sum for this Preliminary and General item which appears in the Bill of Quantities.

The amount of money retained by the client against possible default by the contractor also seems to depend on the personal preferences of the various clients, and is set out in the "Conditions of Contract" which accompany the tender documents. In the recently revised SAICE standard conditions of contract the percentage is agreed separately for every contract. One half of this retained sum becomes payable to the contractor at the end of the contract and

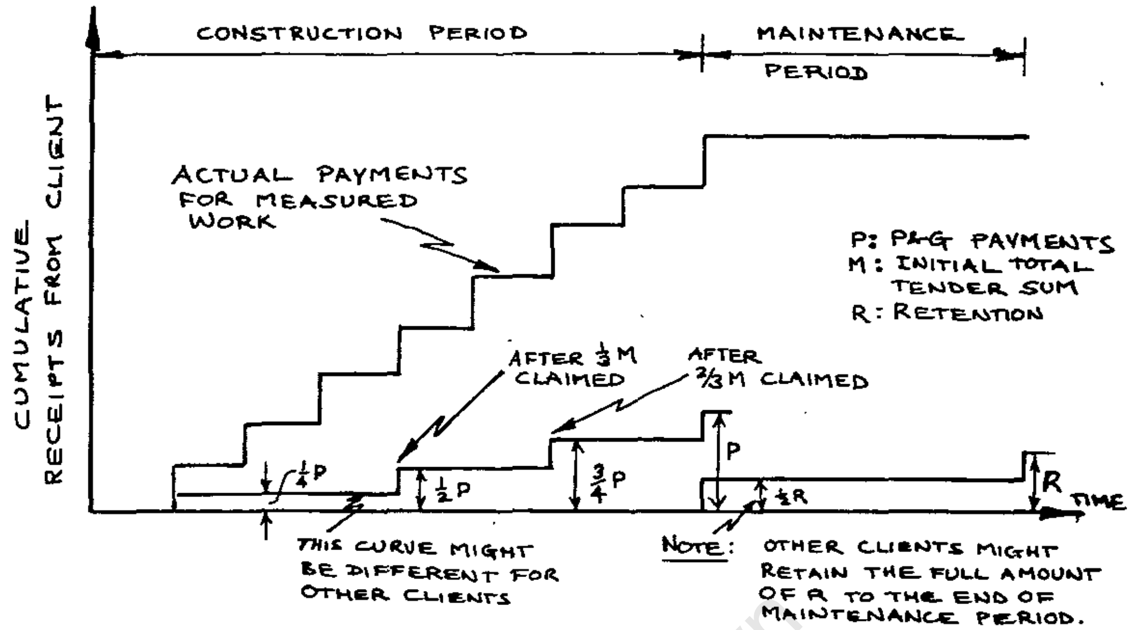

FIGURE 4.2: Typical Receipts from a Contract with the Cape Provincial Administration

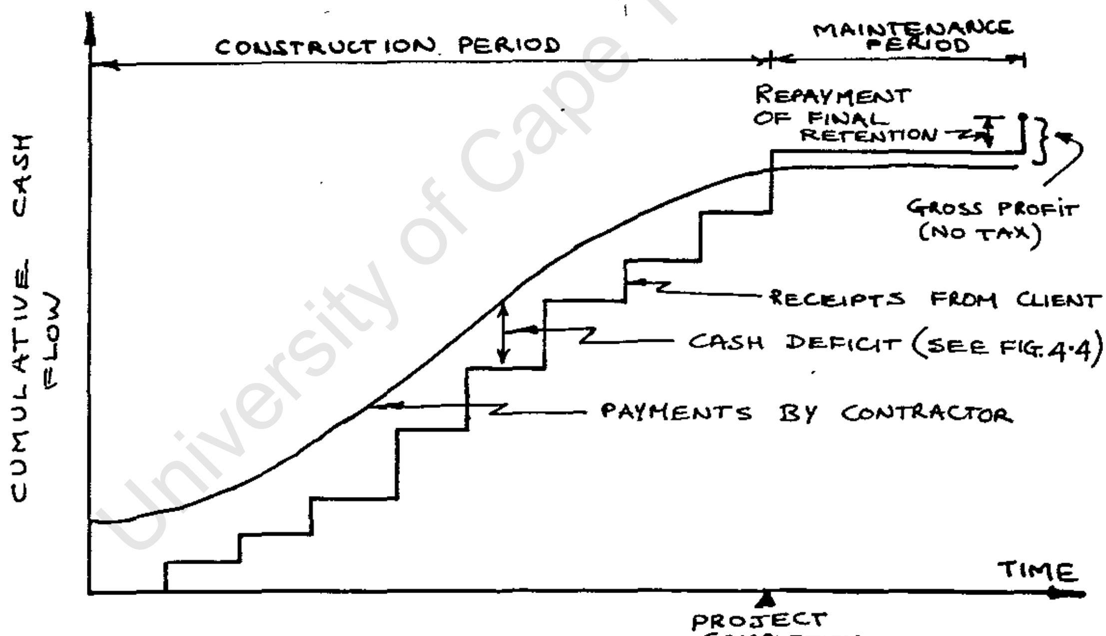

FIGURE 4.3: Cumulative Project Cash Flow

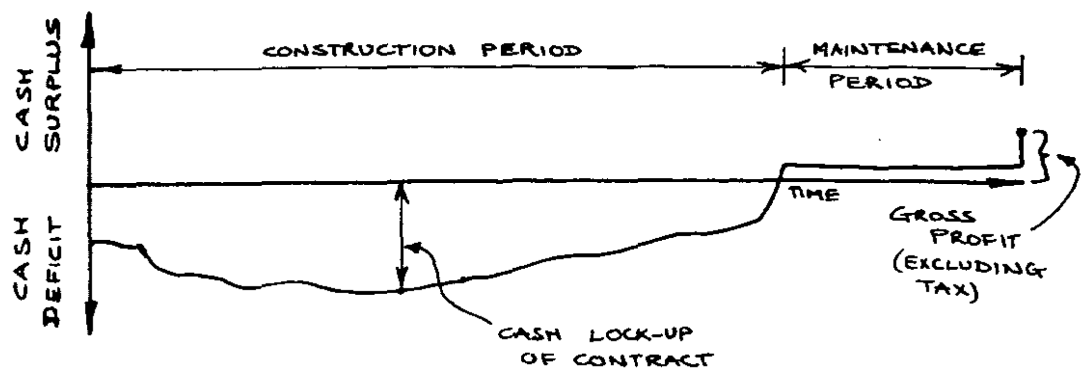

FIGURE 4.4: Project Nett Cash Balance during Construction

one half at the end of the maintenance period. On certain contracts the retention money might be invested by pre-arrangement by the client on behalf of the contractor so that the contractor eventually receives retention money plus interest.

Contractors are also usually required to provide the client with an acceptable security in the form of a performance Bond from an insurance company or bank, the value of which is paid to the client should the contractor go bankrupt. In the SAICE conditions of contract the suggested value of this Bond is ten percent of the total sum tendered by the contractor. On some contracts this takes the form of an actual down-payment which the contractor must make to the client and which is retained till completion of construction.

Cash payments for a contract are made by the contractor when he pays his bills for plant, labour, materials, etc. The timing and value of most of these cash outflows can be assessed from the work programme as described in Section 4.1.2. Certain payments such as for head office overheads, interest on capital borrowed and income tax are often difficult to associate with a particular contract and are generally determined for the firm as a whole, and added to the overall company cash flow forecast. These overheads are only allocated to separate contracts for the purpose of cost control (see Chapter 3) but in cash flow purposes the company is usually considered as a whole.

Since the rate of construction on a contract is influenced by many external factors such as weather, soil conditions and the reliability of subcontractors the cash flows are difficult to predict with accuracy for long periods into the future. For this reason contractors sometimes prepare these as often as once every two months, for say, twelve months in advance.

Figure 4.3 shows typical cash flow curves which might be obtained from a cash flow analysis for a particular contract.

The vertical difference between the curves in Figure 4.3 represents the nett cash balance or amount of free cash required by a contractor as interim finance for a particular construction contract (see Figure 4.4). This negative cash balance is the direct result of the fact that the contractor's cost payments for a certain section of work are usually made before the corresponding reimbursements are received from the client. This interim cash lock-up must be financed by the contractor's financial assets as described in Section 4.2.

4.1.2 Models for forecasting cash flows of construction contracts

As described previously the objective of preparing a cash flow forecast for a particular contract is to determine the timing and value of the contractor's payments and receipts during construction. This forecast is then used in an overall company-wide cash flow analysis which is used by financial management for cash budgeting purposes.

In this section two models are described for analysing only those cash inflows and outflows of a contract whose timing can be easily related to the timing of the construction work on site. In these models the various cash flows are assumed to take place at a known time after (or before) a section of work has been constructed on site. Other cash flows, such as purchase payments of plant and equipment, income tax and head office overheads, are then added (for the company as a whole) when the cash flow forecasts of the various contracts are summed to determine an overall company-wide cash flow forecast.

In Section 4.2.2 A a more rigorous procedure is described for determining the total cash capital of the contractor tied-up on a particular contract during construction. Here all cash flows of the contract are taken into consideration, including plant purchase payments, income tax, etc.

A) Conventional manual contract cash flow forecasts

Figure 4.5 shows a manual procedure which can be used by accountants in construction firms for preparing a cash flow analysis of a construction contract.

Starting with a forecast of the expected contract earnings (measured work only), as determined by the contract manager from the construction work programme (see Section 3.2.3), the accountant prepares a breakdown of cost and revenue as shown in Figure 4.5. The proportions of plant, labour and materials depend on the type of contract and are usually determined from past experience. For

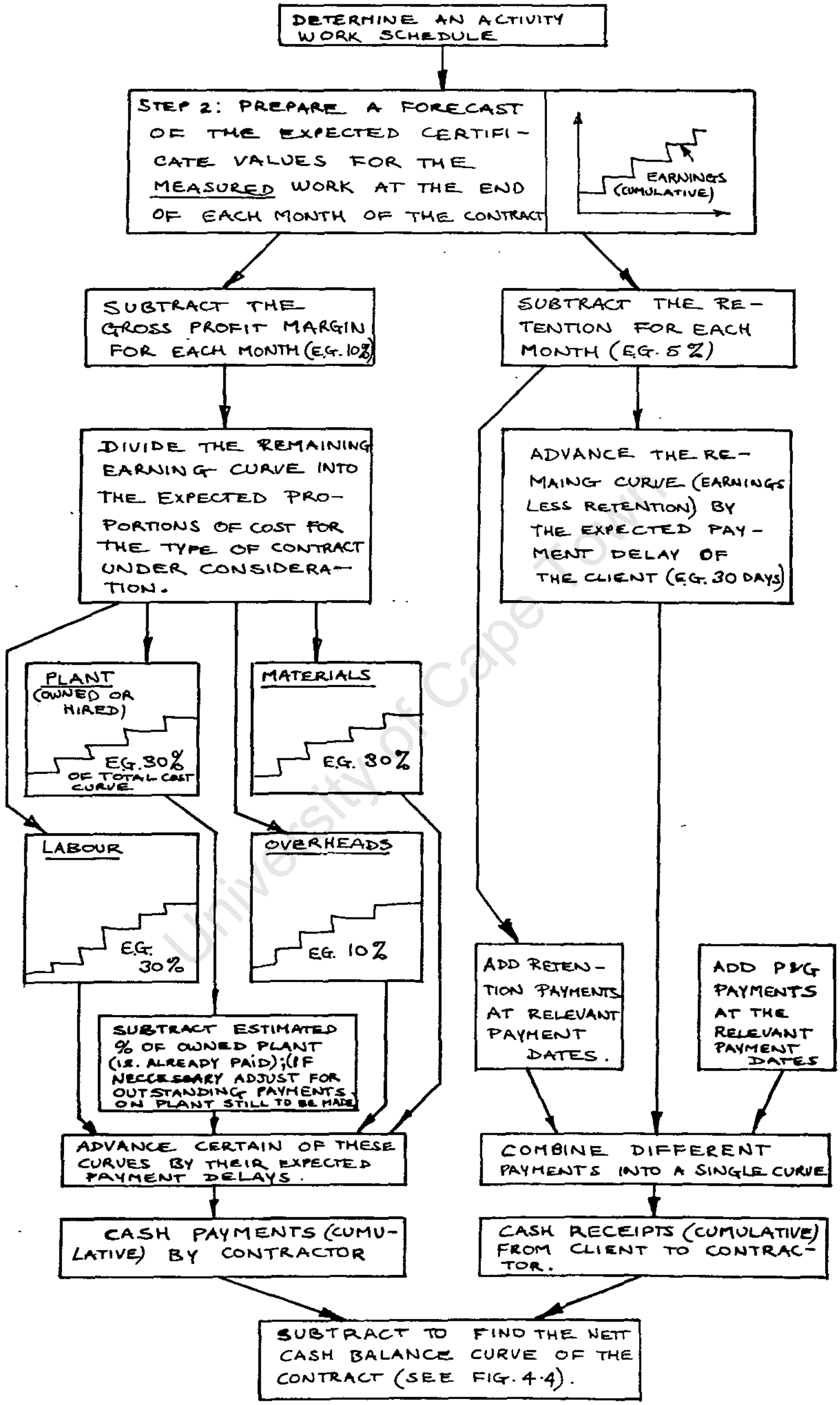

FIGURE 4.5: Conventional Approximate procedure for preparing a Cash Flow Forecast for a Construction Contract

example, typical percentages of plant, labour and materials on a roadworks contract might be 30% plant, 15% labour and 45% material costs. Similarly the expected delay between incurred costs and actual payments are determined from experience.

Further refinements to the procedure shown in Figure 4.5 might be to split material costs into different proportions of delay categories (e.g. 30 day, 60 day and 90 day payments).

Various errors are possible if the procedure in Figure 4.5 is used. Firstly it is assumed that the proportion of the monthly costs devoted to plant, labour and material are constant throughout the construction period. Secondly, since costs are determined from the construction revenue (by subtracting the gross profit margin) some correction would have to be made either to the current profit margin or cash flow when it is known that costs have increased due to inflation. Also, when a tender has been unbalanced the payments from the client will be affected by the amount of unbalancing, but the contractor's expected costs are those estimated before unbalancing and hence the contractor's costs at some stage of the contract can therefore not be determined simply by subtracting the gross profit margin from the expected earnings.

In the case of an unbalanced contract, the final costs might be equal to the expected earnings minus the gross profit margin, but this is less likely to be true at interim periods during the contract.

If the final measured quantities are different from the initial quantities in the Bill, the expected costs and expected earnings for the contract will be altered, irrespective of whether the tender is a balanced or unbalanced tender.

The method described in Figure 4.5 is never the less a useful technique which can be easily performed by hand.

B) Cash flow forecasts from network analysis

The second approach to be described is an extension to the network planning model in Chapter 2. Figure 4.6 shows the basic inputs and outputs of this cash flow forecasting model.

This model is not based on the assumption that labour, plant or materials form specific fixed proportions of the current costs of the contract. Instead the predicted cost proportions of labour, plant and materials are calculated from knowledge based on the activity-time network, and hence these cost proportions will vary throughout the time of the contract.

It will be seen that this model is similar to the activity costing procedure described in Section 3.3.3 where the expected expenditure pattern of a contract was modelled using the network planning model. In the present model the timing of the activity costs (and the expected revenue from these) is also determined from the network planning model. Additional time delay

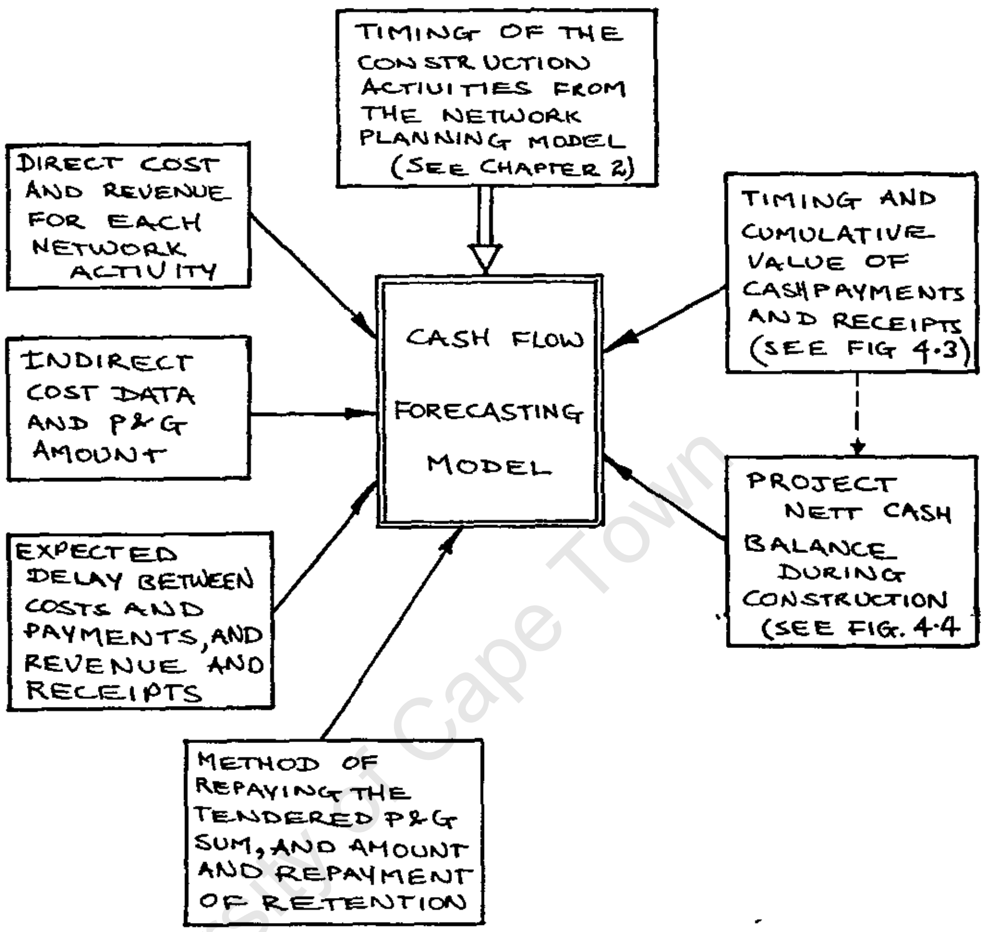

Figure 4.6: Inputs and Outputs of a network based cash flow forecasting model.

values are added to the separate plant costs, labour costs, material costs, and to the revenue expected from each activity. Hence the timing of the actual cash outflows and inflows is determined.

Although the calculations of the model in Figure 4.6 are similar to those for the manual procedure described in the previous section greater accuracy is expected from cash flow forecasts prepared by the technique described in Figure 4.6. This is because the proportions of plant, labour and material costs are determined from the actual work in progress rather than as fixed proportions over the whole construction period.

Although both the manual procedure (Figure 4.5) and the network cash flow forecasting model (Figure 4.6) could be computerised, the second model has the advantage of being integrated with the planning model. When changes are made to the construction method a new cash flow forecast is more easily prepared.

The main disadvantages of the second model are the fact that the costs must be determined for each network activity and also their expected revenue must be extracted from the tender rates which might not be activity related.

The new activity-related or method-related Bills of Quantities provide greater assistance to the contractor for estimating cash flows which are activity related (Figure 4.6).

In Section 4.2.2 A a more rigorous analysis will be described to determine the total cash capital of the contractor tied-up on a particular contract during its construction period. The objective here being to isolate the cash requirements of a particular contract rather than to aid the contractor in preparing a general company-wide cash flow forecast.

4.1.3 Important considerations in making contract cash flow forecasts

Four problems, relating to the preparation of cash flow analysis for construction contracts and often neglected in literature, are discussed briefly:-

(a) Materials on site - At the end of each month there is generally a certain proportion of material in stock on a contract site, which will be consumed in a subsequent period (e.g. cement, pipes, bricks, etc.). This expenditure is offset by the fact that the client usually agrees to pay at least a fixed proportion of their delivery cost (e.g. 75%) on the earliest certificate after the material delivery. Some correction should therefore be made to the contract cash forecast to make allowance for the proportion of materials on site which are not paid for by the client. For example one might add a fixed proportion (e.g. 8%) of the total material cost for a month to the cash payments of that month. The actual percentage depends on the type of contract and could be determine by examining records of past contracts of a similar nature.

(b) Material payments in general - The timing of material payments is sometimes difficult to estimate as contractors often buy in bulk at the start of a contract to obtain discounts, and to decrease the effect of price escalation in contracts where no variations are permitted for price increases. As cash flow forecasts generally assume that material is bought at the same rate as the corresponding work is performed and that there is no stockpiling, some error might result. If necessary, some correction might have to be made to the cash flow forecast to determine the exact timing of material payments. In general, however, it will probably be sufficiently accurate to assume that the corresponding material costs are incurred as the work is performed.

(c) Depreciation of plant and equipment - In Section 3.3 it was mentioned that the purchase cost of plant and equipment is added as a depreciation charge to a particular Bill item to determine the item's total cost. Although certain plant costs such as for repairs, fuel and maintenance are cash flows, depreciation is not. Cash flow occurs when plant is originally purchased and the estimator's concept of depreciation is simply an attempt to allocate a charge rate for the machine to various work items.

Various authors seem to have assumed that the timing of plant cash payments are always at some known time interval after the plant incurred costs. However, when a contractor uses his own plant on a contract this plant has often been paid for already but has not yet "earned its keep". The contractor now allocates a portion of this previous payment to the various contracts by using a depreciation charge rate (e.g. R/hr) which the estimator uses to calculate the plant cost of the Bill items on which this plant is used.

These depreciation charges are not actual cash flows and therefore they should be deducted from the cash costs in order to estimate the actual cash outflow (see Figure 4.5). This has apparently not been done by certain authors.

Referring to Figure 4.1 it is seen that plant purchase payments can be added either to the project cash flows or included in the overall company cash flow analysis. The writer prefers the latter approach since plant and equipment are most often bought for the firm as a whole.

When plant is hired, either externally or from a sister plant hire company depreciation is not considered, as the total hire charges are representative of the actual cash flow which will take place. In this case one can determine the timing of plant cash flows from the time at which work is performed, since payment for plant hire will usually occur at an approximately known duration after the time the work is done.

(d) Taxation - Taxes are generally assessed for a year and are paid for the company as a whole. They are calculated on normal accounting profit and not on cash flow. The present income tax rate (1973) is 40 cents in the Rand on taxable income for a company (Ref. 17).

The calculation to determine the taxable income of a company is generally lengthy and specialist advice is often required. For example, various allowances for plant and equipment are possible (e.g. the contractor may make a 15% deduction of the purchase cost of a machine from his taxable income for each item of plant bought).

When preparing a cash flow forecast for a particular contract one would not normally include income tax, since this is more easily added to the overall company cash flow forecast by assessing the tax for the firm as a whole. When an exact forecast is, however, required, for example to determine the total tied-up capital of a contract (see Section 4.2.2), some allowance would have to be made for income tax. Since income tax is usually paid some time after a contract has been completed one might consider income tax to be 40% of final profit which becomes a cash flow some time after completion of contract (depending on where the taxable period ends).

4.2 The Construction Contract as an Investment to the Contractor

Ballard (Ref. 3) stated that the service which the contractor renders to the client can be divided into:-

(i) The temporary tying-up of capital during construction,

(ii) The provision of the necessary managerial and technical skill to complete a contract,

(iii) The taking of the risks which accompany construction work.

Referring to point (i), the financial assets* of the contractor, some of which are temporarily allocated to the various contracts on which he is engaged, are generally expressed in monetary terms as:-

(a) Fixed Capital** - This describes all fixed investments in plant (e.g. bulldozers, graders, trucks, etc.) and equipment (e.g. staging, special formwork, power tools) as well as buildings (e.g. the contractor's head office, plant work shops, stores, etc.) and land (e.g. on which new offices are to be built in the near future). Table 3.2 B(c) shows where these items are normally found on a company balance sheet. Obviously, head office buildings and land are not physically transferred to a particular contract (as is the case with plant and equipment) but are nevertheless an important part of the contractor's assets which are needed in the operation of his business (see Section 4.2.1 A).

(b) Working Capital - This is the constantly circulating pool of capital which is used by the contractor to finance the interim costs of the various contracts (such as wages, materials, plant hire, plant maintenance, site overheads, administrative costs, etc.) before payments are received

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*The term asset is used in accounting to denote resources purchased at a certain monetary cost. This naturally also includes cash.

**Capital is defined as funds locked-up in investments (e.g. plant, buildings, cash in the bank, etc.)

from the client for work which has been completed (see Section 4.2.1 B).

In Figure 4.7 a simplified diagram is shown which illustrates the application and circulation of capital within a construction company. The diagram should be read in conjunction with the balance sheet and income statement in Table 3.2 B. It is interesting to note that the contractor uses the owners' equity* as well as any profits retained from the previous years' trading (i.e. profit not paid out to the owner or as dividends to the shareholders) and also long term loans (e.g. mortgages on land, bonds, etc.) to finance both fixed capital and working capital. During construction, fixed assets in plant and equipment are used to do work for which revenue is earned from the client. Working capital provides the necessary short-term finance from which materials suppliers, labour wages, subcontractors and other short-term debtors are paid before payment is received from the client. The profits (if any) which are generated by the various contracts and which have not been paid out to the contractor (or to the shareholders) are retained in the business (as retained earnings) for possible future expansion (growth) and serve to increase owners' equity (i.e. the shareholders' or alternatively the proprietor's claim in the business).

4.2.1 <u>The concepts of Fixed and Working Capital in a firm</u>

In this section the concept of Fixed capital and Working

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*In a private firm this is the contractor's own capital originally invested in the business. For a public firm owners' equity refers to the finance provided by the shareholders.

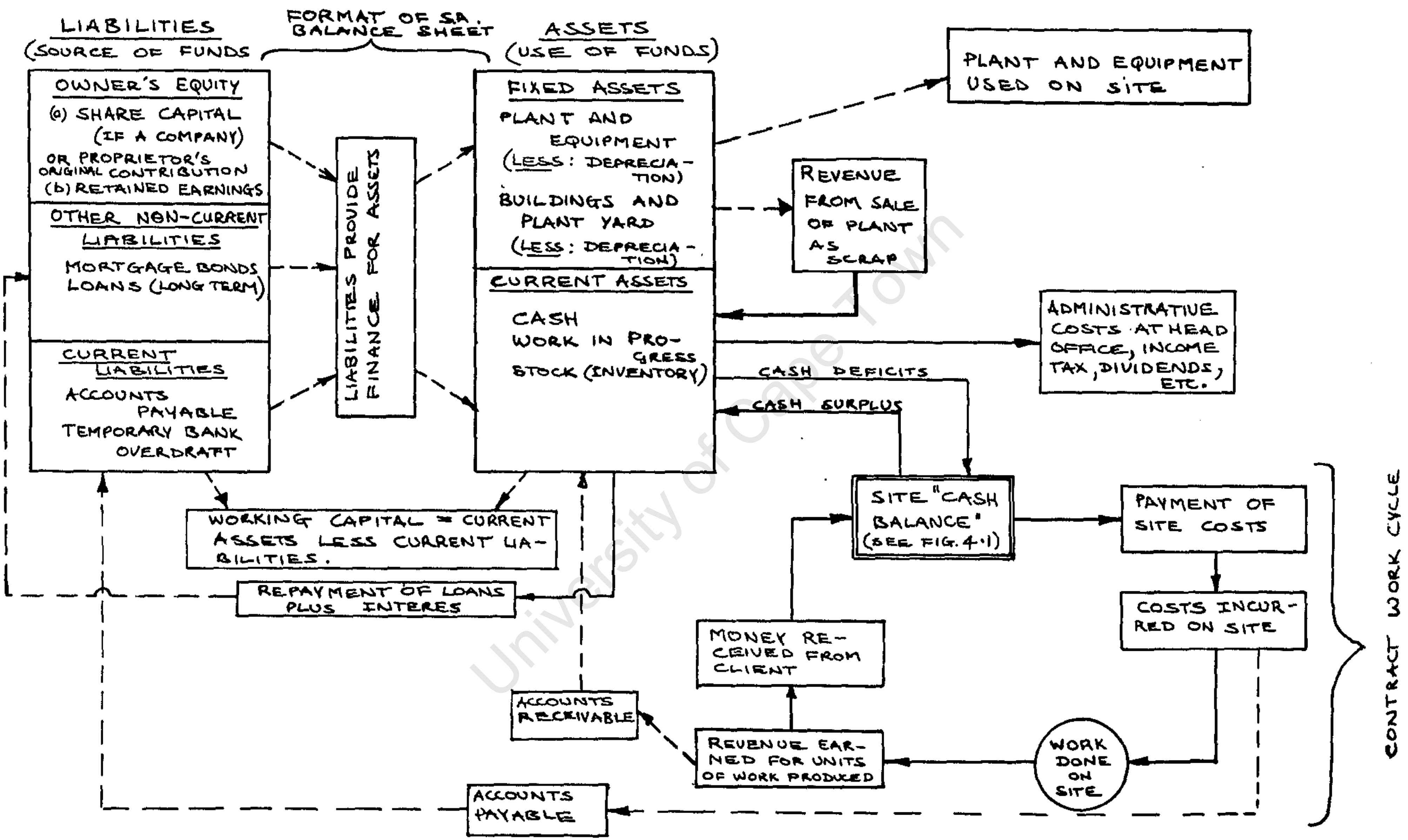

FIGURE 4.7: Circulation of Capital within a Construction Company (with reference to Balance Sheet in Table 3.2 B(c))

capital with respect to an overall construction firm will be discussed briefly. In Section 4.2.2 consideration is given to the evaluation of the Fixed and Working capital required for a particular contract.

A) Fixed capital in a firm

An important difference between the contractor's capital in fixed assets (i.e. plant, equipment, buildings, etc.) and that in working capital is that fixed capital is often subject to a decline in value (i.e. depreciation). This is generally true in the case of the contractor's plant and equipment, but fixed assets such as buildings and land usually increase their market value with time. When considering the aspect of depreciation a distinction must be made between the following two types:-

(i) Accountants' depreciation - At the end of each accounting period the accountant automatically reduces the value of a fixed asset on the balance sheet (see Table 3.2 B) in order to gradually convert its original expenditure to expenses. It will be seen in Table 3.2 B that this expense is then charged to the "total incurred costs" section of the Income Statement for the corresponding accounting period in order to determine the profit of this particular period.

(ii) Wear and tear depreciation - This is the contractor's concept of depreciation and refers to the natural reduction in value of an item of plant or equipment due to normal wear and tear on site and the fact that more modern machines are being developed which reduces the market price of the older models. As mentioned previously, certain fixed assets actually increase their value (e.g. buildings, land and even certain items of plant).

In order to recover the loss in value of plant and equipment the contractor adds depreciation charges to the rates of the items in the Bill of Quantities when preparing a tender (e.g. a common procedure for plant is to use an equivalent hourly charge rate which is calculated from the total expected cost of operating and owning a machine during its lifetime and the total number of working hours expected from it).

Referring to Figure 4.7, it is interesting to note that the owners' equity and long term liabilities are used to finance fixed capital (in plant and equipment). These costs are then recovered from the various clients through the depreciation charges allocated to tender rates of the items in the Bills of Quantities of the contracts on which the contractor is engaged.

B) <u>Working capital in firm</u>

In an accounting sense working capital in a firm is defined as the difference between current assets (e.g. work completed on various contracts but not yet paid for or certified by the clients, inventory, cash, etc.) and current liabilities (e.g. bills payable to materials suppliers, for wages, for plant hire and also bank overdrafts). Both current assets and current liabilities appear on the company balance sheet (see Table 3.2 B(c)).

The significance of subtracting current liabilities from current assets to determine working capital is as follows:-

> Current assets describe the amount of capital of the contractor in short-term investments such as material in stock, work completed on a contract but not yet paid for by the client (work in progress) and also cash in the bank. A contractor is, however, required to physically finance only part of these current assets because of the fact that he can defer certain of their payments through the temporary time credit extended by materials suppliers (e.g. sixty days), subcontractors (e.g. two months), plant hire firms (e.g. two months), etc. By subtracting from current assets the current liabilities (the money due to the short-term creditors described above) the true value of the current assets which are actually financed by the owners' equity (i.e. the money invested in a firm by its owner or shareholders plus any long-term loans)is found. This difference is then referred to as working capital.

4.2.2 Fixed and Working Capital required for a contract

On a contract fixed capital refers to the money of a contractor which has been invested in plant (e.g. bulldozers, graders, compressors, etc.) and equipment (e.g. scaffolding, purpose-made formwork, etc.) allocated to this contract. The manner in which the amount of capital thus tied-up during construction can be evaluated will be discussed in the next section. When plant is hired (e.g. from an outside plant hire company) these hire charges will be included under working capital described below.

Working capital on a contract is the contractor's money which is tied-up during construction as a direct result of the fact that he is required to pay his interim costs (for materials, plant hire, professional salaries, establishment of site, etc.) before being reimbursed by the client.

A large portion of working capital is also locked-up in Retention money which is money due to the contractor but retained by the client against possible default by the contractor. On certain* contracts the client is allowed to retain as much as ten percent of the value of each certificate during construction. Fifty percent of the retained amount is then repaid at the end of construction and the remainder at the end of the maintenance period.

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*The amount of retention money depends largely on the "Conditions of Contract" in use on a contract. The quoted example is common of contracts with the Cape Town City Council.

A) <u>Evaluation of the contractor's tied-up capital on a contract during construction</u>

Referring to Table 3.2 B(c), it will be seen that fixed and working capital (current assets less current liabilities) can be identified as two separate items on the company balance sheet. For a particular <u>contract</u>, however, the two items do not need to be separated since both are financed by the same source (i.e. owners' equity, retained earnings and long-term loans (if any); see Figure 4.7). The contractor is mainly interested in determining the total amount of this temporary investment. Fixed and working capital required by a contract can thus be evaluated together.

It might be inconvenient for a contractor to allocate certain tax costs or head office overheads to specific projects. However, the theoretical temporary investment carried at any specific time by a contractor on one particular contract as suggested by Professor A.D.W. Sparks (verbal communication) is shown in Figure 4.8.

Referring to Section 4.1.2, it will be seen that the above approach is similar to the preparation of a cash flow forecast. In both techniques (i.e. a cash flow analysis and the equation in Figure 4.8) the cash deficit (or amount of capital tied-up) during construction is evaluated, with regard to both the amount and the time at which this amount is locked-up.

