UNIT 5

PROJECT MANAGEMENT

Introduction

In this unit, we will consider the issues which arise whenever a project is planned and undertaken. We examine the logic principles underpinning the techniques used in project management. You will learn the basic principles underlying the technique of network planning.

We shall consider critical path methods, PERT, precedence diagrams and line of balance technique.

We will emphasise the use of the network planning approach for the effective control of resources during the planning and execution phases of projects. We will examine the role of operations managers and the importance of operational management techniques will be discussed in relation to cost/time aspects of a project. We consider how much help PC packages can provide in designing and controlling a project.

As a discipline, project management is continually developing, in this unit, we will refer to wider issues and applications. However, we have restricted them as appropriate for this module. A list of recommended reading is provided at the end of the unit if you wish to undertake further study.

Note that differing notations appear in textbooks dealing with project management techniques. Although the underlying principles are the same, you may find the different styles of presentation confusing. You should follow the notation and terminology given in this unit when undertaking the activities.

Objectives

By the end of this unit, you should be able to:

- explain what is involved in the planning of projects
- observe the significance of the resources and their inter-relationships in a project
- use network planning techniques to determine the critical path and project duration
- highlight the differences between the activity-on-arrow and the activity-on-node approaches
- calculate the various kinds of float which occur in a network and appreciate the significance of each
- design and calculate through networks
- appreciate why computer applications are widely used in network planning and be aware of the benefits and limitations of packages
- use the data produced from the network to plan manpower (and other resource) requirements

- draw Gantt charts and manpower load histograms for project control purposes
- understand why probabilistic concepts have to be introduced into many projects
- calculate the activity durations when the PERT weighting approach is used
- understand the 'line of balance' technique.

SECTION 1

Project Management

Introduction

In this section we will define, and look at the growth of project management, its techniques and key features, as well as the main participants in it. We will look at project life cycles and documentation and introduce the family of network planning techniques.

1.1 Growth of project management

The satisfactory completion of project work involves the organised utilisation of all the resources being used:

- money
- manpower
- machinery
- materials
- time.

Project management is concerned with the setting of clear objectives, using forward looking control procedures and sound decision making. A project is any task which has to be managed and which has a definable beginning and end, for example, constructing a building, recruiting a senior manager or launching a new product.

The processes of planning, scheduling and controlling all the resources required for completion of a project, involves the balancing of three factors, cost, quality and time, as illustrated in Figure 1. In this case we have an example of a project which has to be completed within a given timescale, with little emphasis given to costs or to quality.

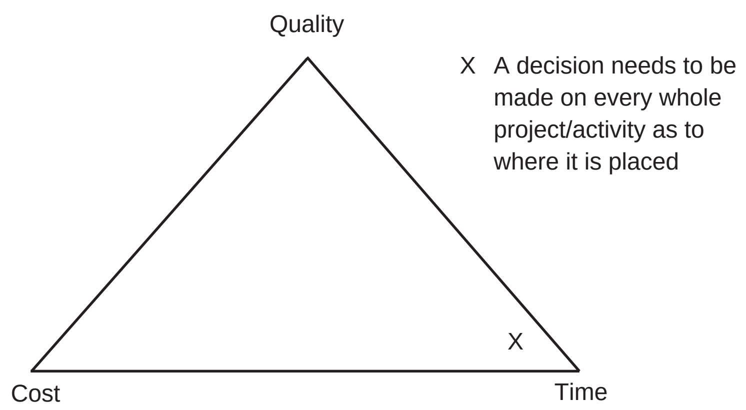


Figure 1: The balancing of cost, quality and time factors

There will always be a tension associated with the co-ordination of these three factors. The reduction of time taken on a task often results in reduced quality unless the method itself is changed. The raising of quality standards will often raise both cost and time.

Operations managers, who can precisely define methods and standard job times, are generally able to produce realistic data for use in project management. An experienced member of the operations management team should make an ideal project manager and be able to work in an independent way as a negotiator with all the personnel involved. He or she will be able to use a range of operations management techniques for either qualitative or quantitative selection of the activities and job methods to be used when sensitive decision making is required.

Project management has grown over the last few decades. Socio-economic factors have played a key role. The growth of international trade, increasing competition driving down unit labour costs and the increasing speed with which new products and service ideas must be converted into commercial realities, have all been contributory factors. Whilst mass markets exist for many products and services in which the factors of high volume, low cost and appropriate quality levels apply, there is also a growing demand for special customised products and services. These are often 'one-off' and require individual planning so that the resourcing cost is minimised.

ACTIVITY 1

Identify two situations in which planning is required. One should be an example of manufacturing or processing high volumes of a commodity. The other should be an example of one-off service provision (like a concert or a wedding reception).

List two similarities and differences which you feel exist between the two situations.

You might have chosen for your high-volume situation the planning required to harvest a seasonal crop on a farm, for example, strawberries.

This requires: plants; fields; fertiliser; staff attention whilst growing; water; cropping; packing; and financial planning and control.

For a ‘one-off’service you might have chosen arranging a village festival.

This requires: fixing a date; location; facilities; staffing; financial management; publicity; and tidying up afterwards.

These are not exhaustive lists of the many things that have to be done to make these two projects a success, but already we can see certain common features emerging. There are also aspects which are very different! Some activities need to follow others in sequence, others can happen at the same time.

Project management techniques can be used to handle situations being driven by factors such as:

- increasing complexity of products and services
- sophisticated computing facilities within organisations
- availability of large knowledge data-bases
- rapid rate of technological change.

Project management is increasingly used because it:

- stimulates thought on tasks
- involves co-ordination of the work effort
- aims to minimise the cost of achieving the objective
- provides a good overall resource control focus
- minimises the project completion time
- leads to achievement on time, providing customer satisfaction
- lends itself to computerisation in complex situations
- leads to higher profit margins
- recognises and delivers quality standards

- can provide a secure and confidential framework where needed
- provides on-going reports which are easily understood
- gives opportunity for rapid re-scheduling.

In setting up a project, three fundamental criteria must be considered:

- end result of undertaking the project must satisfy the needs of the customer in terms of performance, cost and quality.
- authorised and agreed financial budgets must not be exceeded without good reason.
- actual progress will need to match the plan if the completion date is to be met. Delays on a major project can result in contractual cost penalties. This will not only reduce profits, but will also send out undesirable messages to potential customers.

A **project** is defined as a set of activities that has both a recognisable start and a definable ending which achieves an objective. Every project contains a number of clearly identifiable stages, each of which must be understood and controlled.

Project management is defined as planning, directing and controlling the resources needed to achieve a goal, whilst meeting the technical, financial and time constraints required.

Some examples of undertakings which are regularly handled on a project management basis include:

- organising conferences
- planning and running the Summer and Winter Olympics
- developing a new product
- reducing labour requirements
- building a bridge
- launching the space shuttle
- building a boat
- installing a new computer system.

The project manager needs to undertake the following steps:

- define the project, identifying all constraints and objectives
- determine the activities required and their times
- build a model of the process which will achieve success
- use the model to optimise all resources
- produce a project plan and denote calendar dates
- monitor progress and iterate through these steps as necessary.

You must appreciate that no project manager is an expert in the full range of managerial disciplines and techniques, and the skills of many specialists will be required in planning and controlling a project. Specialists in marketing, operations, management services, personnel and finance will all need to be consulted for information, and may well assist with the application of allied techniques such as:

- management by objectives
- management by exception
- probabilities and forecasts
- work methods and standard time values
- costing
- staffing levels and loadings
- quality, quantity and customer expectations.

Every project has a degree of novelty about it. Even if it is a 'repeat project' which has been done before there will probably be features which are beyond the control of the organisation.

