CRITICAL PATH ANALYSIS

OF

THE FEA BUILDING PROJECT

(LECTURE THEATRE BLOCK)

UNIVERSITY OF MALAYA

by

Tan Teong Boon

A Graduation Exercise presented to
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ABSTRACT

Before critical path methods were developed, it was virtually impossible to organise the multiple tasks comprising large complex projects into one correlated "master" plan. As a consequence many portions of the project were accomplished independently of other portions. This resulted in a loss of co-ordination and control, non-critical activities being needlessly emphasised while critical activities were often neglected. In managing the affairs of modern enterprise and government however, more scientific decision methods are needed. The development of critical path methods (PERT and CPM) for the planning, scheduling and control of projects has provided a basis for a more formal and general approach towards project management.

Since their introduction, critical path methods have been applied with considerable success to a wide variety of projects, ranging from construction work, research and development programs, production of motion pictures and even open heart surgery. The aim of this study will be to apply this new management tool to the Faculty of Economics and Administration Building Project. Normally, only 10 to 20 percent of the activities involved in any major project control the time required to complete the project. The critical path, which is the principal analytical tool of the critical path methods points out these critical items in the project. This study will therefore be an attempt to focus attention on the critical activities of the project that is most constraining on the schedule.

The application of the Critical Path Method (CPM) to the Faculty of Economics and Administration Building Project entails the development of a network plan. The network which is the heart of the critical path concept is a graphical portrayal of the plan for carrying out the project. It depicts clearly the essential relationships and interdependencies between the various tasks comprising the project. Once the network is drawn, it can be completed by adding the expected duration time for each activity. From the scheduling computations and subsequent analysis, the critical path and the project duration time can be determines. A well tried and useful way of representing work to be carried out is to present the network in the form of a bar chart. This enables the project activities to be calendar oriented and also provides a convenient means of recording and comparison of the actual work against the plan.

Critical path procedures require a greater planning effort than is necessary with conventional methods. One of the most significant values of applying the Critical Path Method to the Faculty of Economics and Administration Building Project is that it has encouraged and demanded more long-range and detailed planning of the project. In developing the network systematically from the beginning of the project,

the site engineers and architect were forced to think through the whole project in a more complete manner than ever before.

Despite the successful application of critical path methods (PERT and CPM) in a wide range of projects, the technique has been received with mixed emotions. Some people fear that the technique will be used as a whip and not as an aid. This difficulty was encountered in carrying out this study. The implementation of CPM or PERT requires the education of the managers as well as the operating people in order to overcome the psychological barriers, fears and skepticism associated with the system. The task is not easy, and for this reason the acceptance of critical path methods has not been unanimous.

A common misconception associated with critical path methods is that they are only applicable to large projects. This need not necessarily be so, although the use of CPM or PERT is imperative if a complex project is to be conducted efficiently. It may be interesting to note that the technique can even be used to plan the school picnic or a dinner party in the home. In fact, one might say that critical path methods are applicable to the management of a project from the cradle to the grave.

Although critical path methods are being used extensively in the United States and other western countries, its implementation in this country has not been widespread. This may be due to the fact that it is a relatively new concept in this country. However, there is an increasing awareness to this powerful management tool. The use of critical path methods could very well become a natural mode of expressing project plans in Malaysia in the next few years.

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CHAPTER I

INTRODUCTION

Until a few years ago, there was no generally accepted formal procedure to aid in the management of projects. In order to manage efficiently and accomplish a project on schedule, the project manager had to plan and schedule largely on the basis of his experience with similar projects, applying his judgement to the conditions of the project at hand. During the course of the project, he had to continually replan and reschedule because of unexpected, changing conditions of the project. Each manager had his own scheme which was often limited in usefulness, and unadequate for large complex projects.

In managing the affairs of modern business and government. More scientific decision methods are needed to aid management. The project manager can no longer rely upon hunch and intuition as the basis for his decisions. The development of critical path methods in 1958-1959 has provided the basis for a more formal and general approach toward a discipline of project management. It has enabled new and rapid progress to be made in the development of better management information and control systems.

Basically, critical path methods involve a graphical portrayal of the interrelationships among the elements of a project, and an arithmetic procedure which identifies the relative importance of each element in the overall schedule. Normally only 10 to 20 per cent of the elements in a project control the time required to complete the project. Critical path methods point out these 'critical' items in a project.

Before critical path methods were developed it was virtually impossible to organise the multiple tasks comprising large projects into one correlated plan because unaided, the human mind cannot cope with the sheer size, interrelatedness and complexity of the project as a whole. This resulted in a loss of co-ordination and management control.

Since their development, critical path methods have attracted widespread interest and have been applied with considerable success to large scale research and development programmes, Construction work, the military and aerospace industry, manufacturing industries and even the motion picture industry. This study will be an attempt to apply this useful technique to the Faculty of Economics and Administration Building Project.

Objective of Study

The objective of this graduation exercise is to prepare a critical path network for the construction of the Faculty of Economics and Administration Building Project.

This study will also be an attempt to compute a realistic Total Project Time for the Faculty of Economics and Administration Building Project.

Scope of Study

The Faculty of Economics and Administration Building Project consists of the Lecture Theatre Block and the Administration Block. They are two separate physical units connected by a linkway. Although the title of this study is "Critical Path Analysis of the Faculty of Economics and Administration Building Project", this study will be confined to the Lecture Theatre Block. The Administration Block forms the subject of another study under the same title by another student.

This study commences on the 1st April, 1968. The network for the construction of the Faculty of Economics and Administration Building Project therefore depicts only the unfinished activities to be completed after the above date. Activities completed before the date were disregarded, since they do not affect the total project time of the Faculty of Economics and Administration Building Project which is to be computed in this study.

Besides the construction of the network for the Faculty of Economics and Administration Building Project, the main consideration will be computing a realistic duration time for the project. Although there is direct relation between the time and cost of any activity, the time-cost function will be omitted in this study since it would be too involved and complicated. Similarly, the problem of "smoothing" or resource allocation is ommitted in this study. The main consideration will be the time factor.

Methodology

The methodology used in this study may be divided into 3 phases:

(1) Reading

(2) Examination of the architectural plans

(3) Informal interviews on the site.

The first step undertaken in this study was to read up all about critical path concepts. The reading up and familiarisation with the critical path technique was necessary, because, prior to the study the critical path concept was entirely new to the writer of this study. It was only after a detailed and thorough study of the subject from books, articles and management journals that the writer could proceed to the study proper.

The first step in applying the critical path method to the Faculty of Economics and Administration Building Project is the construction of a network diagram showing all the activities and events comprising the project in their logical sequence. This presentation of a graphic network forces and demands complete project planning. It involves the establishment of project objectives and depicts the relationships and interdependencies of the activities that must be accomplished to attain the end objectives. Before drafting the network diagram for the Faculty of Economics and Administration Building Project, a detailed study and examination of the architectural plans was made. From the general plans, the main events and activities to be completed, such as the foundation, the basement and the brickwalls were listed down systematically, though not in logical construction sequence. The events were arranged by listing in groups according to location, and type of work.

In constructing the network diagram for the Faculty of Economics and Administration Building Project, a series of informal interviews were held on the site with the site engineers and the site architect. In the Faculty of Economics and Administration Building Project there are two main categories of activities, namely,

(1) the structural activities

(2) the architectural activities.

The site engineer is responsible for the proper accomplishment of the structural work, and the site architect is in charge of the architectural work. It is essential when drawing the network to enlist the aid of the appropriate and responsible managers, since they are the people responsible for getting the work done. Therefore the network diagram for the structural work was drafted in conjunction with the site engineers on the site. Similarly, the network diagram depicting the architectural activities was drafted in conjunction with the site architect. In drafting the network diagram, three basic questions were constantly asked regarding each activity. They were:

(1) What events and activities must be accomplished before this event can start?

(2) What events and activities can start until after this event is completed?

(3) What events and activities can be conducted concurrently?

After the main and final network, incorporating the structural and architectural work was finalised, time estimates for each activity were obtained from the respective engineers and sub-contractors responsible for the job. These time estimates were based on the amount of work to be done, site conditions and their personal experience. Since the duration time of the activities in a construction project can be predicted with an accuracy that is sufficiently meaningful, only one time estimate was assigned to each activity.

The basic scheduling computations involving the forward and backward pass were then done manually on the network itself. The critical path through the network and the total project duration of the Faculty of Economics and Administration Building Project were obtained from the computations.

Finally, for control purposes the completed network was converted into a bar chart and set against a calendar scale.

<u>Limitations of the Study</u>

Since this study involves the application of a relatively new and unfamiliar management tool to a complex project such as the Faculty of Economics and Administration Building Project, the scope of this study has been simplified considerably. Simplification of the study imposes certain limitations on the usefulness, realism and also reduces its accuracy as an aid in decision making. The very fact that this study is confined only to the Lecture Theatre Block renders the study less realistic.

The network diagram for the Lecture Theatre Block should be interrelated with that for the Administration Block, since the whole project is to be carried by the same contractor using the same resources, equipment and manpower. However, this division is necessary since it is not feasible for a single student to complete the study of the whole Faculty of Economics and Administration Building Project within the limited time.

The implementation of a CPA system to any project requires the education and co-operation of the managers and the people responsible for the accomplishment of the project.

Although the co-operation received in this study was very enthusiastic especially from the site engineers and architect, they had some difficulty in comprehending what information was actually needed from them. This may be due to the fact that the critical path concept is relatively new in this country, and therefore the concepts and conventions are unfamiliar.

Since the critical path concept is relatively new in Malaysia, there is a corresponding lack of appropriate reading material and references on the subject. In the University of Malaya Library there are not more than ten books on the critical path technique, while in the main bookstores and other libraries no books on the subject can be found. This is especially evident and the writer of this study has to make the best out of the limited reading material.

Another main limitation is that the writer of this study, being unfamiliar with the technicalities of building construction and engineering has to make the most out of his limited knowledge in such a field supplemented for the most part by the invaluable help of the site engineers and architect.

CHAPTER II

HISTORICAL DEVELOPMENT OF PERT-CPM

In managing the affairs of modern business and government, the manager can no longer depend on intuition, guesswork and other rule of thumb methods as the basis for decision making. Complex projects which are characteristic of our Space Age comprise of thousands of interrelated, and interdependent tasks. It is virtually impossible to organise the multiple and myriad activities comprising the large project into one correlated plan. The unaided human mind cannot cope and weigh effectively the sheer size, complexity interrelatedness and interdependencies present on a large project such as the development of a nuclear missile, the construction of a complex building such as our Faculty of Economics and Administration Building Project or the construction of a ship. As a result, many parts of the project are usually accomplished independently of other parts, with a resulting loss of co-ordination and control. Conventional methods of planning and scheduling do not reveal the best course of action and this cannot be left to chance or trial and error.

During recent times the need for improved planning and progress evaluation techniques to help managers control the utilisation of manpower, facilities and materials has given great impetus to research in more scientific management technique. One of the most important advances in this search for better and more scientific methods of managing large research, development and construction projects has been the introduction of PERT (Program Evaluation and Research Technique) and CPM (Critical Path Method) in the mid 1950s.

The pioneering research and application of the network or arrow diagram and the critical path concept was a jointly sponsored venture of the E.l du Pont de Nemours Company and the Remington Rand Corporation. In 1957, the engineers developed a technique known as the Critical Path Method (CPM). Its objective was to improve the planning, scheduling and co-ordination of the company's large engineering projects and during the first complete years use of CPM it was credited with saving the company $1 million. Subsequent use underlined the basic simplicity and extraordinary usefulness of this method and by 1959 Dr. Mauchly who had worked on the Du Pont Project set up an organisation to solve industrial problems using the critical path method.

At the same time, allied techniques such as PERT (Program Evaluation and Research Technique) which is a variant of CPM, were being developed by other institutions. In 1958, the U.S. Navy Special Projects Office set up a research team to devise a means of dealing with the planning and control of its complex Fleet Ballistic Missile Weapons System development effort. The research team was composed of representatives from the Special Projects Office, and the management consulting firm of Booz, Allen and Hamilton, and the Lockheed Missiles and Space Company. The research team developed and implemented the PERT technique as a research and development project management tool to the Fleet Ballistic Missiles Program, where it was credited with saving two years in the developmentof the Polaris Missile.

Since 1958 considerable research work has been carried out in improving and consolidating these initial techniques, especially in the United States. Much of the research has been expended by the computer companies who have devised special names to distinguish their work. Many of these improved techniques are basically similar but only touted under different names, which is rather unfortunate since it adds confusion. Indeed there are over forty names in current use such as:- COMET (Computer Operated Management Evaluation Technique), CRAM (Contractual Requirements Recording, Analysis & Management), IMPACT (Inplementation, Planning and Control Technique) and LESS (Least Cost Estimating and Scheduling) to name a few of the allied techniques. Although PERT and CPM have some minor differences, both techniques are very similar in concept and in actual use. The approach taken in this study is that there is a "critical path methodology" that is common to both of these methods and to their variations. As such, the name Critical Path Analysis (CPA) will be used in this study. Except for this unfortunate resultant confusion of names, the concentration of effort is commendable and since 1958 PERT-type systems have aroused widespread interest and are being applied on an increasing scale in the construction, aerospace, motion picture and other industries. Despite the fact that no other management tool has been given so much publicity in recent years as PERT-CPM, these two allied techniques are still very poorly known and understood. This is especially true in Malaysia where PERT-CPM is relatively new to our management circles.

Basically, PERT-CPM are management planning and analysis tools which make use of a graphic display or network diagram. The network diagram provides a complete picture of all activities in logical sequence from project start to project completion. The completion of the network diagram allows the project to be analysed systematically and the information derived is vital for control. Normally, only 10 to 20 per cent of the activities comprising the project control the time required for the completion of the project. The critical path points out these critical activities of the project. In preparing this network diagram, the PERT-CPM technique indirectly forces and demands three vital functions namely, Planning, Analysing and Scheduling and Controlling. In this way, PERT-CPM is a fine tool of management.

<u>Advantages of Using PERT-CPM</u>

Despite the widespread publicity given to PERT-CPM techniques and their increasing use especially in the United States, PERT-CPM has been received with mixed emotions and varying success. Critics have branded it a 'gimmick', some look to PERT-CPM as the cure for all management planning and decision-making ills while others are not so sure. Whatever misconceptions which have been created, it must be stressed that PERT-CPM was not intended to cure or be a panacea for all management ills. It will not and cannot automatically solve all the problems associated with directing a program. PERT-CPM does not make decisions but it aids the decision maker.