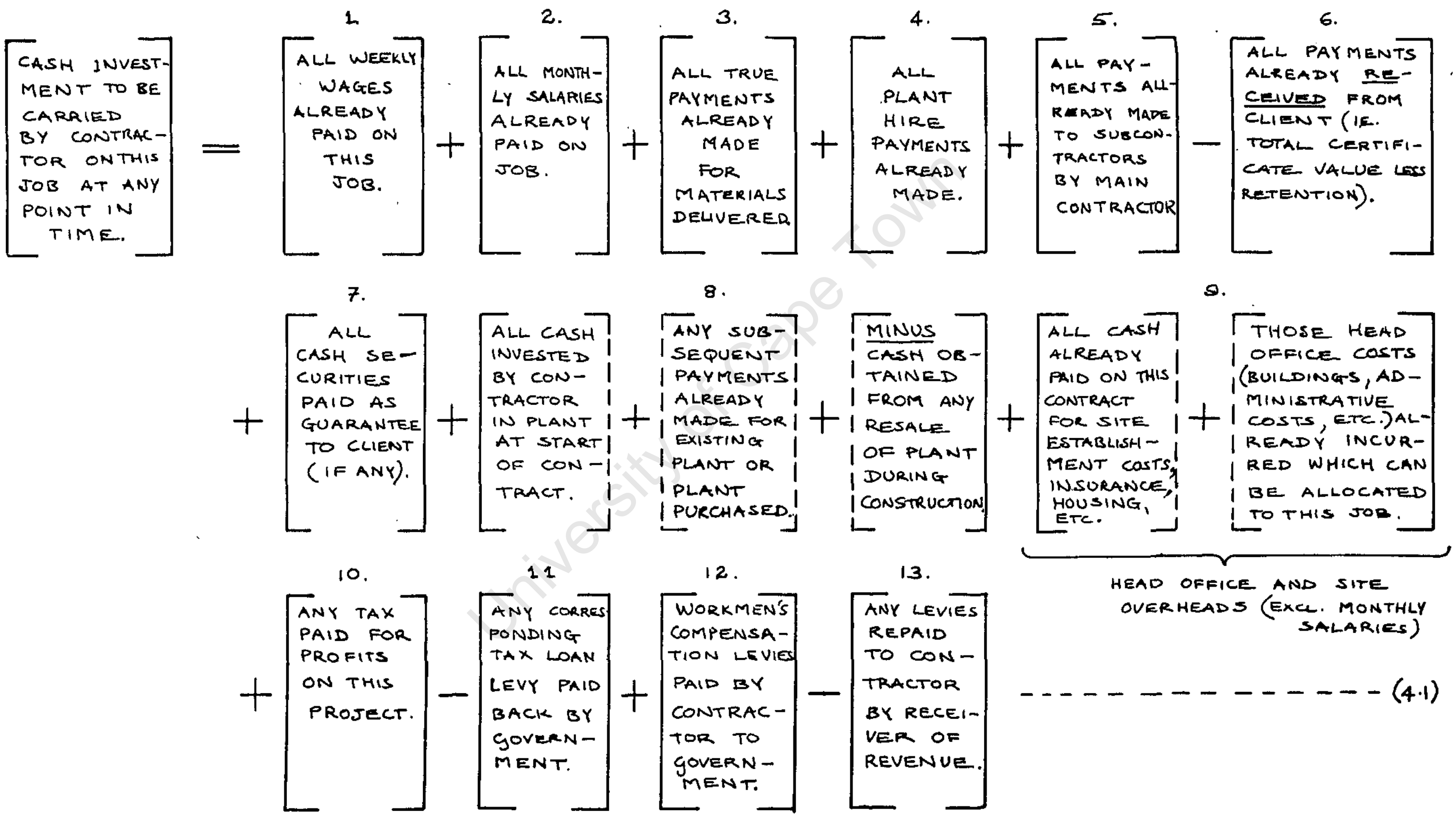

FIGURE 4.8: Equation to determine the total capital of a contractor tied-up on a contract at a certain point in time

However, many of the items considered in Figure 4.8 would not normally be taken into consideration when preparing a contract cash flow forecast. Project cash flow analysis are usually prepared with the objective of finding an overall company cash flow forecast and hence many cash flows such as plant purchase payments and income tax payments would normally be considered for the firm as a whole. In addition, head office overhead costs (e.g. for buildings, office administration, drawing office, etc.) are allocated costs which are not always actual cash flows occurring as a result of a particular contract, such as payment for weekly labour wages. Instead these are often general charges based on a percentage (e.g. 5%) on total contract costs. However, in order to make a complete evaluation of the contractor's capital tied-up due to his involvement on a particular contract it is considered necessary to include also these allocated costs which are difficult to identify with a particular contract.

In the remainder of this section two examples are shown to illustrate the calculation of the expected tied-up capital on a construction contract.

B) Example I: Contractor's capital tied-up on a simple contract

Table 4.1 shows the expected cash flows of a simple imaginary contract in which there are no establishment costs (e.g. site set-up costs), no retention money, no

TABLE 4.1: Analysis of the contractor's capital tied-up on a simple imaginary contract where there is no retention money, no establishment costs, no income tax and all the plant is hired. (See section 4.2.2 B)

CASH FLOWS*	MONTH 1				MONTH 2				MONTH 3				MONTH 4				MONTH 5				MONTH 6				MONTH 7			
LABOUR PAYMENTS	2	2	2	2	3	3	4	4	5	5	5	5	5	5	5	4	4	4	4	3	3	3	2	2				
MATERIALS PAYMENTS						6		6		10		10		10		10		10		10		5		5		5		5
STAFF SALARIES				4				6				6				6				4				4				
PLANT HIRE PAYMENTS								8				10				10				10				10				10
SUBCONTRACTOR PAYMENTS								2				2				2				2				2				2
TOTAL CONTRACTOR PAYM.	2	2	2	6	3	9	4	26	5	15	5	33	5	15	5	32	4	14	4	29	3	8	2	23		5		17
CLIENT RECEIPTS – NO PROFIT								34	** SEE FOOTNOTE			52				58				57				41				36
CASH DEFICIT NO PROFIT	-2	-4	-6	-12	-15	-24	-28	-54 -20	-25	-40	-45	-78 -26	-31	-46	-51	-73 -15	-19	-33	-37	-66 -9	-12	-20	-22	-55 -14	-14	-19	-19	-36 0
CLIENT RECEIPTS – WITH PROFIT								37				57				64				63				45				40
CASH DEFICIT WITH PROFIT	-2	-4	-6	-12	-15	-24	-28	-54 -17	-22	-37	-42	-74 -17	-22	-37	-42	-64 0	-4	-18	-22	-61 +2	-1	-9	-11	-34 +11	+12	+7	+7	-10 +28
CLIENT RECEIPTS UNBALANCED TENDER								41				61				70				57				41				36
CASH DEFICIT UNBALANCED TENDER	-2	-4	-6	-12	-15	-24	-28	-54 -13	-18	-33	-38	-71 -10	-15	-30	-35	-67 +3	-1	-15	-19	-48 +9	+6	-2	-4	-27 +14	+14	+9	+9	-8 +28

* IN THIS EXAMPLE CASH FLOWS ARE ASSUMED TO TAKE PLACE AT THE END OF THE WEEK IN WHICH THEY ARE SHOWN.

** TEMPORARY CASH PEAKS WHICH OCCUR IF CLIENT PAYS ONE WEEK LATER THAN EXPECTED.

income tax, and all the plant is hired. The cumulative cash payments of the contractor for plant hire, materials, monthly staff salaries, weekly labour wages and subcontractors have been plotted to a time scale in Figure 4.9. In Figure 4.10 the total cumulative cash payments are given together with three cumulative cash inflow curves each corresponding to a different way in which the contractor receives payment from the client; namely, for a contract with no profit, for a contract with profit, and a contract with profit and whose payment pattern has been unbalanced*. The cash balance (i.e. the cash lock-up or cash surplus) was determined as the difference between the cumulative contractor's payments and his receipts (from the client). This cash lock-up was considered to be the capital tied-up during construction (see Figure 4.11).

It will be seen from the stepped curves in Figure 4.11 that the tied-up capital for the no-profit contract is higher than for the contract with profit. For the unbalanced contract, where the profit of the second half of the contract was added to the receipts of the first half, the value of the tied-up capital is considerably reduced when compared with that of the previous two cases.

*Unbalancing is a technique used by contractors to increase the money received from the client near the beginning of a contract. When preparing a tender the rates of the Bill items which will occur near the start of a contract are increased and the rates for the work which will occur towards the end of the contract are reduced by an equivalent amount.

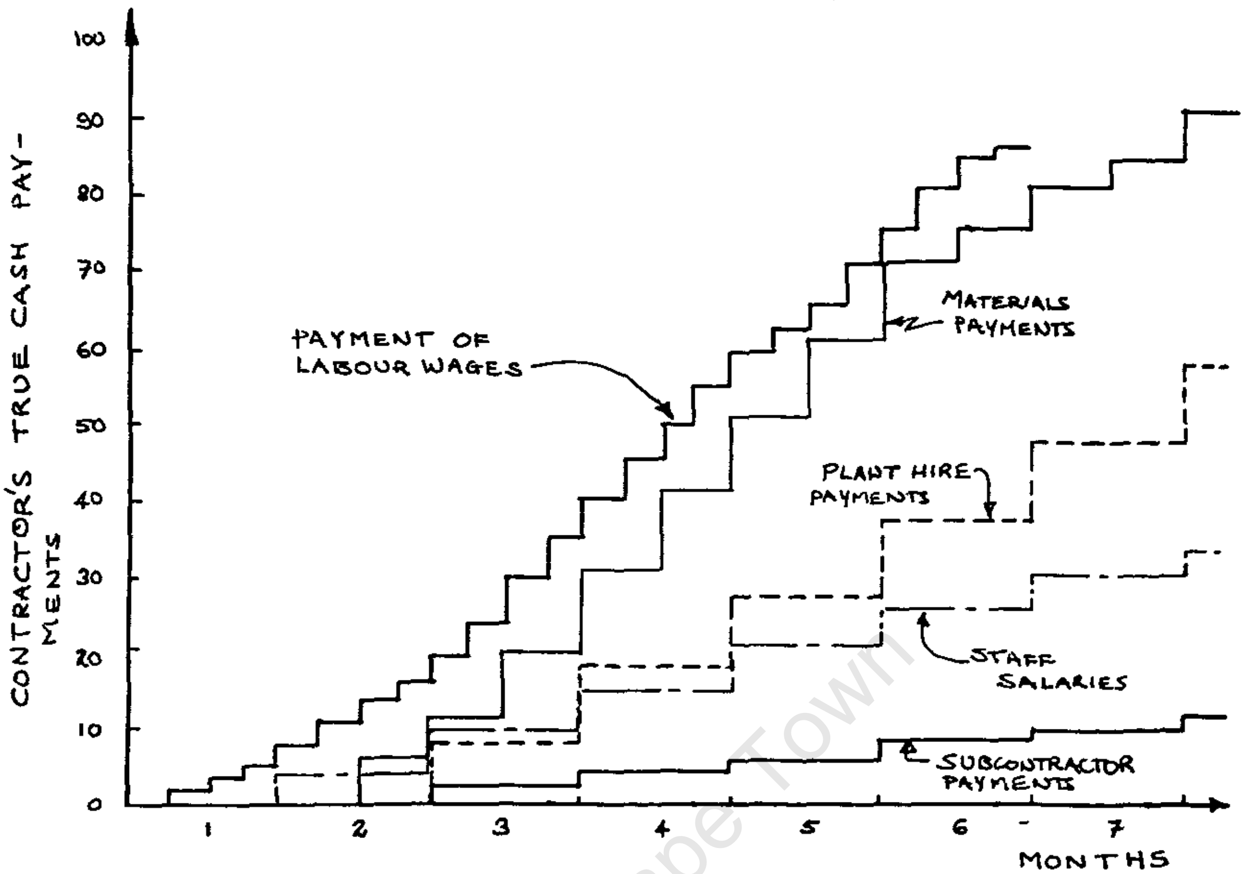

FIGURE 4.9: Payments by the Contractor (Example I)

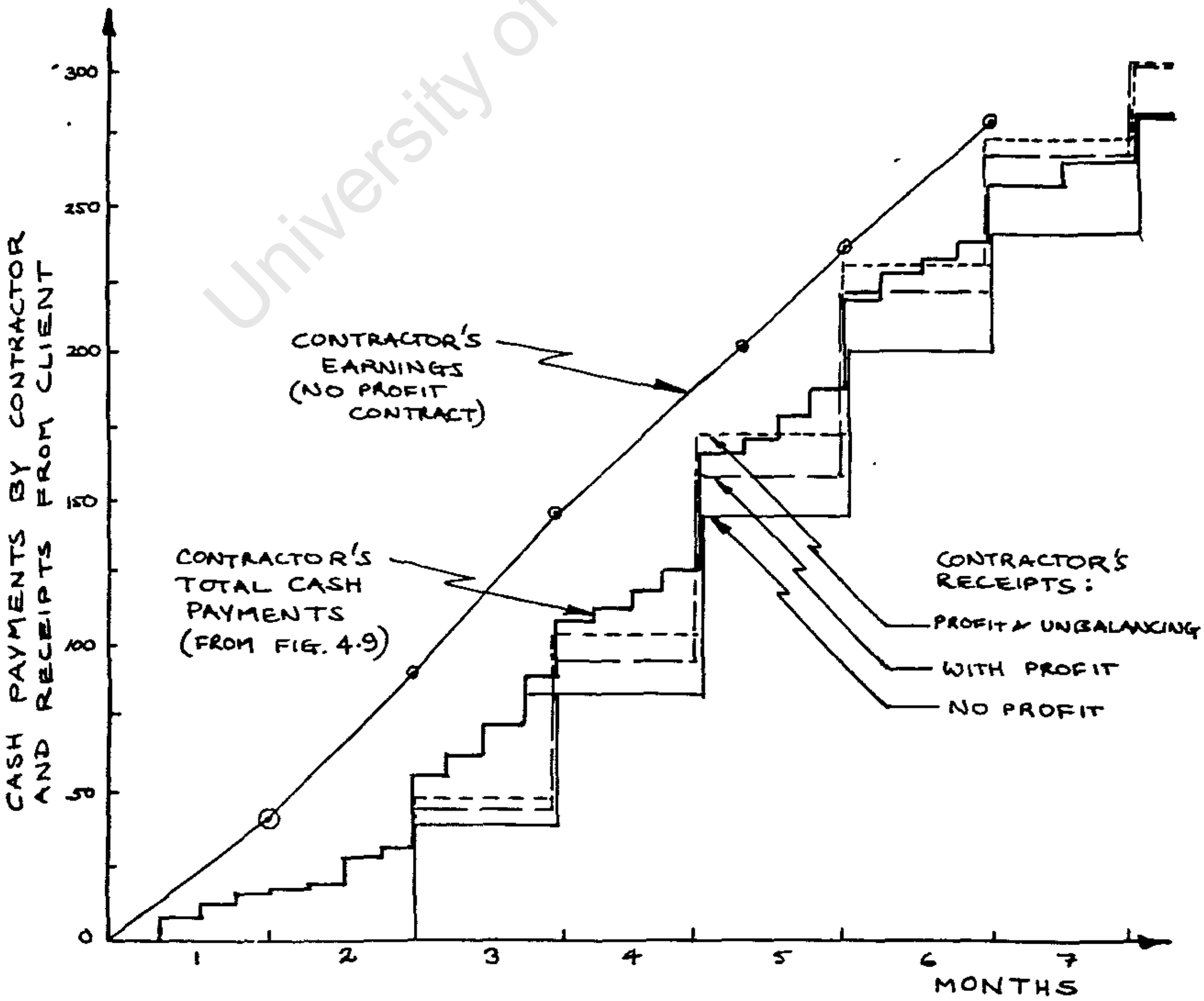

FIGURE 4.10: Receipts from Client to Contractor (Example I)

It is interesting to note that the changes in the tied-up capital (for the contracts with profit and the contracts with both profit and unbalancing) are zero during the first two months of the contract, and then the reductions in tied-up capital increase in magnitude towards the end as more payments are received from the client.

Figure 4.11 also shows the predicted value of the contractor's tied-up capital using an approximate technique which plots the value of z weeks of money received or paid-out; where z is defined to be the time delay between the centre of gravity of all the contractor's payments for the costs incurred on work done during a certain period of time (e.g. during a month) and the time when the corresponding payment is received from the client for this work. The value of z may be determined from the following equation:-

$$z = d_r - \frac{\sum_{i=1}^{n} C_i d_i}{\sum_{i=1}^{n} C_i} \qquad \text{.................. (4.2)}$$

Where d_r is the expected average delay between the start of the month during which the work will be done and the time when payment is received from the client for this work (e.g. 2 months in Table 4.1),

C_i is the total cost of a certain cost category i (e.g. plant hire, labour wages, etc.),

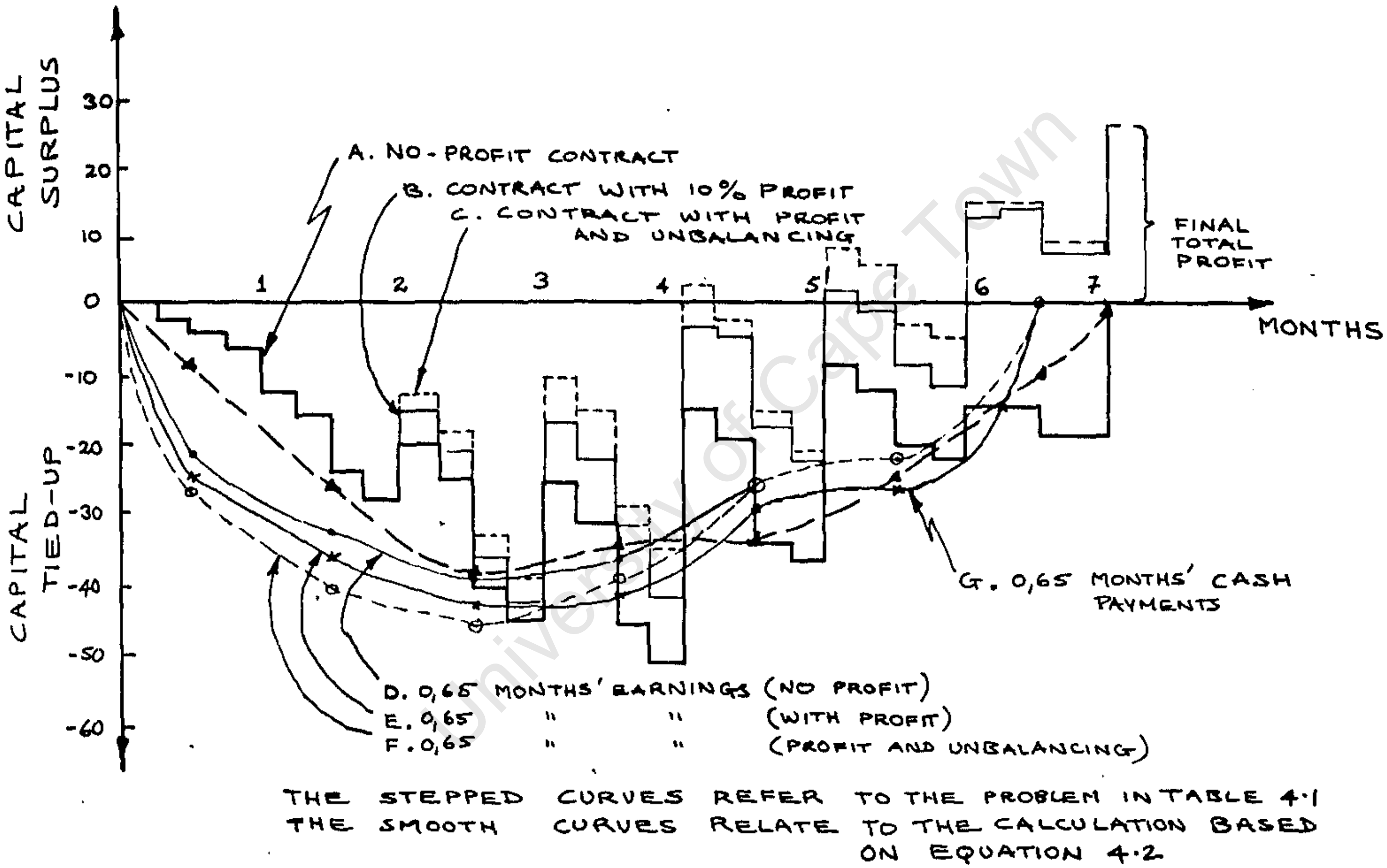

FIGURE 4.11: <u>Contractor's Capital tied-up during Construction</u> (Example I; No retention, no establishment costs and all plant hired)

d_i is the expected average time delay between the start of the month during which the cost of cost category i will be incurred and the time when the corresponding payment is made by the contractor (see example below),

and n is the number of cost categories considered.

The second term of equation 4.6 is then the average time delay between the start of the month during which the costs were incurred and the payment of these costs by the contractor.

For example described in this section (see Table 4.1) the value of z was calculated as:-

$$z = 2 - \frac{\frac{1}{2}x86+30x1+92x1,75+2x58+2x12}{278}$$

$$= 0,65 \text{ months}$$

In this calculation the total costs for each category were considered to occur at time delays measured from the start of a typical reference month (for example, the centre of gravity of material payments is approximately 1,75 months after the beginning of the reference month; hence the total material costs of 92 units is multiplied by 1,75). Client payments were assumed to be received 2 months after the start of a particular month in which work is done.

In Figure 4.11 curves are shown which represent z weeks of earnings (i.e. money due from the client) for the no-profit, with profit and unbalanced contracts. In addition z weeks of contractor's cash payments were also plotted.

The method described above is similar to a technique used by Ballard (Ref. 4) although it is not clear from the text whether the author plotted z weeks of earnings or cash payments.

Referring to Figure 4.11 it is seen that for the no-profit contract both the curve of 0,65 months of earnings and 0,65 months of cash payments have failed to take into account two large peaks near the end of months four and five.

This is mainly due to the fact that the technique of plotting z weeks of earnings or payments is an averaging technique which is not intended to take into account local peaks.

For the contract with profit (curve B in Figure 4.11) the curve of 0,65 earnings (curve E) over-estimates the capital tied-up predicted by the cash flow method in Figure 4.8. This is mainly due to the fact that the earnings now include profits which cumulatively reduce the tied-up capital. For the contract with profit a better approximation therefore seems to be obtained when 0,65 months of no-profit earnings or actual cash payment curve (see Figure 4.10) are plotted.

For the contract with unbalanced earnings neither curve F nor G are very accurate in estimating the capital tied-up and some correction for profit and unbalancing effects might have to be applied to the cash payment curve approximate technique described above is to be used.

When the client's payments to the contractor are slightly delayed at the end of a month (e.g. by one week) excessive temporary peaks in the tied-up capital can result (see Figure 4.11) which the contractor is required to finance with his working capital (or as a temporary bank overdraft).

From the simple contract examined in this section it might be concluded that for a contract with profit but no unbalancing a reasonable estimate of the tied-up capital during construction can be obtained by plotting z weeks (equation 4.2) of contractor's actual cash receipts (client payments to the contractor), as shown by curve G in Figure 4.11. When the earnings curve is used instead a poorer fit is obtained but which is still close to the tied-up capital curve determined from equation 4.1 (curve E in Figure 4.11). It also appears from Figure 4.11 that this estimate can be further improved if one subtracts the gross profit margin from the earnings curve (i.e. this is equivalent to the no-profit curve D in Figure 4.11).

The advantage of using the approximate technique described above is that the earnings curve can be found relatively quickly for a contract from the work programme and the expected revenue of the various construction operations. Similar contracts often have similar earnings patterns. Hence approximate standard earnings curves can be established as shown in Figure 4.18.

C) Example II: Contractor's capital tied-up on a more complicated contract

In Table 4.2 the contractor's tied-up capital, on a contract with retention money, establishment costs (i.e. head office and site costs), income tax and owned plant, was determined using the technique shown in Figure 4.8. The calculated values of capital tied-up at various stages during construction are shown plotted to a time scale in Figure 4.12. The figure also shows local peaks in tied-up capital which can occur if the client pays a few days later than expected (e.g. a week later). These additional short term demands in cash will not cause the contractor undue concern if he has a large cash reserve or overdraft facilities in a banking account. If the contractor, however, is operating his business near the limit of his available capital it is expected that any excessive short-term peaks in cash demand will be of particular interest to him.

Figure 4.13 shows the contractor's cumulative cost payments for plant hire, materials, labour wages and subcontractors and also the cumulative total payments from client to contractor (plus retention money). The difference between the vertical ordinates of these two curves (see Figure 4.14 (a)) is then the excess (or deficit) of the client receipts over the direct cost payments of the contractor (i.e. excluding plant

TABLE 4·2: ANALYSIS OF CONTRACTOR'S CAPITAL TIED-UP DURING CONSTRUCTION FOR A CONTRACT WITH RETENTION, ESTABLISHMENT COST, INCOME TAX AND OWNED PLANT (SEE FIG. 4·12).

CASH FLOW ITEMS	MONTH 1				MONTH 2				MONTH 3				MONTH 4				MONTH 5				MONTH 6				MONTH 7				MONTH 8				MONTH 9				MONTH 10				Σ
PAYMENT OF LABOUR WAGES	2	2	2	2	3	3	4	4	5	5	5	5	5	5	5	4	4	4	4	3	3	3	2	2																	86
" " MATERIALS SUPPLIERS						6		6		10		10		10		10		10		10		5		5		5		5													92
PLANT HIRE PAYMENTS								1				1				2				2				1				1													8
SUBCONTRACTOR PAYMENTS								2				3				3				4				3				2													17
SUB TOTAL	2	2	2	2	3	9	4	13	5	15	5	19	5	15	5	19	4	14	4	19	3	8	2	11		5		8													203
PLANT INVESTMENTS																																									
(a) INITIAL PURCHASES	10			5				5				5				5																									30
(b) SUBSEQUENT PURCHASES												20																													20
(c) LESS: CASH FROM RESALE																								-5																	(5)
TOTAL FIXED INVESTMENTS	10			5				5				25				5								-5																	45
ESTABLISHMENT COSTS																																									
(a) SITE OVERHEADS	10			5				4				4				4				4				12																	43
(b) ALLOCATED HEAD OFFICE O/HEADS				3				3				3				3				3				3				3													21
TOTAL INDIRECT COSTS	10			8				7				7				7				7				15				3													64
INCOME TAX																																									
TAXES PAID ON PROFIT																																								12	12
LOAN LEVIES, W.C.A., ETC.																																								2	2
REFUNDS FROM RECEIVER OF REV.																																									
TOTAL INCOME TAX																																									14
A. TOTAL PAYMENTS BY CONTRACTOR	22	2	2	15	3	9	4	25	5	15	5	51	5	15	5	31	4	14	4	26	3	8	2	21	0	5	0	11												14	326
RECEIPTS FROM CLIENT																																									
(a) MEASURED WORK								32				51				57				57				41				35													273
(b) PRELIMINARY AND GENERAL								17								18								18				17													70
(c) LESS: RETENTION								-4				-5				-7												+8												+8	–
B. TOTAL RECEIPTS FROM CLIENT								45				46				68				57				+59				60												8	343
NETT CASH FLOW (B-A)	-22	-2	-2	-15	-3	-9	-4	+20	-5	-15	-5	-5	-5	-15	-5	+37	-4	-14	-4	+31	-3	-8	-2	+38	0	-5	0	+49												-6	+17
PROJECT TIED-UP CAPITAL (Σ(B-A))	-22	-24	-26	-41	-44	-53	-57	-37	-42	-57	-62	-67	-72	-87	-92	-55	-59	-73	-77	-46	-49	-57	-59	-21	-21	-26	0	+23												+17	FINAL NET PROFIT
TEMPORARY TIED-UP CASH PEAKS IF CLIENT PAYS 1 WEEK LATE !								-82				-113				-123				-103								-6													

CASH INFLOW TO THE CONTRACTOR

REPAYMENT OF RETENTION MONEY

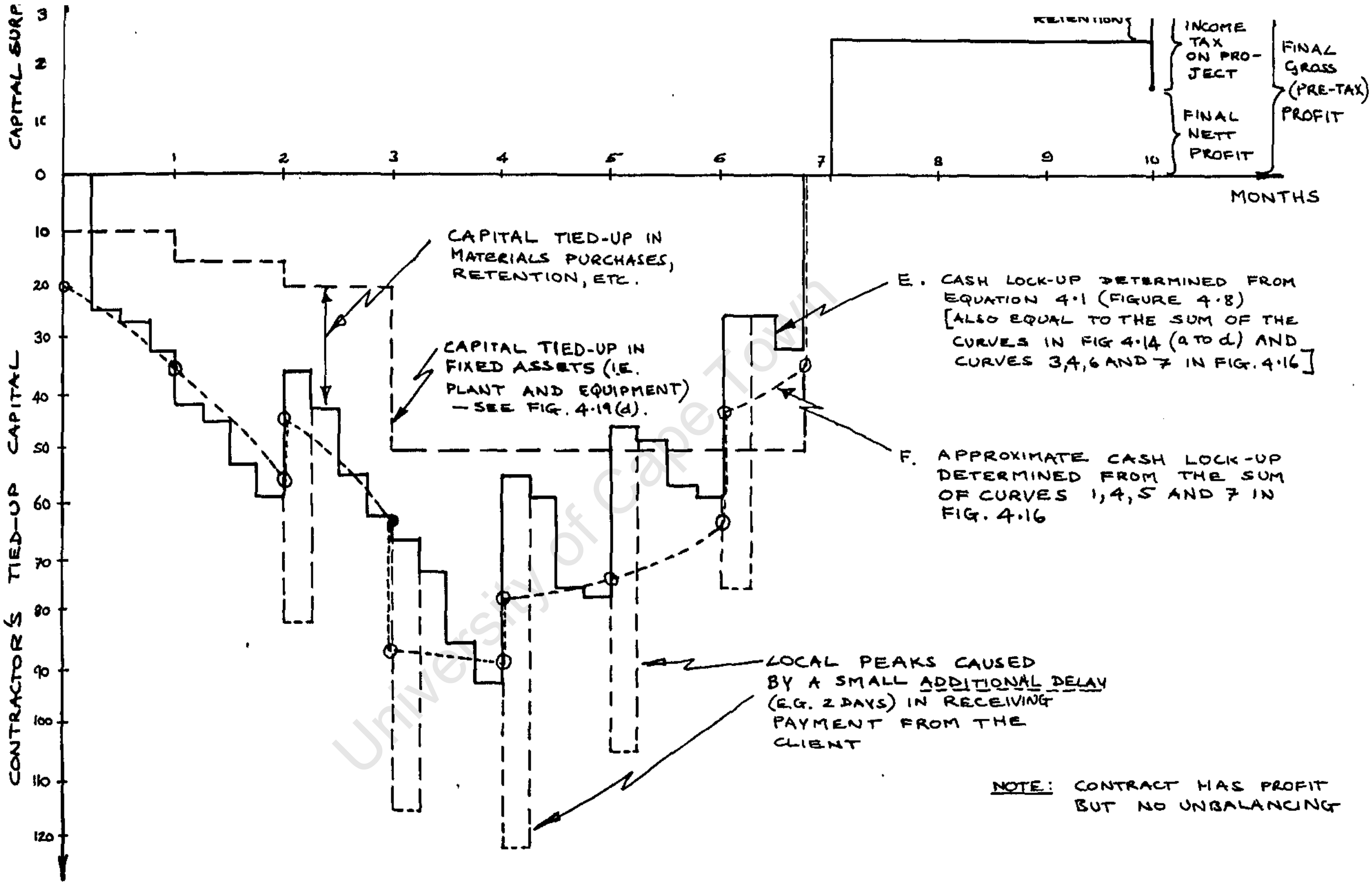

FIGURE 4.12: Contractor's Capital tied-up during Construction (Example II - contract with retention, establishment cost, income tax and owned plant)

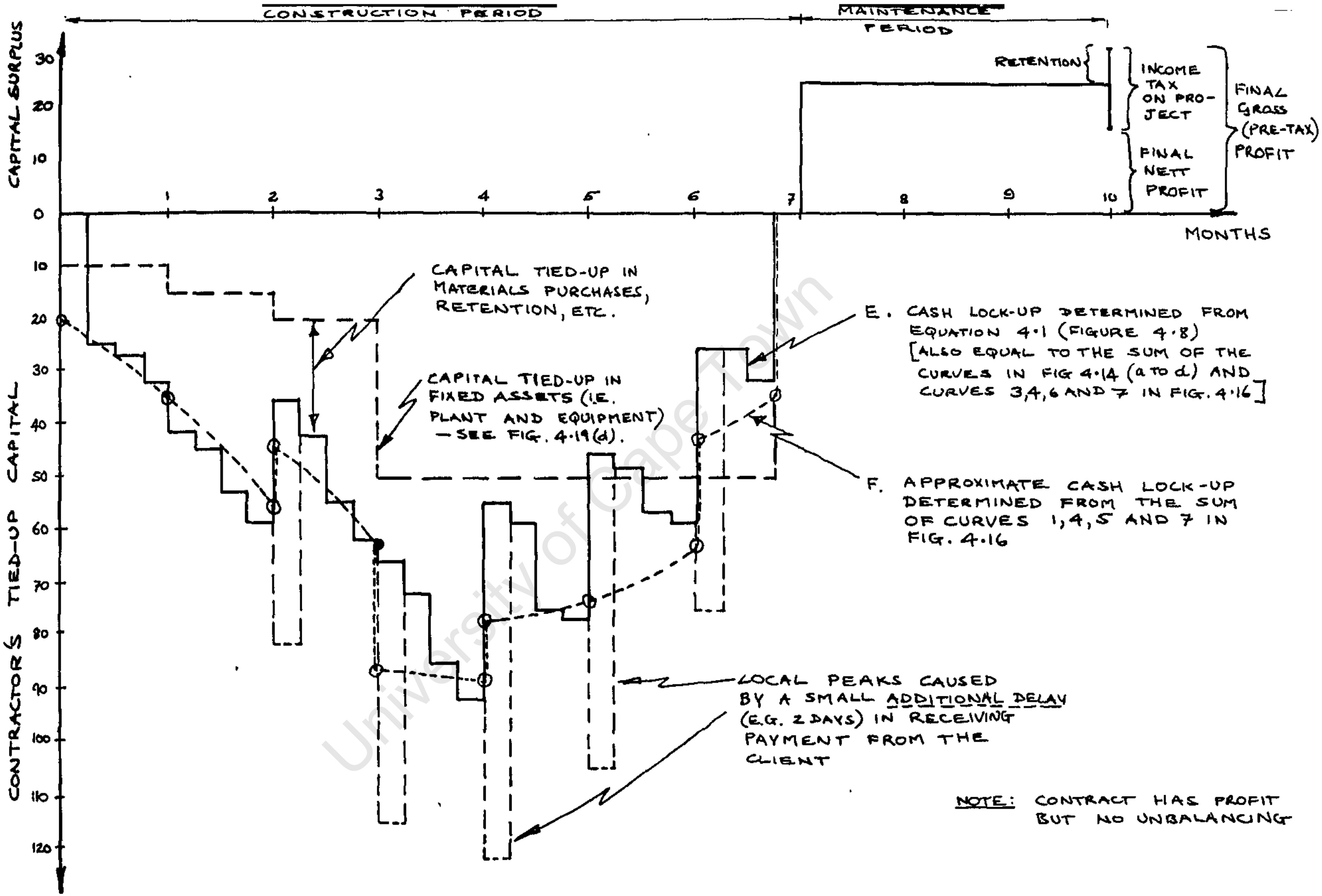

FIGURE 4.12: **Contractor's Capital tied-up during Construction** (Example II - contract with retention, establishment cost, income tax and owned plant)

purchase payments). When this curve (shown in Figure 4.14 (a)) is added to curves showing retention money retained by client (Figure 4.14 (b)), capital invested in plant (Figure 4.14 (c)) and total payments made for overheads such as establishment of site, monthly staff salaries and insurance (see Figure 4.14 (d)), the same curve of total capital tied-up during construction will be found as described previously by using the method in Figure 4.8 (see curve E in Figure 4.12).

By plotting on Figure 4.12 the tied-up fixed capital of the contract (as shown in Figure 4.14 (c)) the amount and timing of the short-term financing which the contractor's working capital must provide during construction is found. Any point on the total tied-up capital curve above (Figure 4.12) represents the amount of money tied-up in retention, work completed but not yet paid for, materials paid for, etc.; over and above the money tied-up in plant and equipment (fixed assets).