ACTIVITY 2

What factors, which are beyond the control of staff, could affect a project?

You might have identified: the weather; illness in the workforce; trade union activity; shortages from suppliers; machinery breakdown; macro-economic environment; and actions of governments.

Different types of projects have different types and scales of such problems associated with them:

- Some projects must largely be completed out of doors on a particular site, for example, building a sports stadium. Huge capital investment is required and many sub-contractors will be involved.
- Some projects must be undertaken in a controlled environment by a small specialist team over a short time, for example, a heart surgery.
- Some projects will largely be of an administrative nature, like the design of a new security system for an office block. The task may take months but the installation might only take several days.
- A special kind of project is found in R&D. In pure research as you saw in Unit 2, a defined start can be made, and an objective broadly defined, but time-scales may vary.

1.2 Major participants in project management

PROJECT MANAGER

The project manager is responsible for the successful outcome of the project. He or she needs to be a good communicator and able to co-ordinate the efforts of people who will be making specific contributions, often in a teamwork capacity. The project manager should have the skills to develop plans using both manual and computer package techniques. He or she will need to be able to monitor the progress of the project and provide or authorise feedback in various formats to the line managers, accountants, technical staff and external contacts.

SENIOR MANAGERS

Senior managers make the final decisions on projects and have vested in them the authority to provide resourcing and give strategic guidance. They also provide essential lines of communication to staff of all levels who are involved in the project, and with suppliers, trade union officials and customers. Senior managers will also select staff who will spend part if not all of their working time in the project team.

CUSTOMERS

A project ultimately is designed to meet the needs of a customer. The customer may be an individual person wanting an extension to their house, or an organisation wanting something done, for example, an education authority wanting rough land turned into a school playing field and sports complex.

PROJECT TEAMS

A well-balanced team will need to be put together, and the project manager will probably be proactive in arranging this. The team should be able to provide a great deal of support for the project manager, with each member inputting specific skills and expertise. Liaison with external sources, suppliers and regulatory authorities will be necessary at times on most projects of any size.

When organising a project team, we need to remember the general principle of **unity of command**. Accountability and responsibility are always vital issues in project management, and the execution of the whole plan can flounder due to weaknesses in these areas. The publication of the organisational chart prior to the commencement of the project will greatly facilitate a smooth running process.

For a small project, an organisation chart may look like Figure 2.

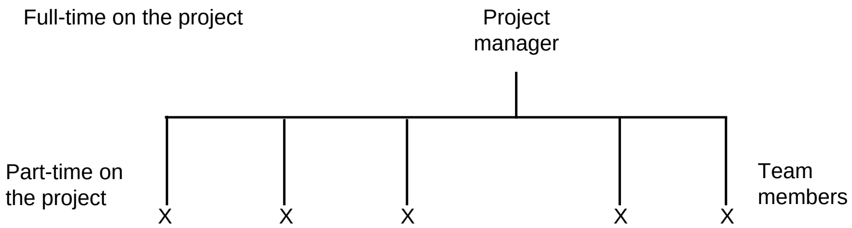


Figure 2: Organisation chart for a small project

For a more complex project, all staff may be seconded from their normal work to become effectively full-time participants, and another managerial layer may be inserted below the project manager for co-ordination purposes, as in Figure 3.

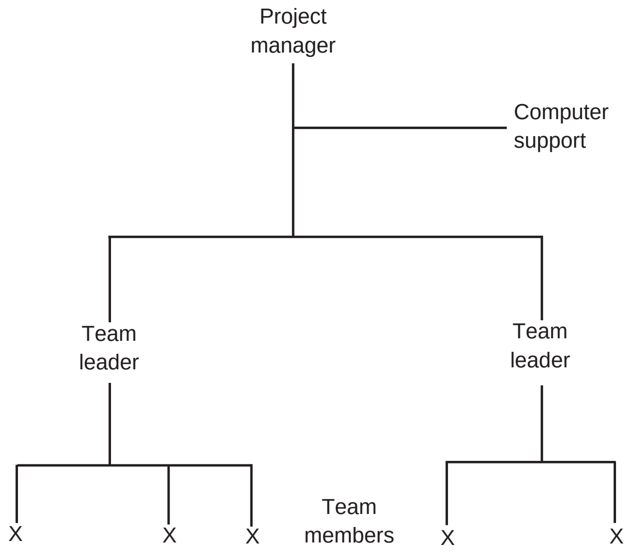


Figure 3: Organisation chart for a more complex project

Within the last 20 years, many projects have been managed on a matrix organisation basis, thereby reflecting the managerial style currently operating within a particular business. Lines of authority and responsibility are drawn both laterally and diagonally to overlay the structures shown in Figures 2 and 3.

The unity of command principle is usually amended to make team members answerable to two managers: their functional manager and the project manager. The project manager is not the owner of the complete project, but shares in the decision making with functional managers. This can lead to conflict and the degree of authority vested in the project manager may not fully match the level of responsibility. Sometimes the matrix can ‘lose’ information, exhibit inertia and lead to duplication. Proponents, however, claim that a matrix approach:

- more fully integrates team members
- has a greater degree of flexibility
- helps to overcome individual shortcomings, for example, in the project manager
- optimises the use of resources
- readily leads to group identity.

1.3 Project life cycles

As we saw in Unit 2, products and services tend to go through life cycles. A project can be viewed in the same way. One business, or part of a business, is providing a service for another. There will be finite starting and ending points, and the project itself will link them.

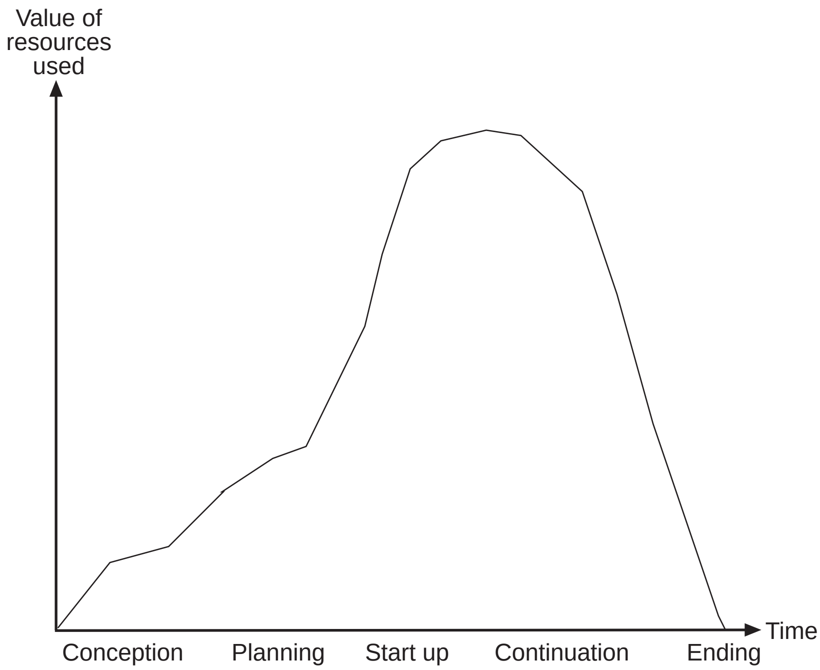


Figure 4: The project life cycle

Sometimes additional stages will be a feature of particular projects, for example, feasibility studies, to ensure the project is achievable, may be essential between conception and planning. When constructing a new motorway or airport runway, it will be necessary to undertake extensive technical simulations, resolve legal issues and consult with the public, before working plans can be drawn up.