The advantages of using PERT-CPM are:-

(1) It creates a detailed realistic and easy to communicate plan which is readily understood by all potential users and therefore improves the chances for achieving the objectives of the project. The use of the network diagram forces logical though, it compels planners to recognise the relationship of the parts to the whole. Its use as a planning tool is its single most important advantage.

(2) The PERT technique is extremely useful for work which involves a great deal of uncertainty such as research and development programs. The three time estimates assigned to each activity not only predicts the time but also the uncertainties of performance. The computation of the 'variance' shows the degree of uncertainty of the time estimates. The greater the variance, the greater the uncertainty of meeting the scheduled date of any given event. The statistical information predicts the probability of completing a project on schedule.

(3) The PERT-CPM techniques are also useful in focusing managerial attention on parts of the project most likely to impede or delay its accomplishment. Latent problems that require decisions and solutions are brought out. Normally only 10 to 20 percent of the activities in a project control the project time. Any speeding or slowing of the critical activities will directly influence the completion date of the project.

(4) Information is provided about project resources that are not being fully utilised. This problem is solved by CPM technique through doading or resource allocation. Theprocedures and adjustments regarding time, resources or performance improve the capability of meeting target dates.

(5) The presentation of the network diagram enables the simulation of alternative plans and schedules.

(6) PERT-CPM is credited with the provision of thorough and frequent project status reports, this enables the project to be controlled while it is being undertaken. A note of the actual performance compared with the plan summarised will show whether the overall project time is going to be achieved.

Disadvantages of PERT-CPM

One limitation of the PERT-CPM technique is that it cannot contribute directly to the solution of problems associated with industrial relations, quality control, day to day production and many other areas requiring management control. It will not and cannot solve automatically all the problems but it focusses managerial attention on problem areas. The PERT-CPM system does not replace good judgement but relies on good judgement to be effective. This dependence is a limitation since the judgement may be wrong. The implementation of such a system also relies on the co-operation of the operating people on providing information.

Another disadvantage of the PERT-CPM system is that the networks are unintelligible to outsiders who are not familiar with the concepts, conventions of PERT-CPM, except the creator of the networks. This situation is especially true where large networks with myriads of activities are shown. To overcome this disadvantage, the network should be constructed so that it can be easily read and understood by the person who is responsible for the performance of the activities.

Although a computer is not a 'must' for projects where the network consists of fifty or less events, it is essential for large networks. The amount of calculations would be too great to perform manually. This has discouraged small firms from using PERT-CPM systems for their projects because they do not have electronic data processing facilities.

CHAPTER III

THE PLANNING PHASE

Basic Elements of CPA

CPA is one form of the graphic network analysis technique. Essentially, Critical Path Analysis (CPA) can be considered to proceed in three distinct phases.

Phase 1: Planning

Phase 2: Analysing and Scheduling

Phase 3: Controlling.

Although these three phases are by no means independent of each other, it is convenient to consider each phase separately in this study. It is perhaps the best way to understand this new management technique, and to apply it to the Faculty of Economics and Administration Building Project.

What is Project Planning

The first phase Planning consists in determining what operations and activities must be performed to complete the project, and arranging the individual operations into a logical sequence. It entails the establishment of program objectives, and the determination of the sequence of requisite activities which will best achieve the objectives.

In order to perform the function of "Planning", it is necessary to find answers to such questions as:-

(1) What operations and activities must be performed to achieve the project objective?

(2) How will the operations and activities be achieved?

(3) Who will perform the work required to accomplish the operations?

(4) How much time will be needed to perform the operations?

(5) What relationships exist between the various operations and activities?

The answers to these questions involve the function of planning. In CPA, these plans are presented graphically in the form of a network diagram.

The Network

In planning a project, one is to a greater or lesser degree concerned with developing an optimal or at least workable plan of the activities that make up the project. This plan is in the form of a network, which is a graphic representation made up of Events that are joined by Activity lines to depict their interdependencies and inter-relationships. It is essentially a graphic mathematical portrayal of the plan for carrying out the project and provides an intelligible visual picture of the goals to be achieved and their interrelationships. As a planning technique, network preparation provides a most valuable service in drafting a plan for the future. If management used nothing more of CPA except network preparation - even without time estimates - then it would still derive considerable benefits from its use. Some industry representatives have attributed to network preparation to be 70 to 90 percent of the technique. Although this may be an exaggeration on the part of over-enthusiastic individuals, the usefulness of the network cannot be denied. Briefly, the network provides the following:-

(1) A disciplined and systematic basis for the planning of a project.

(2) A clear picture of the whole project that can be easily read and understood.

(3) An important vehicle for evaluating strategies and objectives.

(4) A means of preventing the omission of jobs that naturally belong to a project.

(5) A pinpointing of the responsibilities of the various groups or departments involved - because it shows the interrelationships among the operations.

(6) An aid in refining the design of the project.

Elements of a Network

The network which is the heart of CPA, consists of two basic elements.

(1) Events

(2) Activities

(1) Events

An event is an instantaneous occurrence of a definite recognisable nature whose accomplishment must be known at a point of time.

The essential criterion is that a definite, unambiguous point in time can be isolated - a broad band of availability is of no use.

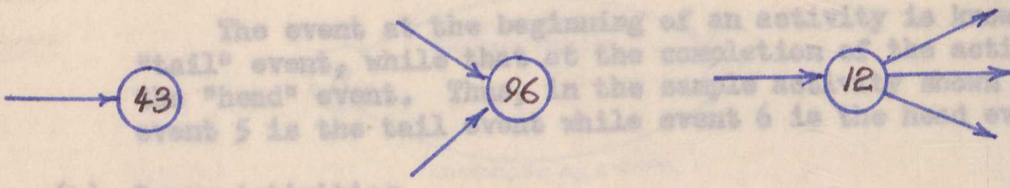
Events represent meaningful accomplishments within the overall plan and they signify the beginning or ending point of one or more activities. There may be work involved in approaching an event, but an event itself takes no time and therefore no work is represented by an event. Synonyms for events are "Node, Junction, Milestone or Stage".

Graphically an event is represented by a number, usually within convenient geometrical shapes - often circles.

Examples of Events may be shown below.

ILLUSTRATION 3.1

GRAPHICAL REPRESENTATION OF EVENTS



(2) Activities

There are two types of activities.

(a) Real activities.

(b) Dummy activities.

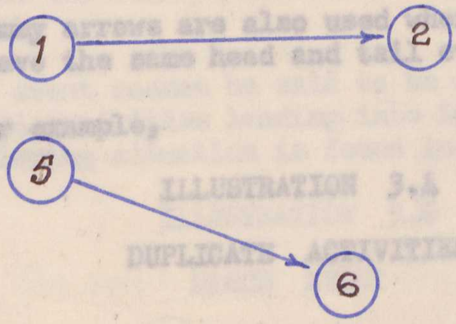
(a) Real Activities

A real activity represents the necessary work or job which must be accomplished to progress from one event to another. Activities, then, are operations which expend time, money, equipment and manpower. Thus, "Excavate for Ground Beams" is an activity just as much as "Concrete 1st Floor Columns", since both activities expend time, resources, equipment and manpower.

Activities are represented graphically by arrows usually with descriptions and duration times. The length and orientation of the arrow has no significance whatsoever, and is not drawn to scale, being chosen only for convenience of drawing. The arrow does no more than show the direction of the activity in time, the arrowhead indicating the completion of the examples of activities are shown by:-

ILLUSTRATION 3.2

GRAPHICAL REPRESENTATION OF ACTIVITIES



The event at the beginning of an activity is known as a "tail" event, while that at the completion of the activity is the "head" event. Thus, in the sample activity shown above, event 5 is the tail event while event 6 is the head event.

(b) Dummy Activities

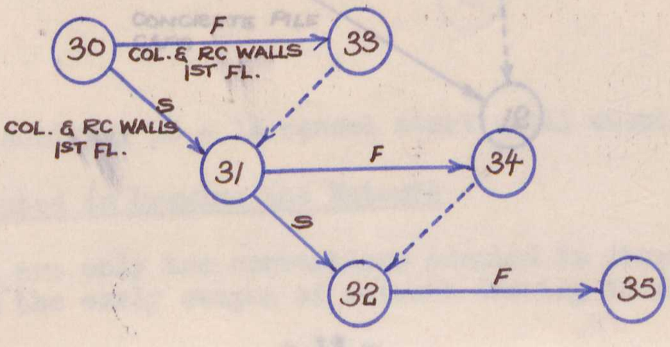
A dummy activity is a constraint which represents the dependency of one event upon another event. Dummy activities may have zero time associated with them or they may involve lead time or wait time. The constraint between the completion of one activity and the start of another is normally a zero time constraint. Dummy activities do not involve the expenditure of money, equipment, and/or manpower. Dummy activities are necessary mainly for sequential completeness and two main occasions may occur when dummies are needed.

(i) When one activity depends on another activity because of the common use of some resource, such as a skilled person or a piece of equipment.

The following example is an extract from the network for the Lecture Theatre Block, Faculty of Economics and Administration Building Project.

ILLUSTRATION 3.3

GRAPHICAL REPRESENTATION OF DUMMIES



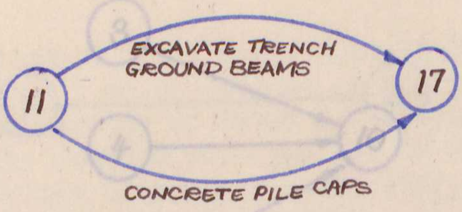
Activity 31 - 34 cannot start until the skilled person is released from activity 30 - 33. The dummy activity 31 - 33 shows the dependency of activity 31 - 34 on activity 30 - 33. No specific operation occurs, the dummy arrow simply indicates the sequence of events.

(ii) Dummy arrows are also used when two parallel activities would have the same head and tail events.

For example,

ILLUSTRATION 3.4

DUPLICATE ACTIVITIES

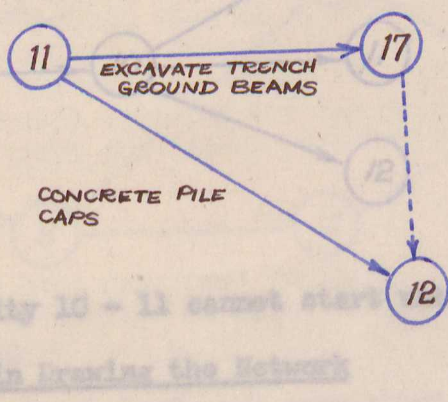


Both activities, "Excavate Trench for Ground Beams" and "Concrete Pile Caps" have the same head and tail events. This results in two different activities labelled under activity 11 - 17. Using only event numbers for identification, the two activities cannot be distinguished from one another. Therefore they may be called "duplicate activities". To avoid the resulting confusion, a dummy activity is introduced.

This may be shown as:

ILLUSTRATION 3.5

CORRECTION OF DUPLICATE ACTIVITIES BY THE USE OF A DUMMY ACTIVITY



Therefore no two activities should have identical head and tail numbers. The numbering of each activity is unique.

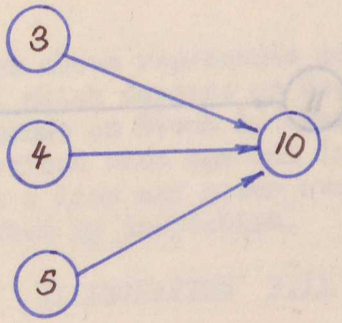
Network Rules

There are two fundamental rules which must be observed when drawing the network.

(1) An event cannot be said to be complete (reached or achieved) until all activities leading into it are complete. For example, the following situation is found in a network.

ILLUSTRATION 3.6

MERGE EVENT

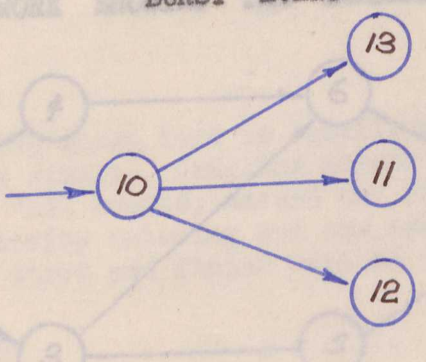


Event 10 can only be said to be complete when activities 3 - 10, 4 - 10, and 5 - 10 are all complete.

(2) No activity can start until its tail event is reached. Thus in the following example:

ILLUSTRATION 3.7

BURST EVENT



Activity 10 - 11 cannot start until event 10 is reached.

Conventions Adopted in Drawing the Network

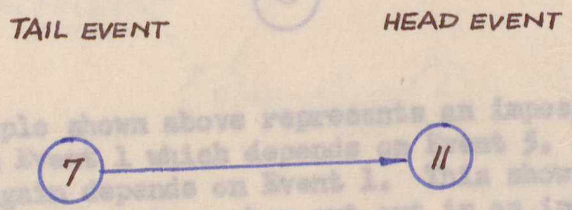
There are only two conventions adopted in drawing networks. It is useful in the early stages of network drawing to follow these conventions.

(1) Time flows from the left to the right.

(2) Head events always have a number higher than that of the tail event. For example,

ILLUSTRATION 3.8

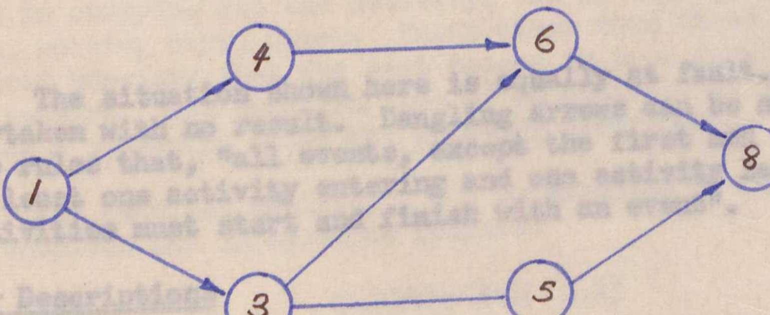
ACTIVITY WITH HEAD AND TAIL EVENT



The head event of activity 7 - 11 has a number higher than that of its tail event. This allows activities to be referred to uniquely by their head and tail event numbers. Activity 7 - 11 means the activity which starts from event 7 and proceeds to event 11. It should be noted that the head and tail event numbers need not follow each other in natural sequence and order, such as 1, 2, 3, 4, 5, 6 and so on. This can be shown by a sample network.