In Figure 4.15 the cumulative client payments for measured work are plotted (i.e. plus retention but excluding Preliminary and General receipts) and also the cumulative payments of the contractor for plant hire, subcontractors, materials and weekly labour wages. The difference between these two curves is then the excess (or deficit) of receipts from client for measured work over the payments by the contractor for

CONSIDER ALL COSTS RELATING TO ONE PROJECT (FIG. 4.13, 4.14)

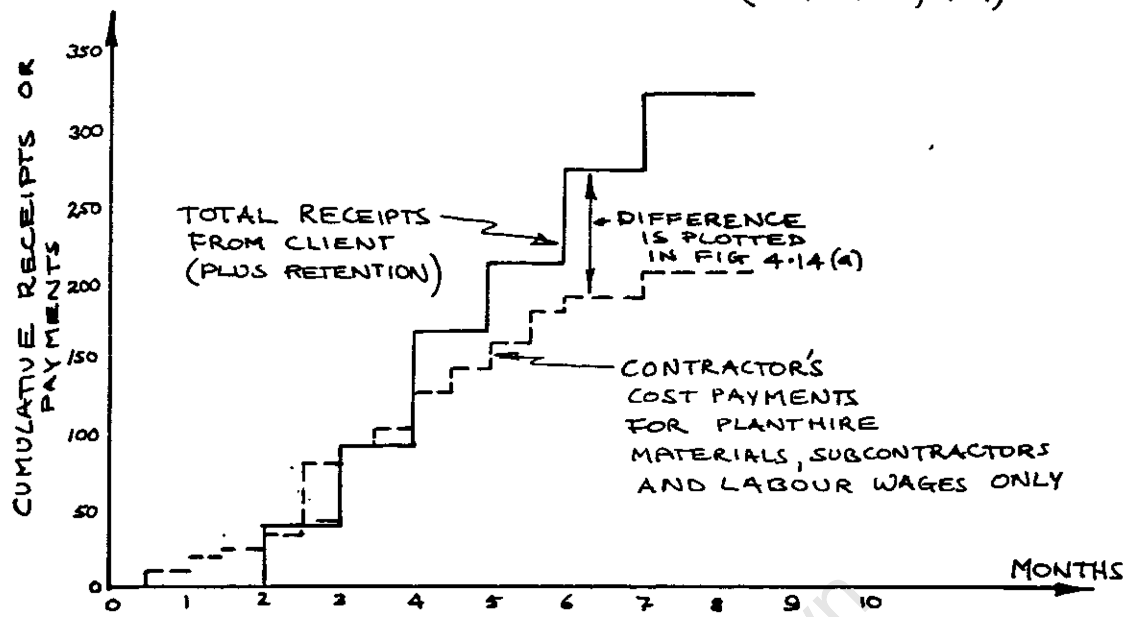

FIGURE 4.13: Client receipts (plus retention) and Contractor's direct cost payments (excluding plant purchases)

SUMMATION OF THESE 4 CURVES PROVIDES CURVE ON FIGURE 4·12

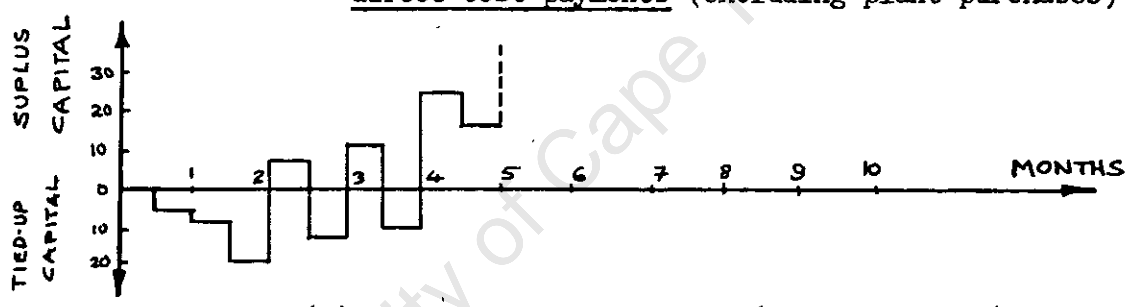

FIGURE 4.14(a): Total client receipts (plus retention) less Contractors direct cost payments

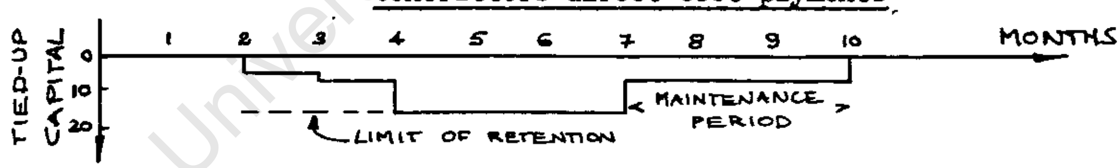

FIGURE 4.14(b): Retention money retained by client

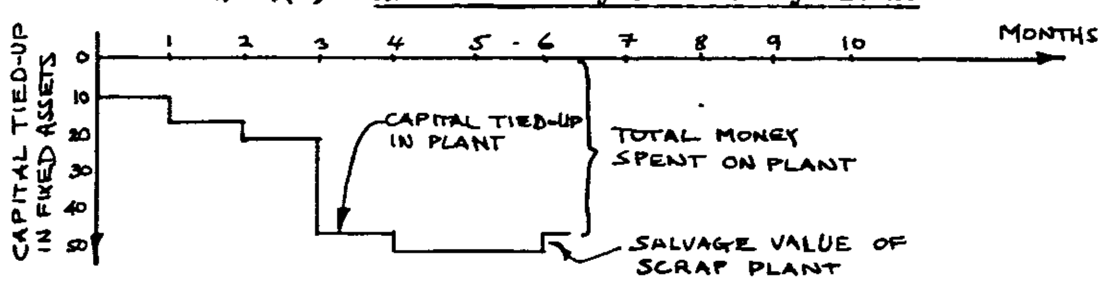

FIGURE 4.14(c): Money invested in Plant and Equipment bought and sold

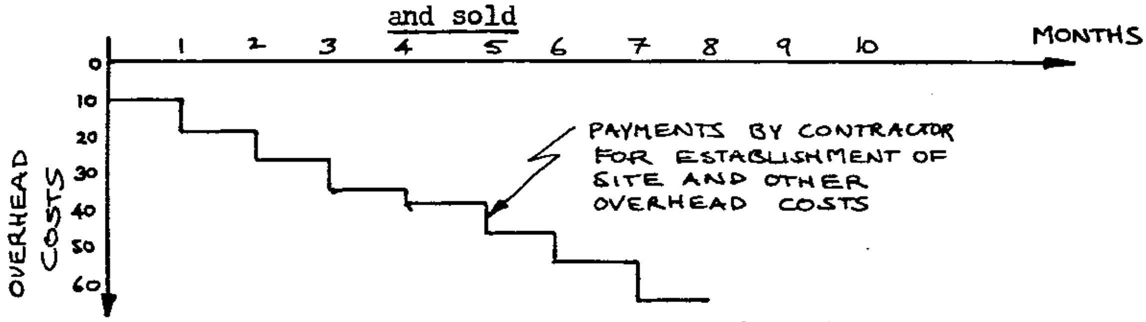

FIGURE 4.14(d): Establishment and Overhead Costs

his direct cost (including hired plant costs but excluding purchase payments for owned plant), as shown in Figure 4.16 (a). An attempt was made to approximate the latter curve by plotting z weeks of contractor's earnings for measured work (curve 1 in Figure 4.16 (a)) and z weeks of contractor cost payments (curve 2 in Figure 4.16 (a)); where z was calculated to be 0,75 months (see equation 4.2).

Referring to Figure 4.16 (a) it is seen that there is a large difference between curve 3 and the approximate curves 1 and 2. In the case of curve 1 (0,75 months of "measured" earnings) the discrepancy is probably also due to the fact that the earnings from which curve 1 was calculated include a provision for depreciation which the contractor attaches to the Bill rates to recover the cost of his fixed assets (i.e. plant and equipment) used on site and due to profit effects. In Figure 4.16 (c) the portion of plant investment (i.e. fixed assets) which is depreciated on site is determined from the difference between the curve showing total cash invested in plant and equipment (see Figure 4.14 (c)) and that showing the depreciated value of plant and equipment on site. The latter curve (curve 5 in Figure 4.16 (c)) was determined by valuing all items of plant as shown in Figure 4.17. The latter figure shows the value of an item of plant purchased at the start of the contract (see Table 4.2). A down payment of 10 units was made at the start of the contract with four subsequent payments of five

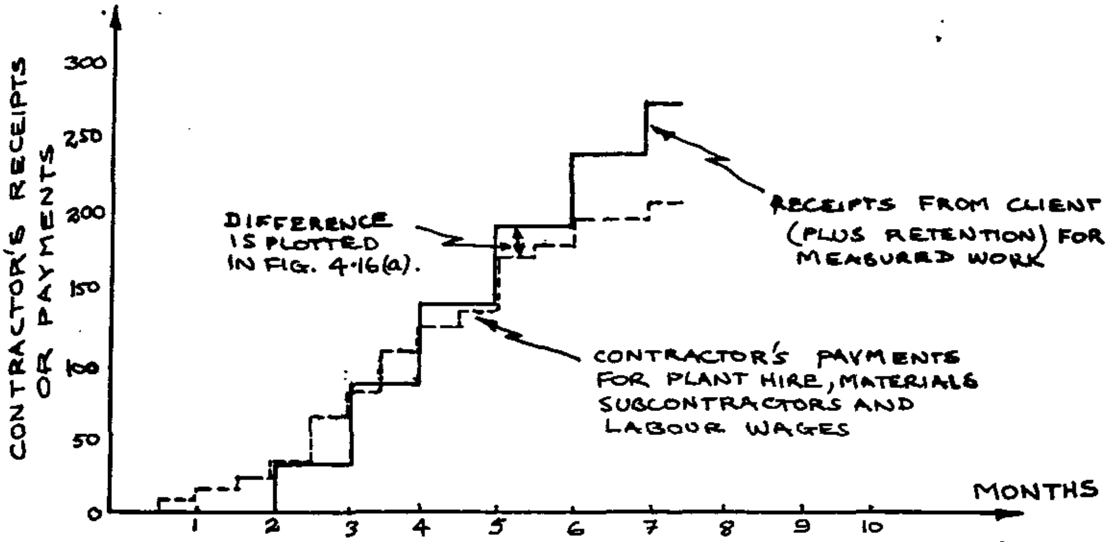

FIGURE 4.15: Contractor's receipts for measured work (plus retention) and payments for direct costs

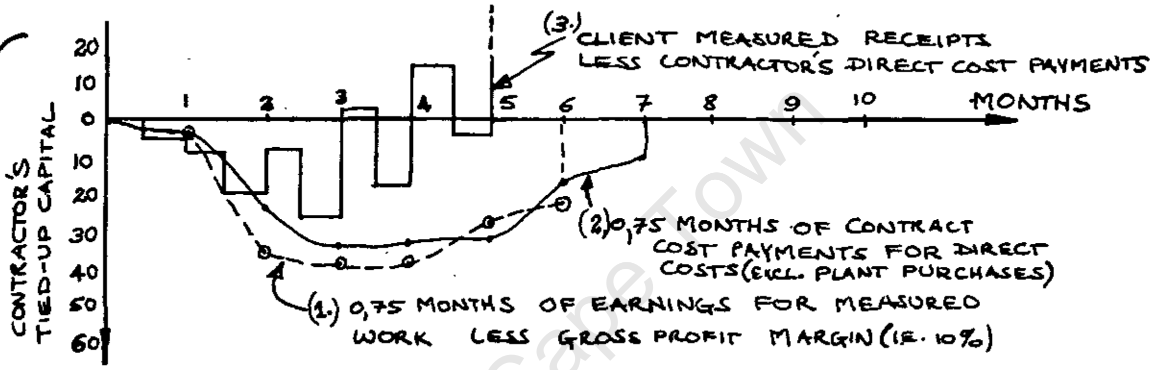

FIGURE 4.16(a): Client receipts (measured work) less Contractor's payments (direct costs excluding plant purchases

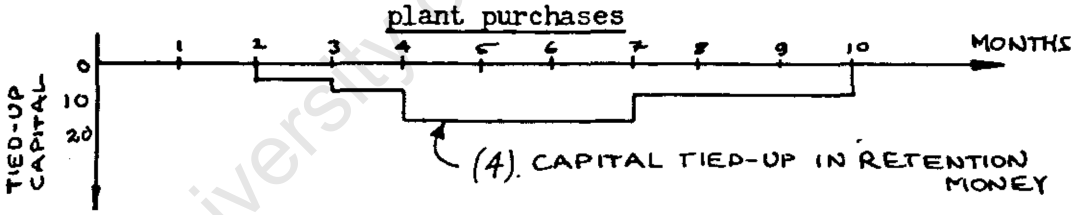

FIGURE 4.16(b): Retention money retained by client

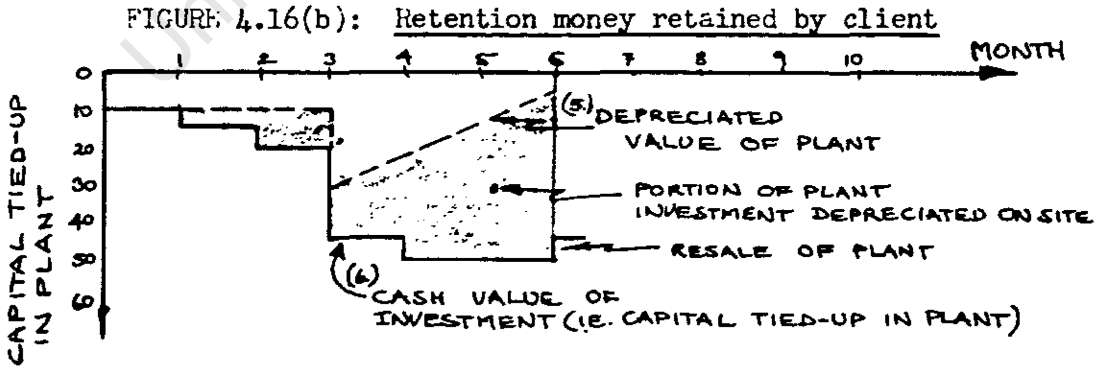

FIGURE 4.16(c): Plant and Equipment bought and sold

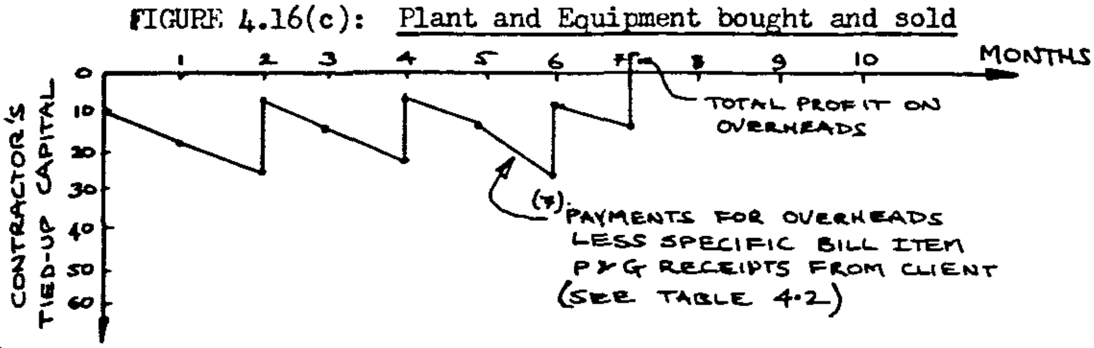

FIGURE 4.16(d): Capital tied-up in Overheads

SUMMATION OF 3, 4, 6 AND 7 PROVIDES CURVE E IN FIG 4·12;
SUMMATION OF 1, 4, 5 AND 7 PROVIDES CURVE F IN FIG 4·12.

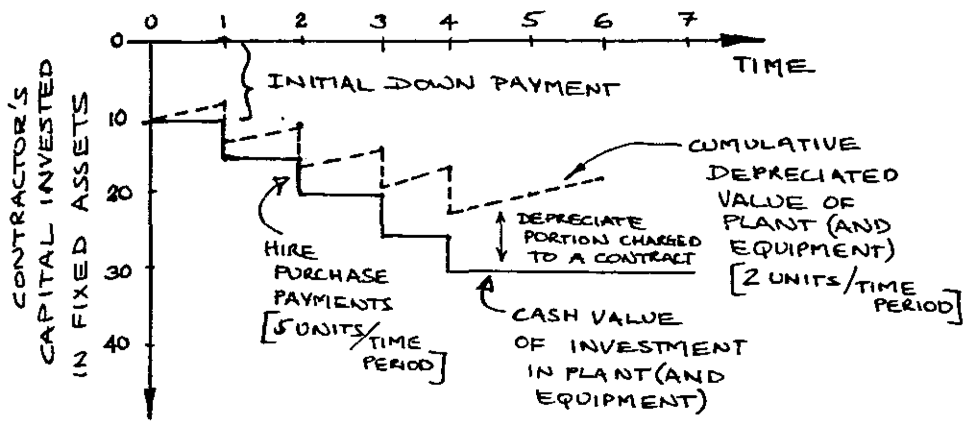

Figure 4.17: "Depreciated" value of fixed assets (plant and equipment).

units each. Assuming straight line depreciation of two units per month the depreciated value of the plant item is shown in Figure 4.17. In the example in Figure 4.16 (c) a depreciation of five units per month is assumed. The other main lump sum purchase of 20 units at the end of month 3 in Table 4.2 can be treated similarly and the two curves summed to find the total depreciated fixed asset curve (curve 5 in Figure 4.16 (c)).

If the depreciated shaded portion of the fixed assets (see Figure 4.16 (c)) is added to curve 3 in Figure 4.16 (a) the combined curve will be closer to the curves 1 and 2 in Figure 4.16 (a) than to the curve 3 in this figure.

Referring to Figures 4.16 (a) to (d) it will be seen that if one adds together the curve 3 (client receipts for measured work plus retention less contractor's payments for direct costs, excluding plant purchases), plus curve 4 (money retained by client, plus curve 6 capital invested in plant and equipment, less cash from resale) and plus curve 7 (overhead cost payments less specific P. and G. Bill item reimbursements from the client) the project total tied-up capital curve will be found (curve E in Figure 4.12).

If instead the approximate curve 1 showing 0,75 weeks of earnings (representing the contractor's capital tied-up in direct costs) plus curve 4 (money retained by client) plus curve 5 (the total depreciated value of plant on site) and curve 7 (the contractor's capital tied-up in overheads such as site set-up costs) a reasonable approximation (curve F) to the total tied-up capital curve E in Figure 4.12 is obtained.

Although the approximate curve F of total tied-up capital does not evaluate the local peaks which might occur if the client pays a few days later than expected, it has the advantage that it is easier to determine than the more rigorous cash flow analysis using the equation in Figure 4.8. Further experimentation would, however, be required to determine whether the approximate curve F will always be sufficiently accurate.

4.3 Financial Control

The objective of Financial Management is to ensure that the monetary resources of a business are planned and controlled to earn the best return on their investment.

Anthony (Ref. 1) very effectively points out that although it may seem to be the case, this objective is never simply one of maximising profit but rather to do what is best for the growth and well-being of a firm in the long run. For example, money will rarely be invested in an undertaking with excessive risk or in something which is against certain ethical principles of a firm.

Although it is beyond the scope of this thesis to discuss company financial control to any great detail brief consideration is given to two techniques which are used by contractors to control their financial resources.

4.3.1 Control of company turnover

It is usually the policy in construction firms to maintain a target level of company turnover (i.e. rate of earnings; e.g. R150 000 per month). This target is then steadily increased with time as the firm grows, and to allow for inflation (i.e. a reduction in the purchasing power of money). When deciding to tender for new contracts consideration is given to the effect which these contracts will have on a firm's total turnover.

The thinking behind maintaining a target company rate of earning is firstly the assumption that it will ensure that sufficient work is available to keep the fixed assets of a firm (i.e. plant and equipment) fully employed, and secondly, this may ensure that full use is made of the total assets of the company. Obviously, it is also hoped that sufficient profits will be generated.

The advantage of the above technique is its relative simplicity if compared with a technique which first requires the total tied-up capital of a contract to be evaluated to determine its suitability as a new contract (as described in the next section). From past experience contractors generally know approximately the time-pattern of earnings on a particular type of contract. Figure 4.18 for example, shows the standard earnings curve used by a local building contractor to determine approximately the expected earnings of a contract at various stages during construction (the curve in Figure 4.18 was determined from the actual earnings of a large number of completed contracts). It is expected that similar standard curves could also be determined for the various types of contracts on which Civil Engineering contractors are engaged (e.g. roadworks, bridges, pipe-lines, etc.).

An additional factor which must be taken into consideration when using the technique of tendering for contracts to maintain a constant level of company turnover is that the relationship between turnover (i.e. earnings) and the contractor's total tied-up capital during construction is not the same for the various types of Civil Engineering contracts. It was seen in the previous section that a labour intensive contract (e.g. a structure such as a bridge) has a lower level of tied-up capital than for example a plant intensive contract, such as a road surfacing construction. The effect of unbalancing a tender also usually has the effect of reducing the capital tied-up on a contract during construction.

4.3.2 Controlling the utilisation of capital in a firm

The importance of cash in a firm was pointed out in Section 4.1 of this chapter. According to Zilly and O'Brien (Ref. 20) one of the main reasons for bankruptcy in American construction firms is the loss of liquidity, caused by inadequate pre-planning of company cash utilisation. The term liquidity is usually used in connection with the ability of a firm to meet its immediate bills from materials suppliers, subcontractor's claims, etc. at a certain point in time. Referring to the balance sheet in Table 3.2 B (c) it is seen that the current liabilities must be covered by a firm's current assets of which cash is an important item.

The company cash flow forecast, consists of the sum of the individual contract cash flow forecasts plus all other expected future company cash flows for capital assets (e.g. buildings) and other expenditures. This company cash flow forecast is an important financial planning tool of the financial manager of a construction firm.

In Section 4.1.2 two techniques for the preparation of a company cash flow forecast were described. These two techniques were designed to aid the accountant mainly in determining the amount and timing of cash flows which could be directly related to the timing of the construction work. Other cash flows such as for plant purchases could then be added for the whole firm to provide the overall company cash flow forecast.

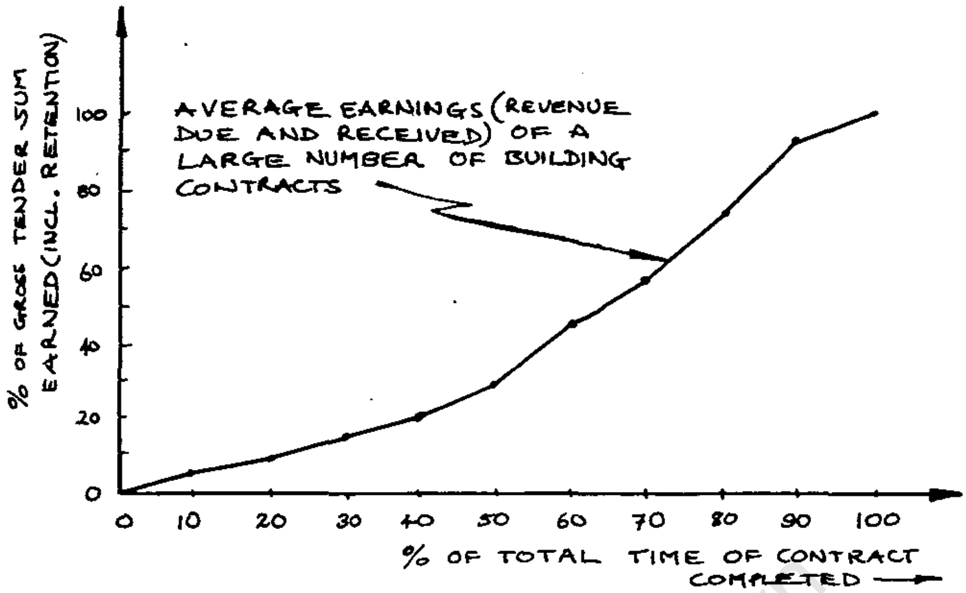

FIGURE 4.18: Standard earnings curve used by a Local Building Contractor

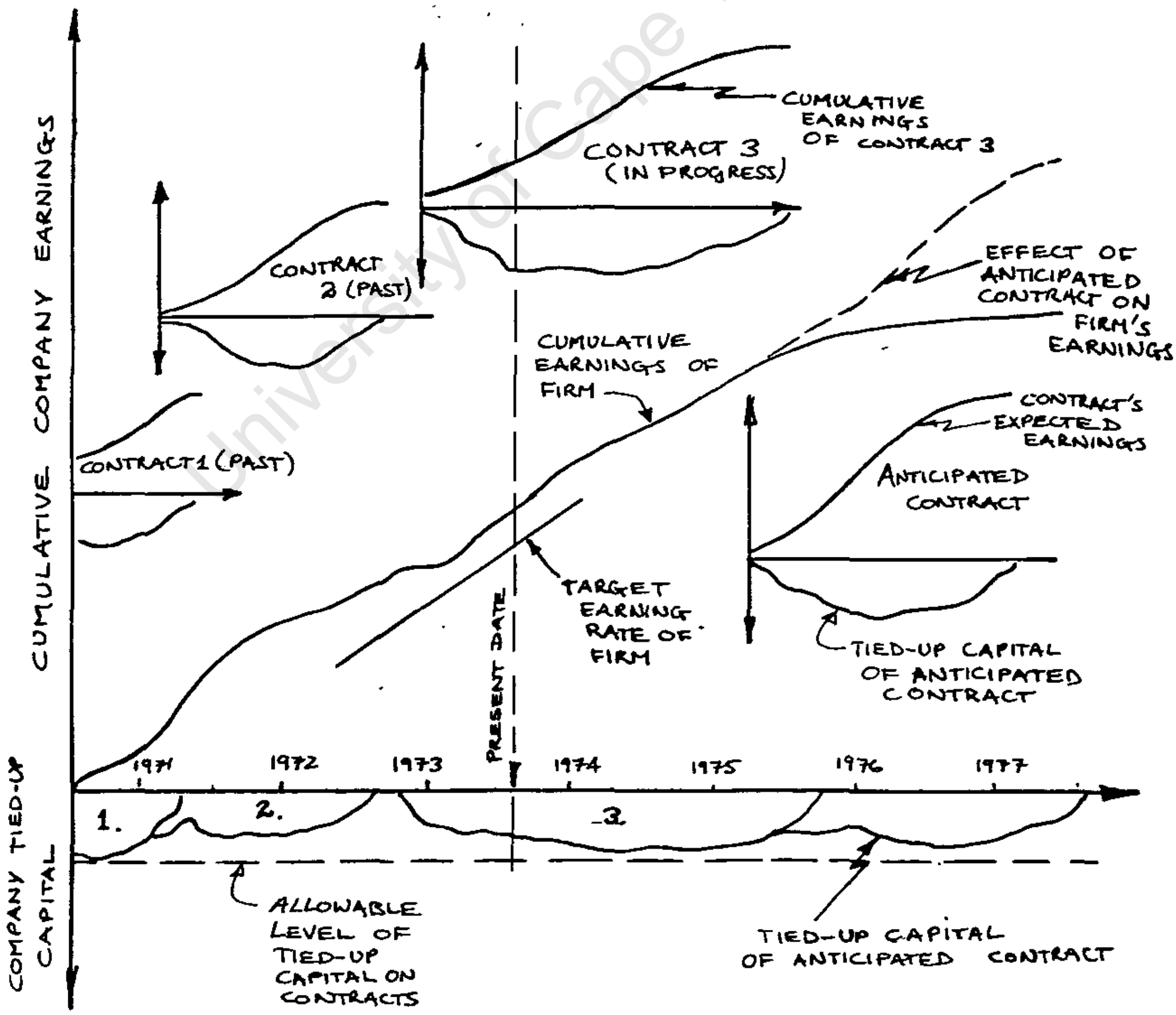

FIGURE 4.19: Tied-up Capital and Earnings of a Number of Contracts

In Section 4.2.2 a complete analysis was made of all the capital of a contractor tied-up on a contract during construction. For a particular contract the curve showing tied-up capital (for example, Figure 4.12) could be used in conjunction with the earnings curve of the same contract as shown in Figure 4.19.

In Figure 4.19 the total earnings and total tied-up capital (see Section 4.2.2) of a construction firm for its various construction contracts are examined together to determine the effect of an anticipated future contract. It is seen that for the given level of tied-up capital and target rate of earnings the firm has enough work till the middle of 1975. Taking into account only earnings and tied-up capital the anticipated contract seems to restore the overall company earning rate to its target value, without exceeding the allowable limit for tied-up capital.

Note:the target earning rate (including profits) for the whole company can be expressed as a function of the tied-up capital of the whole company. This function varies with the type of contract (e.g. building, roadworks, etc.).

4.4 The Time Value of Money

When a contractor decides to commit a portion of his capital to a contract which stretches over a number of years, it becomes important for him to take into account the effect which time has on the value of money.

In Section 4.2.2 a complete analysis was made of all the capital of a contractor tied-up on a contract during construction. For a particular contract the curve showing tied-up capital (for example, Figure 4.12) could be used in conjunction with the earnings curve of the same contract as shown in Figure 4.19.

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Note: the target earning rate (including profits) for the whole company can be expressed as a function of the tied-up capital of the whole company. This function varies with the type of contract (e.g. building, roadworks, etc.).

4.4 The Time Value of Money

When a contractor decides to commit a portion of his capital to a contract which stretches over a number of years, it becomes important for him to take into account the effect which time has on the value of money.

This effect can be divided into:-

(a) The earning power of money i.e. the ability of money to earn interest,

(b) The decrease in the buying power of money; namely, the effect of inflation (i.e. rising prices). (This aspect will be discussed later in Section 4.5.)

4.4.1 The earning power of money

Curve 1 in Figure 4.20 shows the compounded interest value of a sum of money at various points in time. It is invested at compound interest and is thus governed by the equation:

$$F = A(1+i)^n \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.3)$$

Where A is the value of F at the initial time,

F is the value of A after n years,

and i is the yearly interest rate.

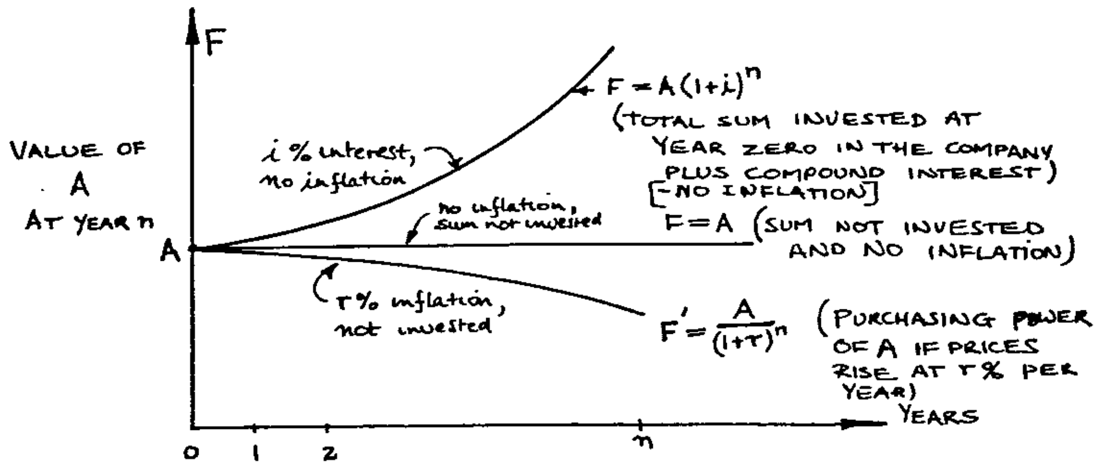

Figure 4.20: The value of a sum of money at various points in time.

Because of the interest earning power of money it is not only the amount of money which is important but also the time at which it is received. In other words, a sum of money received today is worth more to the contractor than the same sum at some point in the future. Since the former sum could have been invested in the meantime.

By the same argument the longer an expenditure is deferred, the better it will be for the contractor.

It is interesting to note the significance of this to routine management decisions. When a manager for example, decides to buy in bulk at the start of a contract to secure a discount, he does this in the hope of having made the least cost choice. Taking into account the effect of time he might find that by spreading his payments he could have earned more if he invests this money as long as possible in the business.

4.4.2 Discounted cash flow techniques

Because a Rand earned today can earn interest if invested, some method must be used to compare future cash values at the same point in time. This can be done by expressing all future sums of money at their present value via the following equation:

$$A = \frac{F}{(1+i)^n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.4)$$

Where A is the equivalent present value of a future sum F paid out or received n periods from the present date,

i is the equivalent target interest rate which should be earned per period of time.

Equation 4.4 describes the interest earning capacity of money (if lent) and applies even if the purchasing value of R1 remains the same (e.g. R1 per kilogram of beef).

Two techniques which are based on equation 4.4 and which are often used to compare capital investments and other problems (e.g. when to replace a machine) involving cash inflows and outflows over a number of time periods are discussed briefly.

(i) The discounted cash flow Present Value method,

(ii) The discounted cash flow Yield method.

The basic difference between these two methods is as follows:-

In the present value method an interest value is assumed and hence an equivalent present value of future profits is calculated.

In the discounted cash flow yield method the interest value (i.e. rate of return) is regarded as the unknown value which is calculated for the case when cash inflow equals cash outflows (if reduced to present day values).

Obviously several different values of interest i could be fed into the formula of the present value method, and that rate of interest i for which there is no profit (by present value standards) would be the solution value (i.e. rate of return) in the discounted cash flow yield method.

As construction contracts are investments which consist of a series of cash flows, often spread over a number of years, these two techniques are largely applicable and might be used to investigate the profitability of a project.

A) <u>The Present Value method</u> (when there is no inflation)

The Present Value method states that for an investment to be acceptable the present value of all investments (cash outflows) must be less than or equal to the present value of all cash inflows:-

i.e. $$\sum_{x=0}^{x=n} \frac{P_n}{(1+i)^x} \leq \sum_{x=0}^{x=n} \frac{R_x}{(1+i)^x} \quad \ldots\ldots \quad (4.5)$$

Where P_x is the cash outflows (payments) and

R_x is the cash inflows (receipts) at time period x,

n is the number of time periods of the project,

and i is the rate of return required by the company (see Section 4.4.2 C).

Note when x=0, P_x and R_x are the initial payments and receipts prior to the first time interval.

Similarly, when comparing two future investment proposals by this method, the proposal with the highest nett present value would be the likely choice.

i.e. $$\text{Nett present value} = \sum_{n=0}^{x=n} \left(\frac{R_x - P_x}{(1+i)^x} \right) \quad \ldots\ldots \quad (4.6)$$

Where R_x, P_x, i and n are defined as for equation 4.5 above.

Figure 4.21 shows the possible effect of discounting the nett cash balance of a project. The new curve B which shows all cash deficits at their present value (year 0) was obtained by plotting the cumulative present value of the nett cash flow (cash inflow minus cash outflow) found from equation 4.6, for each year

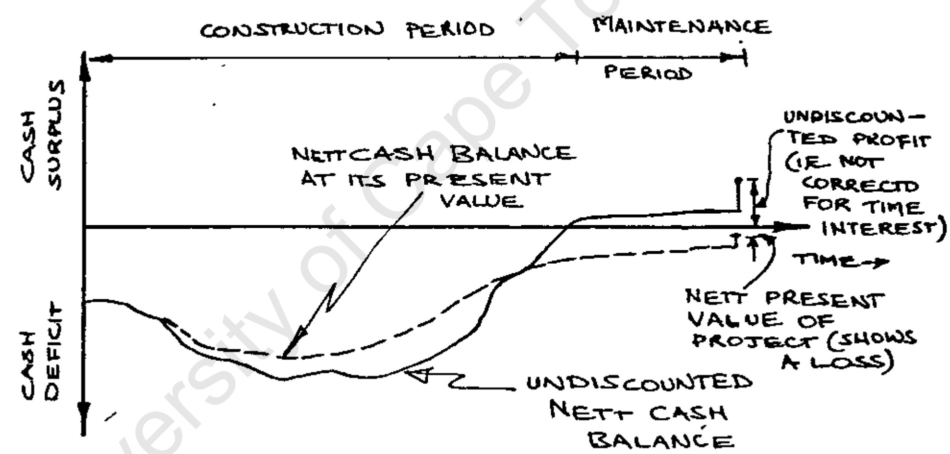

Figure 4.21: <u>The effect of discounting on the nett cash balance of a project.</u>

x (where x = 0, 1, 2, ..., n).