1.4 Project documentation

Many projects run into difficulty through poor documentation and information flow. This leads to ineffective control, wastage and delayed decision making.

The documentation outputs from the project should be:

- easily understood
- in as simple a format as possible
- capable of highlighting concerns, for example, exception reporting
- strategically timed
- capable of presentation
- handling all appropriate information.

Typical documents which need to be designed before the project commences and used throughout are:

- project overview: including terms of reference, scope and scale, dates, costs, the project management approach used and any penalty clause conditions
- plans, schedules, working drawings
- management and milestone reports, for example, costs, problem-solving and progress
- stage agreements and conditions
- modification requests
- technical specifications
- files: electronic and hard copy.

1.5 Network planning techniques

One of the most powerful management techniques for project management is called **network planning**. A whole range of titles are given to the family of network planning techniques.

Basic titles:

project network techniques (PNT)
critical path analysis (CPA)
critical path method (CPM)
activity-on-arrow (AOA).

Special variations:

precedence diagrams (PD)
activity-on-node (AON).

Proprietary types:

PERT (program, evaluation and review technique)
GERT (graphical evaluation and review technique)
PEP (project evaluation procedure)
LESS (least cost estimating and scheduling).

Network planning identifies the **critical path activities** which must be rigorously controlled if the project is to be completed by an agreed date. Some commercial contracts carry financial penalty clauses which reduce the cost of the product to the buyer if delivery is late.

In practice, network planning is used:

- in **management by objectives (MBO)** programmes. Essential features of MBO are shared with network planning. A goal is set, a pathway identified and milestone review points established to monitor progress.

- as part of a **management by exception** process. This highlights the critical activities which could seriously affect progress. A network clearly shows relationships between these activities and other tasks which must also be performed, thereby providing scope for managerial decision-making should slippage occur.
- for detailed **cost analysis**. Cost scheduling can be undertaken to initially assess the costs of a project as various phases are reached. It is also necessary to control expenditure during a project, to ensure optimal use of resources, and to evaluate the effects of operational decisions during the project.
- in **manpower planning and levelling**. Efficient use of the labour force minimises both direct and indirect labour costs, cuts waiting (lost) time, reduces premium wage costs paid on overtime hours and ensures that the right numbers of suitably skilled staff are in place at the correct time. Later in the unit we look at the use of histograms in labour resource levelling.

1.6 Determining project activities

In any complex situation, the project team needs to find a method of identifying all the activities that are to be undertaken for the completion of the project. Information on the sequencing of activities and any possible variations from the norm must be identified. A work breakdown structure (WBS) can be undertaken. This is a top-down method which begins with the whole task and defines all the activities required. Having commenced with large activities, the analysis enforces division into smaller parts. Using systems analysis terminology, this is sometimes referred to as Level 1, Level 2, Level 3 etc.

A good WBS allows:

- activities to be considered and executed independently
- manageable size parts of the whole to be determined
- allocation of suitable activities to the correct staff
- improved monitoring and control during the project.

As an example, Figure 5 shows a maintenance service on a metal press.

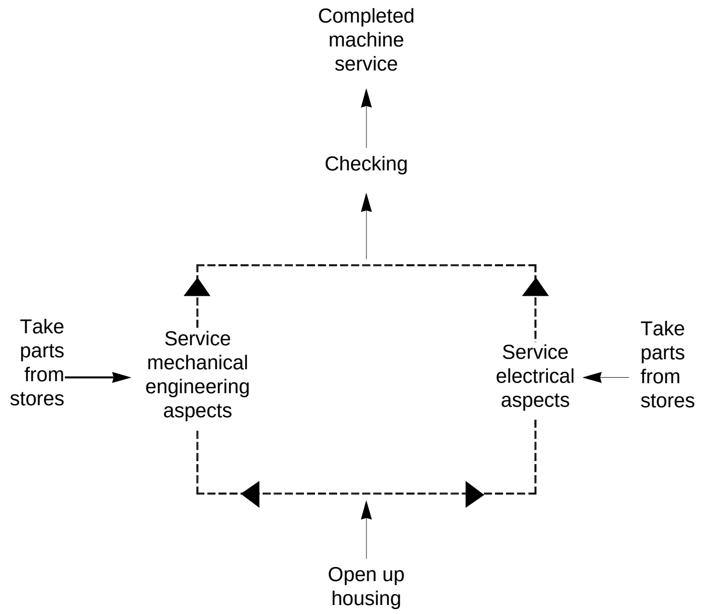


Figure 5: Activities involved in servicing a metal press

In this example we can see six activities which lead up to the completed service of a metal press in an engineering works. If this was a key piece of equipment in operational terms, then it would be necessary to minimise this non-productive period created by servicing (maintaining) the press. In such situations, the allied technique of work study will prove a powerful aid to the project manager. We discuss this technique in Unit 7.

ACTIVITY 3

Consider a job procedure with which you are familiar (e.g. arranging a party, arranging a holiday) and undertake a WBS to identify the activities required. What problems did you encounter?

You will have identified an individual procedure, but note that it is:

- easy to forget activities
- sometimes difficult to define sequences of activities
- often essential to consult with others who have greater expertise on aspects of the subject area
- possible to oversimplify the true situation.

Comparatively simple projects can be handled successfully using a paper and pencil approach to network planning. Complex situations demand a computerised approach and many software packages are now available. Some packages are capable of handling projects with several thousand activities. Others can only cope with 20 or 30 links. They all find the activities which lie along the critical path of the project and produce certain kinds of calculations for managerial action. The more sophisticated packages are capable of drawing the actual network itself and producing calendar dates, costs, bar charts and management reports. Unfortunately these systems are time-consuming to both learn and use. More details on packages for microcomputers are given in Resource 5.1.

In this unit we will concentrate on understanding the logic principles and symbolism used in producing a network. We then learn how to analyse a network and apply the information derived to the scheduling and control of a project.

1.7 Logic principles

First we need to determine all the activities which must be undertaken to successfully complete a project. In practice, this is not easy when a project manager is operating in new territory.

ACTIVITY 4

You have previously been project leader on local government projects which refurbishied vacated houses prior to their allocation to new residents. Now you are asked to lead a project to celebrate the founding of the city.

List several principles which would be applied in both types of project.

Identify two issues which would be significantly different.

Both projects have the following requirements:

Manpower is needed.
Costing is very tight.
Time schedules are set by the council.

With the new project:
Many non-council employees will be involved in planning the event.
There may need to be an alternative ‘bad weather’ plan on the day.

You may have listed other factors.

Summary

In this section we looked at the growth of project management, its techniques and key features, as well as the main participants in it. We looked at project life cycles and documentation and introduced network planning and its family of techniques.

SECTION 2

Critical Path Method

Introduction

In this section, we will detail the various symbols and conventions used in network planning. We will look at how the network is numbered and constructed, and explain the concept, and the three measures of **float**.

In using a network planning approach to project management, we need to undertake certain steps. Firstly, we need to identify the type of network required and secondly, the amount of detail that we really want from the use of the technique.

We learn the basic principles of **critical path method (CPM)** and then go on to consider both **precedence diagrams** and **PERT**. In developing our ideas, we will concentrate upon a ‘paper and pencil’ approach.

2.1 Symbols used in network planning

Symbols are used to produce the arrow diagram, which is a logical construct used in network planning. Three types of symbols are used:

- **activities** are denoted by arrows ⟶

  The length and slope of arrow is immaterial, but the direction of the arrow indicates time flow. By convention time flows from the tail to the pointed head and from left to right on the paper. Activities take up time and other resources. This approach is referred to as **activity-on-arrow (AOA)**.