ILLUSTRATION 3.9

SAMPLE NETWORK SHOWING THE NUMBERING OF EVENTS

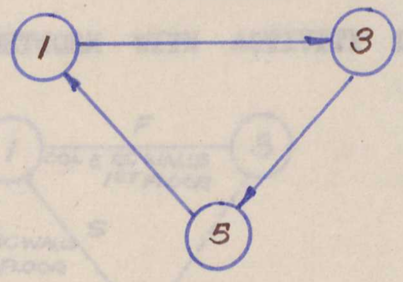


Common Errors in Logic

Errors in network logic may come about inadvertently when drawing a network for a sufficiently large project. These errors are known as Looping and Dangling.

ILLUSTRATION 3.10

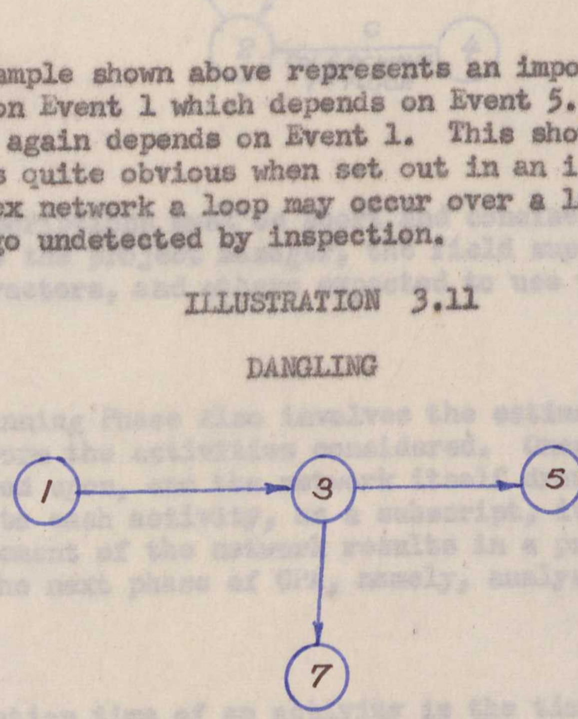
LOOPING



The example shown above represents an impossible situation. Event 3 depends on Event 1 which depends on Event 5. Event 5 depends on Event 3 which again depends on Event 1. This shows an error in network logic and is quite obvious when set out in an isolated form. However, in a complex network a loop may occur over a large chain of activities, and may go undetected by inspection.

ILLUSTRATION 3.11

DANGLING



The situation shown here is equally at fault. Activity 3 - 7 is undertaken with no result. Dangling arrows can be avoided by following the rules that, "all events, except the first and the last must have at least one activity entering and one activity leaving them", and "all activities must start and finish with an event".

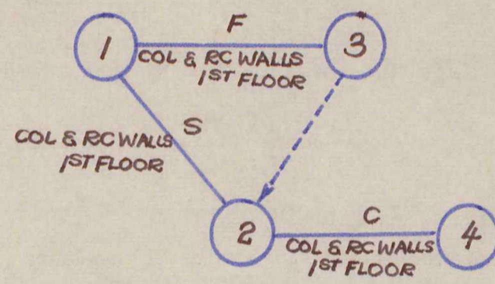
Activity Descriptions

Thus far we have concerned ourselves with the rules and conventions for drawing networks. In doing so the activities in the network have only been identified by the tail and head event numbers. This has been done both for convenience and to emphasis the logic of the network representations. In practice, it is very useful to print several descriptive words of the activity below the arrow. This avoids the necessity for cross reference with a separate list of the activity descriptions.

An example may be given.

ILLUSTRATION 3.12

SAMPLE NETWORK WITH ACTIVITY DESCRIPTIONS



The descriptions must be short and concise, and they must mean the same thing to the project manager, the field superintendent and the various sub-contractors, and others expected to use the network.

Time Estimation

The Planning Phase also involves the estimation of how long it will take to perform the activities considered. Once the logic behind a network is agreed upon, and the network itself drawn, it can be completed by adding to each activity, as a subscript, its estimated duration time. This refinement of the network results in a practical, working draft ready for the next phase of CPA, namely, analysing and scheduling.

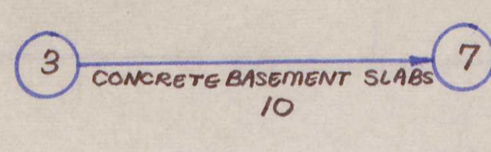
Duration Times

The duration time of an activity is the time which should be expended in carrying out the activity. It is expressed in units such as weeks, working days, hours. Units other than those stated may also be utilised provided that the unit chosen is used consistently throughout the network. The duration time of an activity is shown in the network as a subscript below the activity description.

For example, activity 3 - 7 is expected to take 10 working days to complete and is shown as follows:

ILLUSTRATION 3.13

ACTIVITY WITH DURATION TIME AND ACTIVITY DESCRIPTION



Conventional Assumptions in Time Estimation

The estimates of activity duration do not include such uncontrollable incontingencies as fires, floods, strikes or legal delays.

However as with all scheduling techniques, the duration times assigned to activities must be realistic, that is to say, they must take into account all local circumstances. If these uncontrollable incontingencies such as fire, floods are an inherent part and nature of the activities then they should be considered.

In estimating an activity's duration time the activity should be considered independently of activities preceding or succeeding it.

If activities are considered sequentially in chains it is possible that the duration time assigned to one activity might affect the choice of duration time for later activities.

For example, if it is realised that one long activity might delay the completion date, there is always the temptation to shrink succeeding activity duration times to give an overall acceptable answer.

Methods of Time Estimation

There are two methods of applying time estimates.

(1) The Single Estimate Method

(2) The Three Estimate Method

(1) The Single Estimate Method

This method of time estimation is used for activities which do not involve a great deal of uncertainty. In this method, only one time estimate is assigned to each activity. This estimation of the duration time should be done by the individual who is capable of or is responsible for the accomplishment of the activity. This is because time estimates should be realistic and should be as close to the actual as possible. The single estimate method is used in assigning time estimates to the activities comprising the Lecture Theatre Block, Faculty of Economics and Administration Building Project.

This is because an estimator on a construction's project can state the time which is an activity can be expected to take with an accuracy which is sufficiently meaningful.

(2) The Three Estimate Method

The three estimate method of time estimation is used for activities whose accomplishment is highly uncertain. One field of endeavour which is traditionally uncertain and without precedent, is research. The idea that creative work could be timed has been consistently dismissed as absurd. For example, if a design engineer is asked to estimate how long it will take to complete a piece of design work, he may have considerable difficulty, especially if the work undertaken is novel. However, it is probable that he can set some boundaries on the duration time.

PERT which was developed primarily for research and development programs considers the range of uncertainty inherent in such activities. It assigns three time estimates for each activity. The basis for selecting the three time estimates for each activity are:-

(a) Optimistic Time Estimate (a) .... an estimate of the minimum time an activity will take, a result which would be obtained if unusually good luck is obtained and everything goes right the first time. This is an unrealistic estimate to the extent that it can be expected to occur in approximately one case out of 100.

(b) Most Likely Time Estimate (m) ... an estimate of the normal time an activity will take, a result which would occur most often if the activity could be repeated many times under normal circumstances.

(c) Pessimistic Time Estimate (b) ... an estimate of the maximum time an activity will take, a result which would occur under adverse conditions when "everything which could go wrong goes wrong". The pessimistic time estimate should not be influenced by such factors as "catastrophic events" - strikes, fires, floods, power failures unless these hazards are inherent risks associated with the activity.

The three time estimate may be represented by symbols as follows:

a - the optimistic time estimate

m - the most likely time estimate

b - the pessimistic time estimate

From these three time estimates, a mean elapsed time (te) for each activity is approximated using the following equation:

$$te = \frac{a + 4m + b}{6}$$

Because the most likely time estimate should occur most often, it is weighted by a factor of 4 in computing the expected mean elapsed time (te). As with the single estimate method, the three time estimates should be obtained from the individual responsible for the performance of the activity.

<u>Accounting for Bad Weather</u>

In construction projects such as the Faculty of Economics and Administration Building Project, the weather is one of the greatest sources of scheduling uncertainty. This problem is obvious in a country like West Malaysia where the rainfall is high, and the project for the most part of its duration is vulnerable to bad weather. In a single time estimate system, there are two common approaches for taking the weather into account.

(1) The first approach is to omit consideration of the weather when estimating the duration of each activity, and instead estimate the total effect of weather on the project's duration. For example, suppose a project's duration is computed to be 200 working days, consideration is now made of the seasons in which the outdoor work will be done, the precipitation in the region, type of soil, type of construction and other weather related factors. It may be estimated that 25 days would be lost because of bad weather. Thus the project duration would be increased to about 225 days.

This is by far the best method for accounting for bad weather with respect to this study. At present, a daily record of the weather is taken at the site of the Faculty of Economics and Administration Building Project. The number of days lost due to bad weather may be added to the duration time computed for the project.

(2) The second method involves the consideration of weather effects in making each activity time estimate. In this approach each activity is evaluated as to its weather sensitivity. For example, excavation work is sensitive to rain, concrete work sensitive to freezing and rain, interior work not weather sensitive.

Suppose an activity is estimated to require 10 working days. The weather sensitivity of this activity, the season and other weather related factors may indicate that the activity's estimated duration should be increased by about 20%. The adjusted time estimate is 12 working days. This detailed approach to weather adjustments results in a more accurate schedule for each activity with reference to calendar dates.

<u>Steps in Drawing the Network</u>

We are now in a position to plan systematically the construction of the Lecture Theatre Block, Faculty of Economics and Administration Building Project, and to present these plans in the form of a network. However, it is always difficult to produce order from disorder, represented by the large number of activities that make up the project. This problem is faced by the network planner when planning a complex project. For, unless the network reflects the plan accurately, it cannot be expected to provide management its maximum benefits. In developing a network there are certain steps that should be followed in order to produce better networks in a shorter period of time. The following steps were adopted in developing the network for the Lecture Theatre Block, Faculty of Economics and Administration Building Project.

(1) Define the end objective precisely.

(2) Identify all the major events and activities in the project.

(3) Networking from the beginning event, draw the first arrow to represent the first activity in the project.

(4) As each subsequent activity is entered, three basic questions are asked.

(a) What must be done before we can start this activity?

(b) What activities may be done concurrently?

(c) What activities must immediately follow this activity?

With a thorough knowledge of the project, only these three questions need be answered to develop a complete network showing the essential relationships between the activities.

(5) Check for looping and dangling.

(6) Redraw the network. Numbering the events and adding activity descriptions.

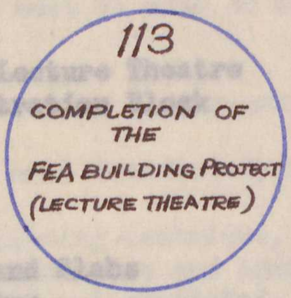
(7) Estimate the duration time for each activity using the Single Estimate Method.

Constructing the Network for the Lecture Theatre Block

The first step in constructing the network for any project is the definition of the end objective. In this study the end objective may be set down as "The Completion of the Lecture Theatre Block, Faculty of Economics and Administration Building Project". This is the last event in the network and corresponds with Event 113 in the main network.

ILLUSTRATION 3.14

END EVENT OF THE NETWORK FOR THE FEA BUILDING PROJECT (LECTURE THEATRE BLOCK)



The second step is to identify all the main events leading to the completion of the project. This step was accomplished by the careful and detailed examination of the architectural plans of the Lecture

Theatre Block. The major events listed may be shown as follows:-

(a) Foundation

(b) The Basement Floor

(c) The Ground Floor

(d) The First Floor

(e) The Roof

The five main events listed were further expanded to include the minor events. It must be noted that the main and minor events were listed systematically and not in accordance with construction logic or in logical sequence.

MAIN EVENTS OF THE FEA BUILDING PROJECT
(LECTURE THEATRE BLOCK)

1. Foundation

Piling
Pile Caps
Ground Beams

2. Basement Floor

Basement Floor Slabs
Seminar Rooms
Reinforced Concrete Walls
Buckwalls
A/C Plant Room
Store-rooms
Toilets - Sanitary Fittings
Underground Drains
Sewerage System

3. Ground Floor

Columns & RC Walls
Ground Floor Slabs
Drain Surrounding Lecture Theatre
Linkway to Administration Block
Doors and Windows

4. First Floor

First Floor Beams and Slabs
Linkway to Jalan Elmu
Columns & RC Walls
Brickworks
Doors and Windows
Glazing

Furniture
Light Fittings and Phones
PA System and Closed Circuit TV
Supporting Slab

5. <u>The Roof</u>

Roof Beams and Slabs
A/C Cooling Tower

The third step is the drawing of the network, beginning from the first event which represents the start of the project. The method of networking from the beginning event was employed instead of networking from the end event. This is because it is more convenient for the mind to take a progressive, step-by-step approach from the beginning of a project.

The preparation of the project network should be done by, or in conjunction with the key management of the project, the person or team of persons who know the most about the objectives, technology, and resources of the project. Towards this end, a series of informal interviews were conducted on the site with the site engineers and the site architect. It must be pointed out that there are two main types of activities in the project:

(a) Structural activities

(b) Architectural activities.

The site engineer is mainly responsible for the proper accomplishment of the structural activities of the project, while the site architect is in charge of the architectural activities. Therefore in drawing that part of the network comprising structural activities, the site engineer was consulted. Similarly, the site architect was consulted when architectural activities were involved.

In constructing the network, either in conjunction with the site engineer or site architect or both, the three basic questions were asked regarding each activity.

(a) What activities must be done so that we can start this activity?

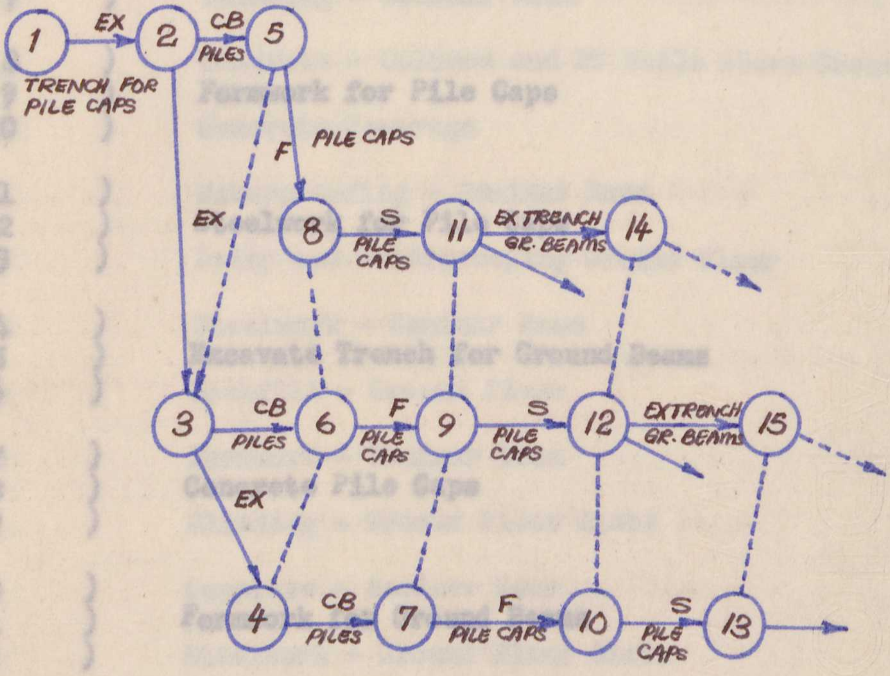
(b) What activities may be done concurrently?