If the nett present value of the whole project (i.e. the income* at its present value) is negative (as in Figure 4.21) then the investment would not be acceptable

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*Income is the difference between Revenue and Expenditure and could denote either a profit or a loss.

since this represents a loss in terms of present cash values.

B) The Yield method

The Yield or Rate of Return method finds the rate of interest (i) at which the present value of all cumulative cash inflows equals that of all cumulative cash outflows.

i.e. $$\sum_{x=0}^{x=n} \frac{R_x}{(1+i)^x} = \sum_{x=0}^{x=n} \frac{P_x}{(1+i)^x} \quad \text{..........} \quad (4.7)$$

Where R_x and P_x are the cash receipts and payments at time x,

n is the number of years for a project,

and i is the interest rate (unknown) which must satisfy equation 4.7. It is found by trial and error calculations.

To determine the acceptability of a project the value of i found from equation 4.7 is compared with the required earning rate below which no investment is undertaken (see 4.4.2 D).

Since the yield rate is sensitive to both the amount of capital and the time over which it is spread this technique will not always discriminate conclusively between two alternative investments with different durations. When this occurs one might determine the Yield rate of the extra incremental investment needed for the more expensive scheme (see Riggs, Ref. 16, pp. 240).

C) <u>The Required Earnings rate</u>

In both of the discounted cash flow techniques described above a company target rate of return t_r is needed to test the acceptability of a project. In the present value method $t_r = i$ is used directly in equation 4.5 while for the Yield method t_r serves as the target standard against which to measure the value of the actual rate of return i calculated from equation 4.7.

In general, the required earnings rate t_r represents the minimum rate of return below which no investment is undertaken.

Although it is beyond the scope of this thesis to determine the required rate of return for a company, a number of factors which might be taken into consideration when calculating this value are:-

(i) <u>The company cost of capital</u> - This denotes the average rate of interest which is paid for the money which a firm uses in financing a business (e.g. interest on long-term loans, dividends to shareholders, interest on short-term bank overdrafts, etc.). Obviously, the interest rate of each different source of finance must be weighted by the proportion (e.g. 20%) which it represents of the total money (i.e. 100%) borrowed by a company.

(ii) <u>The risk involved</u> - For example, a contract where no provision is made for increased contractor's costs due to inflation, will be considered a greater risk than one where such a provision is made; i.e. although the contractor might have made corrections to his estimated cost to allow for expected inflationary increases in the cost of plant, labour of materials during construction (see Section 4.5) there is always the possibility that he has under-estimated these cost escalations.

(iii) <u>Interest on alternative investment</u> - It is often stated that the rate of return required from an invesment will be higher than that which is possible from other investment possibilities (e.g. from a savings bank). This is not necessarily true for a Civil Engineering contractor who might be willing to accept a low rate of return when work is scarce, when competition is keen or simply because he enjoys this type of work.

D) <u>Comments</u>

When the Yield and Present value methods are used to evaluate the acceptability of a particular project (i.e. as accept or reject criteria) then both techniques will provide the same solution.

When one is required to compare two or more investment possibilities, both techniques may still be used to rank the various proposals in order of attractiveness (with regard to monetary considerations) as long as they all involve the same span of time over which cash inflows and outflows occur. A disadvantage particular to the Yield method is that it does not always rank a number of investments with different investment lives in the true order of their financial attractiveness. This is not encountered with the Present Value method where the investment proposal with the highest nett present value is considered to be the most attractive. When the Yield method is required to compare investments of different lives, an alternative approach which finds the rate of return of the difference between the nett cash flows of the two schemes should rather be used (Ref. 14, 16).

Two further disadvantages of the Yield method are that the solutions to equation 4.5 are largely trial and error problems, and also that when the nett cash flows over a certain period of time have a number of reversals of sign (i.e. a positive cash flow followed by a negative cash flow, or vice versa) it is possible that equation 4.7 will have more than one solution (i.e. value of interest rate i). Special extensions of equation 4.7, described by Grant and Ireson (Ref. 11), Merret and Sykes (Ref. 14) and others, have been developed to find the true Yield rate of return when this multiple solution problem occurs in the Yield method.

The Yield method, however, has the advantage that the rate of return (i) calculated by this technique is generally more acceptable to business-men who find this figure easier to grasp than the Present Value of an investment which will show a larger variation from project to project than the Yield rate of return (Merret and Sykes, pp. 149; Ref. 14). In addition there seems to be an advantage in being able to calculate the expected rate of return of a project without first knowing the acceptable rate of return t_r of the company. (In the present Value method a rate of interest must be assumed.)

E) Applications of Discounted cash flow techniques

Although the techniques described in this section are mainly used to evaluate capital investment proposals there are various problems to which Civil Engineering contractors might also apply these methods.

A contractor engaged on a design and construct contract might for example, be required to make a comparison between two possible design proposals with different expenditure cash flows (payable by the client), as shown in Table 4.3.

Table 4.3 shows the expected cash payments of the client for two alternative four year contracts. It will be seen that if total cash flows are compared without taking into account the earning power of money, proposal A seems most favourable. When cash flows are discounted

	Proposal A		Proposal B	
Year	Normal cash flow*	Discounted cash flow**	Normal cash flow*	Discounted cash flow**
1	100	91,0	100	91,0
2	150	123,9	100	82,7
3	150	112,4	100	75,4
4	100	68,5	210	143,5
Total	500	395,8	510	392,6

* Based on current estimated cost.

**Equation 4.3 is applied to each cash flow (i=10%).

Table 4.3: A comparison of the cash flows two design proposals (no inflation)

using the present value equation 4.4 (assuming i equals 10%) proposal B has a lower total cash flow because of the fact that on this contract the client can defer a large portion of his expenditures to the end of the contract, thus reducing the present value of the whole contract.

Another application of discounted cash flow techniques in a contractor's organisation might be to determine the profitibility of a construction contract (i.e. the discounted rate of return or yield; Section 4.4.2) by applying equation 4.7 to the nett cash flows of a particular contract.

4.5 The Effects of Inflation

Inflation is the process by which the purchasing power of money declines with time.

The overall inflation rate which is so often quoted for a country (e.g. 4%) is in fact a complex combination of the inflation rates of the individual elements making up its economy (e.g. manufactured goods, imported items, raw materials, wages, etc.). In the same way the inflation rate of a particular construction contract is a function of the proportions of plant, labour and materials involved.

A contract "price adjustment factor", based on published cost indices for labour, plant and materials has recently been introduced in South Africa (Ref. 8). If the prices increase, this factor permits a partial extra payment (i.e. 85% of the extra cost) to be made to the payments received by the contractor and allows for any changes in the plant, labour and materials prices from those at the tender date. Figure 4.22 shows a plot of the three indices on which the price adjustment factor is based and a combination of these for a general Civil Engineering contract consisting of 30% plant, 30% labour and 40% materials; contractor's payments are adjusted by 85% of the increases reflected by the combined effect (curve F). Although there are large fluctuations in the individual indices the overall effect on projects of this type has been a steady increase in cost of approximately 7.0% for the year 1971 and 9.4% for the year 1972 and for part of 1973 (see Figure 4.22).

In general, inflation can affect the contractor in the following ways:

(1) Increases in the cost of owned plant and equipment; this can include both an increase in the purchase cost and that of subsequent maintenance (e.g. oil, labour) and repair (e.g. spare parts, mechanic wages),

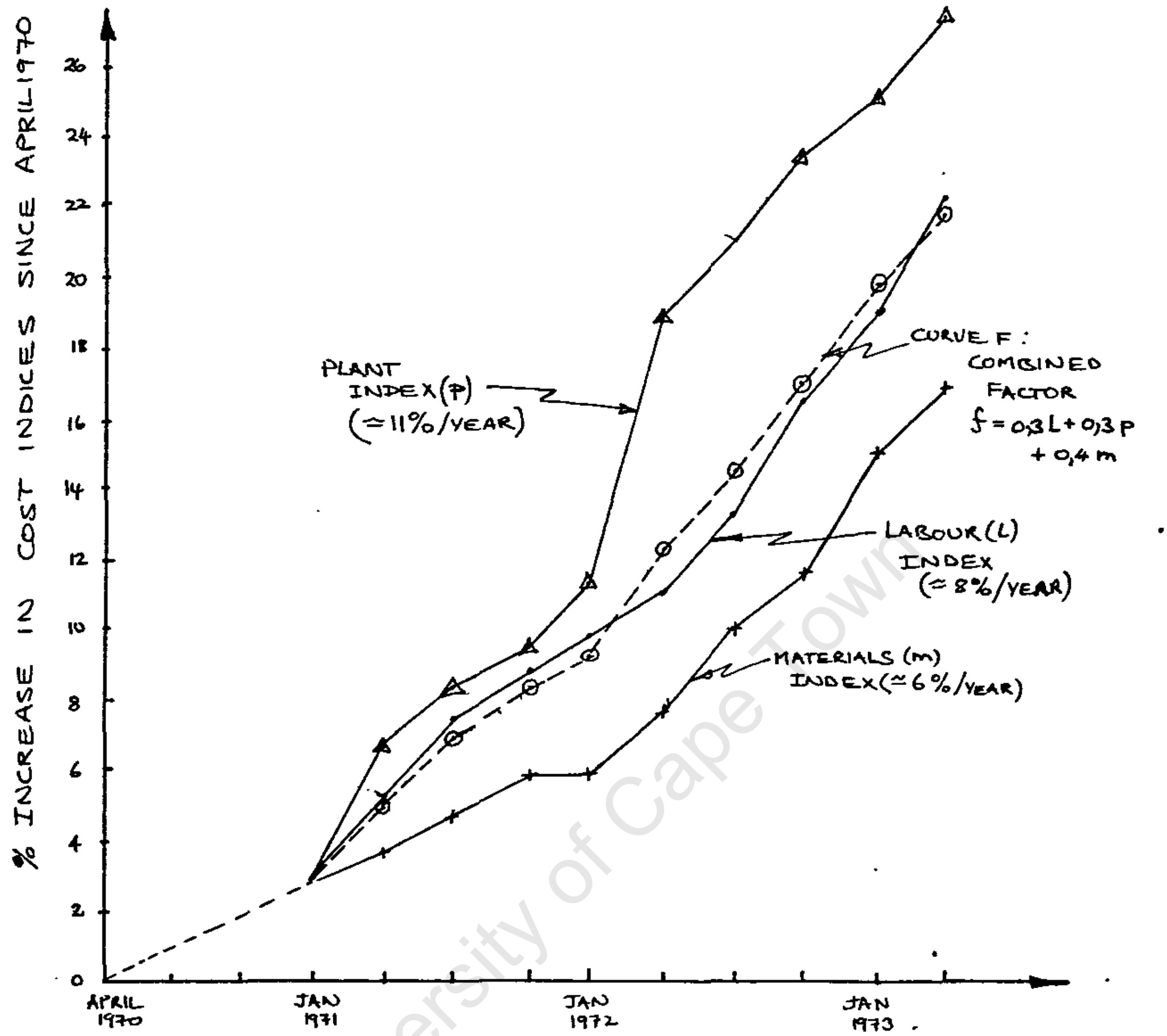

Figure 4.22: Price indices and their combined effect on a project of 30% labour, 30% plant and 40% materials.

(2) Increased unit materials, labour and plant hire costs as the project progresses,

(3) A decrease in the purchasing power of both the fixed and working capital tied-up during construction,

(4) A decrease in the equivalent purchasing power of receipts from the client.

This has an effect which is similar to that of interest; i.e. it is preferable to receive a sum of money today than at a later date. The reverse applies for future payments by the contractor.

The time effect of inflation on a sum of money can be described by an equation which is similar to equation 4.4 (which took into account the effect of interest);

i.e. $$F' = \frac{A'}{(1+r)^n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.8)$$

Where F' is the equivalent purchasing power of A' after n periods of time (see Figure 4.20, curve 3)

and r is the percentage of inflation assumed constant for each time period (e.g. yearly).

The present value equation (4.4) can then be altered to:-

$$A = \frac{F}{(1+i)^n(1+r)^n} = \frac{F}{(1+t)^n} \quad \ldots\ldots\ldots\ldots\ldots \quad (4.9)$$

Where A is the present value of F,

n is the number of time periods between A and F,

F is the value of an expected future sum (paid or received),

i is monetary or <u>true</u> interest rate earned,

r is the percentage of inflation,

and t is the overall* (i.e. apparent) equivalent interest rate which should be earned : a combination of i and r (see equation 4.11).

Armstrong (Ref. 3) applied equation 4.9 to the various cash flows of a capital investment problem to take into account the

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*The value of t in equation 4.9 (with inflation) represents the overall target interest rate at which money should be earned. The value i in equation 4.9 is still the target interest rate which would be required when no inflation is present (see equation 4.4).

effects of inflation. A similar procedure might be followed for a construction contract by applying the corrected form of equation 4.7 to the contract's cash inflows R'_x and outflows P'_x ($x=1, 2, \ldots\ldots\ldots, n$) and solving for i (the Yield rate).

$$\text{i.e.} \quad \sum_{x=0}^{n} \frac{(R'_x - P'_x)}{(1+i)^x(1+r)^x} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.10)$$

Where r is the estimated rate of inflation,

i is the Yield rate of return (for which equation 4.10 must be solved),

R'_x and P'_x are the expected cash payments and receipts at time x under r% inflation

also $R'_x = R_x + \Delta R_x$

$P'_x = P_x + \Delta P_x$

Where ΔR_x and ΔP_x are the expected increases due to inflation of the cash flows R_x and P_x which are based on current costs ($\Delta R_x = 0$ when no allowance has been made for inflation and no adjustment clause exists which enables the contractor to claim additional payment from the client to recover for cost escalation).

Equating the denominator of equation 4.10 to $(1+t)^x$ the overall rate of return is found to be:-

$$t = (1+i)(1+r) - 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.11)$$

$$\simeq i+r \text{ when } ir < 0{,}005$$

Equation 4.10 can in addition be simplified to:-

$$\sum_{x=0}^{n} \frac{R_x - P_x}{(1+t)^x} + \sum_{x=0}^{n} \frac{\Delta R_x - \Delta P_x}{(1+t)^x} = 0 \quad \ldots (4.12)$$

When adequate allowance has been made for inflation in the tender mark-up or when the contractor's receipts are automatically corrected by the use of a price adjustment factor the second term will be close to zero and hence have a negligible effect on the value of t. In this case t can be found from the expected cash flows based on current costs; i.e. using only the first part of equation 4.12.

Conclusions

From equation 4.10 and 4.11 it is seen that the discount cash flow Yield rate of return (i) which is normally found takes on an increased value t under inflation; this can make an investment appear more acceptable. The true rate of return is:-

$$i = \frac{1+t}{1+r} - 1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.13)$$

$$\simeq t-r \quad \text{when } t_r - r^2 \text{ is small (say 0,005)}$$

From equation 4.12 it is concluded that the value of t can be approximated* using the cash flows based on current prices. The true rate of return (i) can then be found from 4.11.

The problems in making suitable allowances for inflation in the tender estimates are:-

(a) Forecasting the expected escalation rates - Figure 4.22 shows that although cost indices are useful they are not reliable for making a long term forecast.

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*If the second term of equation 4.12 is small

For example, a one percent error in the average inflation rate of labour on a 4 year contract of R1,0 million with no escalation clause can mean a loss to the contractor (assuming 30% labour cost spread evenly over the 4 years) of;

$$R1\ 000\ 000 \times \frac{30}{100} \left[(1.01)^2 - 1\right] = R6\ 000$$

or about ½% decrease in total profit (assumed to be 10% of R1,0 million).

(b) <u>Assessing the timing of the construction costs</u> - A common procedure used is to increase the project costs of plant, labour, subcontractors, etc. as in equation 4.14 less any benefits expected from rise and fall or price adjustment clauses.

$$C' = C(1 + \frac{rn}{2}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4.14)$$

Where C' is the increased total cost due to cost escalation,

C is the cost of plant, labour, etc. based on current prices,

r is the expected inflation rate corresponding to c per period of n,

and n is the number of time periods during the duration of construction.

The assumption here is that costs are symmetrically spread about the centre of the construction period.

An increase of 6 months in the duration of the above project will cause a change $\frac{n}{2}$ by 3 months and hence cause an increase in labour costs due to inflation only (assumed 5%) of

$$R1\ 000\ 000 \times \frac{30}{100} \times \left(\frac{1.05 \times 4}{2} - \frac{1.05 \times 4.25}{2}\right) \doteq R3,940$$

or about $\frac{1}{4}$% decrease in profit (assumed to be 10% of R1,0 million).

A more accurate estimate of the centre of gravity of the contractor's costs might be obtained by finding the duration corresponding to half of the total project earnings on the cumulative cash outflow curve (Figure 4.3).

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C H A P T E R 5

A PROPOSED MODEL FOR PLANNING AND CONTROLLING CIVIL ENGINEERING CONSTRUCTION CONTRACTS

5.1 Introduction to the Planning Model mentioned in Appendix D

In this chapter the inputs and outputs of the proposed general planning and control model shown in Appendix D are discussed.

Since there are many variations to the specific form of the individual inputs and outputs normally found in a system of this type, different ways of specifying the same inputs and outputs are discussed in this chapter. The form in which the inputs and outputs are finally presented in Appendix D are considered to be the most practical of those examined.

As mentioned previously in Chapter 2, contractors might find it necessary to make further simplifications to the inputs and outputs of the model proposed in this chapter. It was, however, considered advisable in this thesis to first present a general model which has as much pertinent output information as possible. Subsequent investigation might then show that further simplification by the contractor is necessary to suit practical limitations; for example, one of the practical limitations is the inadequate feedback of information from site caused by a shortage of suitably qualified site staff.

In this chapter a comparison will also be made between four specific planning and control systems currently available for use by construction companies (see Appendix A) and the proposed general system (see Appendix D).

5.2 The Incorporation of Planning and Progress Control within the Planning Model

With reference to the model in Appendix D is proposed that the scheduling of the construction operations be decided by either the network time analysis or resource allocation procedure (see Sections 2.3.1 and 2.4.1). There are, however, certain projects for which the contractor might consider these approaches to be difficult or unnecessary, in which cases he might wish to use the manually prepared bar chart as input to the model (see Section 5.3.2 D).

Although the Critical Path time analysis has become firmly established as a planning technique in the construction industry, opinions vary concerning the use of the resource allocation model (Section 2.4.1). For example, according to Rist (Ref. 17) the John Laing Construction Company is mainly concerned with finishing a contract on time, thus preserving their reputation and avoiding any penalty costs. For every new contract the firm prepares only a Critical Path time analysis to find a construction schedule. For these time schedules the instantaneous resource requirements might also be determined by allocating to each activity the amount of plant, labour and materials required. Any peak resource demands are evened out by <u>manually</u> altering the work programme. Campbell (Ref. 5) compared the schedules calculated by five different commercial resource allocation models for the same project and found the predicted contract durations to differ by about 10 to 15% in some cases. The author concluded that the general inaccuracy of the time-schedules produced by these models would make them unreliable for determining an exact work timing programme, and suggested that one should only use resource allocation models to find the initial resource requirements and approximate duration of a project, and then use the network time analysis for detailed activity time control during construction. Other authors (e.g. Ref. 3, 12), however, regard the resource allocation analysis to be a particularly useful technique, which is largely suitable for the time and resource planning of construction contracts.

It is the opinion of the writer that a computerised resource allocation routine should be used with particular care as the basic assumptions used within the programme must be known and considerable expertise is required in both its implementation and the interpretation of the output.

For the remainder of this section the inputs and outputs, relating to the planning and progress control aspect of the model proposed by the present writer, in Appendix D are discussed.

5.2.1 Pre-construction Planning Input (Inputs 1, 3, 7 and 8 in Appendix D)

Before the start of a contract the information available to the contractor for compiling a construction programme might be grouped into:-

(a) The descriptions and interdependancies of the various project operations - as determined by the structure and other external influences such as site access, top management decisions concerning the method of construction, etc.,

(b) The resource requirements of the above operations - e.g. plant, duration, labour, etc. according to the method of construction,

(c) The type and amount of resource to be made available by the contractor to the contract - e.g. the required project duration, the amount of labour and plant, their expected output, the capacity of certain items of plant (e.g. cranes), unit resource costs, etc.,

(d) General project time data - concerning holidays, working days in a week, paydays, project start date, intermediate due dates for certain parts of the structure, completion date, etc.

Although most of the above data is usually relatively fixed by the nature of the structure, as agreed in the tender document (e.g. completion dates) or as decided by top management, the planner is sometimes required to make tentative assumptions concerning certain items of information. These assumptions might have to be corrected during construction (e.g. output of plant and labour, activity duration, etc.).

A) Activity Descriptions and Interdependancies (Input 1 in Appendix D)

It is the opinion of the writer that a flexible company-wide list of standard work items be compiled from which the necessary activity descriptions for each project can be chosen. The advantages of such a list, of which an example is shown in Table 5.1 (Section 5.3) are that:-

(a) Standardisation of descriptions will ensure uniformity of work-programmes. It is expected that this will improve the co-ordination between planner and site staff who are often geographically separated,

(b) The interpretation of feedback information will be simplified. For example, an operation described as "shuttering to bridge deck" on one contract might have meant the same as "erect staging and deck formwork" on another. If the planner subsequently wishes to use the recorded achieved duration, actual man-hours or other recorded data to programme a similar future contract, it might be necessary to make a detailed examination of the networks of the two contracts,

(c) In addition to this, the achieved outputs for the various contracts can be recorded against the standard activity descriptions for later use. Since it is frequently argued that such information is of little value because of the varying conditions from one site to the next, a brief description might be included with all recorded date (e.g. abutment - in rock, frequent rain),

(d) When the descriptions are stored in a computer it is only necessary to specify the relevant code numbers for each future proposed activity from which the full descriptions from similar past activities will be printed,

(e) Should the contractor wish to integrate planning and cost control, as described in Section 5.3.1, he can do this by choosing the project cost centres (Section 3.3 D) from the same list as the activity descriptions (see Table 5.1).

The activity details into which a project is broken down depends largely on the relative importance of the part of the structure under consideration and the degree of control required. For example, on a large roadworks contract the construction of an abutment might be simply defined as "construct abutment" while on a bridge contract there will be separate operations for "formwork to abutments", "reinforcements to abutments", etc. It is therefore necessary for a list of predefined work elements such as Table 5.1 to be relatively flexible.

B) <u>Resource Requirements of the Project Activities</u>

(Inputs 1 and 3 in Appendix D)

When planning is by the Critical Path time analysis, the only resource data required are the durations of the various operations (see Section 2.3.1). However, for a more detailed analysis these resources must also be specified for each activity to determine for example, the level of demand and the timing of a certain item of plant, labour or materials during construction or for a project resource allocation analysis (see Section 2.4.2).

It is the opinion of the writer that the manner and detail in which the resource information of an activity is specified is an important factor in determining the success of the model. The following considerations are important:-

(a) The form in which the activity resource data is most readily available. This depends on how the information is to be collected for example, from the tender estimate, discussion with site staff, etc.,

(b) The factors which are most likely to require revision or updating during construction should be identified. On certain contracts, for example, roadworks, the work quantities are frequently reviewed, while on a structure the durations of the operations often require to be altered,

(c) The availability and expertise of the staff who are required to compile, revise and supervise the processing of the data,

(d) The accuracy required. This applies particularly if the activity resources are to be used for cost planning purposes where activity costs are evaluated from the estimated amount of plant and labour required and their unit costs. Here the activity resource information must be estimated in great detail (e.g. plant hours) if an accurate answer is required,

(e) The economics of the computer calculations. The resource allocation routine often requires a long computer computation time which depends partly on the manner of specifying the activity resources (i.e. input) and partly on the complexity of the solution routine (i.e. the type of programme).

Factor (e) is difficult to assess before a programme has actually been used. The writer, however, expects that unless the manner of specifying activity resource requirement, differs radically from those presently in use. The computation time of the model in Appendix D will be similar to that of similar models presently in use.

In Section 2.4.2 and Appendix A various ways of specifying activity input data were described. The advantages and disadvantages of three approaches are briefly discussed:-

(i) A common technique used for the activity input data in many of the commercial computer programmes (e.g. Ref. 5, 10) is to specify independantly the plant, labour and resource requirements of an activity, as either a constant rate per unit of activity time or as a total quantity to be spread over the activity duration.

For example,

activity duration	:	6 days
activity labour	:	2 carpenters/day (rate per day)
activity materials	:	120 cubic metre of concrete (total quantity)

For both labour and materials the model will assume a constant rate of resource consumption over the activity duration (i.e. 2 carpenters per day and 20 cubic metres of concrete per day). The main difference in the two methods of specifying the data (i.e. rate/day or total quantity) is found when an activity duration is subsequently revised. If for example, the planner specifies a new duration of 9 days for the above activity the model will still assume 2 carpenters per day for this new duration, but for materials where the total quantity was fined the model (e.g. model 1 in Appendix A) will now assume 15 cubic metres per day over the new duration. Alternatively, if the planner updates the 6 day activity by specifying that 5 days have been devoted to this activity and 4 activity days are still required then the model will assume 2 carpenters per day for four days but will assume that 100 cubic metres of concrete have been used and the remaining twenty are then spread over the remaining four days.

Since a constant rate of consumption of resources within an activity is not always correct (particularly for large activities), the ICL 1900 PERT system (Ref. 10) for example, allows one to fix the resource positions within an operation (see Figure 5.1).

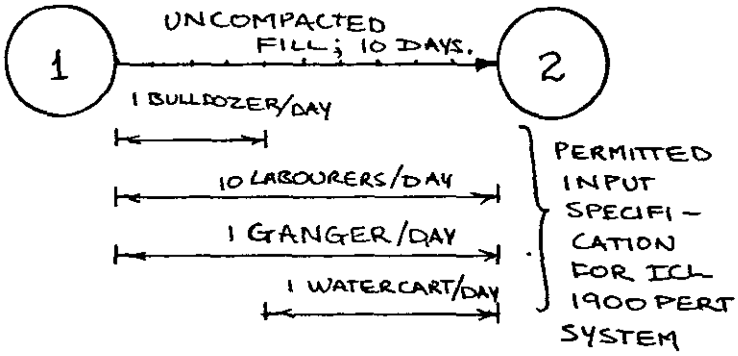

Figure 5.1: Activity with partitioned resources (Ref. 10)

Although the above approach of specifying the activity duration independently from the plant, materials and labour requirements is relatively simple to use the planner is required to personally re-examine the original assumed relationship between plant or labour output and activity duration when updating the activity, and when the quantity of work in an activity changes.

In the next approach the programme automatically adjusts the rate of usage of the resource during updating. This updating is done according to certain rules which are built into the computer programme.

(ii) This second approach relates the activity resource requirements to the quantity of work to be processed. Although precise details are not presented it appears that the model by

Barnes and Gillespie (Ref. 3 and Appendix A) uses this approach.

For example,

Total work quantity	:	5 000 m^3 excavation
Resource team	:	One D8 Bulldozer, one 950 loader and two lorries
Expected team output	:	500 m^3/day

The model will calculate the activity duration as $\frac{5\ 000}{500} =$ 10 days

When an activity requires updating a new total work quantity is specified by the planner from which the remaining duration is calculated as above.

It is expected that for long operations involving large quantities of work this approach will yield more accurate results than the previous manual method of updating. Since the type of work in an operation will usually coincide with one or more Bill of Quantity items, the amount completed at the end of a month can be estimated from the monthly certificate. A disadvantage is that when an operation involves two or more different quantities of work (e.g. formwork and steel) one might have to specify a combined output.

When there are many operations of the same type or where an operation is of particular interest the actual quantity produced on site might be plotted on a control graph as shown in Figure 5.2. Should the actual output differ from the expected target output originally used in the model for calculation purposes then it might be necessary to re-programme the work using this new achieved output value.

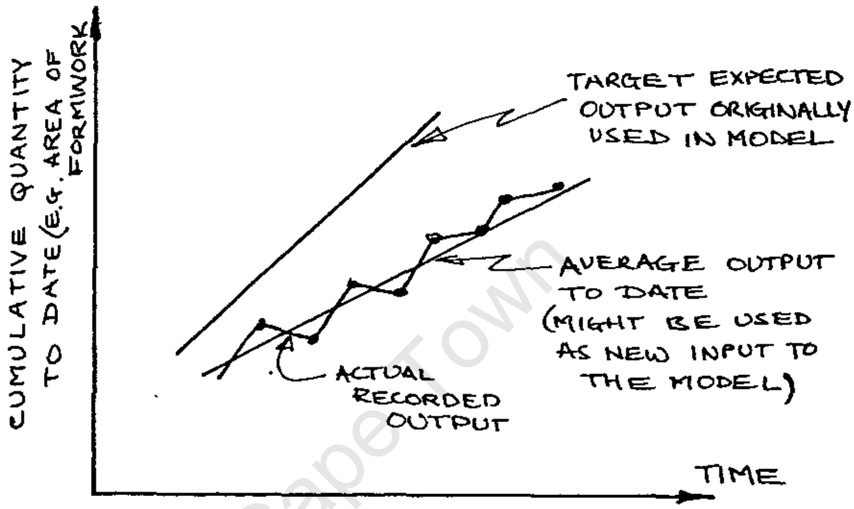

Figure 5.2: Control Graph showing the cumulative output of selected operations

(iii) A third method of specifying activity resource requirements is that used by Bennet's resource allocation model (Ref. 4). For each activity only the total amount of resource required by the activity and the maximum and minimum size of team which might be employed on this activity are specified.

For example,

60 carpenter-hours
3 carpenters (maximum team size)
1 carpenter (minimum team size)

No initial* time network analysis is performed

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*Referring to Section 2.4.2 it will be seen that all the resource allocation models described there, started with an initial time analysis in order to determine the allocation priority of an activity. Bennet's model (Ref. 4) ranks the activities in order of descending start node numbers which the planner allocates to the activities. An activity duration is influenced by simultaneous activities which might need the same labour or plant resources.

in Bennet's resource allocation model and each operation is scheduled within the constraints of the network interdependancies and the amount of resources available for each activity at the time of scheduling. The latter determines the activity durations which are not known at the start of the analysis.

Although the planner is not required to estimate the duration of an operation he might have difficulty in justifying to site staff the eventual duration chosen by the model. To illustrate point (e) in Section 5.2.1 B above, Bennet (Ref. 4) found that the model required a particularly long computation time of 30 minutes which will have to be reduced before this model is economically workable.

A similar approach of specifying a maximum and minimum team size was also used by Wiest (Ref. 18) with the difference that an activity duration is also specified corresponding to an average team size with which an initial time analysis is performed (see Section 2.4.2, Table 2.2). Subsequently the computer programme varies the activity durations. It is, however, doubtful whether the benefits to be derived from these additional refinements are worth the extra effort in compiling the data and the possible increased computer processing costs.

(iv) It is the opinion of the writer that the best results will be obtained if the contractor has the option of using either one or other of the first two techniques described in Sections 5.2.1 B(i) and 5.2.1 B(ii). The input 3 (Appendix D) is based on these two methods and it can be seen that one can specify one of the following for an activity:-

(a) The activity duration; and the plant, labour and material requirements per unit of time - The model assumes the total resource requirements (e.g. carpenter-hours) of an activity to be proportional to its duration (i.e. the rate of usage, e.g. carpenters/day, is constant),

or (b) the quantity of work (e.g. the area of formwork), the team of plant and labour to be used (e.g. 2 carpenters) and their expected target output (m^2/day) - In this case the model takes the activity duration (days) and the total resource requirements (carpenter-days) as being proportional to the quantity of work (m^2).

It is expected that for most scheduling purposes (a) above will be sufficient, but on certain contracts involving large quantities of work a more precise determination of the activity resource requirements will be obtained if (b) is used. Updating is easier as only the amount of work (e.g. m^3 fill) need be altered. An additional advantage is that the expected target output can be used for control purposes as shown in Figure 5.2 by plotting this and the actual site output to a time scale.

C) <u>Project Resource Availability</u> (Inputs 7 and 8 in Appendix D)

Input 7 of Appendix D shows the level of the resource (plant, labour and materials) which is to be made available to a contract during its construction. This input is necessary when the model is used as a resource allocation model (see Section 2.4.2).

The model in Appendix D incorporates the method described in Section 2.4.3 which might be used when there are limits not only to the amount of plant and labour available but also a target project completion date which may not be exceeded (see time inputs in Appendix D).

Input 8 also shows other project time data such as annual holidays, working days in a week, and project interim completion dates for certain important parts of a structure.

D) <u>Bar Chart as Input</u>

As discussed previously in this chapter a contractor might find it difficult to use the network planning model on certain contracts (e.g. roadworks contracts).

As an additional extension to the model in Appendix D the writer therefore suggests that it should be possible for the start and completion dates of the activities determined from the manually prepared bar chart or line-of-balance (Ref. 27, Chapter 2) work schedule to be entered directly in the computer programme. Even for contracts where only a bar chart is available the model can still be used to determine resource demand versus time curves (see Section 5.2.2 B), cash flow forecasting (see Section 5.4.2), etc.

5.2.2 Planning Output

The planner's reports prepared during planning form the basis of both communication and control during construction. Particular care must therefore be taken in the design of their content and layout. The objective should not only be to get the right information to the right man (Ref. 7) but also to present it in an acceptable form.

A) Work Programmes

The advantages and disadvantages of six of the most commonly used computer construction schedules are briefly discussed.

(a) Calendar dated printout - This consists of a list of network activities tabulated vertically and showing their early start dates, early finish dates, float times, and whether critical, etc. For precedance networks the numbers preceding and succeeding work items (i.e. activities) are sometimes also shown. On average about thirty activities are contained on a page of computer paper, and hence few pages are required for the printout for the whole project. Although the information is shown precisely, site staff prefer the easy to read bar chart which can be constructed from this computer printout.

(b) Computer bar charts - The activities are listed vertically in the computer printout and horizontal bars consisting of alphabetic characters drawn to a time scale represent the bar chart (e.g. ccccc for critical activities). As the number of type positions in one horizontal line on a standard computer printout page is limited (e.g. it is sufficient for daily records for approximately 3 months) a project of about three hundred operations which lasts for 24 months will give a printout of about 80 - 100 pages. According to Jha (Ref. 7) this volume of computer output is regarded to be one of the main disadvantages of using computers to programme construction work schedules. Construction managers do not normally have the time to study a pile of computer printout in order to extract information for decision making. Various techniques for condensing these schedules to more manageable proportions are proposed in this section.

(c) The Cascade chart - It seems that this technique was developed by the John Laing construction company as an extention to the conventional bar chart. Vertical lines are used to indicate the interdependancies between the operations (see Figure 5.3). Although the cascade chart can be drawn manually, certain IBM programmes will prepare a printout on sheets of computer paper which must be taped together to form the complete diagram. The most ideal solution, however, appears to be the use of the graph plotter which can construct a schedule for up to 200 operations on a single sheet.