- **dummy activities** are denoted by broken arrows - - - - - -➤

  These are not as common as normal activities, and are a logic device inserted into the network to show the relationships and dependencies of activities. They consume no time or other resources.

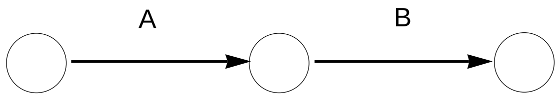
- **events** are denoted by ○

  Events are also called **nodes**. They identify a point in time between two or more activities. In conventional networks, events take up no time or other resources.

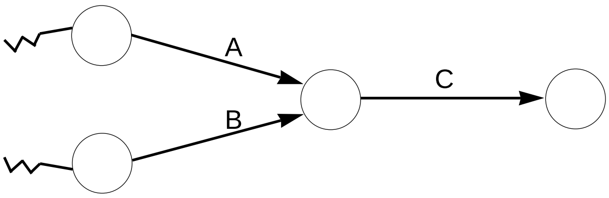
  In precedence diagrams, time occurs on the node rather than the arrow. This is referred to as **activity-on-node (AON)**, and we return to this later in the unit.

Some events are recognised as having particular significance in the life of a project. The end of a phase may have been reached, or a decision is required based upon the prevailing circumstances. These events are referred to as **milestones**.

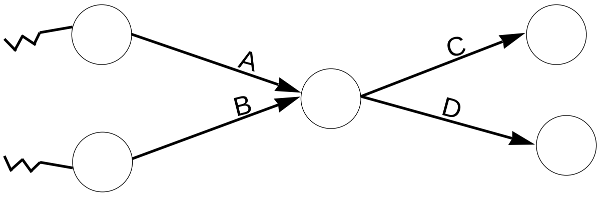
2.2 Logic conventions used in constructing the network



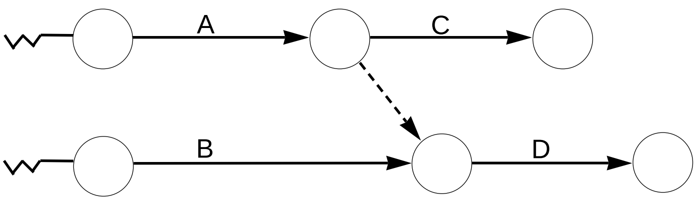
Activity A **must** precede activity B.



Activities A and B must both be completed before C can commence.



Activities A and B must both be completed before either C or D can be commenced.



Activity A must be completed before C and D commence.

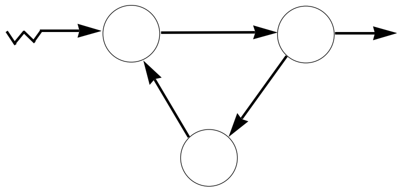
Activity B must be completed before D commences but it does not influence the start of C.

Note how the dummy activity, indicated by the broken arrow, is used to develop the logic.

If these conventions are followed any project can be put into a network format. There are however two common logic errors which must be avoided: **looping** and **dangling**.

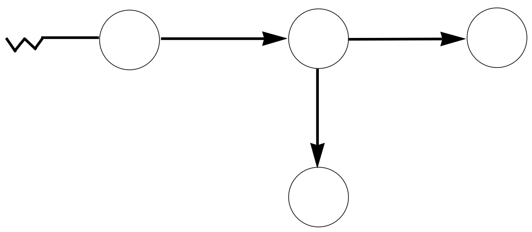
- **looping**

  This is avoided by keeping the time flow from left to right.



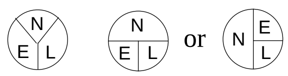
- **dangling**

  This is avoided by ensuring all events except the first and last have at least one activity entering and another one leaving them.



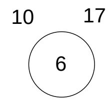
2.3 Subdivision of event symbols

Various approaches are taken to enable the arrow diagram to be evaluated. Probably the most common way is to divide the event symbol into three sections and observe the following notation:



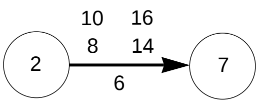
Where:
N = the event or node number.
E = the earliest start time for the next activity.
L = the latest start time for the next activity if the overall project completion time is to be achieved.

Various other notations are used, some of which appear rather untidy when the complete network model is drawn. For example:



where 10 is the earliest time, 17 is the latest time and 6 is the event reference number.

Another notation provides five pieces of information at each node:



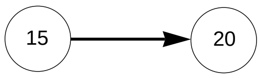
where 10 is the latest starting time
8 is the earliest starting time
16 is the latest finishing time
14 is the earliest finishing time
2 and 7 are the event reference numbers
6 is the activity duration.

2.4 Numbering the network

In some simple networks, activities can be assigned letters of the alphabet A, B, C. Such approaches are however rather limited and a numerical system is much more flexible.

The event *N* is allocated following a general set of rules which will enable each activity to be precisely designated with a unique number. Therefore computer analysis of large numbers of activities can be speedily undertaken, and the potential for managerial misinterpretation of ongoing data is reduced.

Each activity can be referred to, for example:



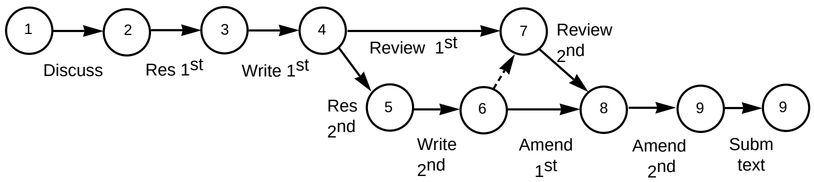
Activity 15–20

The network numbering commences with low numbers on the left-hand side (the commencement) and proceeds to the highest number at the closing right-hand side event. It is common practice to leave gaps in the numbering system in all real project situations. This is to provide facility for the introduction of additional activities as the project unfolds. Failure to leave gaps involves renumbering and likely confusion in the accompanying documentation. Gaps in the early part of the network tend to be small whilst large gaps provide the facility for major changes or restructuring in the later stages of a project.

ACTIVITY 5

Construct a straight-line sequence for a project of writing a textbook and add some event numbers.

Activities included are: discuss and decide objectives
- research material for first half
- write first half
- first half is reviewed whilst second half is researched
- write second half
- first half is amended whilst second half is reviewed
- second half is amended
- complete text is submitted to the publisher.



You might have made the event numbers consecutive if there were not going to be any changes to this network. You perhaps left some gaps to allow for, say, an additional review process. In some networks, you may see the start event numbered as zero. This is simply a convention which some project managers use.

In considering this example you probably thought about how long each of these activities took. You may have also wondered if the reviewing of the first half of the text took exactly the same time as the research needed for the second half. So we will revise the material and see what difference it makes to the sequencing of the project.

ACTIVITY 6

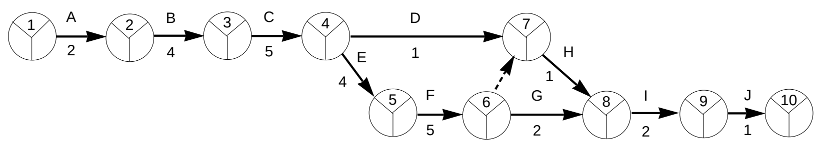
Construct the network for these revised activity details and number the events. The times given are in unit of a week, alphabetic references are given, as are the precedences. Two staff members work on this project X and Y. Precedence means it comes directly before.

How long can we expect the project to take?