(c) What activities must immediately follow this activity?

Using this questioning technique, the network for the Lecture Theatre Block, Faculty of Economics and Administration Building Project was systematically developed and completed. An extract from the main network may be shown on page 24.

ILLUSTRATION 3.15

AN EXTRACT FROM THE NETWORK FOR THE FEA BUILDING PROJECT (LECTURE THEATRE BLOCK)



Sub-contractors play a major role in the Faculty of Economics and Administration Building Project. Therefore they should also play a major role in the critical path planning, scheduling and control, since they are the people who actually perform the activities. In developing the network for the Lecture Theatre Block, the various sub-contractors were consulted occasionally by the site engineer and site architect to clarify certain points regarding the activities. However, it is not practical to call in a group of people unfamiliar with network theory and expect them to contribute effectively to the construction of the network. Thus the contributions of the sub-contractors towards the network were limited to clarifying, occasionally, how certain activities could be performed and their expected duration times.

TABLE 1

LIST OF ACTIVITIES COMPRISING THE FEA BUILDING PROJECT (LECTURE THEATRE BLOCK)

Activity Number	Activity Description
1 - 2 2 - 3 3 - 4	Excavate Trench for Pile Caps

Activity Number	Activity Description
2 - 5 3 - 6 4 - 7	Cutting and Blinding of Piles
5 - 8 6 - 9 7 - 10	Formwork for Pile Caps
8 - 11 9 - 12 10 - 13	Steelwork for Pile Caps
11 - 14 12 - 15 13 - 16	Excavate Trench for Ground Beams
11 - 17 12 - 18 13 - 19	Concrete Pile Caps
17 - 20 18 - 21 19 - 22	Formwork for Ground Beams
20 - 23 21 - 24 22 - 25	Waterproofing for Ground Beams
23 - 26 24 - 27 25 - 28	Steelwork for Ground Beams
28 - 29	Concrete Ground Beams
29 - 30	Waterproofing Basement Floor
30 - 31	Steelwork for Basement Floor Slabs
31 - 32	Formwork for Basement Floor Slabs
32 - 33	Concrete Basement Floor Slabs
33 - 34 34 - 35 35 - 36	Steelwork - Columns and RC Walls Above Ground Floor
30 - 37	Excavate - Sewerage System
33 - 38	Excavate - Seminar Room Floor
34 - 39 35 - 40 36 - 41	Formwork - Columns and RC Walls Above Ground Floor

Activity Number	Activity Description
37 - 42	Lay Pipes - Sewerage
38 - 43	Blinding - Seminar Room
41 - 44	Concrete - Columns and RC Walls Above Ground Floor
42 - 45	Concrete Sewerage
43 - 46	Waterproofing - Seminar Room
44 - 47	Delay and Waterproofing Ground Floor
46 - 48	Steelwork - Seminar Room
47 - 49	Backfill - Ground Floor
48 - 50	Formwork - Seminar Room
49 - 51	Blinding - Ground Floor Slabs
50 - 52	Concrete - Seminar Room
51 - 53	Steelwork - Ground Floor Slabs
53 - 54	Formwork - Ground Floor Slabs
54 - 55	Concrete - Ground Floor Slabs
55 - 56	Formwork - Seminar Room Staircase
55 - 57	Excavate Drain Surrounding Lecture Theatre
55 - 58	Steelwork - Linkway (1) LT - Administration Block (2) LT - Jalan Elmu
55 - 59	Formwork - 1st Floor Beams and Slabs
56 - 60	Steelwork - Staircase Seminar Room
57 - 61	Lay Precast U-drains
58 - 62	Formwork - Linkway Columns
59 - 63	Steelwork - 1st Floor Beams and Slabs
60 - 64	Staircase - Seminar Room
61 - 65	Concrete - Drain
62 - 66	Concrete - Linkway Columns
63 - 67	Concrete - 1st Floor Beams and Slabs

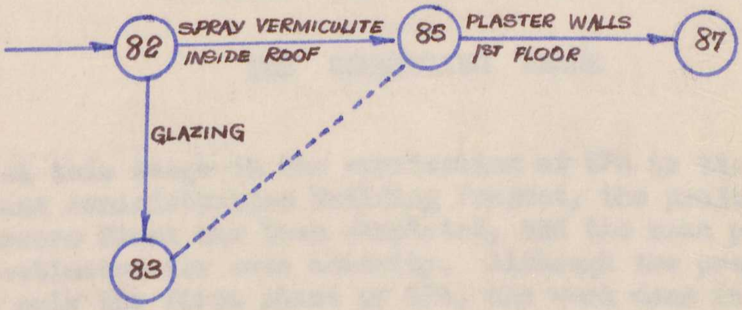
Activity Number	Activity Description
67 - 68	Steelwork - Columns and RC Walls Above 1st Floor
68 - 69	Steelwork - Columns and RC Walls Above 1st Floor
69 - 70	Steelwork - Columns and RC Walls Above 1st Floor
65 - 71	Brickwork - Drain
66 - 72	Formwork - Linkway Slabs and Beams
67 - 73	Install A/C Plant - Basement
68 - 74 69 - 75 70 - 76	Formwork - Columns and RC Walls Above 1st Floor
71 - 77	Plaster - Drain
72 - 78	Steelwork - Linkway Slabs and Beams
73 - 79	Doors and Windows - Ground Floor
73 - 80	Brickworks - Basement
78 - 81	Concrete - Linkway Slabs and Beams
80 - 82	Sanitary Fittings - Ground Floor
76 - 83	Concrete - Columns and RC Walls Above 1st Floor
83 - 84	Formwork - Supporting Slab
84 - 85	Steelwork - Supporting Slab
85 - 86	Concrete - Supporting Slab
86 - 87	Formwork - RC Walls Above Supporting Slab (Outside)
87 - 88	Steelwork - RC Walls Above Supporting Slab
88 - 89	Formwork - (Inside) RC Walls Above Supporting Slab
89 - 90	Concrete - RC Walls Above Supporting Slab
90 - 91	Install A/C Cooler
91 - 92	Formwork - Roof Beams and Slabs
92 - 93	Steelwork - Roof Beams and Slabs
93 - 94	Concrete Roof Beams and Slabs

Activity Number	Activity Description
94 - 95	Curing
95 - 96	Removal of Props
96 - 97	Brickwork - 1st Floor Walls
96 - 98	Doors and Windows - 1st Floors
96 - 99	Plaster Walls - Ground Floor
96 - 100	Car Park - East Wing
96 - 101	Car Park - West Wing
97 - 102	A/C Ducts - 1st Floors
99 - 103	Tiling Walls and Floor - Ground Floor Toilet
102 - 104	Glazing
103 - 105	Floor Finish - Ground Floor
104 - 106	Plaster Walls - 1st Floor
106 - 107	Floor Finish - 1st Floor
107 - 108	Painting - Ground and 1st Floor
108 - 109	Light Fittings and Phones
108 - 110	Furniture
110 - 111	PA System and Closed Circuit TV
111 - 112	Clearing Site
112 - 113	Lawning

The completed network for the Lecture Theatre Block, Faculty of Economics and Administration Building Project, was then checked for looping and dangling. This was done by inspection. Dangling activities which were revealed, were corrected by means of dummy activities. An example of such a correction may be shown on page 29.

ILLUSTRATION 3.16

DANGLING ACTIVITIES CORRECTED BY THE USE OF A DUMMY ACTIVITY



The completed network was then redrawn, and the events numbered. Activity descriptions in accordance with the Rules for Activity Descriptions were then added to each arrow on the network.

Symbols representing each type of work were used.

F — Formwork

C — Concreting

Ex — Excavation

WP — Waterproofing

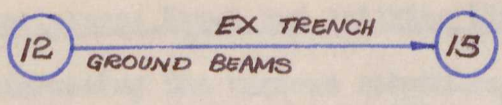
CB — Cutting and Blinding

S — Steelwork

An example of an activity with the tail and head events numbered including the activity description may be shown.

ILLUSTRATION 3.17

SAMPLE ACTIVITY FROM THE NETWORK FOR THE FEA BUILDING PROJECT (LECTURE THEATRE BLOCK)



The final step in producing a practical working network ready for scheduling computations is the addition of the activity duration times. The duration times for the activities in the network were obtained from the site engineer and site architect and occasionally the sub-contractors. The unit used is in working days.

CHAPTER IV

THE SCHEDULING PHASE

At this stage in the application of CPA to the Faculty of Economics and Administration Building Project, the project plan for the Lecture Theatre Block has been completed, and the mean performance times have been estimated for each activity. Although the preparation of the network is only the first phase of CPA, the work done in constructing the network has imposed a discipline upon the planners, forcing the consideration of:

What has to be done?

When?

By whom?

In what time?

The planners are forced to think through the project in a more complete manner than ever before. Its accomplishment has provided a clear, unambiguous statement of the plans which is readily understood by all.

The second essential phase in CPA is the scheduling of the activities and the determination of the network critical path(s). The scheduling phase imposes a set of times on the plans. The question "How long will the whole project take?" can be answered from the scheduling computations. The total project time is the shortest possible time in which the project can be completed, and this is determined by a sequence of events known as the Critical Path.

The basic scheduling computations consist of two steps.

(1) A Forward Pass Through the Network

(2) A Backward Pass Through the Network

Computational Nomenclature: Event and Activity Times

Before discussing the various scheduling computations adopted in this study, the following terms which will be used in the computations need to be clarified.

(1) Event Times

TE - the earliest occurrence time. It is the earliest expected

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Computational Nomenclature: Event and Activity Times

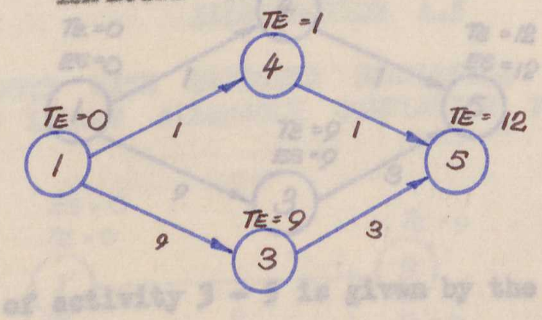
Before discussing the various scheduling computations adopted in this study, the following terms which will be used in the computations need to be clarified.

(1) Event Times

TE - the earliest occurrence time. It is the earliest expected completed date of the event. It is shown in the network as follows.

ILLUSTRATION 4.1

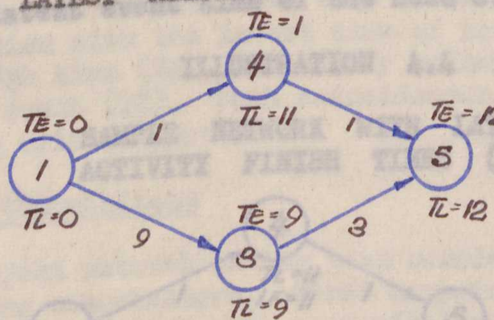
SAMPLE NETWORK WITH EVENT
EXPECTED COMPLETION TIMES (TE)



TL - latest allowable event occurrence time. It is the latest date on which an event can occur without delaying the completion of the end objective(s). It is shown in the network as follows.

ILLUSTRATION 4.2

SAMPLE NETWORK WITH EXPECTED COMPLETION TIMES (TE)
AND LATEST ALLOWABLE COMPLETION TIMES (TL)



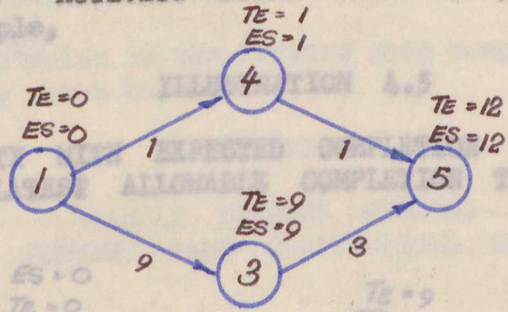
(2) Activity Times

According to network logic, activities cannot start until their tail events are complete, and must not finish beyond the starting time of their head events. Therefore the head and tail event times can be regarded to fix time boundaries within which activities can be carried out or "move". These "movements" of the activities within the tail and head event can be described by four types of times.

(a) ES - earliest activity start time. It is the earliest possible time an activity can start, and is given by the earliest event time (TE) of the tail event. For example,

ILLUSTRATION 4.3

SAMPLE NETWORK WITH EARLIEST ACTIVITY START TIMES (ES)



The ES of activity 3 - 5 is given by the TE of Event 3, which is 9 days.

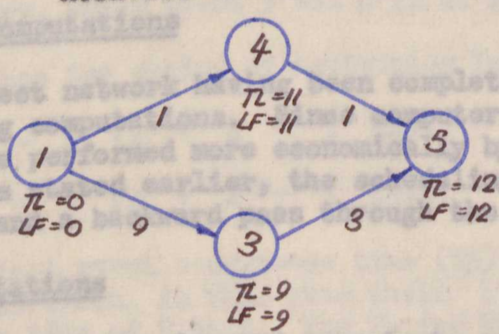
(b) EF - earliest activity finish time. It is the earliest possible time at which an activity can finish, and is given by adding the duration time of the activity to the earliest activity start time.

EF = ES + te

(c) LF - latest allowable (activity) finish time. It is found by taking the latest event time of the head event. For example,

ILLUSTRATION 4.4

SAMPLE NETWORK WITH LATEST ACTIVITY FINISH TIMES (LF)



The LF of activity 3 - 5 is the TL of the head event, i.e. event 5, which is 12 days.

(d) LS - latest allowable activity start time. It is the latest possible time by which an activity can start, without which the activity will finish beyond the starting time of the head event. It is given by subtracting the duration time from the latest event finish time.