(d) Time-scaled networks - In the experience of the writer a particularly useful form of a graphical work programme which is easily understood by all levels of site staff can be obtained by manually plotting the arrow diagram to a time scale (see Figure 3.2). The main drawback is that this can be tedious procedure especially when there are many small operations involved. Certain computer programmes (Ref. 5) will reproduce both Arrow and Precedence diagrams to a time scale; As in the case of computer-prepared bar charts a completely unmanageable diagram can result consisting of many pages of computer paper taped together to form a single chart.

(e) Milestone reports - This is a listing of the main project events showing, for example, the originally start or completion expected dates, the currently (calculated) expected dates, the actual dates if the event has been completed, etc. The report is mainly for top management who require a quick assessment of progress for a project, and this report will typically include items such as the start or completion of a major portion of a structure (e.g. bridge deck) and the completion of the contract as a whole.

(f) Summary bar chart - This is in effect a condensed form of (b) showing only a few bars for the whole project. Although it is generally prepared for top management, the programme used by Jha (Ref. 7) has also produced summary bar charts to reduce the size of the normal computer bar chart printout.

From this brief review it can be seen that the main problem with schedules prepared by computer is the unwieldy form in which the data is presented. This disadvantage can be minimized if reports are designed with care, taking into consideration the requirements of a particular company, i.e. the levels of management for which the information is required.

For general use the writer expects that the following three types of reports will suffice:-

(i) Bar chart for top management - not more than two computer printout pages summarising the project and its general progress (e.g. in about fifteen major items).

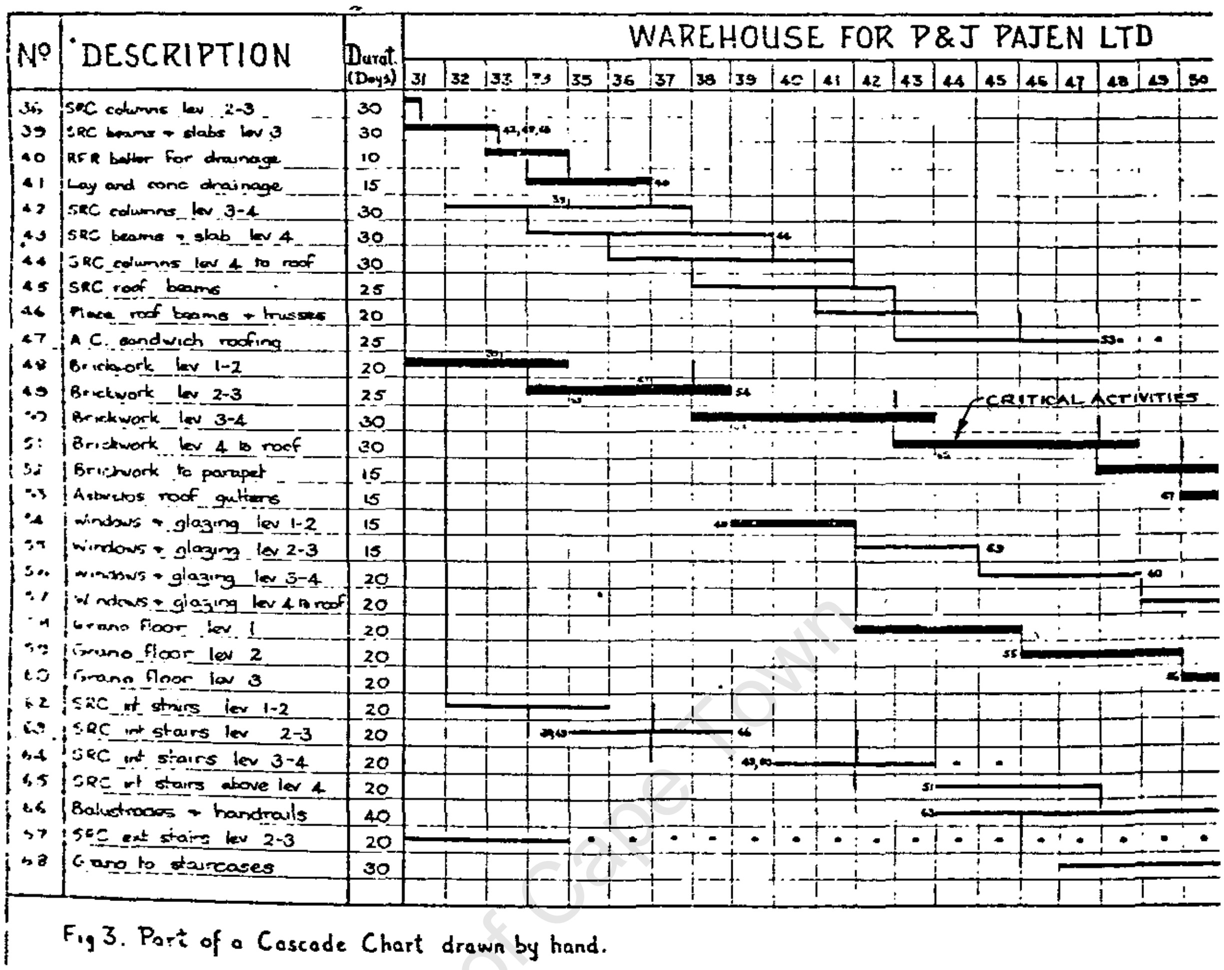

FIGURE 5.3: An example of a Cascade Chart (Rist, Ref. 17)

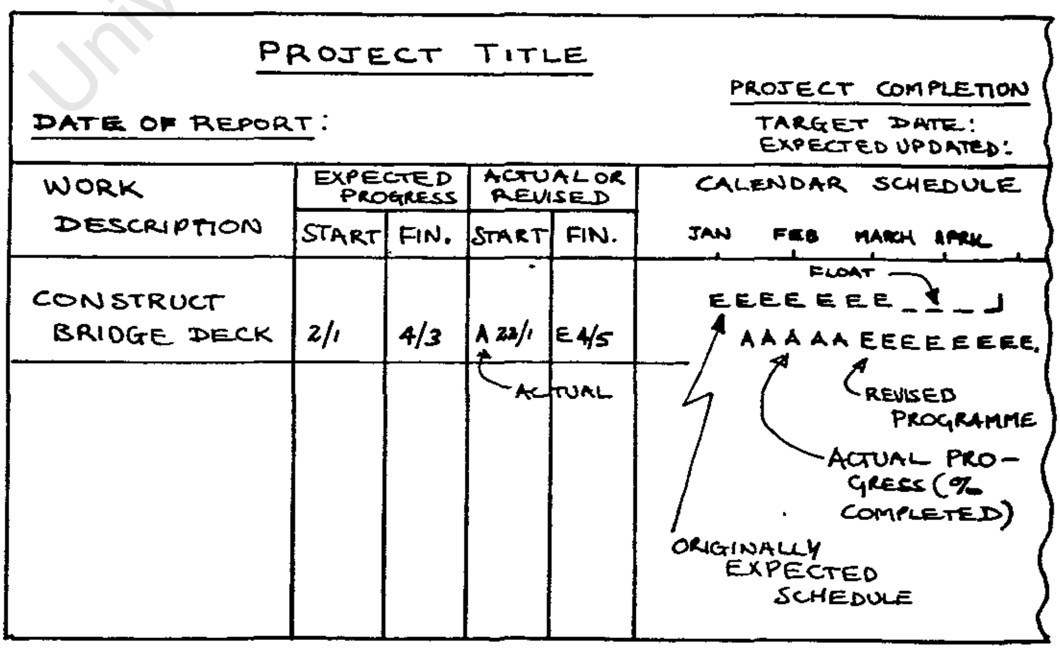

FIGURE 5.4: Suggested layout for a Computer printout of a top Management bar chart

(ii) <u>Bar chart for site staff</u> - a detailed printout of the above bar chart which is made either for the whole contract or portions of the contract (not more than say 20 pages). This detailed bar chart is taped together or redrawn by a draughtsman (Output B).

(iii) <u>Detailed calendar printout</u> - this should preferably not be taken to site and should only be used by the planner to check the computer calculations, input data, etc. An example of this printout is shown in Output A of Appendix D.

A suggested layout for a top management report produced by a computer programme is shown in Figure 5.4. This will show only the fifteen to twenty main portions of a contract, their expected start and completion times, their actual progress and any revised times.

One way of obtaining such a condensed report from a computer would be for the planner to draw the network in skeleton form first where each major operation is actually a subnetwork. Alternatively, one might use a common input code mark for certain activities when the details of these activities are fed into the computer programme. This code mark causes the programme to combine the computer output for these activities into one major operation shown as one bar on the top management report (e.g. all computer input cards for bridge deck operations might be marked with B/D).

An important point to note is that each subnetwork should ideally be an entity with a single start and end point. If this is not done a split bar might be scheduled as shown in Figure 5.5. As each segment of the activity in Figure 5.5 can have a different amount of float, this fact must be taken into consideration when reviewing progress. In Figure 5.5 the first segment can be delayed slightly but the second portion might have no float.

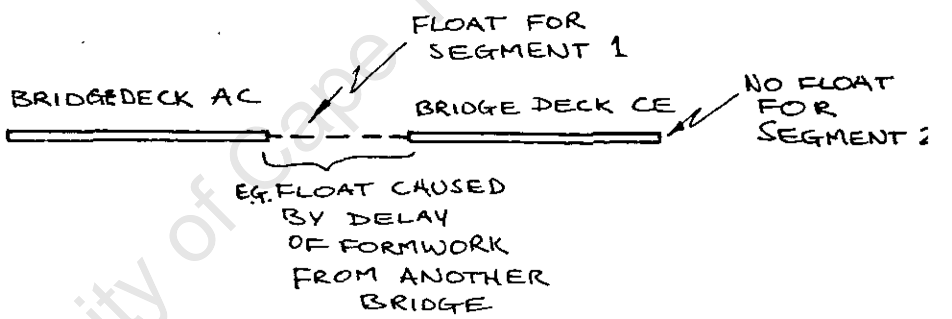

Figure 5.5: Significance of split bar in the top management report

If actual progress is recorded graphically on the chart, this is best done as shown in Figure 3.1 by colour shading from the left to show actual progress to date on each bar. For progress reports prepared by computer a second bar is drawn showing actual starts, finishes and revised dates (see Figure 5.4). Actual progress for a particular subnetwork is determined by the time progress (i.e. percent of work completed) of those operations with the least total float, since these determine the overall duration of the bar representing this subnetwork.

As a contractor is generally required to provide the client or consultant with a work programme it is expected that a chart similar to the top management bar chart might also be suitable for this purpose.

The approach for condensing a computer-prepared site bar chart into a usable document depends largely on the size of the contract. For a small project (e.g. 100 operations) a computer printout will not be excessive, the pages of which can be pasted together to form a single diagram. On a medium-size contract one might consider only those operations which will occur three months in advance, using the top management bar chart for a complete review. Alternatively, separate schedules might be prepared for various portions of the contract for example, concrete work, substructures, earthworks, etc.

On very large projects where sections are often still at the design stage it is unlikely that the contractor will be able to prepare a detailed network for the whole contract at the start. There might for example, be a master network showing only the main components of the structure (e.g. dam foundations, main wall, etc.) each consisting of smaller skeleton networks with slightly more detail (e.g. first level concrete, pumphouse structure, spillway, etc.) and for which overall time estimates have been made. Detailed subnetworks are then drawn only when they are required or when the plans become available from the designer.

On this type of contract the computer outputs would have to be designed with particular care to avoid complete confusion. It is suggested that the subskeleton operations be treated as medium sized contracts for which the outputs described above can be used.

A cascade diagram as shown in Figure 5.3 will be more useful than the conventional bar chart because the interdependancies between the various operations are shown.

The procedure suggested by Rist (Ref. 17) for constructing a cascade chart is as follows: When the network has been drawn, the activities on each path of consecutive activities are numbered consecutively from start to finish. Activities are numbered only once which means that certain paths to which numbers are initially assigned will be long, while the remaining parallel paths which are subsequently numbered might consist of only one or two activities. When the activities are then listed in numerical order a diagram as shown in Figure 5.3 will result. It is the opinion of the writer that a better approach will be to sort the operations firstly by their increasing total float and then by increasing early start time. This will avoid the intermingling of critical and subcritical operations shown in Figure 5.3 and will group the most important activities near the top of the diagram. The small numbers on the bars in Figure 5.3 show the number codes of other dependent activities and hence provide additional information concerning the logic of the project.

B) <u>Project resource utilisation</u> (Outputs D and E in Appendix D)

In Section 5.2.1 B it was described how the plant, labour and material requirements of the project can be allocated to the various network operations. Using the activity timing as determined for the project network programme a forecast showing the demand of these resources during construction can be obtained. The output diagrams D and E will lend themselves to various purposes; for example:-

(a) <u>Preplanning of inventory</u> - The construction industry frequently experiences periods of shortage of certain materials (e.g. reinforcing steel, bricks, cement, etc.). Contractors are therefore required to plan their stocks or place their deliveries long beforehand to avoid delays in construction. Figure 5.6 shows a possible procedure for preplanning the delivery of cement to site (e.g. monthly) taking into account that the material may not be retained in the store for too long to avoid spoilage (e.g. S = one month). A line xy is found on the cumulative diagram (Figure 5.6) such that S' does not exceed the permissible maximum retention period S. The slope of this line is then plotted as an ordinate on the demand diagram (see Figure 5.6) which shows the comparison between the average quantity to be ordered and the actual pattern of use for each period of time.

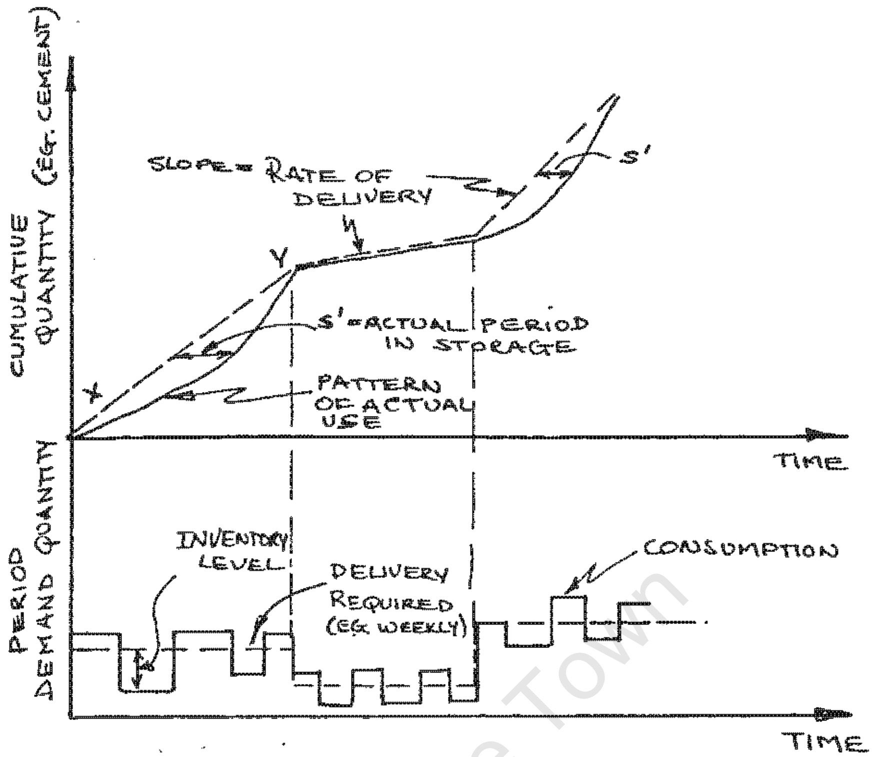

Figure 5.6: Preplanning cement delivery

From the certical difference between the demand and delivery curve (Power diagram Figure 5.6) the size of the store can be deduced for;example, the maximum difference plus 10% to allow for possible stockpiling caused by delays in consumption.

(b) Setting productive output targets - For certain materials the actual quantity completed is often a good measure of the physical progress of a site. For example, if on a concrete intensive project the average monthly output of constructed concrete is expected to be 2 000 m^3 and the cumulative total to date is 3 000 m^3 short of the target quantity (see Output D in Appendix D) then one might assume that the contract is about 6 weeks behind schedule.

(c) Determining project plant and labour schedules - Once the project demand curves for plant and labour have been drawn (either after a resource allocation or Critical Path time analysis) further refinements might have to be made to the network until these demand curves are acceptable. At this stage the contract manager can then draw up a schedule as shown in Figure 5.7 which must be correlated with other projects requiring the same resource.

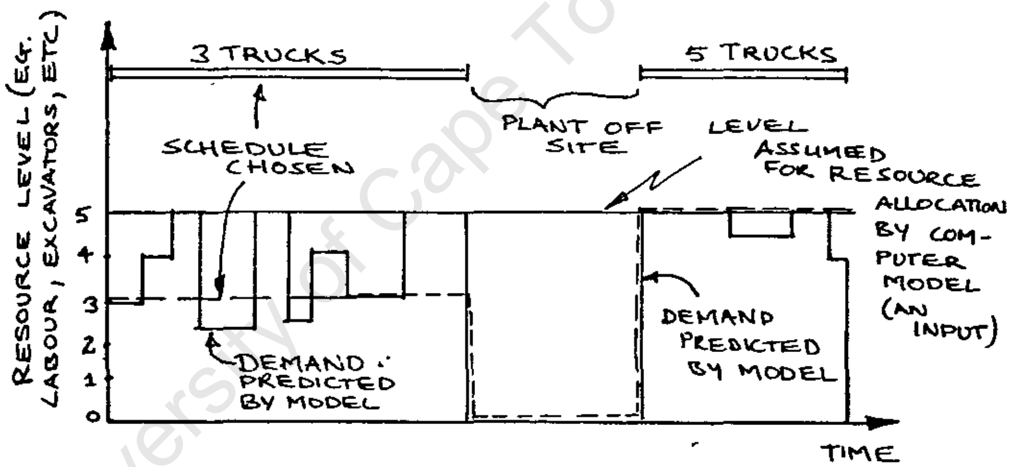

Figure 5.7: Plant schedule derived from a resource demand curve

It might be noted that various multi-project resource allocation models have been developed which will automatically pre-allocate all the resources of a company to all of its committed projects (e.g. Ref. 10). A process similar to that for project resource allocation is followed (see Section 2.4.1). The writer is, however, of the opinion that this would be completely unacceptable to large contractors who generally prefer to allow the contract managers a certain amount of freedom to negotiate between themselves or via the top executive (e.g. director) in charge of a number of contracts. However, a computer programme which attempts to allocate major plant to the various different contracts can be useful to serve as a warning guide for possible future demands by the various site managers, even if the actual allocation is done via top executives. The programme could for example, warn a company of the need to order a crane or to make an advance booking for the hire of an extra crane. For smaller contractors the amount of programming required to revise the plan when plant breakdowns, delays and hold-ups due to weather occur would be too costly. It is nevertheless important that the cost of transporting plant to and from site and the relative priorities of the various projects are taken into account.

(d) Preplanning subcontractor requirements - As the concrete batching plant has limited output capacity it might be necessary in urban areas for the contractor to use ready mixed concrete to avoid delays during certain periods of peak demand. It can be seen from Figure 5.8 that certain local peaks can be accommodated by overtime work while other large peaks will require an outside supply.

Using the same diagram the contractor might also investigate the possibility of either using a bigger site mixer or more ready mixed concrete.

This could be done by comparing the relative costs of the areas above and below the horizontal capacity line of the batching plant (Figure 5.8).

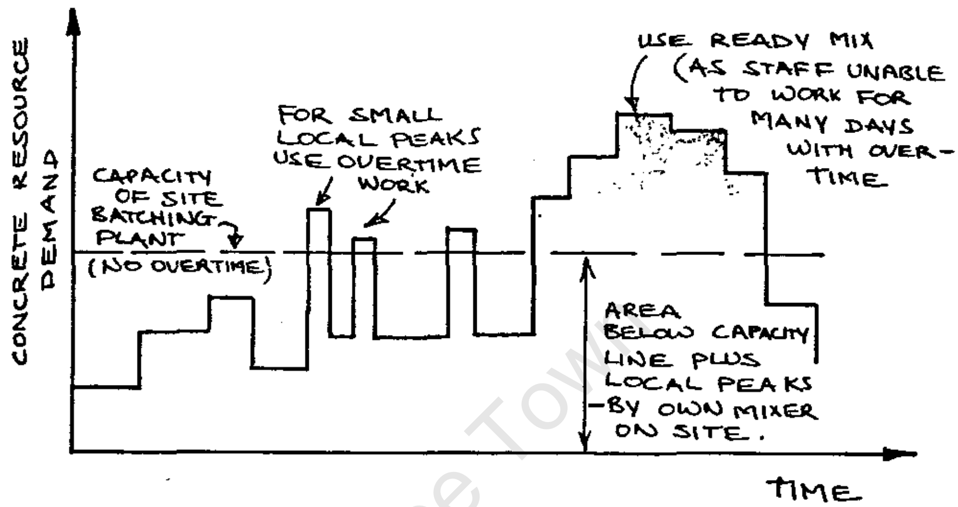

Figure 5.8: <u>Planning concrete supply</u>

For the ready mixed supply the cost per unit quantity will be relatively constant while that for site mixed concrete will decrease with the total quantity for the project because of the set-up, dismantling, maintenance and idle time costs. In Figure 5.9 (a) the total cost of two batching plants with different capacities (and hence different quantities of ready mixed concrete which must be supplied during peak periods) are compared. The small mixer (or batching plant) has a lower set-up and dismantling cost (including transportation) than the large mixer, but other costs (e.g. labour, servicing) which are approximately proportional to the amount of concrete placed are lower for the large mixer. For both the small and large mixer the amount of ready mixed concrete can be determined as shown in Figure 5.8. The output capacity line of each mixer is plotted on the same diagram as the project concrete demand curve.

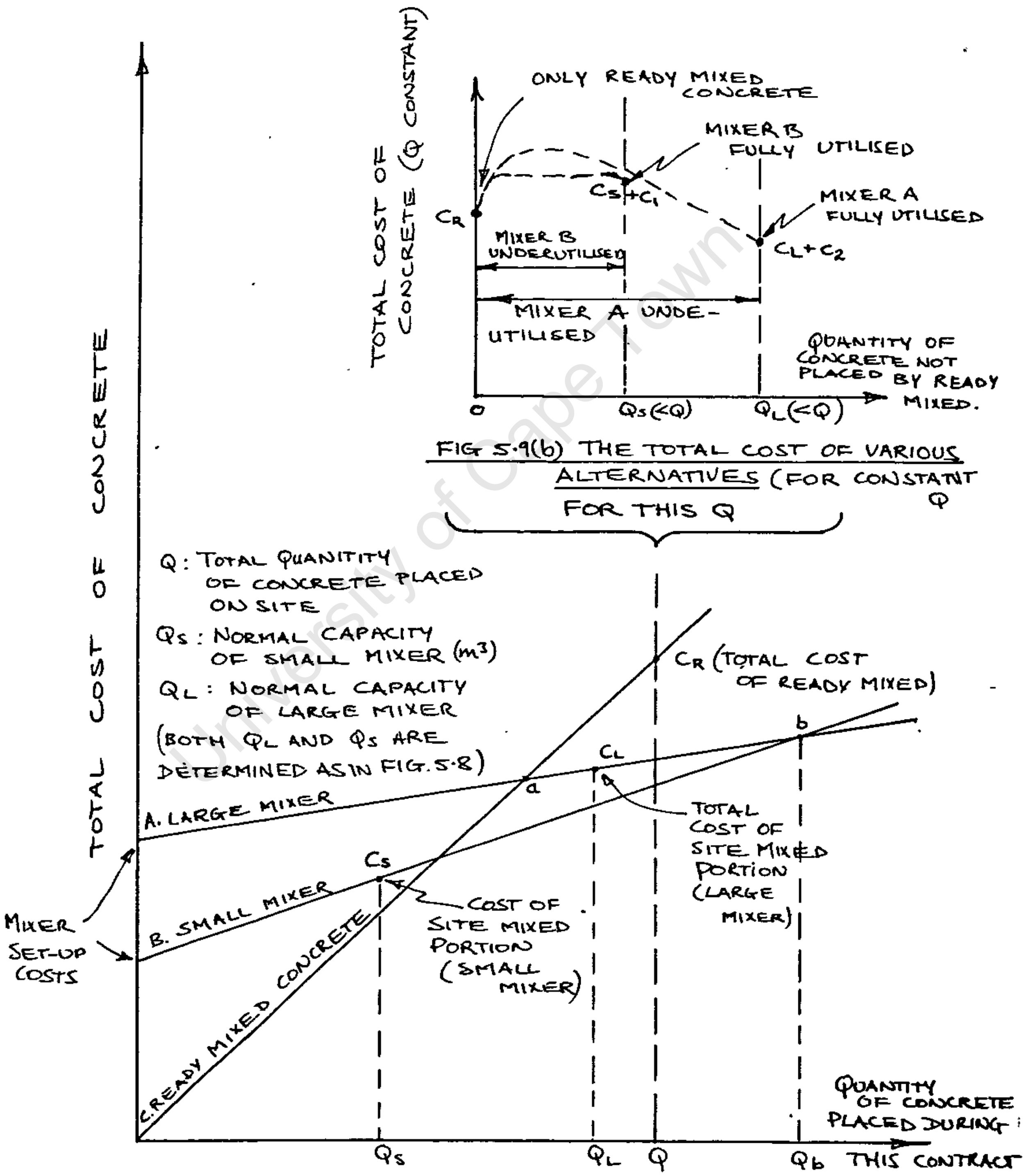

FIG 5·9(b) THE TOTAL COST OF VARIOUS ALTERNATIVES (FOR CONSTANT Q)

Figure 5.9 (a): The cost of concrete placed during construction

Any concrete demand peaks above the capacity line of each mixer which cannot be accommodated by working overtime, can be regarded as the concrete quantity which must be obtained from an outside source. The remaining quantity (i.e. not obtained as ready mixed concrete) is the amount of concrete which will be mixed on site during construction.

For the hypothetical site in Figure 5.9 (a) the total quantity of concrete (Q) which is required during construction can be obtained from three different sources. Firstly, all concrete might be ordered from an outside firm in the form of ready mixed concrete. The total cost of this proposition is the vertical ordinate C_R (Figure 5.9 (a)) which intersects the ready mixed concrete total cost line (curve C), when this vertical ordinate is plotted at point Q (the total quantity of concrete required by the site). The second possibility is to use a small mixer to mix a certain portion of the concrete on site and to obtain the remainder in the form of ready mixed concrete from an outside source. The quantity of concrete to be mixed by the smaller mixer during construction (Q_s) is determined from Figure 5.8 as described above. (The total area of the concrete demand curve below the mixer capacity line plus any overtime peaks.) The total cost of this proposition is then $C_s + C_1$. Where C_s is the total cost of mixing the quantity of concrete

Q_s on site with the small mixer, and C_L is the cost of obtaining the remaining quantity $(Q - Q_s)$ as ready mixed concrete (see Figure 5.9 (a)). For the large mixer a similar calculation is performed to determine the cost (C_L) of mixing a certain portion (Q_L) of the total quantity of concrete (Q) on site, and the cost (C_2) of obtaining the remaining quantity of concrete $(Q - Q_L)$ from an outside source. The total cost of this alternative is then $C_L + C_2$.

The total costs of the three propositions (i.e. C_R if only ready mixed concrete is used, $C_s + C_1$ for part small mixer plus part ready mixed concrete and $C_L + C_2$ for part large mixer and part ready mixed concrete) are shown plotted against the quantity of concrete not obtained in the form of ready mixed concrete in Figure 5.9 (b). It will be seen that for the particular example in Figure 5.9 (a) the cost of using the large mixer to mix quantity Q_L of concrete on site, and using ready mixed concrete for the remainder $(Q - Q_L)$ is the most economical alternative. This conclusion will hold even if the total volume Q changes during construction, as long as Q does not become less than Q_L (Q_L assumed fixed) or larger than the quantity (Q_b) which corresponds to the break-even point (b) between the large and small mixer (see Figure 5.9 (a)).

5.2.3 Progress Control

This is the process which starts when the construction manager compares the actual and planned physical progress of a contract. In previous sections a number of techniques were described which might be used to control the physical progress on a site; for example, one might examine the activity work programme (Section 3.2.1), or compare the actual and expected quantities completed (Section 5.2.2 (b)) or evaluate the total earnings to date (Section 3.2.3).

The target standard against which actual progress is measured in these three methods depends largely on the frequency of updating (i.e. revising the original plan by re-evaluating the remaining work as if it were a new project). The two possible courses of action here are:-

(a) Schedules are frequently updated - actual progress to date is compared with the most recently revised plan,

(b) Schedules are revised only when there is a fundamental change to the original plan - actual progress is compared with the original schedule.

Many authors (Ref. 3, 7, 12) are of the opinion that frequent updating (i.e. method (a) above) is essential for proper control. Performance to date is used to forecast the performance of future work, and where necessary the programme for the remaining work is altered to make up for previous time slippage. Jha (Ref. 7) for example, has suggested that weekly site meetings should be held at which the previous work schedule is updated manually, and once every month the activity durations should be revised and the programme re-processed on the computer.

In the experience of the writer one of the arguments against frequent updating is that the project might appear to be on schedule unless all the early schedules are retained for comparison with the later time estimates. It is considered to be most important that site staff are constantly motivated into trying to catch up on lost time and they should be aware of this lost time. Another problem is the cost of collecting and processing the data. For most projects frequent updating is feasible only when a computer is readily available and when site staff co-operate with the feedback of information.

It is the opinion of the present writer that taking into account local conditions it is better to avoid too frequent revision of the schedule. The choice should be left to site management who must decide when this is necessary. For example, when there are changes to the fundamental construction approach, when progress is so far behind that supervisory staff begin to lose interest when the activity dates are no longer meaningful. Office management might request an updating of the schedule when progress is so good that the schedule can be tightened up. For normal site progress control one or more of the graphical techniques described in Sections 3.2.1, 3.2.3 and 5.2.2 can be used. At each review date (e.g. weekly) the actual progress can be marked-up manually on these diagrams; for example, by colouring in the bars on the bar chart, plotting the actual quantity of formwork fixed, etc., and then comparing this to the expected progress.

When it becomes necessary for the planner to update the project plan he will then specify the following information:-

1. The remaining duration of each operation (this will be zero if the operation has been completed) - see Input 11.

2. Alternatively, one might prefer to specify the completed percentage from which the model can then calculate the remaining duration.

3. The quantity of work remaining for each operation in the case of those activities where the duration is determined from the work quantity and expected team outputs (see Section 5.2.1) - see Input 11.

4. Revision of the original activity input such as the daily plant and labour required (Input 3), their expected target work output (Input 3), logic changes to the network (Input 1), additional operations (Input 1), etc.

5. Revision of the project input for example, required completion date (Input 8), plant and labour available (Input 7), etc.

New schedules and expected output curves can then be constructed by the computer model which treats the remainder of the work as a new project.

5.3 Cost Control within the Proposed Planning Model

The principle of cost control as previously introduced in Section 3.2.2 is to divide the project into one or more sections (cost centres) for which both actual and allowable costs can be determined with the objective of identifying portions of the contract which are proving less economical than expected.

In this section a brief outline is presented of the cost control system suggested for use with the model in Appendix D. The emphasis is on a flexible overall approach which operates as follows:-

(i) Detailed site financial control is through the direct cost centres (in which the cost varies directly with the work quantity). For these only the plant (hired and owned) and labour costs are collected (i.e. allocated) on site. These costs include the contractor's concept of allocated plant depreciation costs.

(ii) Material costs are only considered for the project as a whole and not to the same detail as the various cost centres.

(iii) Overhead costs (e.g. site establishment, staff salaries, insurance, head office building costs, tax, etc.) are mainly collected in the head office and are allocated and reviewed via indirect cost centres.

(iv) Allowable target costs for all cost centres are derived from the estimator's cost estimate on which the tender price was based. These are used for comparison with the costs in (i), (ii) and (iii) above.

5.3.1 Pre-construction Cost Control Input

A) Cost centres (Input 4 of Appendix D)

It is proposed that a list of standard descriptions be established for company-wide use, from which a contract manager can compile a list of the necessary cost centres (i.e. cost headings) required for each contract (see Section 3.3.3 D). An example of such a list is shown in Table 5.1.

Ref.	Operation	Ref.	Type of Material	Ref.	Location
E	Earthworks				
1	Filling	1	Topsoil	1	Foundation
2	Cutting	2	Rock	2	Sewers
3	Excavation	3	Extra for Hard	3	Manholes
4	Trenching	4	Bulk	4	Pipes
	etc.		etc.		etc.
R	Roadworks				
13	Subbase	9	Crusher-run	15	Parking area
14	Basecourse	10	Chip and spray	16	Shoulders
15	Surfacing	11	Bitumen treated	17	Sidewalks
16	Kerbs/channels	12	Concrete storm-water works	18	Roadways
	etc.		etc.		etc.
C	Concrete Structures				
24	Formwork	17	Steel panels	18	Columns
25	Reinforcement	18	Timber	19	Abutments
26	Concrete	19	Ready mixed	20	Substructure
27	Prestressing	20	Site mixed	21	Culverts
	etc.		etc.		etc.

Table 5.1: Predefined cost centres and work items

There are various advantages in having a list of predefined cost centres for the firm. Standard descriptions will contribute towards reducing possible errors caused by misinterpretation both on site and in the office. It is expected that staff will soon become familiar with the descriptions corresponding to the various cost centres. This applies particularly to estimators who might wish to use the recorded productive output of labour* (e.g. area of formwork fixed per carpenter hour) for the pricing of subsequent contracts. Furthermore when computers are used to prepare cost reports it will be an advantage to have only one set of cost centre descriptions which can be stored in the machine, rather than having to prepare a fresh list for every contract.

It is the opinion of the writer that a list of flexible predefined cost centres, (e.g. an enlarged version of Table 5.1) will be suitable for all the various types and sizes of construction contracts on which a Civil Engineering contractor might be engaged. A breakdown into three simultaneous code divisions as in Table 5.1 is preferred to one of only two divisions (as suggested in Ref. 6, 3) as greater extremes of detail are possible.

Although the eventual choice of specific cost centres, for both the company-wide standard list and for a particular contract, will vary from contractor to contractor,

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*Plant output is generally very sensitive to location, type of material, slope of ground, etc. and more formal method study is required to collect this data.

a number of examples are described to illustrate the manner in which a list such as Table 5.1 might be used in practice.

When resources for collecting costs on site are limited the contractor might decide to establish only one or two cost centres consisting of the largest cost items in the Bill of Quantities. On a roadworks contract a likely choice would be the subgrade quantity item while on bridgeworks formwork costs can be chosen because the erection and stripping of formwork is often prone to cost overruns. When there are only one or two cost centres on a contract it is usually possible for the site engineer to collect the necessary cost data himself without seriously affecting his other duties on site (see Section 3.2.5). The advantage is that no additional costing clerk is needed to allocate costs and in any case the engineer is usually more aware of the engineering factors contributing to the costs.

For more detailed cost control one might divide the work into the various general items of production such as formwork, subbase, concrete, excavation, etc. Further subdivision is also possible; for example:-

24.00.19	Formwork to Abutments
24.00.18	Formwork to columns
14.11.15	Base course; bitumen treated to parking areas, etc.

Should a contractor wish to use the activity-costing* approach for a particular contract he can do so by choosing the cost centres and network operations from the same list.

Major cost centre:	24.00.00	Formwork
Operations :	24.00.19	Formwork to abutments
	24.00.18	Formwork to columns. etc.

The network operations are related to the cost centre by virtue of their first code numbers and hence can be grouped under a single cost centre heading for cost control purposes (see Section 3.3.3 D).

Alternatively, one might use the operational approach suggested by Barnes and Gillespie (Ref. 3) which uses a few large elements of work to depict the project cost centres which would also correspond to network activities.