		Time	Precedes	Staff
A	Discuss and decide objectives	2	B	X
B	Research material for first half	4	C	X
C	Write first half	5	D, E	X
D	First half reviewed	1	H	Y
E	Second half researched	4	F	X
F	Second half written	5	G,H	X
G	First half amended	2	I	X
H	Second half reviewed	1	I	Y
I	Second half amended	2	J	X
J	Text is submitted	1	none	X

This proved a bit more difficult. It is essential that we get the logic relationships right, otherwise later calculations will be erroneous.

This was the first network:

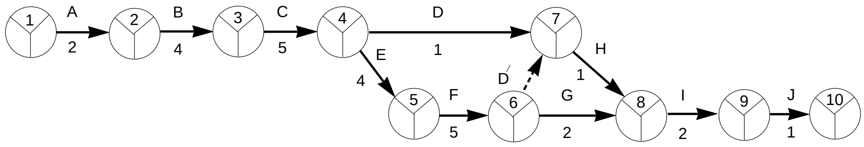


Route ABCEFGIJ adds up to 25 weeks.

Route ABCDHIJ adds up to 16 weeks.

Did you identify a problem with logic though? Staff member Y cannot begin reviewing the second half material until F is complete. This is where the logic device defined earlier, the dummy activity, is required.

This is the new network:

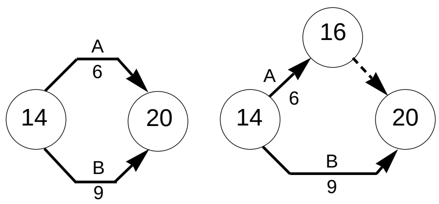


There is a new route now through the dummy: ABCEFD′HIJ, this adds up to 24 weeks. It is essential that we account for all the logic issues and all the possible routes through the network.

OTHER WAYS OF INTRODUCING AND NUMBERING DUMMIES

On occasions two or more activities with different time allocations are structured between the same two events. This provides an opportunity to insert a dummy, which will itself be included in the calculations and have its own unique number.

The following example illustrates this:



2.5 Determining activity times

The project manager will need to identify all the activities which must be undertaken to execute the project completely. Consultation with all who are knowledgeable about these activities is essential, and problems inevitably arise during the project if this process is treated superficially. Activities may be omitted or extra ones included to the detriment of the network.

The identification of all activities leads on to some form of classification in which each can be slotted into the work realm of particular managers. For example, activities under the control of a chief electrical engineer may occur intermittently throughout a six-month construction job.

The project manager will then personally meet all individual managers whose workforce is to be deployed on the project. This often involves sub-contractors also. At each meeting it will be necessary to:

- Confirm all the activities required from that source and amend the list if further things arise during discussion.
- Agree whether each activity is to be treated as a whole, or whether sub-division is desirable or possible.
- Agree activity sequencing and any variances which are possible.
- Precisely define the method of work to be adopted. This may mean a statement about work conditions/weather, machine performance and quality assurance. Resourcing factors must be determined in the light of the agreed method. For example, how many bricklayers are required for the task?
- Determination of the activity duration to be used in the network under the agreed conditions. Various approaches are adopted:
  - past records if similar jobs have been done before
  - work measurement, for example, time study synthetic data or predetermined motion time standards
  - estimation, preferably a system which involves some objectivity, for example, analytical estimating, comparative or category estimating.

Note that the process of agreeing activity duration times is often a sensitive one. Functional managers are thereafter going to be accountable to achieve these target times. There may only be a lot of work and worry associated with achieving a correct time with no hidden margins if anything goes wrong! Particular problems arise in green-field situations which have no past data to draw on. The development of state-of-the-art products as technology moves on is a prime example.

USING THE PERT APPROACH TO DETERMINE ACTIVITY DURATION TIMES

Sometimes activity duration times cannot be established using the normal deterministic methods. The activity itself may be subject to a degree of uncertainty and probabilistic concepts need to be introduced.

During the late 1950s the project managers of the Polaris missile programme were faced with complex problems in establishing activity durations because many of these activities were breaking new ground. The approach which was finally adopted by the US Navy has since been handed down to today's users. It is usually called the PERT approach after the full title of the network planning technique used: program evaluation and review technique.

Functional and technical managers are required to provide the project manager with three different time estimates for each of the activities that they are responsible for. These times may well have to be justified and so they must be based upon as much sound evidence as possible.

The three activity duration times provided are: **most optimistic, most likely** and **most pessimistic.**

MOST OPTIMISTIC DURATION TIME (*O*)

This is the shortest time in which the activity could be completed if everything goes exceptionally well. The manager should bear in mind that the chances of beating this time is no greater than one in a hundred.

MOST LIKELY DURATION TIME (*M*)

This time would be expected to be achieved on the greatest number of occasions if the activity was repeated many times under similar conditions. Statistically, this is known as the mode of a distribution.

MOST PESSIMISTIC DURATION TIME (*P*)

This time estimate indicates the longest time which the activity will take if everything that can go wrong, does go wrong. Once again, the manager should not expect this desperate scenario to occur more than once in a hundred occasions.

A weighted average is determined using these three time estimates:

$$\text{activity duration time} = \frac{O + P + 4M}{6}$$

We look at how probability is used in the control of projects later in the unit.

ACTIVITY 7

When a network is numbered, gaps may be left in the numbering system. Why?

Consider the following project. Office equipment, desks, computers, filing cabinets, etc. are being transferred from one building to another 1 km away. The project is scheduled for three working days, Wednesday, Thursday and Friday. On Thursday, the lift in the receiving building broke down for five hours causing major delays on the network schedule. As the project manager you decide you must take alternative courses of action to get the project completed by 5.00 p.m. Friday. What could you do, and how would it affect the numbering of the network?

Gaps in the numbering are left to allow changes without a complete renumbering of the whole network.

With the office move scenario, it would obviously have been beneficial to leave gaps in the numbering. Let’s look at some possible activity changes which might help:

- keep all the furniture moving and stock it near the base of the lift until it is required.

- reschedule activities to run through into Thursday evening.
- draft in extra personnel to complete the layout once the furniture is in the office.

If you adopted any or all of these activities, you would need to allocate an activity number and make a time assessment. The network could cope with the renumbering providing you had left appropriate gaps.

2.6 Constructing the network

The project manager, having collected all the relevant data regarding activities and their relationships, must then begin to construct the network itself. This involves a logical thought process if the network is a comparatively simple one using a paper and pencil approach.

Data should be in this kind of format for each activity:

Activity description

Precedence relationships (i.e. must be done before...)

Agreed method of work and resourcing

Agreed times	Most optimistic	
	Most likely	Selected or PERT time
	Most pessimistic	

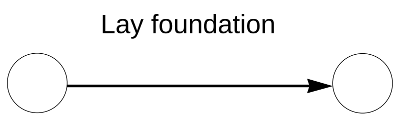
Possible variants

Significant calendar dates

Activity manager

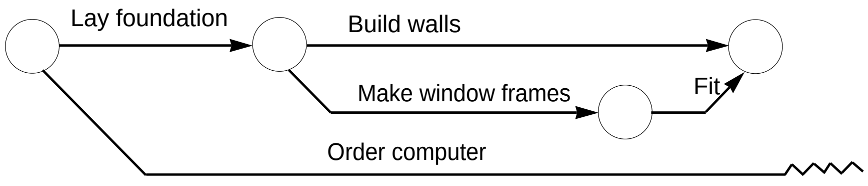
Figure 6: Starting the network.

The next step is to identify the first activity or activities which must begin the project. Suppose we are modelling the construction of a building extension. Sketch on paper a circle near the left-hand side and draw the activity arrow from it, moving in a right-hand direction. At the arrow point draw another circle.