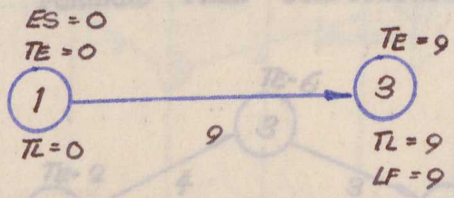
LS = LF - te

Event times should not be confused with activity times. The earliest activity start time (ES) coincides with the earliest time of its tail event (TE), and the latest finish time of an activity (LF) coincides with the latest time of its head event (TL).

For example,

ILLUSTRATION 4.5

ACTIVITY WITH EXPECTED COMPLETION TIMES (TE) AND LATEST ALLOWABLE COMPLETION TIMES (TL)



The ES of activity 1 - 3 is the TE of Event 1 which is the tail event. The LF of activity 1 - 3 coincides with the TL of event 5, the head event.

However, the latest start time of an activity (LS) does not necessarily coincide with the latest time of its tail event, nor does the earliest finish time (EF) necessarily coincide with the earliest time of its head event (TE). Such coincidences apply only to the activities on the critical path.

Basic Scheduling Computations

The project network having been completed, it is now appropriate to begin scheduling computations. Since computers will not be used, the computations may be performed more economically by hand directly on the network itself. As stated earlier, the scheduling computations first involve a forward and a backward pass through the network.

Forward Pass Computations

The purpose of the forward pass is to compute the earliest activity start (ES or TE) and finish times (EF) for each activity in the project on a working day basis. To accomplish this, the following technique may be used.

(a) Start from the left of the network, that is, at the first event.

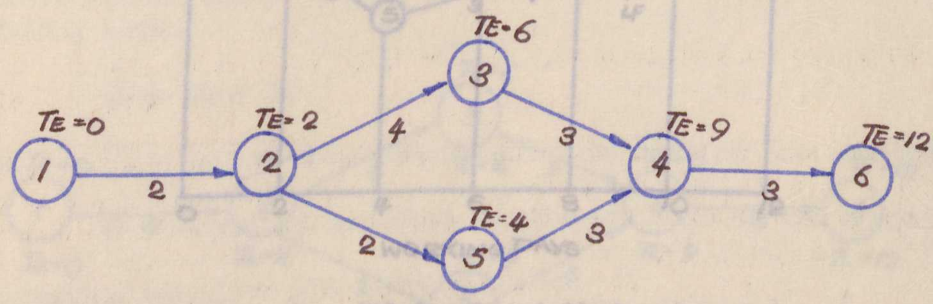
(b) Arbitrarily give the first event in the network an earliest event time (TE) of zero, and then assume that each activity starts as soon as possible, i.e. the instant its predecessor event occurs.

(c) Proceed to each event in order and calculate the earliest possible time at which the event can occur (TE). If several activities merge into an event, the earliest event occurrence time (TE) is equal to the largest of the earliest finish times of the activities merging into the event in question.

The above rules in the forward pass computations may be applied to a simple network shown below.

ILLUSTRATION 4.6

SAMPLE NETWORK SHOWING
FORWARD PASS COMPUTATIONS ONLY



Starting from the left of the network, the first event, i.e. Event 1 is given a TE of zero.

Event 2 has an earliest event occurrence time of 2 days. Event 3 has a TE of 6 days, while Event 5 has a TE of 4 days.

Event 4 has two chains of activities leading into it.

(i) 1 - 2 - 3 (2 + 4 + 3 days)

(ii) 1 - 2 - 5 (2 + 2 + 3 days)

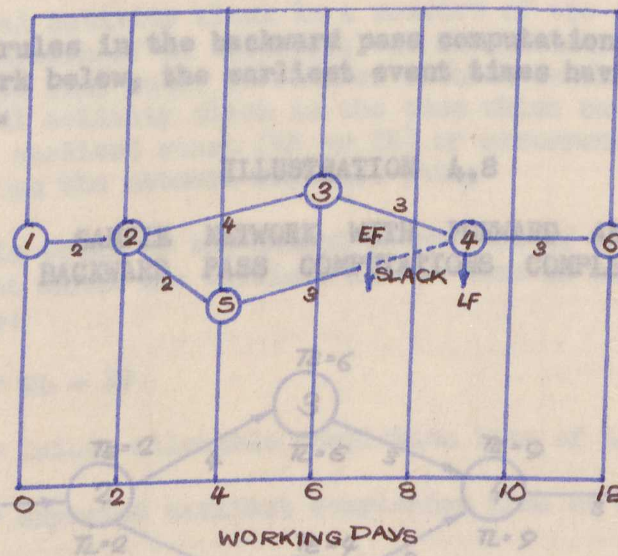
The earliest event occurrence time (TE) for Event 4 is determined by the longest chain, in this case chain 1 - 2 - 3 which has a combined duration time of 9 days. The TE for Event 8 is therefore 9 days.

Regardless of how many activities merge to a given event, the rule is the same: "the earliest merge event time is the largest of the earliest finish times of the merging activities".

As a convenient means of showing more clearly, the earliest start (ES) and finish times (EF) for each activity the forward pass network has been drawn to scale on a time base. However, the time scaled network on page 36 will only be used for illustrative purposes.

ILLUSTRATION 4.7

THE FORWARD PASS NETWORK SHOWN ON A TIME SCALE



In practice, it will be found that, when not using a computer, the calculations are best carried out on the network itself.

Backward Pass Computations

The purpose of the backward pass computation is to compute the latest allowable start (LS) and latest allowable finish times (LF) for each activity, which will permit the last event to occur at its earliest expected time (TE), as computed in the forward pass. To accomplish, the following rules for the backward pass computations may be given.

(a) Start from the right of the network (the last event)

(b) Arbitrarily assign to the last event a latest allowable occurrence time.

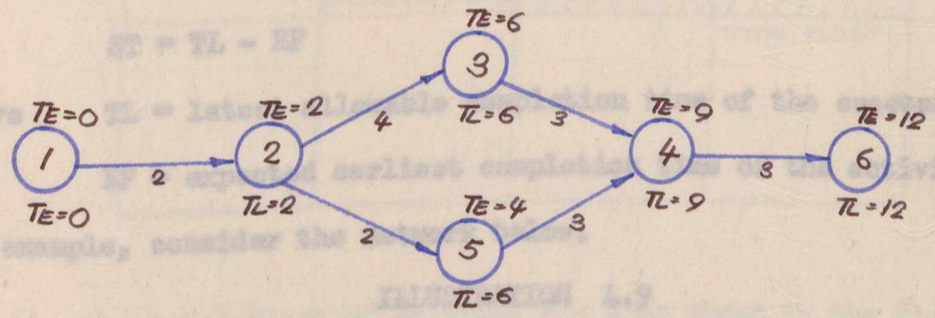
The TL for the last event in the network for the Lecture Theatre Block, Faculty of Economics and Administration Building Project, is assumed to be equal to the TE of the last event, as computed in the forward pass. Therefore TL = TE. However, the TL for the completion of the end event is often a decision that is made independently of the network. It is often a contractual completion date or a scheduled completion date (TS) that is set by the customer prior to issuing the contract to perform work. If a scheduled date exists for the end event on a network, the TL will be equal to the TS. The scheduled date therefore becomes the latest event occurrence time because the customer has directed it to be so. In this study, however, it is assumed that TE = TL.

(c) Starting from the end event, subtract the mean activity time (te) of each activity from the TL of the end event. This will establish the latest event occurrence time (TL) for each event. In situations where there is more than one path leading back to an event, the smallest value is the TL of the event.

The rules in the backward pass computations may be applied to a simple network below, the earliest event times having been computed in the forward.

ILLUSTRATION 4.8

SAMPLE NETWORK WITH FORWARD AND BACKWARD PASS COMPUTATIONS COMPLETED



Starting from the right of the network, Event 6 is the last event. We assume that the TL for Event 6 is equal to the TE which is 12 days.

Starting from Event 6, subtract the duration time (te) of activity 4 - 6 from the TL of Event 6.

TL (Event 6) - te (Activity 4 - 6) = TL (Event 4)

The TL of Event 4 is 9 days.

Similarly, the TL of Event 3 can be computed in the same manner and is 6 days. The TL of Event 5 is 6 days.

For Event 2, two activities lead into it, i.e. activity 2 - 3 and activity 5 - 4. However, the smallest value should only be taken and this is 2 days.

Slack

The forward and backward pass computations having been completed, the results may now be analysed to determine the float or slack. Among the many types of slack, two are of the most value and they are:-

(1) Total Activity Slack or Total Float

(2) Activity Free Slack or Free Float.

(1) Total Activity Slack

Total activity slack is a measure of the amount of time between the completion of an activity, and the latest time that its successor event (TL) could be reached without causing any delay in the project. Total activity slack is the time which can be delayed without affecting the earliest start (ES or TE) or occurrence time of any activity or event on the network critical path.

It is equal to the latest event time of the activity's successor event minus the earliest finish time of the activity in question, thus:

$$ST = TL - EF$$

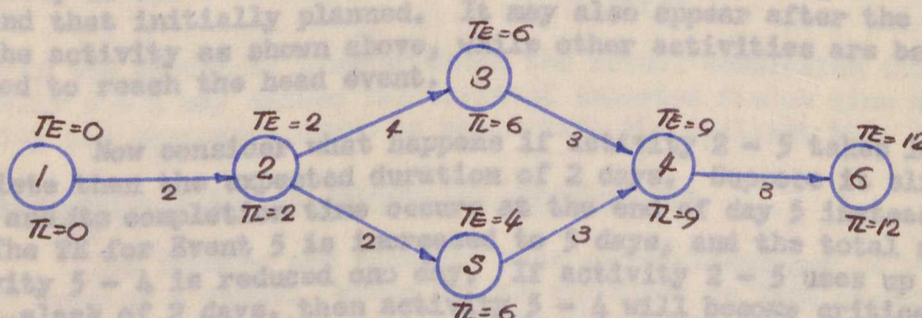
where TL = latest allowable completion time of the successor event,

EF = expected earliest completion time of the activity.

For example, consider the network below.

ILLUSTRATION 4.9

SAMPLE NETWORK FOR THE ANALYSIS OF TOTAL ACTIVITY SLACK



Looking at activity 2 - 5, it will be seen that the earliest possible time the activity can start is day 2, while the latest possible time it can finish is day 6.

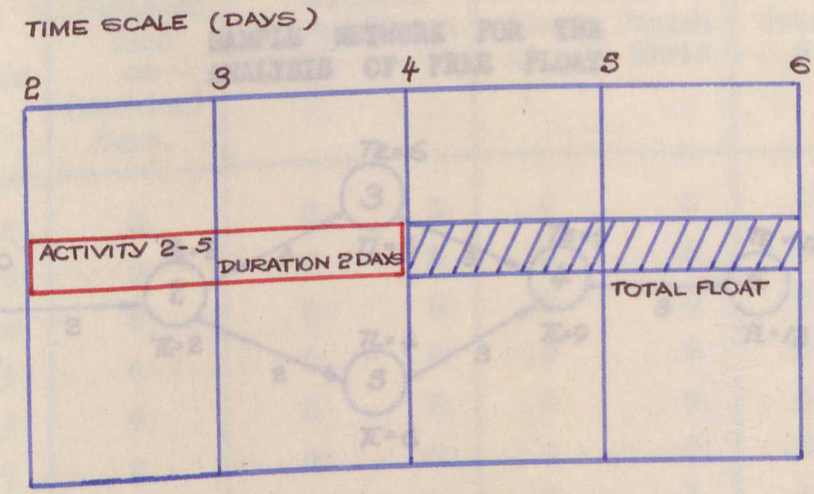
The maximum time available = 6 - 2 days

= 4 days.

However, activity 2 - 5 needs only the duration time of 2 days in order to be completed. Thus the activity 2 - 5, which takes only 2 days to complete is given 4 days. Activity 2 - 5 can therefore move or expand by (4 - 2 days) = 2 days. The time of 2 days is known as the Total Float possessed by the activity.

ILLUSTRATION 4.10

EXAMPLE OF AN ACTIVITY POSSESSING TOTAL FLOAT



The total float of activity 2 - 5 is shown in the figure above as appearing at the end of the activity. This is not necessarily the case, since the float can also appear at the beginning of the activity. The starting of the activity can be delayed after the tail event is reached, it can also appear in the activity, increasing the duration time beyond that initially planned. It may also appear after the completion of the activity as shown above, while other activities are being concluded to reach the head event.

Now consider what happens if activity 2 - 5 takes longer to complete than the expected duration of 2 days. Suppose it slips one day, and its completion time occurs at the end of day 5 instead of day 4. The TE for Event 5 is increased to 5 days, and the total slack for activity 5 - 4 is reduced one day. If activity 2 - 5 uses up all of its total slack of 2 days, then activity 5 - 4 will become critical, since its total slack is reduced to zero. It must start immediately on day 6, otherwise the project will be delayed.

(2) <u>Activity Free Slack or Free Float</u>

Activity free slack is a measure of the amount of time that an activity can slip without delaying completion of the successor event. Activity slack time can only occur when there are two or more activities leading into a single event. Activity slack time is equal to the earliest expected time of the activity's successor event minus the earliest finish time of the activity in question.

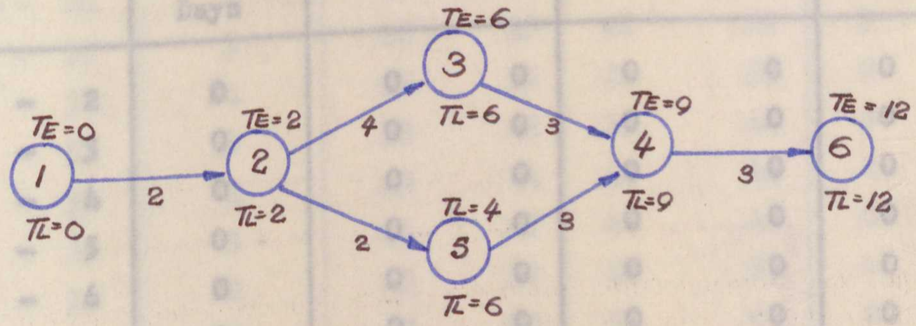
SF = TE - EF

where TE = expected completion time of the successor event, EF = expected completion time of the activity in question.

An example of activity free slack may be given in the network under consideration, at Event 4.

ILLUSTRATION 4.11

SAMPLE NETWORK FOR THE ANALYSIS OF FREE FLOAT



Applying the formula, SF = TE - EF

we have SF = 9 - 7

= 2 days.