For example, two different cost centres are identified by different third numbers:-

00.00.18	Construct columns
00.00.19	Construct abutments

(These network activities might still require start and closure event numbers for arrow network analysis.)

This is somewhat different to the contractor's normal approach of using groups of Bill items with similar units of quantity (e.g. area of formwork, weight of

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*Described in Section 3.3.3.

steelfixing, etc.). It is, however, expected that site clerks will find it easier to collect cost data since plant and labour will be more readily identifiable with particular operations. The one disadvantage here is that one must balance the detail to which costs can be feasibly collected on site and the detail required for future planning purposes.

A predefined list of cost centres could also be established for indirect costs (e.g. site and head office overheads) but this list will be fairly similar for the various types of contracts. As in the case of the direct cost centres (Table 5.1) the breakdown of the indirect cost centres depends on the preferences of a particular contractor and hence those costs might simply be collected under the heading of "overheads". For more detailed control a further breakdown is possible, as follows:-

Staff salaries,
Site offices,
Allocated head office costs,
Transportation of plant to site,
Batching plant,
Dismantling of crusher,
etc.

Whatever the detail used, it is important that indirect costs are collected separately since many of the overhead items also contain plant and labour elements (e.g. the carpenters used in setting up and maintaining the site offices) which would otherwise be collected as direct costs and thus provide false records.

It is interesting to note that site overheads (i.e. staff salaries, site offices) are in fact direct costs with regard to head office accounts of a firm as a whole, since these can be exactly identified with a particular contract. But in this thesis (and in practice) these costs are called indirect costs because in the accounts for a particular site, the staff salaries, costs of setting up site offices, insurance, etc. might be regarded as indirect costs for the site as these cannot be identified with a particular activity or with a particular constructed portion of the final work. Head office overheads (e.g. building costs, typist salaries, director's fees, plant yard, tax) on the other hand are costs which can be allocated to the various contracts on a pro rata basis and hence indirect cost centres for this item can be set up for each contract in order to determine the nett profitability of the contract.

B) <u>Allowable Target Costs of Cost Centres</u> (Input 4 of Appendix D)

In Sections 3.3.2 and 3.3.3 the advantages and disadvantages of various types of target cost standards for cost control purposes were briefly discussed and the writer concluded that the original <u>estimator's cost</u> should be used as the target cost.

Alternatively, other systems (e.g. models 1 and 2 in Appendix A) require that the contractor should determine his target cost standard from the actual expected method of construction.

For the direct cost centres the allowable target costs of the plant and labour* are derived from the estimator's cost (without profit) of the various Bill of Quantities items which are contained in each cost centre. The following example shows that it is important that the estimated costs of these Bill items be examined to ensure that only those costs which can be feasibly recorded for a cost centre are included. Consider a typical Bill estimates for a service supplied by a local Civil Engineering contractor as in Table 5.2.

Bill item: Excavation for culverts 500 m^3

Description	Output per hour	Hourly rate	Total plant cost	Total labour cost
Liebherr excavator	10	4.00	R200	
Operator of excavator	10	1.50		R 75
Backfill by labourers	0,5	.50		R500
Handcompactor	5	1.00	R100	
Water cart and driver @ 30 hours		3.50	R105	
Compressor and breakers @ 20 hours		2.00	R 40	
	Total cost		R445	R575
	Unit cost per m^3		R0.89	R1.15

Table 5.2: Example of a cost estimate for a Bill item

*It is assumed that one can at least identify the estimated target costs for plant, labour, materials and subcontractor for each Bill item in the estimate prepared for a tender.

For practical purposes it will probably be too difficult to associate the hours worked by the handcompactor with a particular operation because no record book is kept for the handcompactor and there is no permanent operator for this equipment. Costs for such items should rather be considered on a weekly or monthly basis as a site overhead and it would therefore be better to remove these costs from the cost centre in which the above Bill item will be included. A separate cost centre for site overheads would then include the costs of the handcompactor.

A number of Bill items are now grouped into a few cost centres and as construction proceeds the allowable target cost for each Bill item (and hence each cost centre) is obtained by multiplying the allowable target cost rate of each Bill item with the corresponding quantity of completed work. (If necessary costs such as handcompactor costs can be kept out of the target cost.)

Materials are considered as a cost centre on their own, either as the sum total for all the Bill items or the materials are separated into different sub-headings. For example, the estimated concrete materials cost for the concrete item in the Bill might be R5,50 per cubic metre (without profit and unbalancing) consisting of:-

Sand @ R0.70 per m^3 of concrete
Stone @ R2.60 per m^3 of concrete
Cement @ R2.20 per m^3 of concrete

Separate accounts (cost centres) can then be established for sand, stone and cement for which the allowable cumulative cost at any point in time is determined from the cumulative volume of concrete placed.

Indirect allowable target costs which are recurring or which occur as lump sum costs during construction must be grouped according to the estimator's breakdown since these are generally summed under a single lump sum Bill item of "Preliminary and General" in the Bill of Quantities. For example, the estimator might have calculated the following Preliminary and General costs:-

Supervision cost : R4 500/month for 10 months

Mixer on site : R 100/month for 3 months

Initial and final transport of plant to and from site : R10 000

(Assume daily plant transport costs to and from site are zero.)

At any point in time the allowable overhead cost is then determined by examining the thinking behind the estimate. In this example, once the work is under way one could assume that 50% of the total transportation cost have been incurred. Similarly the time-related overhead costs (supervision and mixer) are evaluated according to the number of months which the contractor has been on site.

5.3.2 Cost Collection on Site (Input 10 in Appendix D)

A possible precedure for use with the model in Appendix D might be as follows:-

(a) Labour costs - These are allocated daily for the various direct and indirect cost centres on site in the form of hours worked. Working hours are then converted into costs by multiplying hours by an average site wage rate for each trade (e.g. labourers, carpenters, etc.). These labour costs are then included in the computer Input 10 in Appendix D.

(b) Heavy mobile plant - The operating hours of plant can probably best be derived from the operator's machine book which must show the actual working hours for each job as well as breakdown and other idle time. It might be better to use a specific cost rate for each machine since an average rate for groups (e.g. excavators, bulldozers, etc.) will be too sensitive to the mix of high and low cost machines on site (see Input 10 in Appendix D).

(c) Materials - These costs can be determined from the delivery slips which are received. This will also include semi-permanent materials such as timber formwork but not staging and other equipment which might be treated as a site overhead for which costs are allocated monthly.

(d) Small items of plant - Power tools, carting tractors, handcompactors, etc. whose costs are difficult to identify with a particular cost centre can be treated as overhead items which incur costs on a monthly basis.

(e) Fixed plant and equipment - Costs of site mixers, steel formwork, staging and other items of equipment might form a part of a direct cost centre (which also incorporates labour, materials, etc.). The actual plant costs contributing to this cost centre could then be evaluated according to plant time on site. Since these records might not be meaningful for future contracts where the fixed plant will be different, an alternative is simply to treat these plant costs as a separate cost centre called "equipment overheads". These actual and allowable plant costs are then considered on a monthly basis.

(f) Site overheads - Although most of these costs can be collected in the office some will have to be identified and collected on site because the direct costs can be distorted by work which is not directly connected with the permanent work of the contract (e.g. the use of carpenters to set up a site office would be regarded as overheads and not as direct costs).

Various finer points such as whether to treat labour travel time, sick pay and overtime as direct or indirect costs and whether to consider plant idle time as an extra costable item depends on the costing organisation and preferences of a particular contractor.

C) Cost Collection Problems

From discussions with a firm of local contractors it was found that the main implementation problem of their cost control system was the recording and allocating of costs on the site. For this reason the firm had reverted to a system of "prime-costing" for which no data handling is required on site and only the four cost centres namely plant, labour, materials and sub-contractors are considered (see Section 5.3.3 B)). The main problems encountered in the original detailed system were:-

(i) Site foremen who were responsible for allocating labour hours on site made little attempt to do this accurately and generally entered figures hastily on the last day of the week simply to satisfy management,

(ii) Descriptions given by operators in their machine books were often unrecognisable or misinterpreted by site clerks,

(iii) The balancing of total labour hours allocated to the cost centres and total labour hours in the weekly wage sheets was generally time consuming and errors were frequent. These errors were usually due to inaccurate allocation of hours by site foremen.),

(iv) Problems associated with collecting material costs by cost centre and having to collect the records of the loads carted by the various operators and drivers are no longer necessary since the present system does not require this.

Although the writer has no experience of the collection of cost data a number of suggestions are made concerning these problems.

Regarding point (i) it is considered that the use of forms with preprinted descriptions and perhaps a personal cost report back to the site foremen might encourage greater participation by the foremen.

Similarly a book with preprinted headings for recording usage of major plant could be used, which the operator must deliver to the site office at the end of each day.

Very little can be done about reducing the time taken to balance labour hour reports with the total hours on the wage sheets as this check is necessary to avoid gross allocation errors. It will help if the head office master cost record on to which the daily labour hour reports are transferred has been properly designed to clearly show total normal and overtime hours for each trade. This permits easy checks against the total hours shown on the wage sheets.

5.3.3 Cost Control Reports

Three different types of cost statements for project cost control by site management, which might be obtained from the model proposed in this section, are described.

A) Standard cost report (Output G of Appendix D)

A listing of the various direct cost centres is provided in Output G showing their actual and allowable costs to date. A quantity of work completed to date and expected final quantity can also be provided if the Bill items contained in a particular cost centre are all of a similar type (e.g. area of formwork). An average unit cost (to date) can then be calculated for the cost centre (see Section 3.3.1).

The allowable target cost to date for a particular cost centre can be evaluated as follows:-

Cost centre: Subbase course

Bill items	Total quantity	Completed quantity	Plant Target rate	Plant Cost	Labour Target rate	Labour Cost
Subbase in roadway :-	10 000	5 000	1,00	R5 000	0,50	R2 500
Subbase in pavements :-	500	300	0,60	R 180	0,70	R 210
Extra for blasting :-	200	-	0,20	R -	0,30	R -
Total allowable target cost to date				R5 180		R2 710

Table 5.3: Calculation to determine allowable target cost of a cost centre

It is important that the plant and labour costs are also added together and compared with the combined target cost for each cost centre. This is especially important for an operation estimated on the assumption that plant would be used in fact labour was used (see Output G). In addition it might be useful for management to know the percentage proportion of the expected final total for each cost centre in relation to the total cost of the contract. This will indicate to management the relative importance of the various cost centres.

A similar cost report can also be prepared for the various indirect cost centres. Although actual indirect costs can be allocated to a single cost heading (e.g. site overheads) the allowable target cost must be determined from the thinking behind each item in the overhead estimate (see Section 5.3.1 B)).

B) Prime-cost report (Output J, Appendix D)

An alternative form of standard cost report is shown in Output J of Appendix D. This approach which is used by a local firm of Civil Engineering contractors considers labour, plant, materials and subcontractors as the main cost centres. At the end of each month the actual costs for the above cost centres are compared with the allowable target costs to date, which are calculated as:-

$$\text{Allowable total cost (e.g. labour)} = \sum_{i=1}^{n} r_i \; q_i \quad \ldots\ldots\ldots (5.1)$$

Where r_i is the part of the unit rate used for labour cost (without profit) for Bill item i in the tender estimate,

q_i is the cumulative quantity completed to date of Bill item i, from the monthly certificates,

n is the number of Bill items in the cost centre.

(A similar definition for r_i can be expressed for plant or materials.)

The main advantage of this approach is that no cost records need be obtained on site. Actual plant costs are obtained from the plant department, labour costs from pay sheets and material costs evaluated from the invoices (or delivery slips). The costs paid to subcontractors are determined from their monthly claim certificates.

One disadvantage is that specific reasons for cost overruns are difficult to pinpoint. In the practical system described above no differentiation is made between direct and overhead costs since this requires additional work on site.

It is the opinion of the writer that more significant control information will be obtained if separate target costs* are extracted from the Bill items for the most important components of plant, labour and materials.

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*A similar approach has been suggested by Everwyn (Ref. 8)

This depends on the type of contract under consideration. For example, on a roadworks project one might determine separate target costs (from the Bill items) for excavating and hauling plant, while on a bridge contract a separate allowable target cost for carpenters could be identified. The target costs for these items are evaluated in the same way as the overall cost centre using equation 5.1,

where r_i is now the estimated cost rate for carpenters for a particular Bill item i,

and q_i could be the area of formwork erected to date.

C) Combined Time-cost report

Should the contractor wish to combine his progress and cost control into a single diagram, a curve showing the cumulative expected expenditure over the project duration can be obtained (Output K, Appendix D) by allocating the estimated Bill item costs to the network operations (Input 2 in Appendix D). The Bill of Quantity items are grouped according to the activities in which they are expected to occur, either as a whole or in part (for example, see Section 5.4.2 (ii)). The allowable target cost of the activity is then the partial sum of these Bill items. The manner in which this curve might be used as a cost control tool is described in Section 3.3.3.

A particular problem of preparing timely cost control reports to management is often the time taken to collect and process actual costs. Should a contractor require this information more timely a projected forecast of the actual cost could be made by the following procedure.

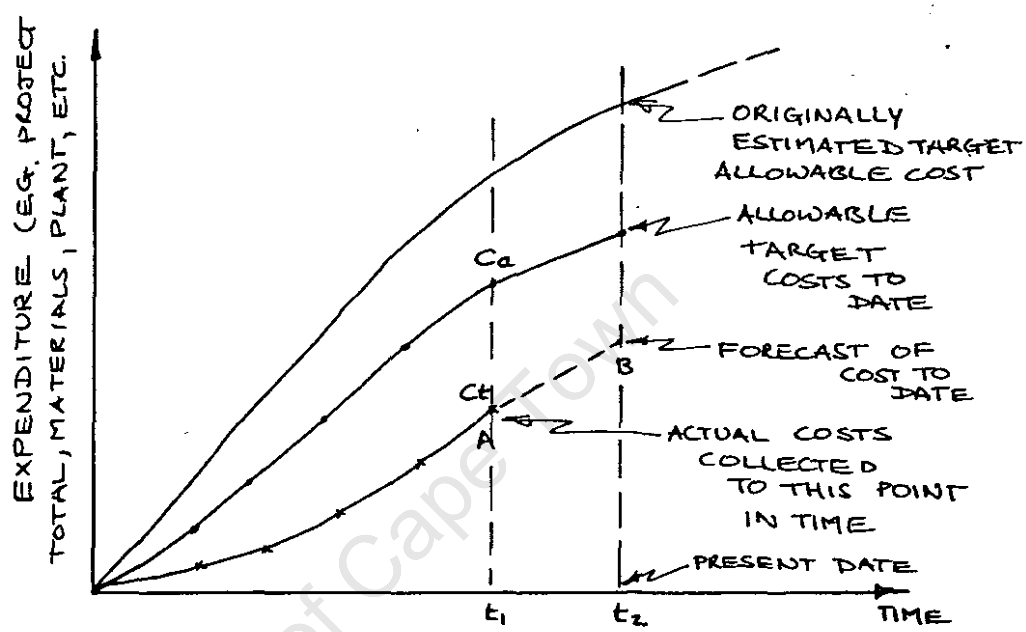

Figure 5.10: Forecast of actual costs to date

In Figure 5.10 actual costs have been collected to time A and an estimate is required for the actual cost to the present time or other date (point B). The ordinate of point B might be determined by either of the following methods:-

(i) The actual cost to time A plus the allowable target cost of the work which is expected to be done in the period t_1 to t_2,

or (ii) method (i) plus a percentage based on the increase (or decrease) in costs to date,

or (iii) the actual costs to A plus a complete revision of the cost for the new or changed operations and portions of operations representing the work in the period t_1 to t_2.

It is expected that for short periods of time method (i) will be sufficiently accurate. For longer periods a percentage trend factor might be used; for example as suggested by Moder and Phillips (Ref. 14).

% increase in estimated cost (period t_1 to t_2) = (after Moder and Phillips)

$$= \frac{C_t - C_a}{C_t} \frac{t_1}{t_2} 100 \qquad (5.2)$$

where C_t is the actual cost to date of the project,

C_a is the corresponding allowable cost,

t_1 is the time from the start of the contract to the present date,

t_2 is the time from the start of the contract to the date at which the estimated cost is required.

The authors (Ref. 14) included the ratio $^{t_1}/_{t_2}$ to take into account the fact that an apparent cost overrun near the start of a contract will probably have less affect than a cost overrun towards the end since there is more chance that early cost overruns will cancel out.

When method (iii) is used, the model directly evaluates the direct cost of the project (or remainder of the project) from the expected amount of plant, labour and materials required by each activity and their expected unit costs (see Section 5.4.2 (ii). Since this approach requires particular accuracy in allocating resources to each network activity (Input 3; Appendix D), it is doubtful whether contractors will consider this method worth the effort required in compiling the necessary input data. However, as stated earlier the model in Appendix D is an unsimplified theoretical model which is intended to show all possible significant inputs and outputs for discussion purposes.

5.4 <u>The use of the Planning Model for the Financial Planning and Control of a Contract</u> (Outputs H and I in Appendix D)

To aid top management of a construction company in making financial decisions relating to a particular contract the following two reports can be prepared with the model in Appendix D:-

(a) A revenue (money due from client) and expenditure (incurred cost) summary of a contract to determine its present and final anticipated profit,

(b) A cash flow forecast for the whole project including the contract's future payments and receipts.

These two reports are discussed in the following two sections:-

5.4.1 <u>Contract Revenue and Expenditure Report</u> (Output I in Appendix D)

Output I (in the model in Appendix D) is divided into two main parts:-

(i) A revenue and expenditure summary of all money due from the client and all costs incurred by the contractor to determine the present profit (or loss) of a contract.

(ii) A forecast of the estimated expenditures and revenue (and hence final profit) of a contract to its completion.

A) Profit to Date of a Contract

In Table 3.2 B (a) an example is shown of a typical cumulative contract revenue and expenditure statement which is prepared at certain predetermined intervals during construction (e.g. every three months). It will be seen that a similar report (i.e. the Income Statement in Table 3.2 B (b)) is also prepared for the firm as a whole, usually at the end of its financial year but sometimes also at shorter intervals. The revenues and expenditures of the various contracts form the bulk of the total revenue and total expenditure (costs) of the whole firm. (Other items such as head office costs and tax must be included.)

Interim contract profit (before tax) was defined in Section 3.3 C to be the difference between the total money actually paid by the client plus any money earned* for which payment has not yet been received) and the total contract and associated head office costs incurred by the contractor (i.e. money spent plus money promised

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*These unpaid earnings refer to all the money legally due to the contractor and include the Retention money retained by the client, dayworks due and a suitable proportion of the Preliminary and General item tendered by the contractors.

by the contractor). Since interim profit is not the true final profit of a contract and also because a certain amount of subjective estimating is needed to assess the amount of Preliminary and General money due (see footnote) this profit (before tax) is referred to as "estimated profit" in Output I of Appendix D.

B) Projected Profit to Completion of a Contract (Output I of Appendix D)

At an intermediate stage an estimate of the final projected profit of a contract can be obtained by making a projected estimate of the final total expenditure and revenue of the contract.

Final revenue of a unit price contract (see Section 3.3 B) might be determined from the sum of the following:-

(i) The total revenue expected from the final expected measured work according to the expected final quantities of all Bill items,

(ii) The total Preliminary and General sum included as a separate item by the contractor in his tender bid,

(iii) The revenue of total dayworks authorised to date by the client or his representative,

(iv) Additional revenue from cost escalation clauses which might be included in a particular contract.

To determine at any point in time during construction the estimated final expenditure a contractor might use one of the following approaches:-

(i) He might use the actual cost to date plus the originally estimated cost for the remaining work (taking into consideration expected increases in the quantities of the various Bill items plus any additional work which might have been added during construction),

(ii) Alternatively, he might use the costs in (i) and increase these by a certain percentage based on the increase in actual costs to date over those originally estimated (for his tender),

(iii) A third alternative would be to use actual costs to date plus an estimate of the cost of the remaining work based on the proposed method of construction and the types of resources (plant, labour, etc.) to be used.

It is expected that if the final costs are estimated towards the end of construction, or when there are few cost increases on a contract due to inflation, underproductivity and similar causes, method (i) will provide a reasonable estimate of the final expenditure.

In method (ii), various methods can be used for calculating a contract cost increase "trend" factor (based on past increases in cost). This factor is used to increase the originally estimated cost to determine an estimate of the final expected cost. One possible approach might be to use the factor suggested by Everwyn (Ref. 8) and used in Output J to determine the expected final cost of the various items in the prime cost summary (see Appendix D).

i.e. Cost increase factor f_i (after Everwyn) $= \left(\frac{C_t - C_a}{C_t}\right) 100$ (%) .. (5.3)

Where C_t is the actual cumulative total cost to date (e.g. of the whole project or a particular item such as labour wages),

C_a is the corresponding allowable target cost (i.e. originally estimated) to date,

and f_i is the percentage factor by which the estimated cost for the remaining work must be multiplied to estimate the expected extra cost for this work.

A similar technique suggested by Moder and Phillips (Ref. 14), which was adapted in Section 5.3.3 C (equation 5.2) for correcting short-term cost forecasts (based on current costs), makes a further adjustment to equation 5.3 to allow for the fact that apparent cost increases near the start of a contract will probably be less representative of the final cost overrun than those towards the end. Equation 5.3 is thus multiplied by the ratio of the time the contract has been in progress divided by the total expected duration of the contract. (In equation 5.2 the value of t_1 remains as defined here but t_2 is taken to be the final expected project duration.)

To use method (iii) the model (in Appendix D) must also be used as a cost planning technique which evaluates the cost of future construction from the method of construction, the amount of plant, labour and materials to be used and their unit cost rates (Inputs 3 and 7 of Appendix D).

5.4.2 Cash Flow Forecast for a Contract (Output H in Appendix D)

The purpose of cash flow forecasting in a firm was discussed in Section 4.1. It was shown there that in order for a construction company to determine a forecast of the firm's cash inflows (receipts) and cash outflows (payments) for a certain period in the future, separate cash flow forecasts are prepared for the various contracts on which the firm is engaged. These contract cash flow forecasts are then summed to determine an overall company cash flow forecast.

The suggested method for determining a contract cash flow forecast with the proposed planning model shown in Appendix D was introduced briefly in Section 4.1.2 B (Figure 4.6). The method of operation is as follows:-

(i) Receipts from the client to the contractor - The value and timing of the money due to the contractor from the client for measured work during construction is determined from the expected earnings for the completion (or partial completion) of the various network activities during each month of the project duration.

The timing and value of the actual money received by the contractor is then determined by delaying the revenue due for a particular month by the expected delay (Input 9 in Appendix D) in receiving payment from the client. The timing and value of the expected receipts for Preliminary and General Bill items, and the amount of money to be retained by the client during construction are also specified in Input 9 of Appendix D.

(ii) Payments by the contractor - In the model in Appendix D there are two ways of pre-calculating the timing and value of the direct cost payments (for measured work) which the contractor is expected to make during construction:-

(a) From the estimator's costs of the various Bill items contained in each of the network activities the total estimated cost of each activity can be determined. Input 6 contains the cost per unit quantity of plant, labour and materials, for each Bill item, while Input 2 indicates the proportion of each Bill item contained in a particular activity.

(b) Alternatively, the expected cost of each network activity can be determined from the actual units of labour, plant, etc. required by the activity and the prevailing unit costs at the time of planning (see Input 3 and 7 in Appendix D).

In both (a) and (b) above the timing of the actual payments for plant, labour, materials and subcontractors is determined from the timing of the activities in the work programme plus an expected payment delay by the contractor for each item (e.g. one month for subcontractors) as shown in Input 7 of Appendix D.

Indirect costs can also be determined by the two methods described above and can be allocated to "hammocks" or equivalent cost-only activities (see Section 3.3.3 C) to determine the timing of the costs from the network programme. A suitable delay can then be applied to obtain the actual timing of these cash payments by the contractor.

During construction the actual payments by the contractor and receipts from the client are specified as input to the model (Input 13 in Appendix D). Subsequent cash flow forecasts (see Output H of Appendix D) are then made by the programme for the remaining part of the project by using the cumulative payments and receipts to date as a starting point (see points P and R in Output H of Appendix D).

5.5 Summary and Conclusions with respect to the Planning Model (and this thesis)

The inputs and outputs of the proposed general idealised planning and control model in Appendix D were discussed in this chapter. Comparisons were drawn between the more extensive model in Appendix D, and the four currently used planning and control models (which are summarised in Appendix A).

The planning aspect of the model in Appendix D is either:-

(i) The Critical Path time analysis (see Section 2.3.1) - This technique can be used for projects where the activity interdependancies and the time restraints are the main consideration in establishing a work programme.

(ii) The resource allocation procedure (see Section 2.4.2) - This method provides activity network schedules for projects where limited levels of plant, labour and materials are available during construction in addition to the constraints in (i) above.

Furthermore, when there is an additional constraint in the form of a required target completion date, the model in Appendix D incorporates:-

(iii) The combined resource allocation and levelling technique (see Section 2.4.3) - In this approach an attempt is made to simultaneously satisfy the suggested plant, labour and material levels for the project and the target project completion date. The output is in the form of a suggested activity-time network.

For projects where the methods (i), (ii) and (iii) might be difficult to apply the model in Appendix D can use as input:-

(iv) The manually prepared bar chart or line-of-balance schedule (see Section 2.1 B) - The pre-calculated activity bar chart (and if necessary the required levels of the activity resources) are direct inputs into the model. Hence, even when there is only a bar chart available for a contract the model can still be used to determine "project cash flow versus time" forecasts, and expected "incurred cost versus time" curves, "future cumulative resource demand versus time" curves, etc.

As a project cost control technique the model uses one or both of the following:-

(v) The standard (or allowable target) cost approach (see Section 3.3.2) - A project is divided into a number of different portions or operations called cost centres. A list of predefined cost centres (e.g. Table 5.1) might be used to aid in choosing suitable cost centres for a project. During construction the actual recorded to date cost within a cost centre is compared with an allowable target cost. The target cost is determined by multiplying the quantity of work completed within a cost centre (to date) by the allowable cost rate per unit quantity from the estimator's tender cost estimate (i.e. this is the tender price less profit, unbalancing and tax effects, etc.).

(vi) The combined time and cost approach (see Section 3.3.3) - The model prepares a "cumulative future project cost versus time" curve (over the project duration) from the time schedule and estimated target costs of the project activities. The model estimates the future allowable target cost to date, according to the future expected time progress of the project activities. At any future point in time the actual recorded project costs can be compared (manually) with this original estimate of the allowable cost to date.

In addition, for projects where the facilities for recording costs on site (e.g. site costing clerks) are limited the model uses:-

(vii) <u>The "prime costing" approach</u> (see Section 5.3.3 B) - This system has only four main cost centres; i.e. labour, plant, materials and subcontractors. During construction the actual recorded costs to date for each cost centre are compared with the estimator's allowable target cost for each cost centre (the latter is based on the number of completed units of quantity for each Bill item).

For the financial planning and control by construction management the model in Appendix D indicates the following two outputs:-

(viii) <u>A project cash flow forecast</u> (see Section 4.1) - A cumulative cash flow forecast is prepared from the activity timing schedule, the expected revenue and costs of the project activities, and the expected payment delays for these various revenues and costs. The future expected costs of the project activities can be calculated from either of the following:-

(a) the estimator's tender cost values, or,

(b) from the expected updated units (e.g. total loader-hours) of plant and labour resources necessary for construction, and their presently prevailing costs per unit working time.

(ix) A contract profit and loss summary (see Section 5.4.1) - The model provides a detailed summary of the project incurred costs and revenues (to date) and a projected estimate of total completion costs and total revenue at completion of contract. As in the case of (viii) above the cost of future construction can be estimated from either of the following:-

(a) the estimator's original allowable cost for the remaining work, or,

(b) from the expected updated quantity and an updated cost per unit quantity of the necessary plant, labour and materials.

Conclusions

Although the model in Appendix D is a general idealised system, it was thought advisable to first present this general model which has as much pertinent input and output information as possible.

Contractors can, if necessary, use the diagram of the model (in Appendix D) to choose simpler inputs and outputs than those shown in this model, in order that these forms of input and output will suit the practical requirements of their firms.

It is, however, strongly recommended that any construction firm contemplating the use of a computerised planning and control model should first undertake a thorough systems analysis:-

(a) To determine the systems which the firm intends to computerise.

(b) To determine whether the timely flow of required data from a site is feasible, both practically and economically.

(c) To ensure that the inputs and outputs of the model are compatible with the firm's method of estimating, recording of data, internal reporting, etc.,

and (d) To determine whether the necessary financial resources are available for the computing equipment and programmes envisaged.

The ultimate criterion as to whether a certain planning and costing model should be used is the degree of usefulness of the output to the managerial staff. No computer model should be used for its own sake.

The object of computing is to aid management.

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A P P E N D I C E S

A P P E N D I X   A

A SUMMARY OF FOUR SELECTED PLANNING AND CONTROL MODELS

The overall structure and basic inputs and outputs of the following four integrated planning and control models which have been specifically designed for construction contracts are summarised*:-

1. The ICL 1900 PERT (used by the Cape Town City Council, Ref. 10).
2. The Barnes and Gillespie cost model (used by Barnes and Partners, London, Ref. 3).
3. The Versprei system (available in Pretoria, Ref. 16).
4. The Cemplan system (used by the Cementation Co., Ref. 12).

Of the above, 1 and 2 are presently available to contractors in South Africa. Applications of the ICL 1900 PERT system, for example, to a large building contract in Durban, has been described in a Master of Business Science report at the University of Cape Town by Irvine (Ref. 15, Chapter 2).

A comparative summary showing the main inputs and outputs of the models is contained in Table A of this appendix.

1. <u>ICL 1900 PERT system</u> (Figure A.1)

   This model is a combination of planning using network techniques and cost control based on the original PERT/COST system of activity costing (see Section 3.3.3).

   (a) <u>Planning input (ICL model)</u>

   The resources for each network activity are specified independently, for example:-

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*These references are contained at the end of Chapter 5.

(i) activity duration; for example, 5 days

(ii) plant and labour for activity; for example, either 5 carpenters per day or 25 carpenter-days

(iii) materials; for example, either 100 m^3 concrete or 10 m^3 per day

If a resource rate per day (i.e. carpenters/day on m^3/day) is specified for an activity the model will use this rate even if a new duration is subsequently specified (e.g. 5 carpenters/day for 4 instead of 5 days). When a total resource quantity is specified (e.g. carpenter-days) the model will proportion this resource quantity uniformly over the specified duration. Should a new duration be specified without altering the resource quantity a new uniform resource usage rate will be calculated by the model. Figure 5.1 illustrates an additional feature of this ICL model which allows one to specify a non-uniform utilisation of resources for an activity.

The amount of plant and labour available during construction can be specified as both a normal and an overtime level. These resource levels are used both for resource allocation and cost control purposes.

(b) Cost control input (ICL model)

Cost centres can either be taken as single network activities, groups of activities (e.g. all formwork activities) or the project as a whole.

TABLE A: A Comparison of the Four Integrated Planning and Control Systems

TYPES OF INPUTS AND OUTPUTS			ICL 1900 PERT (REF. 10, CHAPTER 5)	VERSPREI SYSTEM (REF. 16, CHAPTER 5)	BARNES & GILLESPIE COST MODEL	CEMPLAN SYSTEM
INPUT DATA	PLANNING AND UPDATING DATA	1. NETWORK (I.E. N/W)	ARROW OR PRECEDENCE	ARROW OR PRECEDENCE	PRECEDENCE	PRECEDENCE
		2. ACTIVITY DURATION	SPECIFIED INDEPENDENTLY	SPEC. INDEPENDENTLY	CALCULATED FROM 4 & 5	SPECIFIED INDEPEND.
		3. ACTIVITY PLANT & LABOUR	RATE/DAY OR TOTAL	RATE/DAY ONLY	RATE/DAY	TOTALS PER ACTIVITY
		4. ACTIVITY MATERIALS REQD	DITTO	DITTO	FROM BILL ITEMS	IF REQUIRED FOR 19
		5. PRODUCTIVE OUTPUT OF PLANT AND LABOUR	———	———	FOR EACH ACTIVITY	FOR EACH COST CENTRE
		6. AVAILABLE PROJECT RESOURCE LEVELS	NORMAL AND OVERTIME AVAILABILITY	NORMAL & OVERTIME	NORMAL	NORMAL AND OVERTIME
		7. REQUIRED (TARGET) DURATION OF PROJECT	CAN BE SPECIFIED	CAN BE SPECIFIED	ONLY AS OUTPUT	CAN BE SPECIFIED
		8. DATA OF PROGRESS TO DATE	REMAINING ACTIVITY DURN.	ACTIVITY REMAINING DURATION	ACTUAL 3 AND 4	ACTUAL 2 AND 3
	COST DATA (& PLANNING STAGE)	9. DIRECT COST CENTRES	ONE OR MORE N/W ACTIVITIES	GROUPS OF BILL ITEMS	NETWORK ACTIVITIES	GROUPS OF BILL ITEMS
		10. INDIRECT " "	COST-ONLY ACTIVITIES (HAMMOCKS)	(IE. EQUIVALENT HAMMOCK ACTIVITIES - SEE. SEC 3.3.3)	(IE. EQUIVALENT HAMMOCK ACTIVITIES - SEE. SEC 3.3.3)	NOT DESCRIBED
		11. ALLOWABLE TARGET COSTS FOR 9. AND 10.	EXPECTED UPDATED FROM RESOURCE COSTS	ESTIMATOR'S COST	EXPECTED UPDATED	ESTIMATOR'S COST
		12. UNIT RESOURCE COSTS	FOR PLANT, LABOUR AND MATERIALS	——	FOR PLANT, LABOUR AND MATERIALS	PLANT AND LABOUR ONLY
		13. ACTIVITY COSTS	EXPECTED UPDATED. (3, 4 & 12)	ESTIMATOR'S COST	EXPECTED UPDATED FROM 3, 4 & 12	EXPECTED UPDATED FROM 3 AND 12
		14. SITE COST COLLECTION	ACTUAL COSTS FOR 9 AND 10.	ACTUAL COSTS FOR 9. AND 10.	ACTUAL COSTS FOR 9 AND 10.	ACTUAL COSTS FOR 9. ONLY.
	FINANCIAL	15. PROJECT REVENUE	——	FOR ACTIVITIES	FOR ACTIVITIES	———
		16. PAYMENT/RECEIPT TIME LAG	——	FOR RETENTION ONLY	FOR ALL COSTS AND REVENUES	———
		17. DATA OF ACTUAL CASH PAYMENTS AND RECEIPTS	——	ACTUAL CASH IN/OUT	ACTUAL CASH IN AND OUT	———
OUTPUT DATA	GENERAL REPORTS	18. WORK PROGRAMME	BAR CHART OR DATES	BAR CHART OR DATES	BAR CHART OR DATES	BAR CHART OR DATES
		19. RESOURCE UTILISATION FORECAST	PLANT, LABOUR, ETC.	PLANT, LABOUR, ETC.	PLANT, LABOUR, ETC.	PLANT, LABOUR, ETC.
		20. COST VS. TIME FORECAST	FOR PROJECT TOTAL COST, LABOUR COST, ETC.	PROJECT TOTAL COST, LABOUR, ETC.	FOR PROJECT ONLY	FOR PLANT + LABOUR
		21. CASH FLOW FORECAST	——	DETAILED CASH FLOW FORECAST	FOR PROJECT	———
		22. COST CENTRES RECORD TO DATE	AS A COST-TIME F/CAST	FOR PLANT, LABOUR, ETC SEPARATELY	PLANT, LABOUR, ETC.	PLANT, MATERIALS, ETC.
		23. OTHER COST REPORTS	(20) & ACTUAL TO DATE	? (NO DETAILS)	———	EXPECTED CUMULATIVE COST TO PROJECT COMPLETION
		24. PROFIT/LOSS REVIEW	——	?	TO DATE ; TO COMPLETION	———
		25. TIME RATE OF UNITS CONSTRUCTED	——	?	———	ACHIEVED OUTPUT (SEE 5)

Allowable costs of a particular activity are calculated from the specified type of plant and labour which the planner expects will be used on this activity. The model multiplies the labour and plant hours allocated to each operation by their corresponding unit hourly costs. If the resource allocation model has scheduled an activity to use overtime resources the correspondingly higher overtime rate must be used to calculate activity costs. Material costs can be calculated by the model in the same way or from the quantity to be used and the cost per unit quantity, or otherwise as a single lump sum which is specified for each activity.