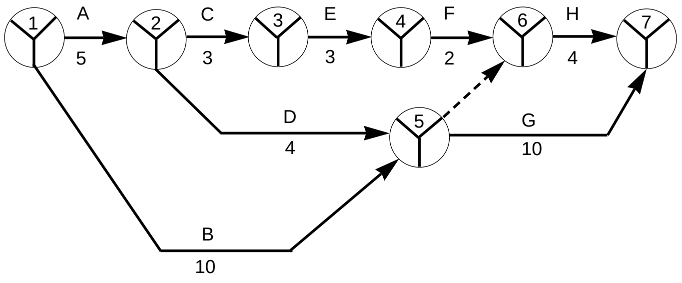


Determine the next activity/activities which can begin once the initial activity/activities have been completed. Draw them in, beginning from the second circle (which represents an event). Do not close with an event until you are sure you have the logic correct. Continue the process until all activities are plotted and when checking the logic insert any dummy activities required.

For example, you probably have something like:



Suppose that this construction project began to shape up like this example:

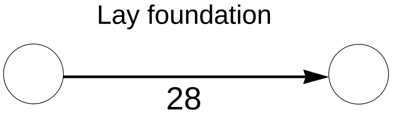


The longest route is through activities B and G, i.e. 1 – 5 – 7, a duration of 20 time units. This is known as the critical path route.

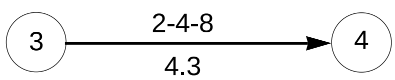
2.7 Entering activity times

Once the activities have all been entered, we usually call it an **arrow diagram**. Note you may need to construct a series of arrow diagrams if there are variances on methods and precedences.

The activity times are then added, by convention they go below the arrow.



Sometimes when drawing a PERT network, the three time estimates are shown in this way:



where the figure 2-4-8 represents the three time estimates and 4.3 is the weighted average.

2.8 Calculating the overall project duration

The project starts at zero. There must be a common time scale for all activities, for example, days, and relationships with calendar dates are determined towards the end of the whole analysis at the practical planning stage.

Enter zero in the bottom left-hand segment of the first event. Then by an addition process add through from event to event using the bottom left-hand segments. These are known as **earliest times**.

There is a rule which must be followed when more than one activity enters an event. The *largest total* is entered in the segment.

The final event will indicate the total time through the longest route. Again this is called the **critical path**.

The final time is now entered also in the right-hand segment of the final event. A subtraction process is then used to enter the right-hand segments, known as **latest times**.

The rule which must be followed when the tail of more than one arrow comes from an event is that the *smallest total* is entered. The latest time on the first event should end up as zero.

2.9 Float

Float, or sometimes called **slack,** is defined as the amount of time an activity can be delayed without affecting the duration of the project. Critical path activities by definition possess no float. The manager responsible for a critical path activity must ensure that it is completed in the allotted time. Failure to do this will extend the overall project duration, unless steps are taken at a later stage to claw back time which has been lost.

Float occurs on non-critical path activities and dummies. It is often possible to avoid having dummy activities in the critical path by careful modelling. If a dummy is non-critical, the float must be determined.

In appreciating the relationships within the network, note that time extensions of only a small amount on some activities will create a new critical path route and extend the network.

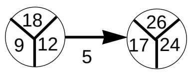
There are three measures of float, **total float, free float** and **independent float** each having special features:

- **total float is** the maximum time which is available to complete an activity. Knowing that an activity has a quantity of total float enables the manager to use discretion as to when the activity is undertaken. Faced with illness, machine breakdown, or departmental overload on certain days, the manager can schedule the activity to maximise the efficient use of resources. Many of the simpler texts on project management, only identify total float, calling it ‘float’ or ‘slack’.

We can calculate total float:

Total float = Latest finish time for the activity (LF) – Earliest starting time for the activity (ES) – Duration of the activity.

For example:



ES = 9   Duration = 5   LF = 24

Total float (TF)

= LF – ES – D

= 24 – 9 – 5 = 10

- **Free float** is calculated by considering earliest times. Many projects are organised and scheduled on earliest times to give the best possible chance of completion on time. The project manager needs to carefully monitor the progress of each activity as earliest time operation puts activity managers under some extra pressure. Not all non-critical path activities have free float.

We can calculate free float as follows:

Free float – Earliest finish time for the activity (EF) – Earliest starting time for the activity (ES) – Duration

In the above example,

Free float = EF – ES – D

= 17 – 9 – 5 = 3

- **independent float** is important when the project is being run on earliest times. Should an activity reach the next stage at the latest time possible, the independent float indicates whether it will be possible to complete it immediately and allow the following activity to begin on its earliest time, as scheduled. Sometimes the calculation results in a negative result. This indicates the degree of lost days still to be pulled back, but counts as zero days in control terms.

  Normally in tabular analysis, negative data is shown as: 0 (– 5)

  We can calculate independent float as follows:

  Independent float – Earliest finish time for the activity (EF) – Latest starting time for the activity (LS) – Duration.

  In the above example:

  Independent float = EF – LS – D

  = 17 – 12 – 5 = 0

Figure 7 illustrates these three types of float.

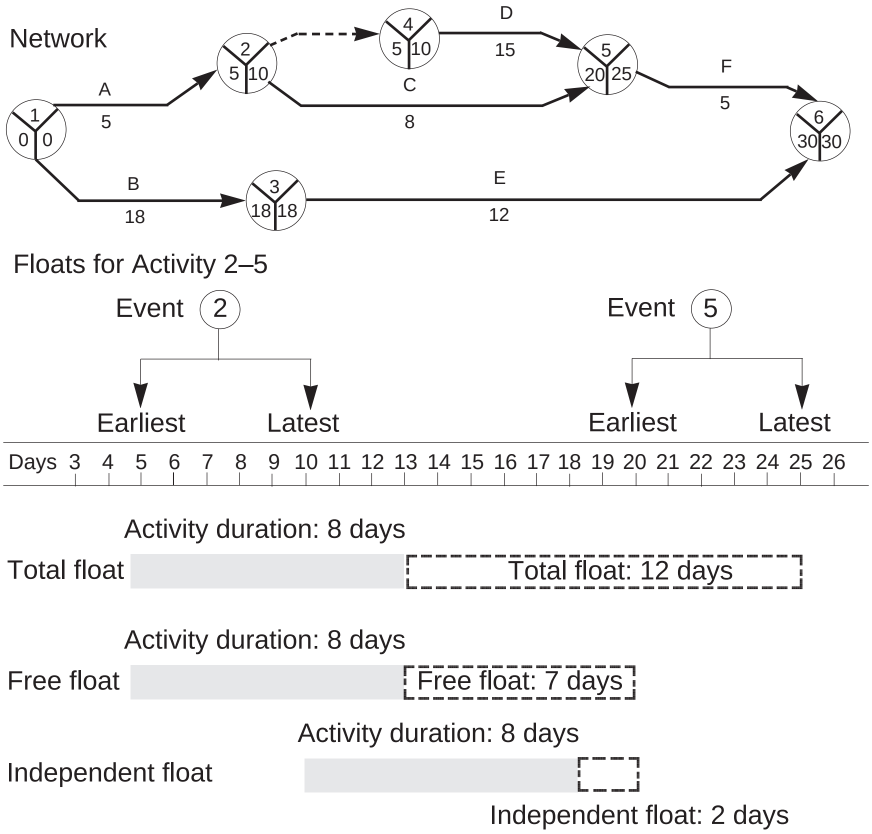


Figure 7: The three measures of float

ACTIVITY 8

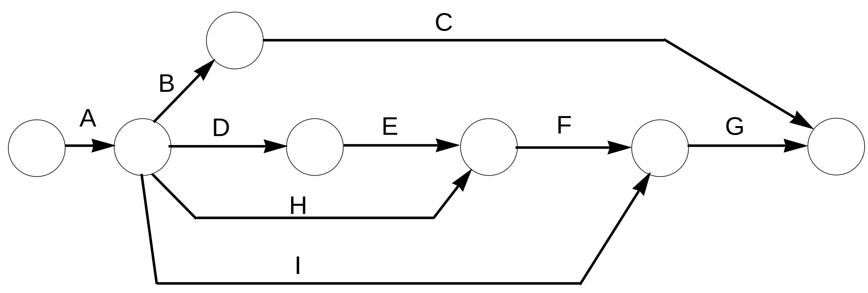
Here are the details of a simple project, putting on a play, which we can use to construct a network in stages.