This is the amount of time by which the actual completion time of activity 5 - 4 may exceed its earliest expected finish time without causing its successor event to occur past its earliest time TE = 9.

Tabular Presentation of Scheduling Computations

The forward and backward pass computations may be presented in the form of a table. While not as efficient as hand computations directly on the network, under certain circumstances one may prefer to make computations on a sheet separate from the network and in a tabular manner. The importance of tabular computations is that it provides an insight into computer procedures. The scheduling computations done on the network for the Faculty of Economics and Administration Building Project (Lecture Theatre Block) may be presented on page 41 in the form of a table.

The Critical Path

Having analysed and calculated the slack time possessed by each activity, it is possible to isolate the critical path(s) from the network.

TABLE 2

TABULAR PRESENTATION OF THE SCHEDULING COMPUTATIONS FOR THE FEA BUILDING PROJECT, LECTURE THEATRE BLOCK

Activity PRE - SUCC	Duration Time te (Working) Days	Earliest Start TE=ES	Earliest Finish EF	Latest Start LS	Latest Finish TL=LF	Slack Total S	Slack Free SF
1 - 2	0	0	0	0	0	0	0
2 - 3	0	0	0	0	0	0	0
3 - 4	0	0	0	0	0	0	0
2 - 5	0	0	0	0	0	0	0
3 - 6	0	0	0	0	0	0	0
4 - 7	0	0	0	0	0	0	0
5 - 8	1	0	1	0	1	0	0
6 - 9	1	1	2	4	5	3	3
7 - 10	1	5	6	8	9	3	3
8 - 11	4	1	5	1	5	0	0
9 - 12	4	5	9	5	9	0	0
10 - 13	4	9	13	9	13	0	0
11 - 14	2	5	7	7	9	2	0
12 - 15	2	9	11	12	14	3	0
13 - 16	2	13	15	14	16	1	0
11 - 17	3	5	8	9	12	4	0
12 - 18	3	9	12	11	14	2	0
13 - 19	3	13	16	13	16	0	0
17 - 20	2	8	10	12	14	4	0
18 - 21	2	12	14	14	16	2	0
19 - 22	2	16	18	16	18	0	0
20 - 23	2	10	12	14	16	4	0
21 - 24	2	14	16	16	18	2	0
22 - 25	2	18	20	18	20	0	0
23 - 26	2	12	14	16	18	4	0
24 - 27	2	16	18	18	20	2	0

(contd)

TABLE 2

Activity PRE	Activity SUCC	Duration Time te (Working) Days	Earliest Start TE=ES	Earliest Finish EF	Latest Start LS	Latest Finish TL=LF	Slack Total S	Slack Free SF
25	28	2	20	22	20	22	0	0
28	29	3	22	25	22	25	0	0
29	30	14	25	39	25	39	0	0
30	31	3	39	42	39	42	0	0
31	32	2	42	44	42	44	0	0
32	33	3	44	47	44	47	0	0
33	34	10	47	57	47	57	0	0
34	35	10	57	67	57	67	0	0
35	36	10	67	77	67	77	0	0
30	37	2	39	41	122	124	83	0
33	38	4	47	54	110	114	60	0
34	39	9	57	66	58	67	1	0
35	40	9	67	76	68	77	1	0
36	41	9	77	86	77	86	0	0
37	42	3	41	44	124	127	83	0
38	43	2	51	53	114	116	63	0
41	44	5	86	91	85	91	0	0
42	45	1	44	45	127	128	83	0
43	46	5	53	58	116	121	63	0
44	47	25	91	116	91	116	0	0
46	48	4	58	62	121	125	63	0
47	49	5	116	121	116	121	0	0
48	50	1	62	63	125	126	63	0
49	51	1	121	122	121	122	0	0
50	52	2	63	65	126	128	63	0
51	53	3	122	125	122	125	0	0
53	54	1	125	126	125	126	0	0
54	55	2	126	128	126	128	0	0

(contd)

TABLE 2

Activity PRE - SUCC	Duration Time te (Working) Days	Earliest Start TE=ES	Earliest Finish EF	Latest Start LS	Latest Finish TL=LF	Slack Total S	Slack Free SF
55 - 56	1	128	129	196	197	68	0
55 - 57	7	128	135	179	186	51	0
55 - 58	1	128	129	193	194	65	0
55 - 59	30	128	158	128	158	0	0
56 - 60	1	129	130	197	198	68	0
57 - 61	7	135	142	186	193	51	0
58 - 62	1	129	130	194	195	65	0
59 - 63	15	158	173	158	173	0	0
60 - 64	1	130	131	198	199	68	0
61 - 65	2	142	144	193	195	51	0
62 - 66	1	130	131	195	196	65	0
63 - 67	8	173	181	173	181	0	0
67 - 68	2	181	183	181	183	0	0
68 - 69	2	183	185	186	188	3	3
69 - 70	2	188	190	191	193	3	3
65 - 71	2	144	146	195	197	51	0
66 - 72	1	131	132	196	197	65	0
67 - 73	7	181	188	183	190	2	0
68 - 74	5	183	188	183	188	0	0
69 - 75	5	188	193	188	193	0	0
70 - 76	5	193	198	193	198	0	0
71 - 77	2	146	148	197	199	51	0
72 - 78	1	132	133	197	198	65	0
73 - 79	3	188	191	196	199	8	0
73 - 80	5	188	193	190	195	2	0
78 - 81	1	133	134	198	199	65	14
80 - 82	4	193	197	195	199	2	0
76 - 83	1	198	199	198	199	0	0

(contd)

TABLE 2

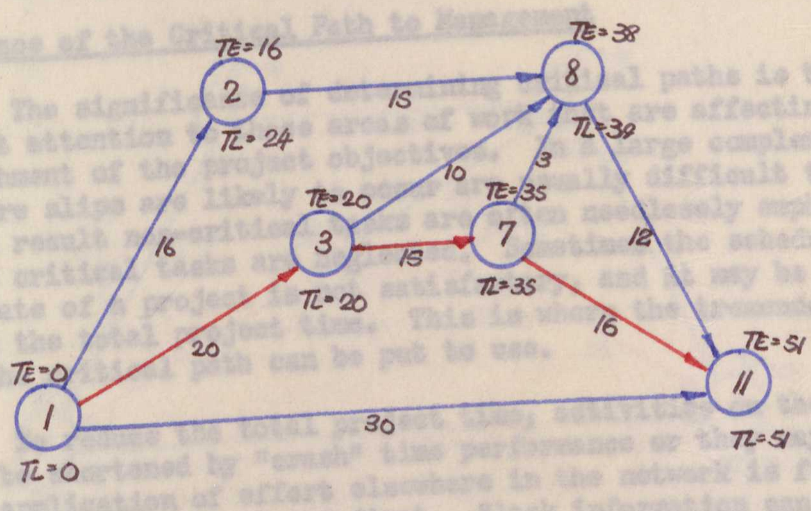
Activity PRE - SUCC	Duration Time te (Working) Days	Earliest Start TE=ES	Earliest Finish EF	Latest Start LS	Latest Finish TL=LF	Slack Total S	Slack Free SF
83 - 84	6	199	205	199	205	0	0
84 - 85	4	205	209	205	209	0	0
85 - 86	2	209	211	209	211	0	0
86 - 87	4	211	215	211	215	0	0
87 - 88	4	215	219	215	219	0	0
89 - 90	2	222	224	222	224	0	0
90 - 91	4	224	228	224	228	0	0
91 - 92	45	228	273	228	273	0	0
92 - 93	15	273	288	273	288	0	0
93 - 94	8	288	296	288	296	0	0
94 - 95	10	296	306	296	306	0	0
95 - 96	7	306	313	306	313	0	0
96 - 97	14	313	327	313	327	0	0
96 - 98	4	313	317	327	331	14	0
96 - 99	8	313	321	344	352	31	0
96 - 100	20	313	333	397	417	84	0
96 - 101	5	313	318	412	417	99	0
97 - 102	4	327	331	327	331	0	0
99 - 103	4	321	325	352	356	31	0
102 - 104	12	331	343	331	343	0	0
103 - 105	4	325	329	356	360	1	0
104 - 106	7	343	350	343	350	0	0
106 - 107	10	350	360	350	360	0	0
107 - 108	10	360	370	360	370	0	0
108 - 109	10	370	380	397	407	27	0
108 - 110	30	370	400	370	400	0	0
110 - 111	7	400	407	400	407	0	0
111 - 112	6	407	413	407	413	0	0
112 - 113	4	413	417	413	417	0	0

Definition: The critical path through a network is the path with the least total float. If we assign TL = TE for the final network event, then the critical path will have zero float.

For example, the critical path in the simple network shown below is made up of activities 1 - 3 - 7 - 11. It is the longest path leading to the end event.

ILLUSTRATION 4.12

SAMPLE NETWORK SHOWING THE CRITICAL PATH



This path is called the most critical path since it establishes the greatest time constraint on the completion of the end event. The sum of the activity times along the most critical path will determine the date upon which the end objective is expected to be completed.

The critical path has two main features.

(1) If the project time is to be shortened, one or more of the activities on this longest path must be shortened or eliminated. The application of efforts elsewhere will be useless unless the critical path is shortened first.

(2) If the time required for the actual performance of an activity on the critical path is in excess of the original estimates, the completion of the end event (program objective) is delayed correspondingly.

For example in the network shown above, the most critical path is 1 - 3 - 7 - 11. If the te for activity 7 - 11 is increased from 16 working days to 20 working days, it will cause the expected completion date (TE) for the end event to change from 51 days to 55 days.

It is possible to have more than one critical path. Where several paths exist, as many as possible should be analysed to evaluate the resulting action of changing one or more events along the paths to impose the schedule.

Criticality may be measured in terms of negative, zero, and positive. Negative slack indicates a behind schedule situation. It occurs when the total mean activity time along the critical path is greater than the time available to meet program requirements.

Zero slack indicates an on-schedule condition when the TE = TL for the end event.

Positive slack indicates an ahead of schedule condition or the amount of time an event can be delayed without adversely affecting the schedule of the end objective.

Significance of the Critical Path to Management

The significance of determining critical paths is to focus management attention to those areas of work that are affecting the timely accomplishment of the project objectives. In a large complex project the areas where slips are likely to occur are usually difficult to isolate, and, as a result non-critical tasks are often needlessly emphasised. while the critical tasks are neglected. Sometimes the scheduled completion date of a project is not satisfactory, and it may be necessary to reduce the total project time. This is where the tremendous advantage of the critical path can be put to use.

To reduce the total project time, activities on the critical path can be shortened by "crash" time performance or they may be eliminated. The application of effort elsewhere in the network is futile unless the critical path is shortened first. Slack information can also be used to determine those areas in the project from which resources (manpower, equipment, materials) may be made available for application to more critical areas.

Isolating the Critical Path

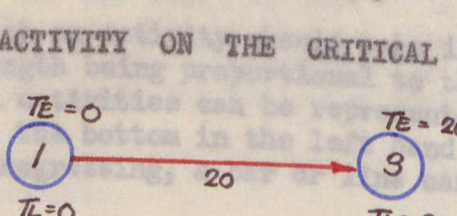
The critical path in a network has been defined as that path which has least total float. Since it has been assumed that TE = TL for the final event of the network for the Lecture Theatre Block, Faculty of Economics and Administration Building Project, the critical path will have zero float.

The critical path may be isolated by applying two tests.

(1) The critical path lies along those activities whose earliest and latest times for the tail events and also for the head events are the same.

ILLUSTRATION 4.13

AN ACTIVITY ON THE CRITICAL PATH



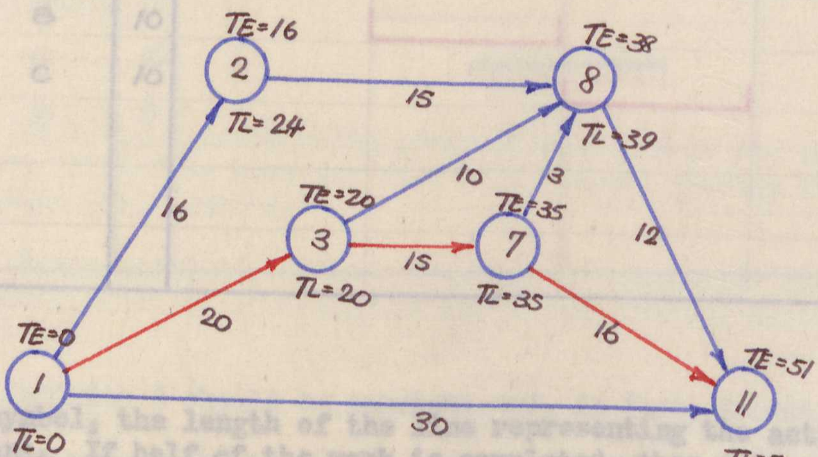
For example, activity 1 - 3 is a critical activity if the TE = TL for Event 1 and the TE = TL for Event 3.

(2) The duration time of the critical activity should be equal to the difference between head and tail event times.

For example,

ILLUSTRATION 4.14

SAMPLE NETWORK FOR ISOLATING THE CRITICAL PATH



Consider activity 7 - 11 whose duration time is 16 days. The difference between the tail and head event times is equal to 16 days. It is therefore a critical activity. Activity 1 - 11 satisfies the first test since TE = TL for both its head and tail events. However, on applying the second test it is found to be a non-critical activity. Both tests should therefore be applied when isolating the critical path.

The Network and the Bar Chart

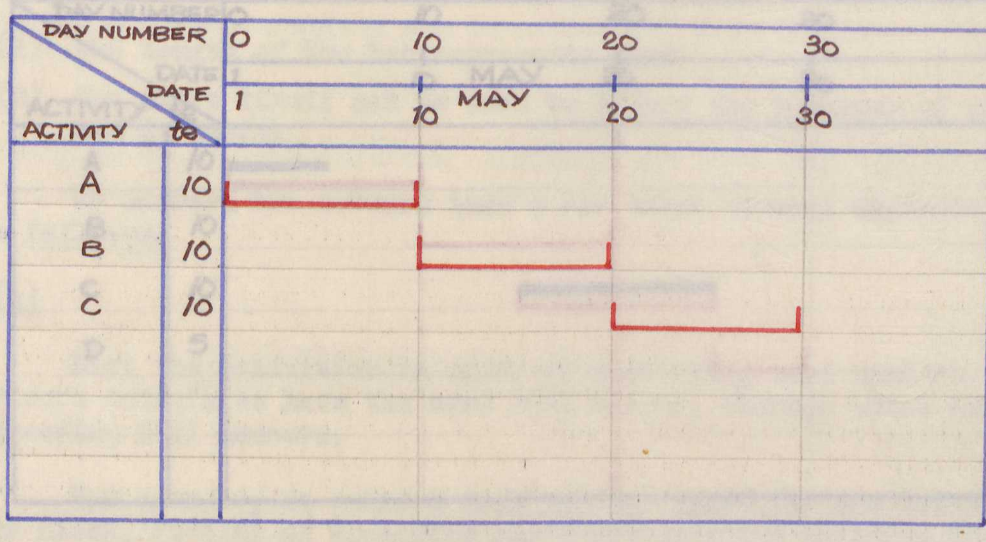
The network may be presented in the form of a bar chart (also known as the Gantt Chart). The bar chart which is one of the most widely used planning tools, consists of a number of bars plotted against a calendar date, each representing the beginning, duration and end of some aspect of the total job to be done.