Indirect costs are included as hammocks or cost-only activities (see Section 3.3.3 C).

From the individual activity costs, graphs of cumulative costs which are expected to be incurred over the project duration are plotted for plant, materials and labour. In addition, "cost to date versus time" curves showing only direct costs, plant costs, labour costs, etc. can be obtained. The manner in which such curves might be used as a control device by site management is discussed in Section 3.3.3 A.

(c) Input during construction (ICL model)

As construction proceeds the basic input for each progress review consists of:-

(i) Time progress - activities completed or their remaining durations,

(ii) The actual plant, labour and material costs of the activities or groups of activities to date (recorded on site),

(iii) The actual costs within the indirect cost centres to date.

Alterations to the input during construction can include new unit costs, revised methods of working (e.g. plant instead of labour), revised estimates of resources required, changed material quantities, etc. At each update a revised schedule is obtained from the above revised input.

(d) Outputs (ICL model)

Although the model is capable of providing a wide range of outputs for different levels of management (e.g. foreman's operations only) these outputs can be classed into three main groups:-

1. Work programmes - in bar chart or calendar date form,
2. The plant, labour or materials required for the whole project in each period during construction - both numerically and graphically (see Output B, Figure A.1),
3. Cost control outputs - from the description provided it appears that the cost control summaries are only prepared in the form of a cumulative cost versus time curve; for example, for plant costs, project total cost, project direct costs, etc. (see Figure A.1). On this graph the cumulative allowable target costs are plotted to a time scale for the whole project duration. A second curve showing the actual costs to date is then drawn to the same scale on this graph.

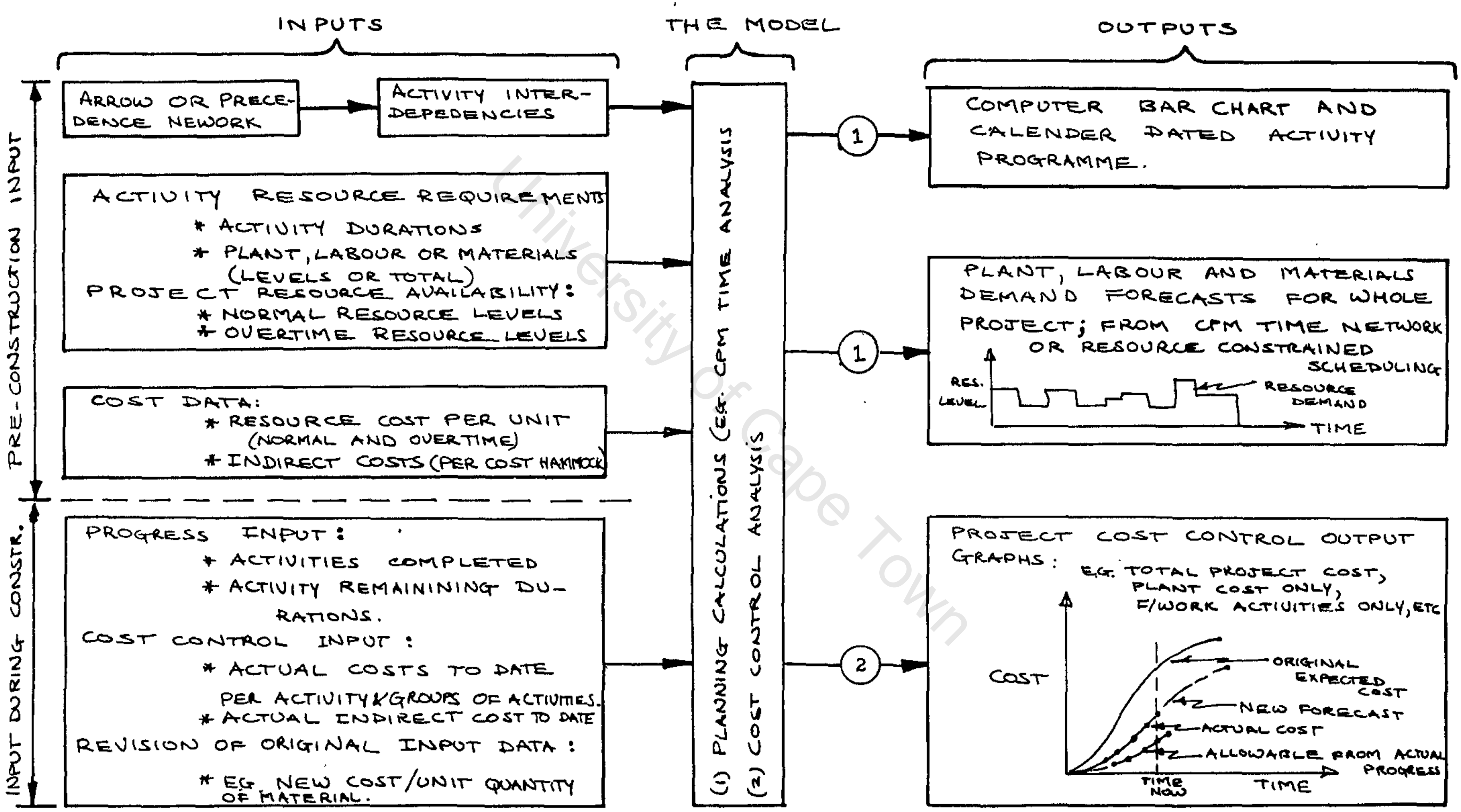

FIGURE A.1: The ICL 1900 PERT Model (Basic Inputs and Outputs)

(e) Calculation procedures (ICL model)

The planning calculations of the model are either by the critical path time analysis (see Section 2.3.1) or by the resource allocation procedure (see Section 2.4.1).

The resource allocation procedure used is typical of the approaches reviewed in Section 2.4.2. A particular additional feature of this ICL model is the combined allocation and levelling procedure described in Section 2.4.3.

The estimated timing of the future construction costs needed to determine the cumulative cost versus time forecasts (described in (d) above) can be calculated by the model from either the critical path time analysis (e.g. all activities at their early start time) or from the subprogramme for which the resource levels have been stipulated.

(f) Conclusions (ICL model)

A particularly useful feature of this model is the fact that it can perform a combined resource allocation and levelling procedure (see Section 2.4.3). This feature allows the planner to specify both limited plant and labour levels as well as a target project duration. The model attempts to specify both these requirements before relaxing one of these restraints.

It is expected that this feature will reduce the number of computer runs which would normally have to be made if a planner wanted to meet a certain project date. If this facility were not available, a planner would have to alter the resource levels until the calculated duration corresponds with the required duration. (This requires several trial and error programme runs through the computer.)

As the cost control procedure is essentially the activity-costing approach described in Section 3.3.3 the same disadvantages apply to the ICL system as discussed in Section 3.3.3 E for the activity costing system.

Allowable target costs of the cost centres are automatically calculated by the ICL model from the specified expected units of plant and labour to be used on the site. These allowable target costs are constantly updated during construction to determine new target costs for future activities on this contract. Although this updating procedure is useful for determining the cost of future activities the writer considers it to be of little value for controlling cost unless the original cost estimates are also kept (see Section 3.3.3 A).

2. The VERSPREI System (Figure A.2)

This model was designed and developed by PROJAT*, a Pretoria firm specialising in project management systems.

The complete system consists of an extensive range of integrated programmes aimed at aiding the contractor in most areas of his organisation. This model includes:-

(i) Estimating and tendering - Bill item costs are automatically compiled according to the estimation procedures which are retained in the computer. Presently prevailing unit costs for plant, labour, etc. must be supplied as input. Profit mark-ups are added according to the percentage specified by the user thus providing a complete tender build-up

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*Project Administration Technique (Pty) Ltd.

which can then be subsequently adjusted by management decisions.

(ii) Project Planning and Cash flow forecasting - By allocating the Bill item costs to the network operations forecasts of the expected cash inflows and outflows corresponding to a particular work network are obtained.

(iii) Project Cost Control - Cost centres are defined as portions of the structure and allowable target costs are derived from the estimator's Bill item costs.

(iv) Company Cost and Financial Control - The model also provides an output of profit and loss statements as well as cash flow forecasts for a project, or for the firm as a whole.

(v) Plant Maintenance - The computer provides an output for heavy plant of the actual hourly operating cost, analysis of maintenance cost, etc.

(vi) General Office Calculations - Additional outputs from this model are designed to assist in quantity surveying, preparation of monthly certificates, materials cost control, ordering control, etc.

In the following review attention is focussed on the above outputs (ii) and (iii) only.

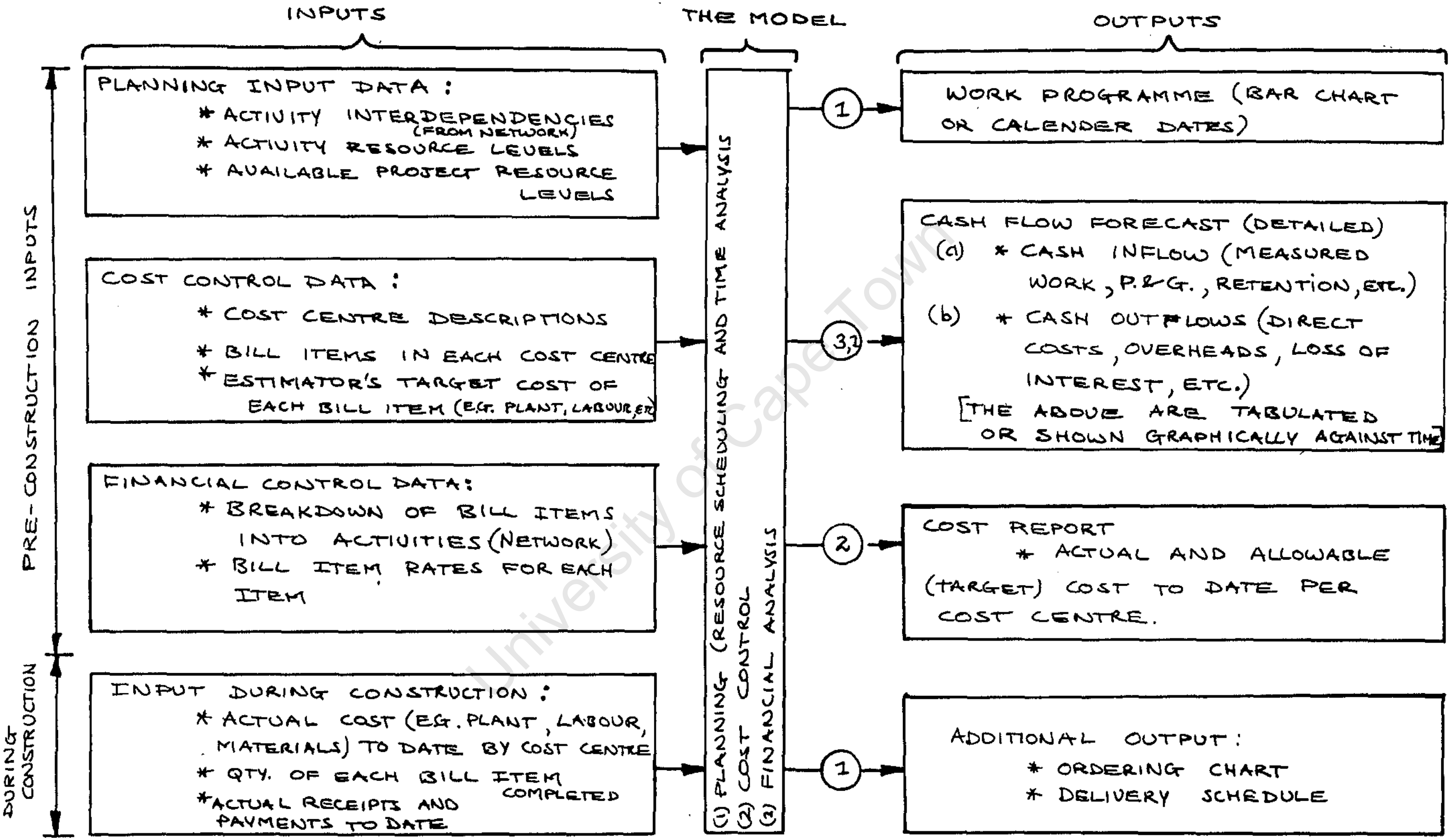


FIGURE A.2: The VERSPREI System (Project Planning and Cost Control only)

(a) Planning input (VERSPREI System)

Scheduling calculations are performed within the VERSPREI system using the locally available K & H PERT computer "package". No details of this package are available to the writer, but as the outputs are the same as those of the ICL 1900 PERT system (described in (1) of this appendix) the writer concludes that this package and the ICL 1900 PERT system are probably similar.

(b) Cost and financial control data (VERSPREI System)

From the examples presented in the write-up (Ref. 16, Chapter 5) it appears that cost centres are either chosen as sections of work (e.g. reinforced concrete framework) or as groups of similar Bill of Quantities items (e.g. piling, beam formwork, concreting).

Allowable target costs are found by summing the estimated cost (derived from the estimator's costs) of all the Bill items contained in a certain cost centre (to the same level of detail to which these were calculated for example, plant, labour, materials or excavation plant, hauling plant, formwork labour, excavation labour, etc.).

Costs are determined for the network activities only for the purpose of forecasting the cash flow during construction. The estimated cost of each activity is determined from the quantities and the estimated cost of the various Bill of Quantity items contained in this activity.

For example,

<u>Activity</u>: Erect abutment formwork and bridge bearings (duration 10 days)

B/Q Items: A) <u>60 m^2 formwork</u>:-

estimated cost: R2.00/m^2 labour
R2.00/m^2 material

revenue (tender price): R4.40/m^2

B) <u>2 no. cast-in-place bearings</u>:-

estimated cost: R 20.00 each labour
R200.00 each materials

revenue (tender price): R240.00 each

Estimated activity cost (A plus B) = R160.00 labour plus R520.00 materials

Total expected activity revenue = R744.00

As it is assumed that these values are spread over the duration of the activity a costing error might occur when the activity stretches over two cost accounting periods. The VERSPREI programme will assume a certain amount of the bearings have been completed when these will most likely only be fixed on the last day of this particular activity. In practice their revenue will only be due at the end of this activity, but the model assumes a uniform rate of earning throughout the period of the activity.

The writer is not certain as to how Indirect costs are handled, but the writer expects that "cost-only" operations will be used (see Section 3.3.3 C).

(c) Inputs during construction (VERSPREI System)

The originators of the system are of the opinion that detailed progress control during construction is unnecessary, and that as long as a project is approximately on schedule no alterations are necessary to the initial activity-time network.

The main emphasis in their model is on cost control. Actual costs are recorded during construction for each cost centre and are broken down within each cost centre to the detail required (e.g. plant, labour, etc. per cost centre).

(d) Outputs (VERSPREI System)

Outputs of particular interest are:-

(i) Cash flow forecast - The model provides a detailed tabulated and graphical report showing the main elements contributing to the flow of cash during construction (Figure A.3). Detailed forecasts for trades (e.g. formwork labour) and other items are also possible. Estimated costs are used in the calculation.

The writer does not agree with two aspects of this model. The first concerns the fact that no delay times have been applied to the various cash flows to represent the fact that, for example in the case of the monthly certificate, the actual cash inflow might only occur a month after the corresponding certificate is submitted. (The model only takes into account the delay in the payment of retention money.)

The second point concerns the definition of profit at any point in time, which is as follows:-

Profit to date = Total revenue - Retention to date - Total Expenditure .... (A.1)

In the opinion of the writer the retention element is money legally due to the contractor and will eventually be received by him. Therefore it should not be excluded from the profit calculation as is done in the model.

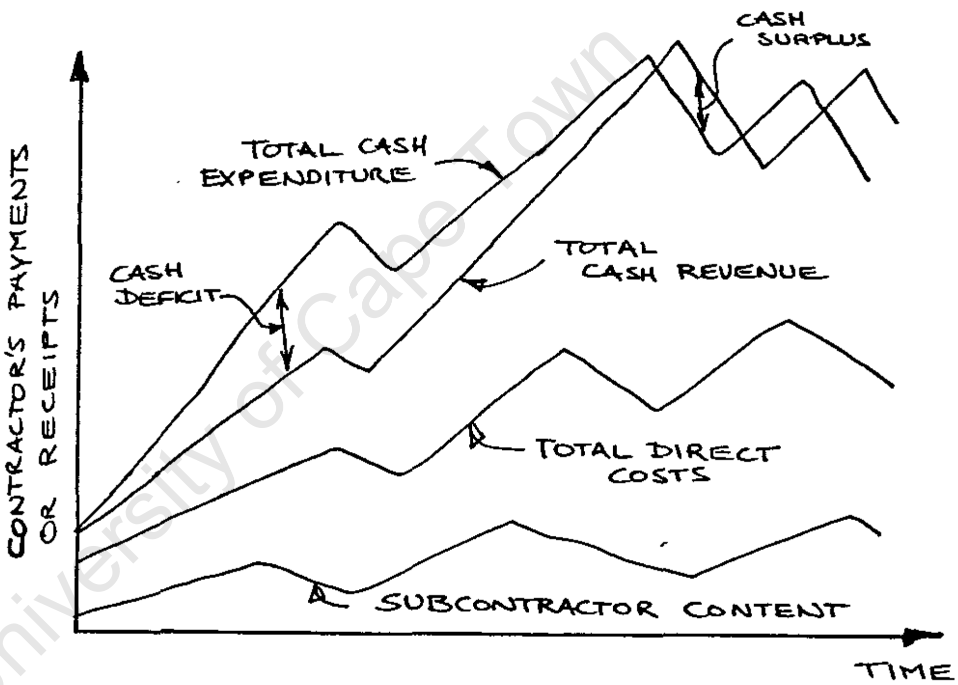


Figure A.3: Part of the detailed cash flow analysis

(ii) Standard cost reports - These show the direct actual and estimated allowable target costs within each cost centre.

(iii) Delivery schedule - This output from the model shows the required delivery time of certain of the Bill of Quantities items. The timing of these is derived as in the case of cash flow forecasting from the network operations. A small safety factor (e.g. 10 days) is subtracted to allow for late delivery.

(e) Conclusions (VERSPREI System)

Very little interaction exists between the cost and planning models within the VERSPREI system. The timings of the activities are used only to prepare a forecast of cash flow during construction.

The originators are of the opinion that updating the times of activities is unnecessary as long as the project is approximately on schedule according to the bar chart programme. However, this updating can be done. There is no provision for updating the allowable target costs, although the programme does provide the total costs to date of each cost centre.

The writer considers that the use of estimated cost for cost centres will give a more conservative (i.e. safer) allowable target cost than the use of updated expected costs as in the ICL model. Estimator's costs will more easily show the area where the contract is unprofitable and require no continuous revision. The writer also prefers the choice of cost centres as groups of Bill of Quantity items rather than groups of network operations. In the latter case one is often required to draw the network to too great a detail for estimating purposes as each activity (e.g. erect columns) consists of several different subactivities (e.g. erect formwork, fix steel, cast concrete) and each of these subactivities has a different corresponding item in the Bill of Quantities (e.g. formwork, steel, concrete). And the latter items must be subdivided in order to allocate portions of their costs to this particular activity (erect columns).

3. Barnes and Gillespie's Cost Model (Figure A.4)

An integrated system for aiding the construction manager with the functions of estimating, planning and network programming, cost control and financial control is described in the paper by Barnes (Ref. 3, Chapter 5).

In the introduction to reference 3 the authors point out that many of the systems presently available are not "integrated" as they are not an accurate model of the factors which affect construction costs but are rather a computerisation of the estimating and planning calculations which were previously performed manually. No example is provided to illustrate this point but an examination of the VERSPREI model (2) shows that if, for example, the quantity of a certain Bill item increased it would be necessary for both the planning input (see Figure A.2) and the cost control data (see Figure A.2) to be amended due to the lack of interaction facilities within the model system.

The objective by Barnes and Gillespie was therefore to develop a comprehensive integrated model of those factors which have a direct bearing on the contractors costs, cash flow, profit, etc. For example, changing the duration of an activity could change the costs of the activity (this is not covered by the VERSPREI system), and changing the quantities might change the cost rate per unit of quantity (this is not catered for in the ICL system).

(a) Planning input (Barnes and Gillespie)

Activity durations need not be supplied to the model, but are determined by the model from the quantity of work, the team of plant or labour to be used and the team's expected output.

An example is not provided by the authors, but the writer expects this method to take the following form:-

<u>Operation</u>: Excavate bases (9 000 m^3).

Resources: (a) plant - 1 front-end loader (available 10 hrs./day).

(b) labour - 1 operator

Expected output : 900 m^3/day by this team (a and b).

Hence the activity duration is $\frac{9\ 000}{900}$ = 10 days.

The required amounts of plant, labour and materials are then derived from the available working hours (per day); e.g. Total required loader-hours = 10 x 10 = 100 hours.

(b) <u>Cost control data</u> (Barnes and Gillespie)

The network operations are taken as the project cost centres. For each cost centre the allowable target costs are taken as being equal to the updated <u>expected</u> costs as determined from the allocation of plant and labour. The calculation of the allowable target cost is done by specifying <u>for each activity</u> a cost matrix (see Figure A.5) which could contain:-

(i) Separate unit cost rates per period of time for plant, and for labour (e.g. Rand/day).

(ii) Separate cost rates per unit Bill item quantity for materials and for subcontractors.

(iii) A lump sum set-up or dismantling cost for (i) and (ii) if applicable.

Both (i) and (ii) are spread over the activity duration while (iii) is assumed to occur at the start or end of the activity. (For calculations involving time and cost.)

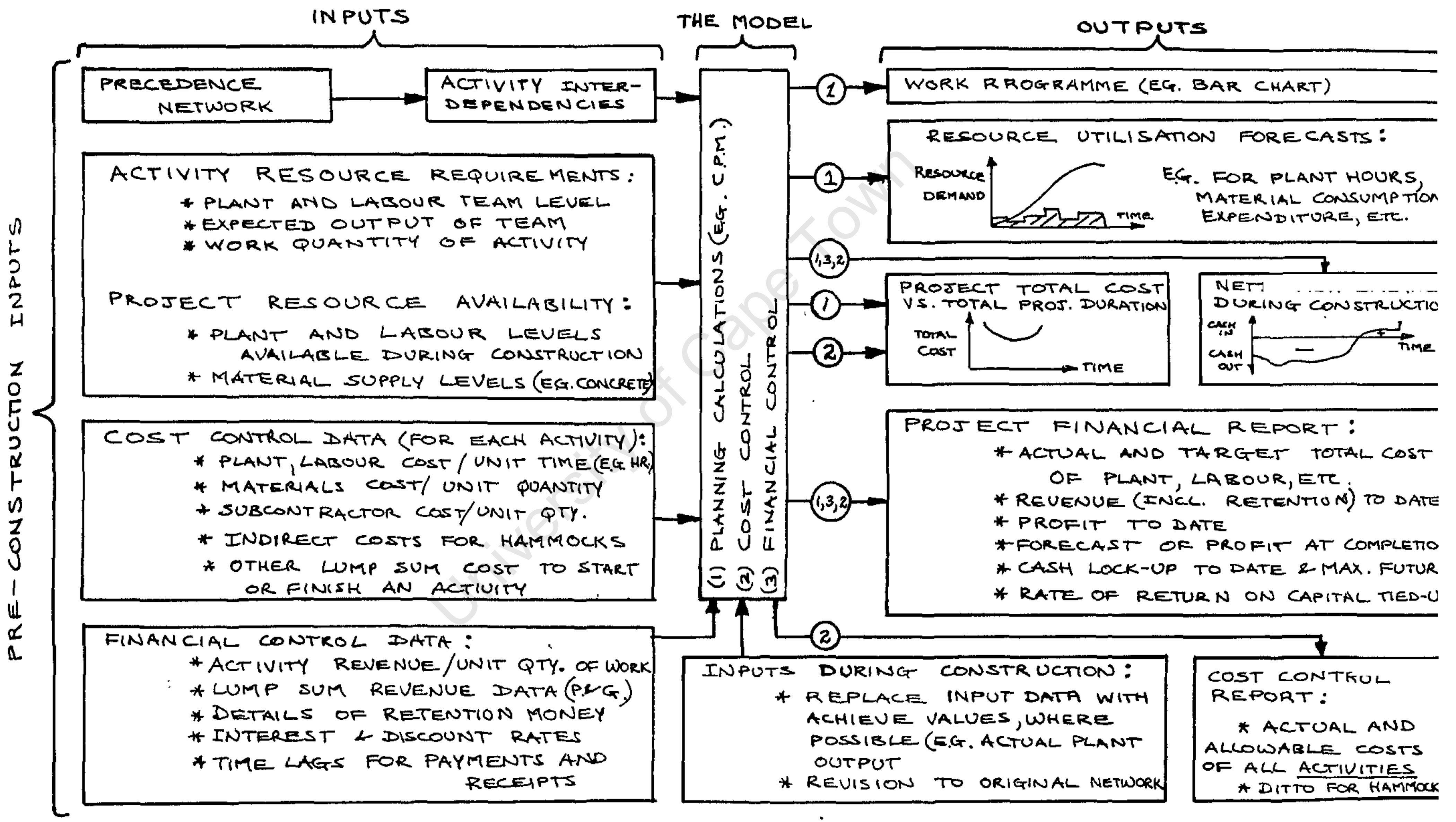


FIGURE A.4: Barnes and Gillespie's Cost Model

THE FOLLOWING DATA CAN BE SPECIFIED FOR EACH ACTIVITY :

CHARACTERISTIC OF THE COSTS:	PLANT COSTS	LABOUR COSTS	MATERIAL COSTS	SUBCONTRACTOR COSTS
VARIABLY (IE. VARY WITH QTY. OF WORK IN AN ACTIVITY	THE COST PER UNIT OF TIME* IS ENTERED HERE		THE EXPECTED COST PER UNIT QUANTITY IS ENTERED HERE	
START-UP (IE. A LUMP SUM COST AT START OF ACTIVITY	LUMP SUM COSTS AT START OF ACTIVITY			
FINISHING (LUMP SUM COST AT END OF ACTIVITY	LUMP SUM COSTS AT COMPLETION OF ACTIVITY			

NOTE: * THE MODEL CALCULATES THE ACTIVITY DURATION FROM THE QUANTITY OF WORK IN AN ACTIVITY

Figure A.5: Example of Cost Matrix used by Barnes and Gillespie

Indirect costs are treated as "hammocks" (Ref. Section 3.3.3 C) either as an amount proportional to the elapsed duration of the hammock or as a lump sum start-up or close-down cost at the beginning or end of the hammock.

(c) Preconstruction Financial input (Barnes and Gillespie)

For making forecasts of cash flow, profit or return on investment the following data is supplied to the model:-

(i) Revenue, i.e. the estimated earnings per unit quantity of each operation, and the expected Preliminary and General revenue (timing and quantity).

(ii) The expected average time lags between incurred costs (work performed), the submission of the corresponding certificate, the actual cash payments (by contractor), and the monthly receipts (from client).

(iii) Additional financial data; - penalty clauses, retention information, interest rates, etc.

(d) Input during Construction (Barnes and Gillespie)

In contrast to the originators of the VERSPREI system Barnes and Gillespie regard updating to be necessary when using their model. The suggested procedure is to continually replace previously estimated data with actual recorded information. For example, as construction proceeds it might be found that the unit costs and productive outputs of certain items of plant have increased. In subsequent calculations the new recorded unit cost and the latest productive outputs are then used for these items of plant.

(e) Outputs (Barnes and Gillespie)

It is seen from Figure A.4, that besides the work programme, activity cost control reports and cash flow forecasts the output also includes a financial analysis of the project. This financial report shows the actual costs and revenue to date, profit to date and a forecast of profit at completion. Profit to date is calculated from the actual costs and revenue to date while profit at completion is evaluated for the expected construction methods and the costs of constructing the remainder of the work.

From the cash flow forecast the model determines the time and quantity of the maximum cash lock-up (total cash inflow - total cash outflow), the discount cash flow rate of return (see Section 4.4.1), and the cash flows reduced to equivalent present values.

(f) Calculation procedures (Barnes and Gillespie)

Very little detail concerning the actual handling of data is presented in reference 3 (Barnes and Gillespie). It is, however, clear from the description provided that the model first performs a network time analysis followed by a resource allocation analysis which takes into account imposed limitations on plant, labour and materials. Personal discussion with Dr. Barnes has verified that the resource allocation procedure uses a heuristic solution technique similar to the approaches described in Section 2.4.2.

One of the outputs for which no explanation was provided is the graph of total project duration versus total project cost (e.g. see Figure 2.21). As far as the writer is aware this can only be obtained by a process of simulation, i.e. altering certain items of data (e.g. types of plant, amount of labour available, etc.) and then evaluating the resulting schedule (see time-cost and resource-cost techniques in Sections 2.5.1 and 2.5.2). As this type of simulation does not appear to have been used the writer concludes that another method has been used by Barnes in the resource allocation model. A possible explanation of this other method is that this curve (total project duration versus total project cost) represents the outcome of various resource allocation computer runs, in which different input priority orders for the activities are used in each computer run. This could be an attempt to overcome one of the main problems of heuristic resource allocation models, namely, that both the project duration and resource demand pattern (peaks and valleys) are influenced by the order in which the model examines the network activities (see Section 2.4.2). It is probable that the direct cost of each network schedule is evaluated by one of the equations described in Section 2.5.2 and the indirect cost is added to give a point on the total cost versus total project duration curve. *Other costs such as penalty clauses and early com*pletion bonuses could also be added. A likely choice of network would then be the network schedule corresponding to minimum total cost. The "best" network is printed by the computer using the Barnes and Gillespie model.

(g) Conclusions (Barnes and Gillespie)

The philosophy when using the model is to continuously up*date the original input information. This updating requires:-*

(i) Continuous collection of actual data for example, activity costs, quantity completed, present costs per unit resource, revised construction methods, etc.

and (ii) Frequent re-calculation of network schedules to give other output data.

The justification for this updating philosophy is that during construction the initial assumptions concerning unit costs, output for plant and labour, the quantities, etc. might be different from those achieved on the site which means that a cheaper network schedule might exist than the original schedule. This cheaper network schedule would be provided during the updating rerun of the computer programme. The updating process requires a certain amount of expertise and increased computer cost which the contractor might not consider to be worth the corresponding cost savings which are possible from this updating approach.

Cost control is by the activity-costing approach (see Section 3.3.3). One of the arguments against the use of this activity-costing technique in countries which are short of recording clerks is that costs have to be recorded to the same detail as the network activities. From the examples shown by Barnes (Ref. 3, Chapter 5) it appears that the authors have found the same problem in the United Kingdom, and for this reason they have used a few large general activities to describe a whole project (e.g. control house substructure, construct tunnel, etc.).

4. The CEMPLAN System (Figure A.6)

This model was developed by the Cementation Company for the planning and control of both their building and Civil Engineering contracts.

(a) Planning input (CEMPLAN System)

From the description provided by Kelsall and Lucas (Ref. 12, Chapter 5) it appears that the activity durations are specified independently of the total quantity of plant, labour and materials required for an activity. These resource quantities are calculated separately as described below.

(b) Cost data (CEMPLAN System)

(i) Cost control system during construction

For each contract similar Bill of Quantities items are grouped to form cost centres (e.g. formwork to bases, concrete for gullies, etc.). For cost control purposes the actual costs to date recorded for the cost centres are compared with their estimated allowable target costs to date (which are based on the quantities completed). The allowable target cost of a cost centre is found from the estimator's cost of all the Bill of Quantity items comprising the cost centre. In this CEMPLAN system these target costs are divided within each cost centre into plant, labour and material costs.

(ii) Cost planning system (prior to and during construction)

For cost planning purposes the updated expected future costs (plant and labour only) are calculated for each cost centre as follows:-

$$\text{Expected future cost centre cost (e.g. for labour)} = \frac{Q}{M} \sum_{a=1}^{p} \left(\frac{R_a}{\sum_{b=1}^{p} R_b} W_a \right) \quad \text{.. (A.}$$

Where Q is the total quantity of future work in the cost centre (e.g. m^3)

M is the total unit output per total manpower hours of all trades (e.g. m^3/hour)

p is the number of trades deployed for the cost centre

R_a is the number of persons employed in trade a (e.g. 1 carpenter to 2 labourers to 2 handymen)

W_a is the hourly wage rate of trade a

The same calculation is followed for plant using machines instead of trades.

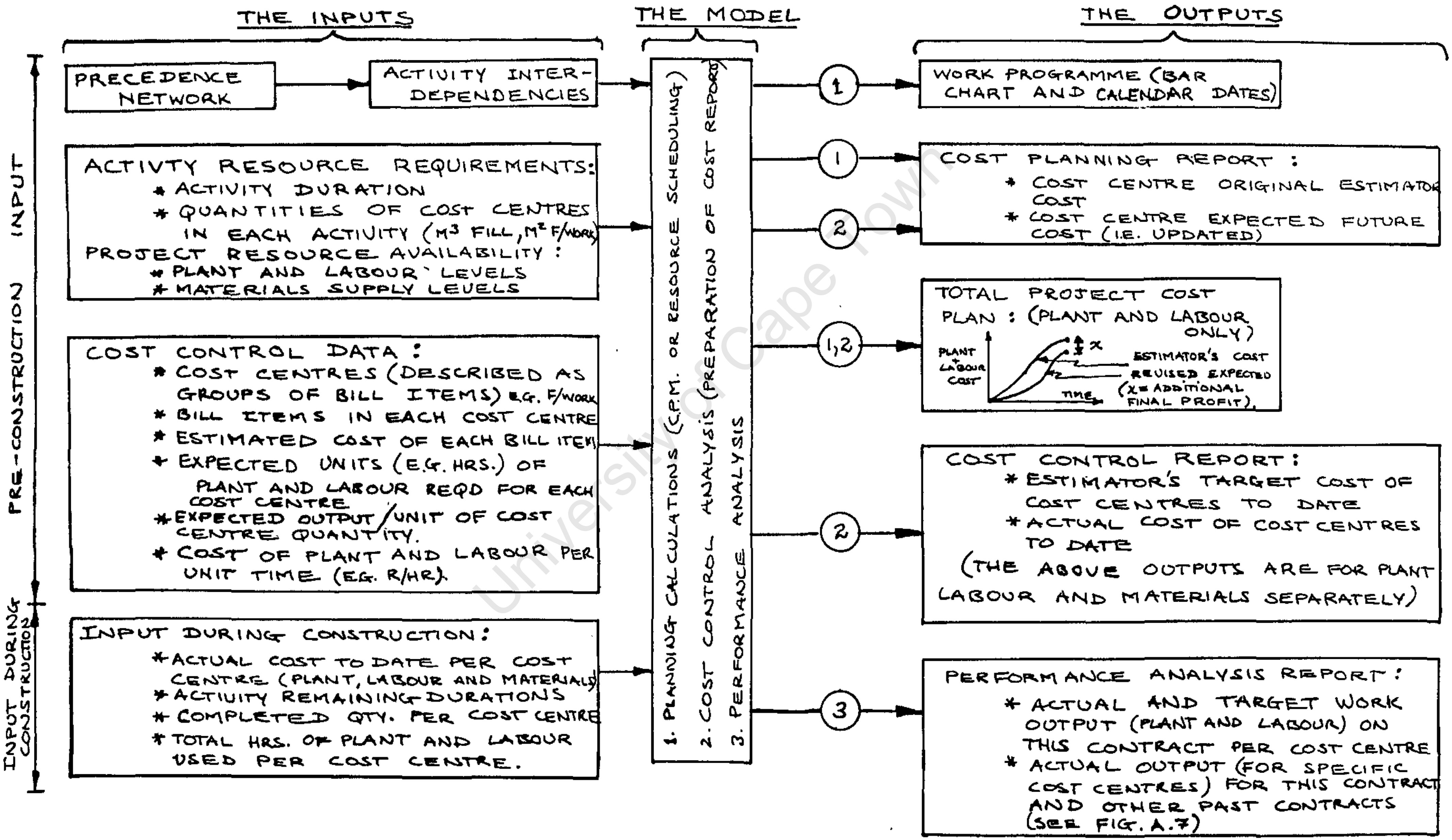


FIGURE A.6: The CEMPLAN System

An implied assumption in the use of equation A.2 is that each man in each trade works for the same total number of hours for this cost centre. If this is not the case, then it seems that the R_a values should be the average number of persons employed (over the period considered) from trade a for this cost centre (i.e. R_a could be a fractional non integer value).