First, construct a network from the following data; determine the critical path activities; and calculate total, free and independent float for each activity.

Activity		**Time (Weeks)**	**Precedes**
A	Decide on the play	2	all
B	Print tickets	3	C
C	Sell tickets	3	–
D	Issue scripts to cast	1	E
E	Cast learn scripts	4	F
F	Rehearsals	3	G
G	Full dress rehearsals	2	–
H	Obtain stage props/equipment	2	F
I	Make costumes for cast	5	G

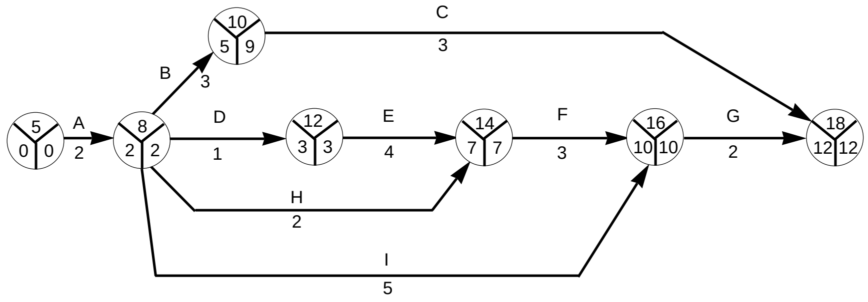
Hint: start every activity as soon as it is logically possible.

It helps to put this network together in stages. First, the logic:



The logic diagram

Then add the numbers and calculate through, using the rules you met earlier in the unit.



Calculated network

Finally calculate the floats and identify the critical path with no floats.

Remember how to calculate the different kinds of float:

Total float (*T*) = Latest Finish – Earliest Start – Duration

Free float (*F*) = Earliest Finish – Earliest Start – Duration

Independent float (*I*) = Earliest Finish – Latest Start – Duration

Tabular analysis

We can present the information in tabular form:

ACTIVITY	CODE	DURATION	START E	START L	FINISH E	FINISH L	FLOAT T	FLOAT F	FLOAT I
A Decide	5–8	2	0	0	2	2	0	0	0*
B Print	8–10	3	2	2	5	9	4	0	0
C Sell	10–18	3	5	9	12	12	4	4	0
D Scripts	8–12	1	2	2	3	3	0	0	0*
E Learn	12–14	4	3	3	7	7	0	0	0
F Rehearse	14–16	3	7	7	10	10	0	0	0*
G Dress Reh.	16–18	2	10	10	12	12	0	0	0*
H Obtain Props	8–14	2	2	2	7	7	3	3	3
I Costumes	8–16	5	2	2	10	10	3	3	3

* Critical path activities: project duration 12 weeks.

2.10 Using Computer Packages in Network Planning

Many real-life problems contain a large number of factors and activities. The resolution of the problem, with optimisation in view, lends itself to computerisation. In the past decade, many efforts have been made to produce programs which will rapidly handle network situations. Mainframe computer programs in FORTRAN were developed in large companies, for example, in construction and aircraft assembly. Specialist staffing was essential to write and run these programs and many project managers were unhappy that output was batched rather than in real time.

The development of microcomputers and associated packages has greatly renewed the interest in solving network problems, within a wide range of organisations. The added facilities of colour and graphics has enhanced the attractiveness of using the packages. Many PC applications concentrate mainly upon the calculation of the critical path duration and total float (slack).

We identify some features to look for in purchasing a network planning package in Resource 5.1.

2.11 Potential problems of computer applications

We can identify a number of problems with using computers in network planning:

- Computer paralysis: too much computer activity, too little real project management thought.
- Information overload: too much data or detail overwhelms staff.
- Dependency: project managers wait for computer reports before acting, rather than proactively avoiding problems.
- Biased reports: data is massaged to provide good reports.

Summary

In this section we described and illustrated the various symbols and conventions used in network planning. We looked at how the network is numbered and constructed, and explained the concept, and the three measures of float. We also considered the use of computer packages in network planning.

SECTION 3

PERT

Introduction

In this section, we will look in detail at PERT, a particular network planning technique that we introduced earlier. It is often difficult to establish the activity times, particularly when work of a particular type, or using a particular method has never been done before. Managers who will have to control parts of the project when work comes into their department or under their authority, are naturally keen to get the best possible time allowance for it. They are pragmatists and realise that they have to cope with staff absenteeism, holiday entitlements, machine breakdowns and material shortages. Having a little extra time on an activity seems like a good idea! The project manager will need analytical and persuasion skills to agree methods and times. A very legitimate question arises whenever estimates involving uncertainty are made.Will the project finish on time? The PERT approach can help answer this question.

3.1 Time estimates on networks

As we saw in Section 2.5, using the PERT approach to establish activity times generates three different duration estimates:

M most likely duration

O optimistic duration

P pessimistic duration.

PERT uses the following weighted average to determine activity durations:

$$T = \text{activity duration} = \frac{O + P + 4M}{6}$$

3.2 Probability of duration

The probability distribution used in PERT is known as the **beta distribution**, which can assume a variety of shapes and allows *M* (called **the mode**) to fall anywhere between *O* and *P*. Note that *M* and *T* will only correspond in a normal distribution. The mode is the value that most commonly occurs.

A statistical measure known as the **variance** can be calculated. This is designated by the Greek letter σ:

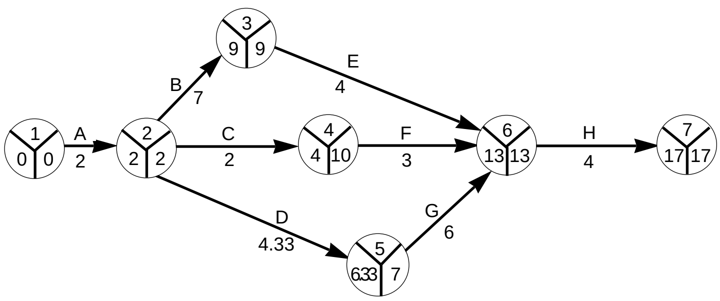
$$\sigma^2 = \left(\frac{P - O}{6}\right)^2$$

The variance increases as the gap between *O* and *P* increases. Thus the greater the uncertainty of accuracy the greater the variance. A major use of variance data is in the determination of the probability of a project being completed by a given day or date.

We can construct a simple network from the following data:

Activity time estimates (days)		**PERT**	**σ^2**	**Precedes**
Code	***O M P***	**Mode**		
A	1 2 3	2	4/36	All
B	6 7 8	7	4/36	E
C	1 2 3	2	4/36	F
D	1 4 9	4.33	64/36	G
E	3 4 5	4	4/36	H
F	2 3 4	3	4/36	H
G	2 6 10	6	64/36	H
H	2 4 6	4	16/36	-

Network model:



The critical path activities are A-B-E-H and the duration = 17 days.