An example of a bar chart may be shown on page 48.

The time which an activity should take is represented by a horizontal bar, the length being proportional to the duration time of the activity. Several activities can be represented on the chart, being listed from the top to the bottom in the left hand column. To show how the work is actually progressing, a bar or line can be drawn above the

ILLUSTRATION 4.15

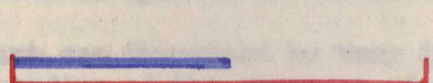
PRESENTATION OF THE NETWORK
IN THE FORM OF A BAR CHART



activity symbol, the length of the line representing the actual amount of work done. If half of the work is completed, then a line half of the length of the activity symbol can be drawn. For example,

ILLUSTRATION 4.16

RECORDING THE ACTUAL PROGRESS OF
THE ACTIVITY ON THE BAR CHART



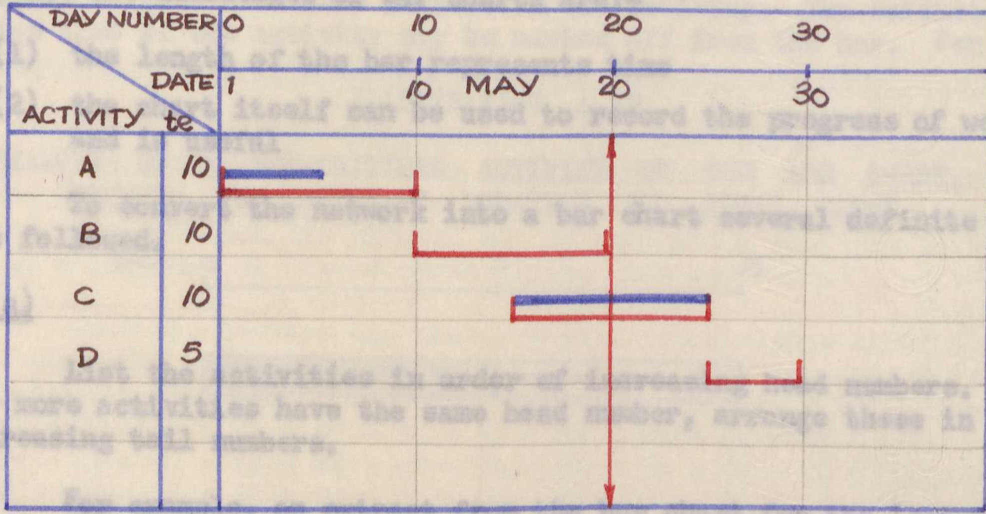
The bar chart thus enables a simple, yet striking representation of work actually done. It enables the manager to see which tasks are currently behind schedule.

For example, the bar chart on page 49 is viewed at the end of day 20 or 20th May (represented by the red line). The manager of the proejct can immediately obtain information on the progress of the activities. From the bar chart the following information is obtained:

Activity A should be complete but, in fact, is only 50% complete.

ILLUSTRATION 4.17

PROGRESS NOTATION ON THE BAR CHART



Activity B should be complete and, in fact, is not started.

Activity C should be 50% complete but is complete.

Activity D should not be started yet and, in fact, is not started.

Therefore it is apparent that bars to the left of the observation line represent under fulfillment, while bars to the right represent over fulfillment. The reasons for the delay can be displayed against the bar in question by means of symbols or codes.

The bar chart can therefore be very informative, combining both planning and recording of the progress of the activities.

Deficiencies of the Bar Chart

Although the bar chart is extremely useful since the progress against the original plan can be displayed for large and complex projects, it has several serious deficiencies.

(1) The bar chart cannot show the interrelationship between the activities. The activities are shown on the bar chart as separate and discrete bars, neglecting the interdependencies which exist between the various activities. This is a main deficiency of the bar chart.

(2) The static scale of the bar chart makes it difficult to reflect the dynamic nature of changing plans.

Converting the Network into a Bar Chart

After the network is completed, it may be desirable to convert and present it in the form of a bar chart. Bar chart presentation has several advantages over the network, although it also has certain deficiencies. The advantages of bar charts are:-

(1) the length of the bar represents time

(2) the chart itself can be used to record the progress of work and is useful

To convert the network into a bar chart several definite steps may be followed.

Step (a)

List the activities in order of increasing head numbers. Where two or more activities have the same head number, arrange these in order of increasing tail numbers.

For example, an extract from the bar chart for the Lecture Theatre Block, Faculty of Economics and Administration Building Project may be shown.

Activity	Activity Description	duration (te)
1 - 2	Excavate Trench for Pile Caps	
2 - 3	" " " " "	
3 - 4	" " " " "	
2 - 5	Cutting and Blinding of Piles	
3 - 6	" " " " "	

Step (b)

A bar chart framework should be constructed, with a time scale along the top and the activity column down the left hand side. The bar chart framework for the Lecture Theatre Block is shown below.

ILLUSTRATION 4.18

FRAMEWORK OF THE BAR CHART FOR THE FEA BUILDING PROJECT (LECTURE THEATRE BLOCK)

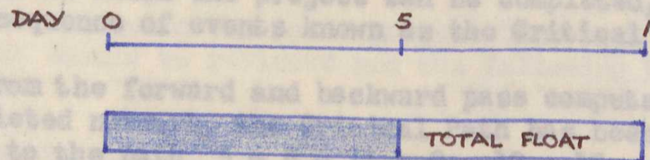
ACTIVITY NUMBER	ACTIVITY DESCRIPTION	DURATION	DAY NUMBER 0 CALENDAR DATE 1968 APRIL 1 ... 15	30 30	60	

Step (c)

Set off the first activity in the bar chart, putting its left-hand end on the 0 day column. The length of the bar is determined by the TE of the tail event and the TL of the head event. The bar represents the amount of time available to perform the activity. The estimated duration time of the activity may be marked off from the bar. For example,

ILLUSTRATION 4.19

EXAMPLE OF A NON-CRITICAL ACTIVITY ON THE BAR CHART, SHOWING THE ACTIVITY DURATION AND TOTAL FLOAT

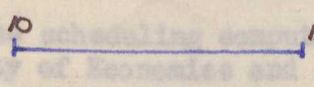


The total float possessed by the activity may be read off from the bars. In the example shown, the total float is shown to appear at the end of the activity. This is again not necessarily the case. The total float may appear in front of the shaded portion indicating that the starting of the activity is delayed after the tail event is reached.

A critical activity on the bar chart will be shown as a completely shaded bar, since critical activities possess zero float.

ILLUSTRATION 4.20

EXAMPLE OF A CRITICAL ACTIVITY ON THE BAR CHART



Step (d)

Set off the second activity on the bar chart, using the procedure adopted in Step (c). Repeat the procedure for all the activities in turn from the network.

Determination of the Critical Path from the Bar Chart

The critical path clearly lies between the point farthest to the right and the point farthest to the left of the bar chart. The critical path through a network has been defined as the path with zero float, assuming that the TE = TL for the final network event. This critical path can therefore be traced from the bar chart. Completely shaded bars indicate that the activity which it represents possess zero float. The critical path therefore passes through such bars in the bar chart. A dotted red line can be drawn on the bar chart joining the critical activities.

Total Project Time of the FEA Building Project, Lecture Theatre Block

One of the main objectives of this study is to estimate the total project time for the Faculty of Economics and Administration Building Project, Lecture Theatre Block. The total project time is the shortest time in which the project can be completed, and this is determined by a sequence of events known as the Critical Path.

From the forward and backward pass computations carried out on the completed network, the Critical Path has been determined and this corresponds to the path 5 - 8 - 11 - 9 - 12 - 10 - 13 - 19 - 22 - 25 - 28 - 29 - 30 - 31 - 32 - 33 - 34 - 35 - 36 - 41 - 44 - 47 - 49 - 51 - 53 - 54 - 55 - 59 - 63 - 67 - 68 - 74 - 69 - 75 - 70 - 76 - 83 - 84 - 85 - 86 - 87 - 88 - 89 - 90 - 91 - 92 - 93 - 94 - 95 - 96 - 97 - 102 - 104 - 106 - 107 - 108 - 110 - 111 - 112 - 113 on the completed network. The total project time is computed by summing up the duration time of all the activities on the Critical Path.

From the 1st April 1968 which is the date of the commencement of this study, the Faculty of Economics and Administration Building Project, Lecture Theatre Block, is estimated to require 417 working days for its final completion. Reading from the bar chart, the scheduled date of completion of the Lecture Theatre Block is expected to be on the 22nd May 1969.

Reducing the Project Time

In this study, the scheduling computations show that the date of completion of the Faculty of Economics and Administration Building Project, Lecture Theatre Block, is on the 22nd May 1969. However, the project completion date specified in the contract for the Faculty of Economics and Administration Building Project is 21st January 1969. The total project time estimated in this study is the shortest time in which the project can be completed. If we assume that the network is implemented exactly as planned and is completed on the 22nd May 1969, this will mean that the completion date specified in the contract cannot be met. The project will therefore be overdue by about 4 months. This can be very costly, since costs increase as more time is taken not forgetting the penalty imposed for failure to complete a project on schedule. However, this is only an assumption and the actual performance need not necessarily turn out to be exactly as planned. It must be stressed that the network is only a statement of policy, that is, a statement of the means whereby an objective is to be achieved. It is very rare that only one acceptable policy can be formulated; further, almost any policy can be improved.

Nevertheless, we cannot rule out the likelihood that the

Faculty of Economics and Administration Building Project will not be completed within the date specified in the contract. We must therefore examine the possibility of reducing the total project time, and this is where the tremendous advantage of Critical Path Analysis may be put to use. By isolating the critical activities, attention can be focussed on those areas of work that are affecting the timely completion of the project. To reduce the project time, one or more of the activities on the critical path must be shortened or eliminated. The application of effort elsewhere in the network will be futile unless the critical path is shortened first. Similarly, it must be remembered that any activity on the critical path that requires time in excess of the original estimates will cause the completion date to be delayed correspondingly.

When reducing the total project time each activity on the critical path should be reviewed and the following kinds of questions asked:-

(1) Is the sequence of the activity in a "must" or "desired" order? If in a "desired" order, can the activity be performed concurrently with others on the critical path? If it can be performed concurrently instead of in series, what added risk is assumed?

(2) Is the time estimate for the activity realistic? Can the time be shortened by adding more resources? Does this decrease in time increase the risk in meeting performance?

(3) Are the technical performance requirements realistic? Are the specifications tighter than they need to be to do the job? Can some performance or reliability objectives be sacrificed?

CHAPTER V

THE CONTROLLING PHASE

The final essential phase in CPA is control. Once a project is underway, the critical path network and the bar chart should serve as a guide to management in the accomplishment of each activity in proper sequence and schedule. The network should be used to monitor and control the operations it represents. Control here is used in a special sense and should not be identified with supervision or direction. The definition of control may be stated as follows.

"Control is determining what is being accomplished, that is, the performance, evaluating the performance and if necessary, applying corrective measures so that performance takes place according to plans."

In other words, control is checking to determine whether plans are being observed and suitable progress towards the objectives are being made, and acting if necessary to correct any deviations.

If the first two fundamental phases of CPA, planning and scheduling were implemented perfectly, there would be very little need for the control phase. However, it is in the fundamental nature of projects that activities will seldom start or finish exactly as planned. Some mistakes, loss of efforts, friction, misdirected efforts are bound to result and give rise to deviations from the intended objectives. For this reason, the final phase of CPA - control is necessary. Control is thus in the nature of follow up to the other two phases of CPA.

Essential Steps in the Control Project

All controlling consists of a control process made up of several definite steps. Regardless of the activities in which management is interested in controlling, these basic steps apply. They should therefore be considered when using CPA as a control technique.

(1) a plan must be made.

(2) this plan must be communicated to the people responsible for its implementation.

(3) measuring the performance.

(4) comparing the performance with the standards set down in the plans.

(5) correcting unfavourable deviations by means of remedial action

to restore the behaviour of the activity to its original planned level.

Control and Critical Path Analysis

(1) Planning

Planning, which is the first step in the control process is an inherent part of CPA in the form of the network. The network's greatest value stems from its usefulness in the construction of a plan showing all the interrelationships and interdependencies of the activities necessary for the completion of the project. In no other way can a plan be developed as efficiently and with as great assurance of completeness as the network. In certain tasks it is the only possible planning technique. Its use as a means of planning has already been discussed in Chapter III of this study, and needs no further comment.

(2) Communicating the Plan

The network is an ideal communications medium. It produces a clear outline of the activities that must be undertaken and of the events that must occur before an objective is reached, and is much more comprehensible than the same material in narrative form. The network communicates a picture of the whole plan to the individuals responsible for the completion of the project. Its clarity leaves little room for confusion and doubt if the network preparation is properly carried out.

(3) Measuring the Performance

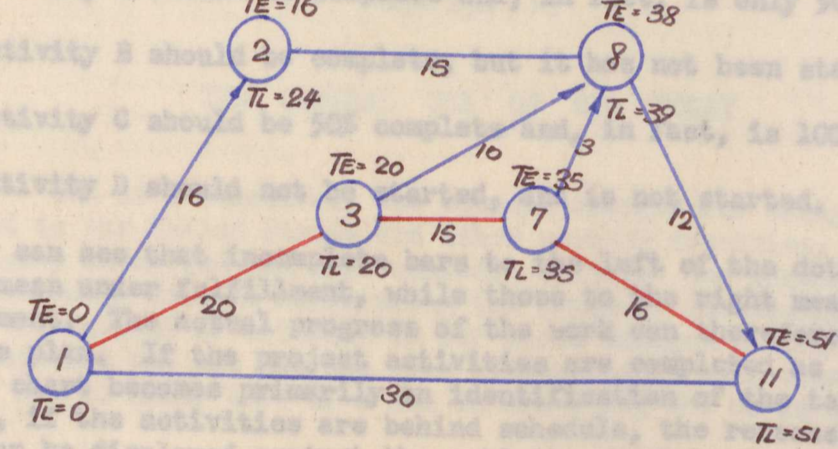
The third step in the control process is to find out what is being accomplished. Although measuring the performance is not an integral part of CPA, the discipline imposed on the planners in constructing the network, and the consequent detailed insight into the project indicates how best the measurements can be made. Since one of the main objectives of this study is to estimate the total project time for the Faculty of Economics and Administration Building Project (Lecture Theatre Block) the measurement of the performance is simplified since it is on a time basis. For example, if an activity has a 12 week estimated span, but at the end of the eight week it is clear that the activity will not be completed for about another eight weeks, it means the performance has not come up to expectation. Corrective action should therefore be taken.