The cost planning report (Figure A.6) which shows both the estimator's and future expected updated cost of each cost centre is used by management to compare the cost of a future proposed method of working with the costs allowed in the tender for the same section of work.

The curves of future expected updated costs and estimator's costs incurred during construction (Figure A.7) are found by allocating the expected and estimator's costs of the various cost centres to the activities in which they occur:-

For example, $$\text{Activity cost} = \sum_{i=1}^{n} C_i \; Q_i \; \ldots\ldots\ldots \quad (A.3)$$

Where C_i is within the expected cost or the estimator's cost per unit quantity of cost centre i (plant and labour only),

Q_i is the quantity of cost centre i contained in the activity,

n is the number of cost centres in the activity.

Materials are not considered for this calculation by the

CEMPLAN model. This is probably because it is usually left to the firm's buyer to obtain materials as cheaply as possible.

(iii) An example of how the expected costs for a cost centre are calculated (see equation A.2):-

Cost centre	:	formwork (240 m^2)
Trades	:	(carpenters: labourers) = (1:2)
Wage rates	:	(carpenters 1.50/hr) and (labourers 0.50/hr)
Expected Output	:	0.33 m^2/total hour
Total labour cost	=	$\frac{240}{0.33} \times (^1/_3 \times 1.50 + {}^2/_3 \times 0.50)$
	=	R600.00

The resource requirements for an activity can be derived from the cost centres. In the above case the resources for the one activity entitled "formwork erection" would be:-

$$\frac{1}{0.33} \times 240 \times {}^1/_3 = 240 \text{ carpenter hours, and}$$

$$\frac{1}{0.33} \times 240 \times {}^2/_3 = 480 \text{ labourer hours.}$$

For calculation purposes the model appears to spread these hours uniformly over the duration of the activity (e.g. carpenter hours/day).

(c) Outputs (CEMPLAN System)

The project cost plan which shows cumulatively the updated expected costs and the estimator's costs provides the comparison between the overall expected cost (of the construction method to be used) and the original total cost (in the tender).

A Performance Analysis printout is prepared showing the actual work output compared with the updated expected future output for each cost centre. This work output is the same as the factor M used in equation (A.2) and is calculated as:-

$$M = \frac{\text{Total units completed}}{\text{Total hours of all trades}}$$

At the end of each contract the actual outputs are plotted by the computer model (see Figure A.7).

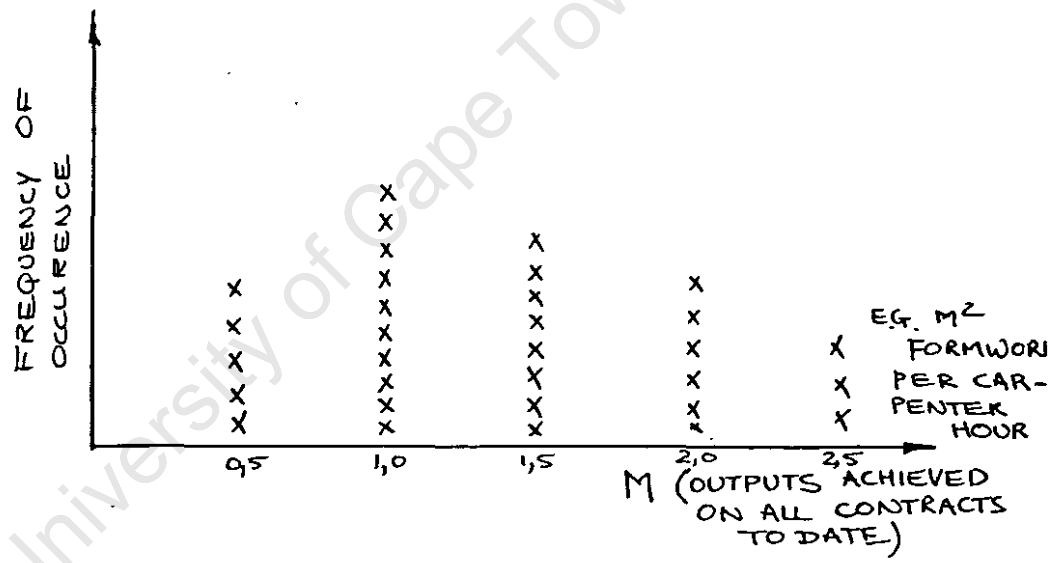


Figure A.7: Company performance analysis diagram

Figure A.7 can be used for estimating purposes for future work of a similar nature.

The Cost Control Report is prepared weekly (from the weekly cost inputs). This report shows the actual cost to date and the estimator's target cost of each cost centre (divided into plant, labour and materials). Allowable costs to date are equal to the estimator's unit costs multiplied by the completed quantity of work.

Conclusions (CEMPLAN System)

A point of difference between the CEMPLAN system and the other models is that both estimator's cost (for cost control) and updated expected cost (for planning the most economical method of future construction) are used.

In contrast to the other models the cost centres are generally shown as being much smaller units than the network activities. This is in direct opposition to the view taken by Barnes and Gillespie (Ref. 3, Chapter 5) that fewer and larger cost centres should be used.

APPENDIX B

LIST OF SYMBOLS* USED IN THIS THESIS

I	activity start event number
J	activity finish event number
T_e	earliest time of an event
T_l	latest time of an event
D(I, J)	duration of activity I, J
EST	early start time of an activity
EFT	early finish time of an activity
LST	late start time of an activity
LFT	late finish time of an activity
p, q	shape factors of the Beta-distribution
K	normalizing constant of the Beta-distribution
N, L	extreme x-axis points of the Beta-distribution
M_o	mode of the Beta-distribution
M_x	mean of the Beta-distribution
	standard deviation of the Beta-distribution
t_e	expected activity duration
	standard deviation of an activity duration
a	estimated most optimistic activity duration
b	estimated most pessimistic activity duration
m	estimated most likely activity duration
T_E	calculated expected project duration
	standard deviation of the project duration
T	general time parameter (e.g. activity duration)
T_s	scheduled (required) project duration

---

*Symbols are listed approximately in the order in which they occur in this thesis.

Q	quantity of work (e.g. volume of concrete)
W	(a) rate of working of a resource team
	or (b) ratio of the overtime divided by the normal wage rate
	or (c) the wastage of material on site
N	the number of labour and plant resource teams
R_t	the project resource level at time t
R_1, R_2	project available resource levels
C	cost of unit resource (e.g. labour-hour)
L	volume of fill carted by truck
X	compaction factor of uncompacted/compacted soil
F	quantity of fill measured in monthly certificate
z	average time delay between centre of gravity of contractors cost payments for work done, and the time when the corresponding payments are received from the client
c_i	total cost of cost category i (e.g. labour)
d_i	average delay between start of month during which cost of cost category i is incurred and the time when the corresponding payment is made by the contractor
F, F'	value of a future sum of money
A, A'	present value of a sum of money
i	interest rate of earning (no inflation)
t	overall interest rate (with inflation)
r	rate of inflation (percent)
P_x	cash payment at year x (no inflation)
P_x'	cash payment at year x (with inflation)
P_x	additional cash payment due to inflation
R_x	cash receipt at year x (no inflation)
R_x'	cash receipt at year x (with inflation)
R_x	additional cash receipt due to inflation
t_r	target interest rate

Q_s, Q_L, Q_1, Q_2	quantities of concrete
C_R, C_L, C_1, C_2	cost of pouring different quantities of concrete
r_i	part of estimated cost rate per unit quantity of Bill item i (e.g. labour cost)
q_i	quantity of Bill item i
C_t	actual project cost to date
C_a	estimate allowable project cost to date
t_1, t_2	time since start of project
f_i	percent increase in costs to date
S	allowable duration of concrete in store
S'	actual duration of concrete in store
M	work output per total manpower hours of all trades
R_a	number of persons employed of trade a
W_a	hourly wage rate of trade a
Q_i	quantity of cost centre i within an activity
x, y, g, h, i, n, p	for general use

APPENDIX C

AN ITERATIVE COMPUTER ALGORITHM FOR THE CRITICAL PATH METHOD TIME ANALYSIS FOR AN ARROW NETWORK

In Section 2.3.1 C it was described that early commercial computer programmes for the Arrow network time analysis required the network nodes (i.e. events) to be pre-numbered according to a set procedure. *Namely, the start node of any activity should always have a lower number than the corresponding finish node.* Subsequent programmes have, however, been developed which automatically re-number the nodes for networks where the nodes have been pre-numbered in a random fashion.

Referring to the manual procedure in Figure 2.4 (for calculating the early and late times T_e and T_l of an arrow network), it will be seen that in the second step only those nodes whose predecessors have been assigned T_e values are examined. In a computer model all the data is pre-sorted to ensure that when a node is considered by the model (in order to calculate the node's early time T_e), all predecessor nodes have been assigned T_e values. When the nodes have been pre-numbered such that the completion node for each activity always has a higher number than the corresponding activity start node, the subroutine which is needed to pre-sort the activities is relatively simple. When the network nodes have been numbered in a random fashion a more complicated subroutine is required to sort the data.

In this appendix a computer algorith for the network time analysis is proposed which operates independently from the node numbers. As far as the writer is aware this approach has not been used before.

The method of calculation is as follows:-

(i) For a given arrow network whose activities have been assigned estimated durations a first approximation of the activity EST (Early start time) and EFT (Early finish time) is calculated:-

EST of an activity = T_e (early time) of the activity start node .... (C.1)

EFT of an activity = EST of this activity + the activity duration .... (C.2)

(For most nodes except the start node the T_e value will initially always be zero.)

(ii) For each node a new T_e value is calculated from the maximum EFT of all activities converging on this node.

(iii) A new approximation of the EST and EFT value of each activity is now calculated as described in step (i) using equations C.1 and C.2.

(iv) Another approximation of the event early times (T_e) is calculated as described in step (ii) but using the values of EFT obtained in step (iii).

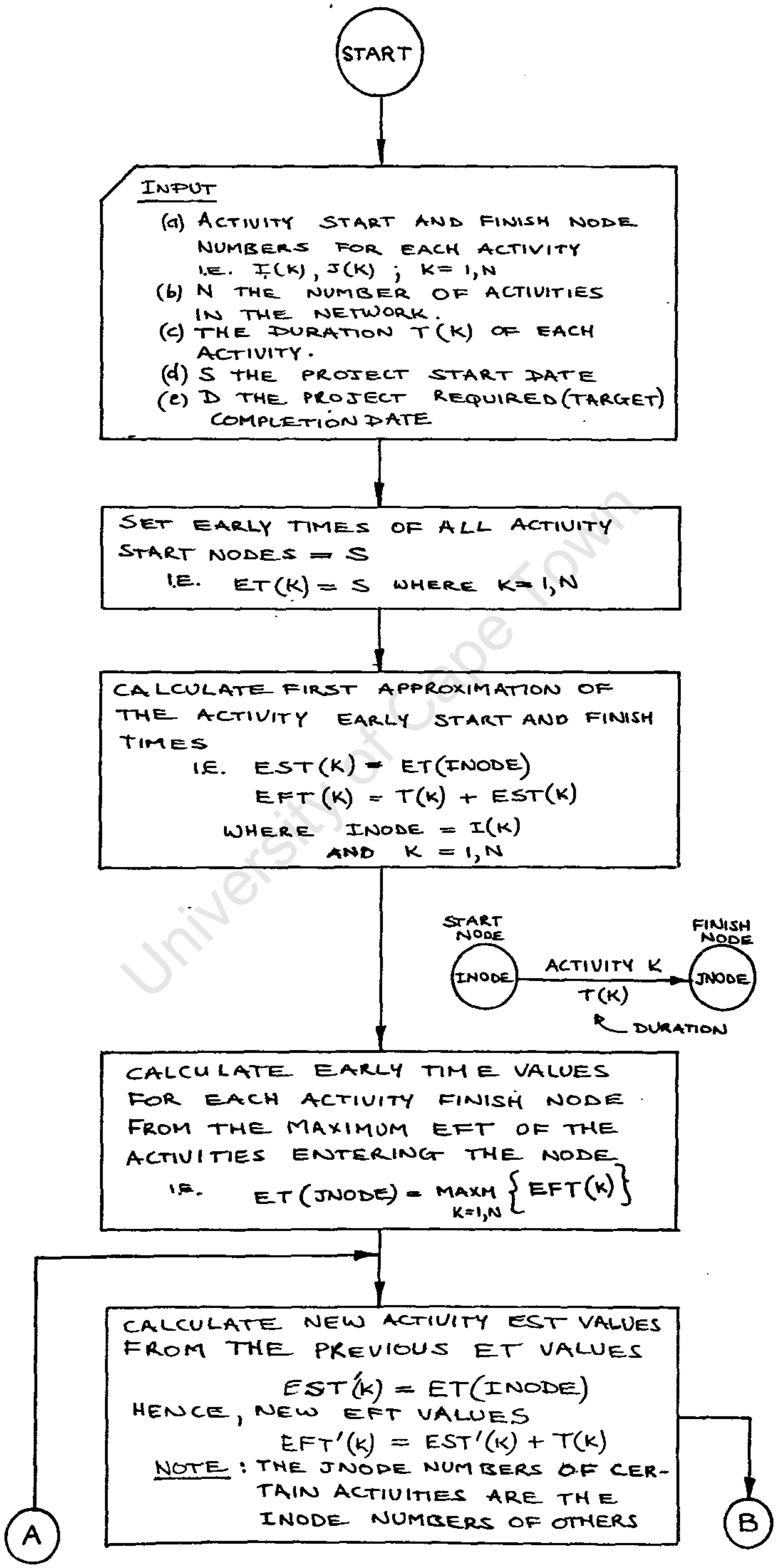
(v) For each node the T_e value obtained in step (iv) is compared with the T_e value calculated previously. The highest value of T_e for each node is retained for subsequent calculations.

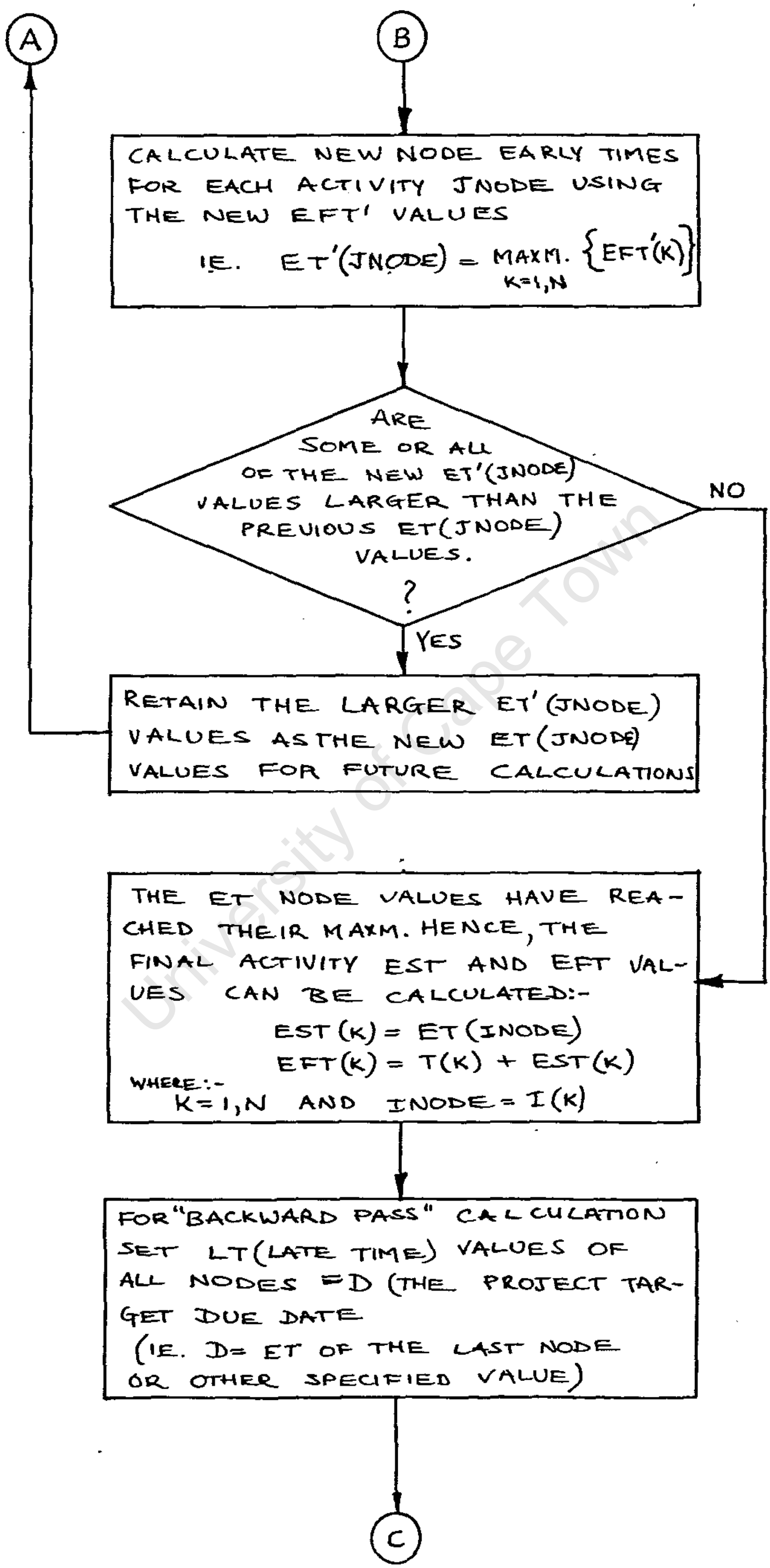
(vi) The model repeats steps (iii), (iv) and (v) until there are no further increases in the T_e values of any nodes. The final EST (early start time) and LST (late start time) is then calculated for each activity.

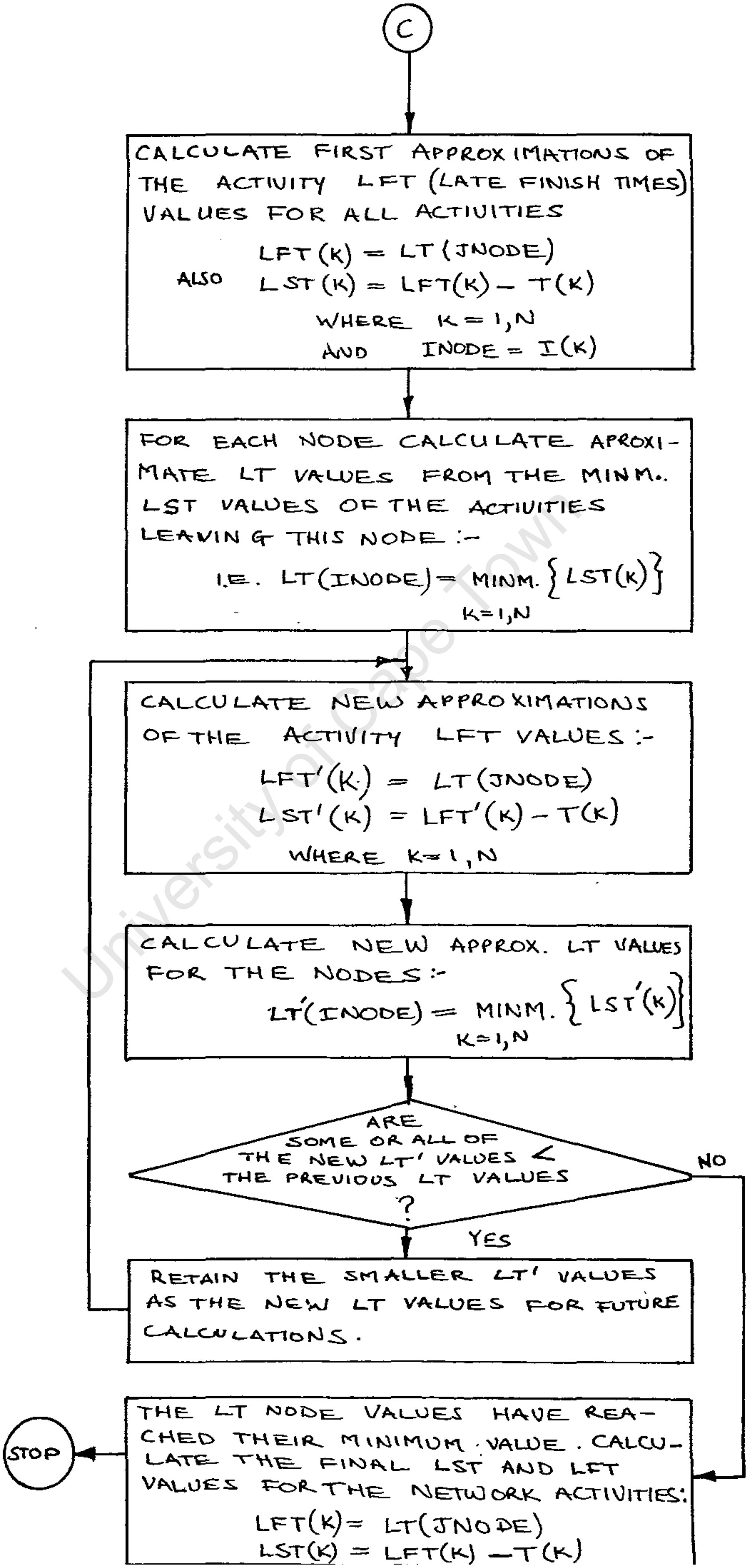
A similar procedure is followed in the above model for the "backward-pass" calculation to determine the T_1 value of each node, and hence the LST (late start time) and LFT (late finish time) for each activity.

In the remainder of this appendix a descriptive flowchart is presented to illustrate the complete calculation procedure of the above iterative critical path time analysis technique. A computer programme based on this method is also provided and an example of part of the printout for a critical path time analysis of a bridge structure is shown.

Fig. C.1: Flowchart of the iterative critical path time analysis model




A
B
CALCULATE NEW NODE EARLY TIMES FOR EACH ACTIVITY JNODE USING THE NEW EFT' VALUES
IE. ET'(JNODE) = MAXM. K=1,N {EFT'(K)}
ARE SOME OR ALL OF THE NEW ET'(JNODE) VALUES LARGER THAN THE PREVIOUS ET(JNODE) VALUES. ?
NO
YES
RETAIN THE LARGER ET'(JNODE) VALUES AS THE NEW ET(JNODE) VALUES FOR FUTURE CALCULATIONS
THE ET NODE VALUES HAVE REACHED THEIR MAXM. HENCE, THE FINAL ACTIVITY EST AND EFT VALUES CAN BE CALCULATED:-
EST(K) = ET(INODE)
EFT(K) = T(K) + EST(K)
WHERE:-
K=1,N AND INODE = I(K)
FOR "BACKWARD PASS" CALCULATION SET LT (LATE TIME) VALUES OF ALL NODES = D (THE PROJECT TARGET DUE DATE
(IE. D= ET OF THE LAST NODE OR OTHER SPECIFIED VALUE)
C


C
CALCULATE FIRST APPROXIMATIONS OF THE ACTIVITY LFT (LATE FINISH TIMES) VALUES FOR ALL ACTIVITIES
LFT(K) = LT(JNODE)
ALSO LST(K) = LFT(K) − T(K)
WHERE K = 1,N
AND INODE = I(K)
FOR EACH NODE CALCULATE APROXIMATE LT VALUES FROM THE MINM. LST VALUES OF THE ACTIVITIES LEAVING THIS NODE :-
I.E. LT(INODE) = MINM. {LST(K)} K=1,N
CALCULATE NEW APPROXIMATIONS OF THE ACTIVITY LFT VALUES :-
LFT′(K) = LT(JNODE)
LST′(K) = LFT′(K) − T(K)
WHERE K = 1,N
CALCULATE NEW APPROX. LT VALUES FOR THE NODES :-
LT′(INODE) = MINM. {LST′(K)} K=1,N
ARE SOME OR ALL OF THE NEW LT′ VALUES < THE PREVIOUS LT VALUES ?
NO
YES
RETAIN THE SMALLER LT′ VALUES AS THE NEW LT VALUES FOR FUTURE CALCULATIONS.
THE LT NODE VALUES HAVE REACHED THEIR MINIMUM VALUE. CALCULATE THE FINAL LST AND LFT VALUES FOR THE NETWORK ACTIVITIES:
LFT(K) = LT(JNODE)
LST(K) = LFT(K) − T(K)
STOP

```
C
C   NETWORK TIME ANALYSIS - RANDOM NODE NUMBERING
C
      DIMENSION I(500),J(500),T(500),EST(500),LST(500),EFT(500),LFT(500)
     1,ET(500),LT(500),ETMAX(500),LTMIN(500),TS(500),FS(500),R(500),A(4,500),D
     1500),DUM(500),C(500)
      INTEGER ET,LT,S,D,ETMAX,T,TMIN,EST,LST,LFT,EFT,LTMIN,TS,FS,DUM
      READ(8,100)S,D,N
  100 FORMAT(3I5)
      READ(8,106)(I(K),J(K),T(K),DUM(K),(A(L,K),L=1,4),R(K),K=1,N)
  106 FORMAT(3I4,I1,4A6,A4)
      ISWTCH=0
      DO 2 K=1,N
      ET(K)=S
    2 ETMAX(K)=0
      TMIN=0
    4 DO 3 K=1,N
      INODE=I(K)
      JNODE=J(K)
      EST(K)=ET(INODE)
      EFT(K)=EST(K)+T(K)
      IF(EFT(K)-ET(JNODE))5,5,6
    6 ET(JNODE)=EFT(K)
    5 IF(EFT(K)-TMIN)3,3,8
    8 TMIN=EFT(K)
    3 CONTINUE
      IF(ISWTCH-1)9,10,9
    9 DO 12 K=1,N
      JNODE=J(K)
      IF(ET(JNODE)-ETMAX(JNODE))12,12,13
   12 CONTINUE
      ISWTCH=1
      GO TO 4
   13 DO 14 K=1,N
      JNODE=J(K)
   14 ETMAX(JNODE)=ET(JNODE)
      GO TO 4
   10 IF(D-1)15,16,16
   15 DO 17 K=1,N
   17 LT(K)=TMIN
```

```
00217          GO TO 19
00220       16 DO 18 K=1,N
00223          LT(K)=D
00224       18 LTMIN(K)=D
00226       19 DO 20 K=1,N
00231          L=N+1-K
00232          INODE=I(L)
00233          JNODE=J(L)
00234          LFT(L)=LT(JNODE)
00235          LST(L)=LFT(L)-T(L)
00236          IF(LST(L)-LT(INODE))22,20,20
00241       22 LT(INODE)=LST(L)
00242       20 CONTINUE
00244          IF(ISWTCH-1)21,23,21
00247       21 DO 25 K=1,N
C0252          L=N+1-K
00253          INODE=I(L)
00254          IF(LT(INODE)-LTMIN(INODE))24,25,25
00257       25 CONTINUE
00261          ISWTCH=1
00262          GO TO 19
00263       24 DO 26 M=1,N
00266          L=N+1-M
00267          INODE=I(L)
00270       26 LTMIN(INODE)=LT(INODE)
C0272          GO TO 19
00273       23 DO 27 K=1,N
00276       27 TS(K)=LST(K)-EST(K)
00300          DO 28 K=1,N
00303          JNODE=J(K)
00304       28 FS(K)=TS(K)-LT(JNODE)+ET(JNODE)
00306          WRITE(5,103)(K,I(K),J(K),EST(K),EFT(K),LST(K),LFT(K),TS(K),FS(K),
00306         1K=1,N)
C0324      1C3 FORMAT(1H ,9I4)
00325          WRITE(5,104)(K,TS(K),FS(K),K=1,N)
00335      1C4 FORMAT(1H0,3I5)
```

```
00336          WRITE(5,105)(K,I(K),J(K),T(K),K=1,N)
00347      105 FORMAT(1H0,4I5)
00350          WRITE(5,108)
00352      108 FORMAT(1H ,'PREC SUCC  REP     ACTIVITY',13X,'DUR CRIT EARL EARL L
00352         1ATE LATE TOT  FREE',/,1H ,'EVNT EVNT CODE',8X,'DESCRIPTION',16X,'S
00352         1TRT FIN  STRT  FIN  SLAC SLAC')
00353          WRITE(5,107)(I(K),J(K),R(K),(A(L,K),L=1,4),T(K),C(K),EST(K),EFT(K),
00353         1,LST(K),LFT(K),TS(K),FS(K),K=1,N)
00377      1C7 FORMAT((1H ,I4,1X,I4,2X,A4,1X,4A6,I4,1X,A4,6(1X,I4)))
00400          END
```

PREC EVNT	SUCC EVNT	REP CODE	ACTIVITY DESCRIPTION	DUR	CRIT	EARL STRT	EARL FIN	LATE STRT	LATE FIN	TOT SLAC	FREE SLAC
1	5	CVH	EXCAVATE BASE A	2	aaaa	0	2	0	2	0	0
5	2	RKJ	SHUTTER BASE A	4	aaaa	2	6	4	8	2	0
1	2	RKJ	SHUTTER ASSEMBLY	3	aaaa	0	3	5	8	5	3
2	3		CONCRETE & CURE	8	aaaa	6	14	8	16	2	2
5	6	CVH	EXCAVATE BASE B	9	aaaa	2	11	2	11	0	0
6	3		DUMMMY	5	aaaa	11	16	11	16	0	0
3	4	CVH	BACKFILL AB	4	aaaa	16	20	16	20	0	0
6	4	RKJ	STRIKE SHUTTER	6	aaaa	11	17	14	20	3	3

FIGURE C.2: Computer Programme for the Iterative Critical Path Time Analysis Algorithm

APPENDIX D

INPUTS AND OUTPUTS OF A PROPOSED

PLANNING AND CONTROL MODEL FOR

CIVIL ENGINEERING CONTRACTS


GENERAL PROJECT PLANNING & CONTROL MODEL
(CONTRACTORS CAN SIMPLIFY THESE INPUTS AND OUTPUTS TO SUIT THEIR OWN SYSTEMS)
INPUTS
OUTPUTS
NETWORK (ARROW OR PRECEDENCE)
INPUT BEFORE CONSTRUCTION
COST CONTROL DATA
1 ACTIVITY DESCRIPTIONS & INTERDEPENDENCIES
ONLY USED IF PRECEDENCE NETWORK IS THE INPUT
2 ACTIVITY — B. of Q. RELATIONSHIP
3 RESOURCE REQUIREMENTS (FOR EACH ACTIVITY)
4 COST CENTRE—B. of Q. RELATIONSHIP
5 PROJECT INDIRECT COST CENTRES
6 DATA FROM BILL OF QUANTITIES (AS TENDERED)
7 PLANT, LABOUR AND MATERIALS AVAILABLE PER UNIT OF TIME (FOR WHOLE CONTRACT)
8 GENERAL PROJECT TIME DATA
9 CASH FLOW DATA — PAYMENTS / RECEIPTS
10 ACTUAL COST TO DATE ON THIS CONTRACT
11 WORK PROGRESS
12 INTERIM CERTIFICATE DATA
13 FINANCIAL DATA
KEY: B. of Q. = BILL OF QUANTITIES
C/C = COST CENTRE
N/N = NETWORK
DATA PROCESSING SYSTEM
A WORK PROGRAMME — CALENDAR DATES
B WORK PROGRAMME-SITE BAR CHART
C WORK PROGRAMME-TOP MANAGEMENT
D RESOURCE DEMAND FOR CONTRACT
E RESOURCE DEMAND FOR CONTRACT
F PROJECT EARNINGS
K PROJECT EXPENDITURE
G STANDARD COST REPORT
H CASH FLOW FORECAST FOR CONTRACT
I INTERIM FINANCIAL REPORT
J PRIME COST ANALYSIS REPORT
NETT CASH BALANCE
NOTE: THE INPUTS AND OUTPUTS SHOWN ON THIS DIAGRAM ARE DISCUSSED IN CHAPTER 5 OF THIS THESIS.


GENERAL PROJECT PLANNING & CONTROL MODEL
(CONTRACTORS CAN SIMPLIFY THESE INPUTS AND OUTPUTS TO SUIT THEIR OWN SYSTEMS)
INPUTS
OUTPUTS
NETWORK (ARROW OR PRECEDENCE)
INPUT BEFORE CONSTRUCTION
COST CONTROL DATA
① ACTIVITY DESCRIPTIONS & INTERDEPENDENCIES
ONLY USED IF PRECEDENCE NETWORK IS THE INPUT
② ACTIVITY – B. of Q. RELATIONSHIP
③ RESOURCE REQUIREMENTS (FOR EACH ACTIVITY)
④ COST CENTRE – B. of Q. RELATIONSHIP
⑤ PROJECT INDIRECT COST CENTRES
⑥ DATA FROM BILL OF QUANTITIES (AS TENDERED)
⑦ PLANT, LABOUR AND MATERIALS AVAILABLE PER UNIT OF TIME (FOR WHOLE CONTRACT)
⑧ GENERAL PROJECT TIME DATA
⑨ CASH FLOW DATA – PAYMENTS / RECEIPTS
⑩ ACTUAL COST TO DATE ON THIS CONTRACT
⑪ WORK PROGRESS
⑫ INTERIM CERTIFICATE DATA
⑬ FINANCIAL DATA
KEY: B. of Q. = BILL OF QUANTITIES
C/C = COST CENTRE
N/N = NETWORK
DATA PROCESSING SYSTEM
A WORK PROGRAMME – CALENDAR DATES
B WORK PROGRAMME – SITE BAR CHART
C WORK PROGRAMME – TOP MANAGEMENT
D RESOURCE DEMAND FOR CONTRACT
E RESOURCE DEMAND FOR CONTRACT
F PROJECT EARNINGS
K PROJECT EXPENDITURE
CALENDAR TIME
G STANDARD COST REPORT
H CASH FLOW FORECAST FOR CONTRACT
NETT CASH BALANCE (FOR CONTRACT)
I INTERIM FINANCIAL REPORT
J PRIME COST ANALYSIS REPORT
NOTE: THE INPUTS AND OUTPUTS SHOWN ON THIS DIAGRAM ARE DISCUSSED IN CHAPTER 5 OF THIS THESIS.