One basic requirement in measuring the performance is that the measurement should be appropriately precise. Any measurement can be increased in precision by an increase in the costs of making the measurement. CPA indicates clearly which activities need to be precisely measured and those which do not need such a high degree of precision. Obviously, the measurement of the activities on the critical path should be precise since they determine the project duration time.

For example, in the sample network shown on page 56.

ILLUSTRATION 5.1

SAMPLE NETWORK SHOWING THE CRITICAL PATH



The activities on the critical path 1 - 3 - 7 - 11 should be measured to the nearest day since any "slippage" of the activities would result in an increase in the project duration time. On the other hand, activities not on the critical path need not be measured precisely since this would result in the unwarranted increase in the costs of making the measurements.

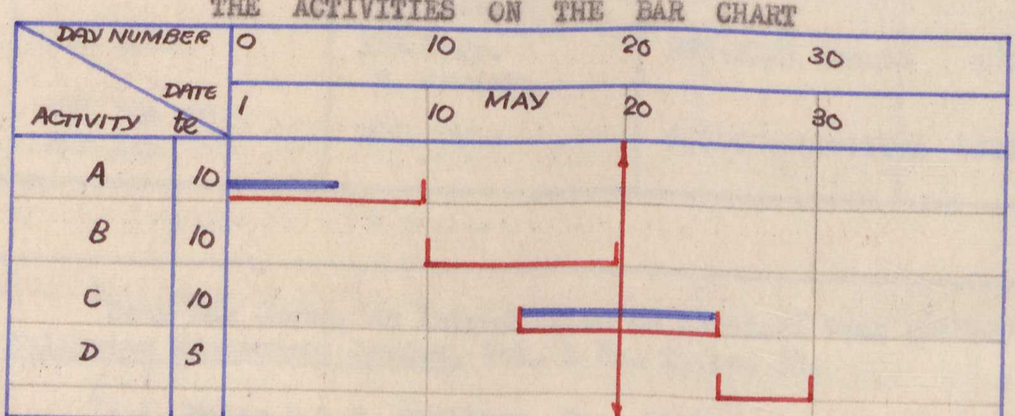
(4) <u>Comparing and Reporting</u>

Comparing the performance with the plans and reporting any deviations, are both quite simple with CPA. Performance can be recorded by drawing a progress bar on the bar chart. (Refer Chapter IV). To show how the work is actually progressing, a bar or line can be drawn above the activity symbol, the length of the line representing the actual amount of work done.

For example, the bar chart may be presented again.

ILLUSTRATION 5.2

RECORDING THE PROGRESS OF THE ACTIVITIES ON THE BAR CHART



The bar chart in Illustration 5.2 is viewed at the end of day 20 (denoted by the dotted line). The following information can be obtained readily:-

Activity A should be complete and, in fact, is only 50% finished

Activity B should be complete, but it has not been started yet.

Activity C should be 50% complete and, in fact, is 100% complete.

Activity D should not be started, and is not started.

Thus we can see that incomplete bars to the left of the dotted line or cursor mean under fulfillment, while those to the right mean over fulfillment. The actual progress of the work can therefore be compared with the plan. If the project activities are completed as scheduled, the bar chart becomes primarily an identification of the tasks completed. However, if the activities are behind schedule, the reasons for the delay can be displayed against the activity which has "slipped". The bar chart is therefore extremely useful, combining both progress notation and planning.

(5) Taking Remedial Action

When performance does not conform with the plans, corrective action should be taken. Simply to establish and publish plans, secure information on performance, spot trouble areas where variances occur and then do nothing about correcting the areas is to reduce control to an impotent concept. CPA by causing areas of authority to be clearly distinguished aids the manager in locating the industrial responsible for an objective.

However, it must be emphasised that CPA is not a panacea for all management ills, and any failures to achieve an agreed plan must not be laid at the door of CPA, they will rest with the manager.

CHAPTER VI

THE GENERAL USE OF CPA TODAY

CPA is a relatively new concept amongst our management circles compared to the United States and other western countries, where it has been highly developed and implemented. Although the potential of CPA as a management tool is known among the academic institutions and has formed the subject of articles in our local management journals,[1] its implementation and use has not been widespread in this country. However, this is not to imply that if a man is not using CPA he is not managing.

Unlike the United States and other westerm European countries, the use of critical path methods (PERT or CPM) has grown at a rapid rate since the successful applications of PERT in the Polaris Program and the initial success of CPM in the chemical and construction industries. The literature in professional and trade journals has amounted to at least 200 articles in the past five years, and public training courses in the subject are offered continuously.

Another indication of the general utility of critical path tools is the number of computer programs written which amount to at least 60 in existence. A few of these CPM and PERT computer programs available to the public in the United States may be given.

TABLE 3

SELECTED CRITICAL PATH COMPUTER PROGRAMS[2]

No.	Computer Equipment	Contact for Further Information	Capacity	Category
1	Honeywell 400 or 1400	Honeywell Electronic Data Processing	3,000 activities 2,000 events	Basic PERT
2	IBM 1401	IBM Corp. N. Jersey	985-2125 events	CPM
3	NCR 304 or NCR 315	NCR, Ohio	5,000 activities	PERT

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[1] Boon Kok Cheng, 'An Introduction to Critical Path Method', MIM, Malaysian Management Review, Vol. 1 No. 2, pp. 33.

[2] J.J. Moder & C.R. Phillips, Project Management with CPM & PERT, Reinhold Publishing Corporation, 1964, pp. 257.

Since the Navy's Special Projects Office first acquired the use of PERT by contractors on the Polaris Missile Program, the number of agencies making the use of CPM and PERT as basic contractual requirements has increased annually.

Almost every research and development program especially weapons system programs in the United States require the prime contractor and major sub-contractors to use some form of network. The table below lists some of the United States Government agencies now requiring network reporting procedures.

TABLE 4

SOME U.S. GOVERNMENT AGENCIES THAT HAVE INCLUDED THE USE OF CPM OR PERT IN CONTRACT SPECIFICATIONS[3]

Department of Navy	Method Required
Bureau of Naval Weapons	PERT
Special Projects Office	PERT, Cost Control
Department of Air Force	
Electronic Systems Division	PERT
Ballistic Systems Division	PERT, Cost Control
Air Force Systems Command	PERT, Cost Control
National Aeronautics & Space Administration	CPM & PERT, Cost Control

CPM and PERT is not confined primarily to defense and weapons programs in the United States, but has also been introduced into contract specifications by architects, engineers, state highway departments, university building authorities, and public utility companies. In addition, manufacturing companies are applying the critical path approach to large maintenance projects, equipment modification and installation, sales promotion programs and a variety of other types of projects.

Considering such a wide variety of fields that PERT and CPM has been applied to in the United States, the use of critical path methods could very well become a natural mode of expressing project plans in Malaysia.

It is hoped that the next few years will see an increase in the awareness to CPM, PERT and other networking techniques, with a resultant increase in the application of these highly useful management tools to the projects in this country.

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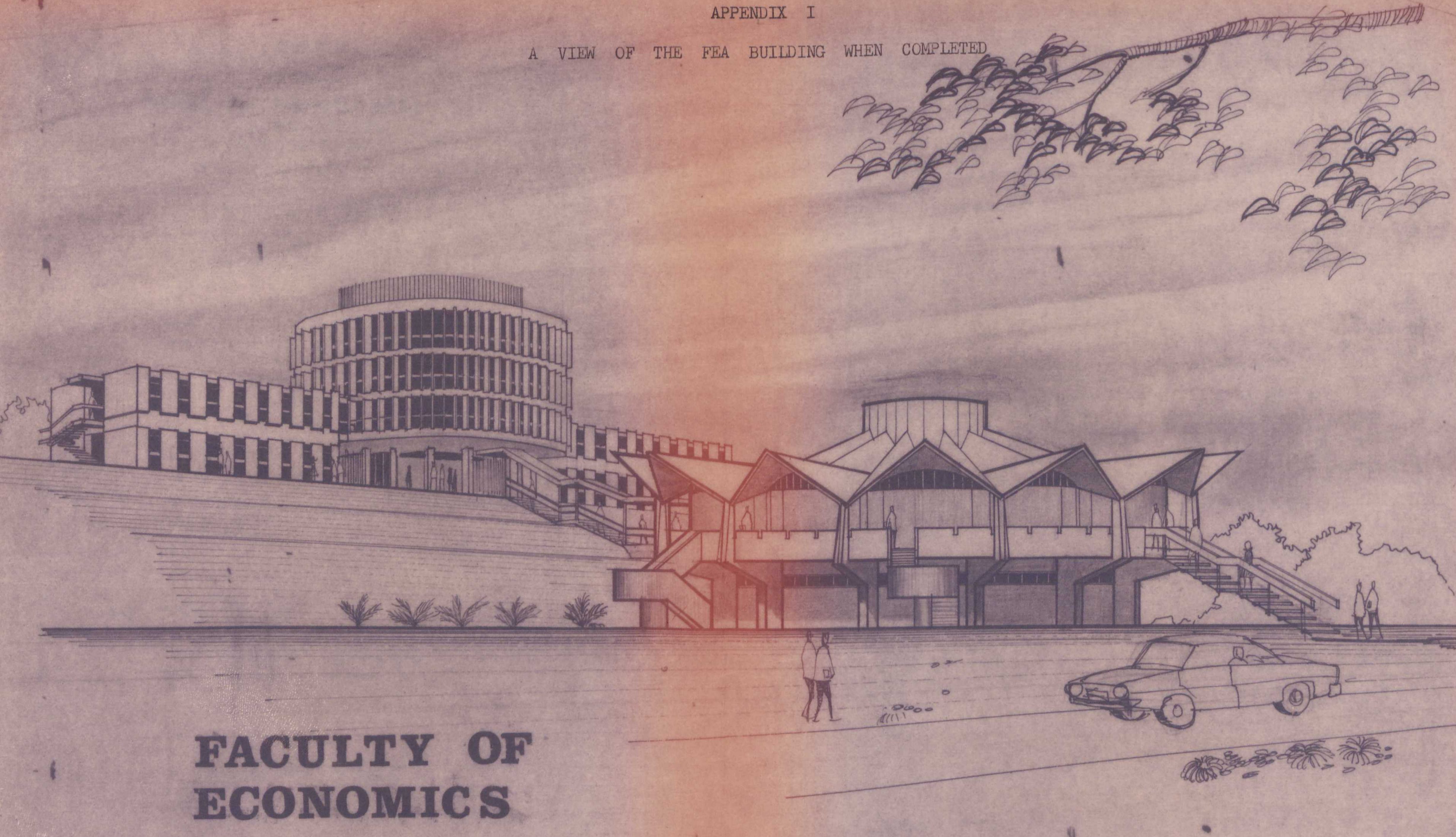
[3] J.J. Moder & C.R. Phillips, Project Management with CPM & PERT, Reinhold Publishing Corporation, 1964, pp. 11.

APPENDIX I

A VIEW OF THE FEA BUILDING WHEN COMPLETED



APPENDIX II

NETWORK FOR THE FEA BUILDING PROJECT, (LECTURE THEATRE BLOCK) UNIVERSITY OF MALAYA

Enclosed in the Envelope

APPENDIX III

BAR CHART FOR THE FEA BUILDING PROJECT (LECTURE THEATRE BLOCK) UNIVERSITY OF MALAYA

Enclosed in the Envelope

APPENDIX IV

GLOSSARY OF SYMBOLS

te	Expected elapsed time for an activity.
TE	The date on which an event is expected to occur.
TL	Latest allowable date that an event may occur without affecting the "on-schedule" completion of the end event.
ST	Total activity slack or total float, the difference between the latest allowable completion date of the successor event (TL) and the expected completion time of the activity (EF). $ST = TL - EF$
SF	Activity free slack or free float, the difference between the earliest expected time of the activity's successor event and the earliest finish time of the activity in question. $SF = TE - EF$
ES	Earliest activity start time.
EF	Earliest activity finish time.
LS	Latest activity start time.
LF	Latest activity finish time.
F	Formwork
C	Concreting
Ex	Excavation
Wp	Waterproofing
CB	Cutting and Blinding
S	Steelwork

APPENDIX V

GLOSSARY OF TERMS

Activity	An activity is a line, or arrow that connects two events and represents the time - consuming effort or work necessary to proceed from one event to another (Real Activity). In addition, an activity may represent a constraint or interdependency between two events on a network and need not consume time (Dummy Activity).
Critical Path	The Critical Path is the longest path or the path with the greatest time constraint on the end event, and it will determine the completion date of the end objective.
Event	An event represents a distinguishable, unambiguous point in time that coincides with the beginning and/or end of a specific activity.
Event Expected Completion Date (TE)	The calendar date on which an event can be expected to occur. The TE value for a given event is equal to the sum of the expected elapsed times (te) for the activities on the longest path from the beginning of the project to the given event.
Event Latest Allowable Completion Date (TL)	The latest calendar date on which an event can occur without delaying the completion of the project. The TL value for an event is calculated by subtracting the sum of the expected elapsed times (te) for the activities on the longest path between the given event and the end event of the project from the latest allowable date for completing the end event.
Network	A network is a flow chart consisting of the activities and events which must be accomplished to reach project objectives, showing their planned sequences of accomplishment, interdependencies, and interrelationships.

Scheduled Completion Date (TS) — A date assigned for the completion of an event for purposes of planning and control within an organisation. It may also be a contractually scheduled date.

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6. H.F. Evart, Introduction to PERT.

7. Albert Battersby, Network Analysis for Planning and Scheduling, Macmillan, 1967.

8. F. Thomas Collins, Network Planning and Critical Path Scheduling, Know How Publication, California.