If management wants to know the probability of the project being completed by day 20, the response can be calculated:

Activity	A	B	E	H	Sum	
σ^2	4/36	4/36	4/36	16/36	28/36	0.777

Thus $\sigma = \sqrt{0.777} = 0.882$.

The probability of completion by day 20

$$\frac{P - O}{0.882} = \frac{3}{0.882} = 3.401.$$

Using a table of cumulative probabilities of the normal distribution curve, we can see that 3.401 gives a probability of .9997, that is, there is a 99.97% chance of completion by day 20.

Note that a negative result indicates the likelihood of it not being achieved.

Summary

In this section we looked at PERT and how this approach to network planning can help establish activity times and indicate whether a project will finish on time.

SECTION 4

Project Resources

Introduction

In this section we will discuss the allocation of resources to the network. We will highlight the use of histograms and Gantt charts by project planners and will also consider project control, project status and exception reporting. We will introduce the term **milestone** and look at project cost scheduling. We will describe the process of **crashing** activities on a network and mention briefly the control of variances. Finally, we will summarise the factors which can lead to project success or failure.

4.1 Calculation of load

The project manager will generally consider the allocation of resources to the network as the logic diagram is being produced. For example, it is not possible to run two activities simultaneously if both have to be done by the same staff, or if there is a demand on the same piece of equipment. Allocation of resources to the network is often called **loading the network**. Computerised techniques are available to handle complex situations, but the simple **Gantt chart** is widely used by project planners.

Amongst the problems involved with the loading of resources to staff, machines or departments are:

- **overloading**: too much work is required from the resource relative to the time available.
- **underloading**: too little work is available for the resource.

The objective is one of **full loading** but in practice we can only attain this in well-designed and balanced systems set up on management services and work study bases, for example a conveyorised product assembly line. In quantifying the duration of each activity in the network, it is advisable to use a standard time unit, and represent all activities in that unit or decimals of it. A standard hour (day or month) will have built-in allowances and performance statements.

For example:	activity 19-37:	manually dig out 70 cubic metres of soil
	work standard:	7 cubic metres/hour
	working day:	8 hours
	duration:	10 hours, that is, 10/8 = 1.25 days of work.

In calculating what is attainable, we need to moderate the technically feasible target by reference to current factors such as:

- absentee rates
- holidays
- breakdowns and maintenance data.

Two problems arise when we calculate resource load:

- **optimisation**: What feature should be optimised? If maximum machine utilisation is achieved in the network, it is likely that other resources will be underloaded. Trade-offs are inevitable and must be explained in the planning documentation.
- **alternatives**; Activities in a network impinge upon each other. Choices have to be made regarding sequencing to achieve optimum efficiency. Three activities which can be carried out independently can be networked in six ways (3! or 3 factorial, 3 x 2 x 1); five activities have 120 alternatives (5 x 4 x 3 x 2 x 1).

4.2 Histograms and Gantt charts

Network loads can be represented as a histogram, with the length of each bar being proportional to the quantity of load. An example is shown in Figure 8.

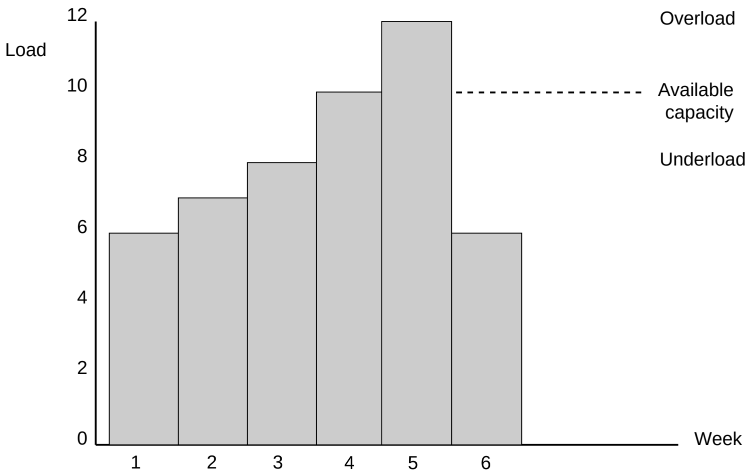


Figure 8: Example of a histogram

Gantt charts can be presented in various ways. Decisions need to be made about the data to be included once the network has been constructed and calculated. One chart may refer to the normal network, a second may refer to a crashing procedure. Charts will often be plotted on the earliest activity times and will indicate any of the types of float of particular interest. Many Gantt charts are plotted showing earliest times and free float and project managers are under pressure to keep to these times. An example is shown in Figure 9.

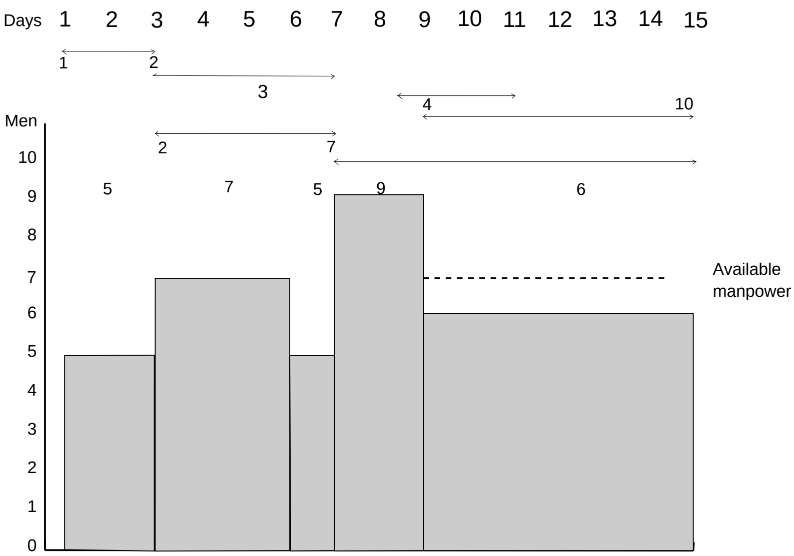


Figure 9: Example of a Gantt chart

SMOOTHING THE GANTT CHART

From Figure 9, you can see that problems of resourcing are going to occur on Days 7 and 8. The labour demands exceed the availability, and the project manager needs to resolve this issue to the best advantage. Usually budgets have been agreed at an earlier stage with operations managers. In the following example, the number of man-days has been agreed as indicated:

Activity	**Duration (days)**	**Men**	**Man-days**
1–2	2	5	10
2–3	4	4	16
2–7	3	3	9
3–4	2	8	16
4–10	6	5	30
7–10	9	1	9
		Total	90

Budgeted man-days: 7 men for 15 days = 105 man-days.

There are enough man-days but the distribution needs adjustment as no more than seven men are to be provided at any one time. One activity (3-4) requires eight men and this must now be carefully re-examined.

Careful consideration is given to the method, and discussions held with the managers concerned to see if there are alternative methods, or whether the 16 man-day requirement could be spread over four days instead of two. The relevance of float time will be seen at this stage, not only on the activity concerned, but also impinging other activities. In a fuller Gantt chart than this example provides, the three types of float can be shown. These will obviously change as activities are revised through consultation. The aim of the project manager will be to find a way of getting Activity 3-4 done within the budgeted man-days and to avoid an ‘extra allowance’ request due to manpower shortfall.

4.3 Project control

This is the next phase of project management and it is achieved by constantly monitoring the progress made on each activity. Constant referencing to time schedules and cost budgets is necessary, and the project manager will need to find the appropriate ways to act whenever signs of ‘slippage’ begin to occur.

In practice, monitoring of the progress of time is done by relating the actual start and finish times of each activity against either a time-scale relating to overall project duration or to actual calendar dates. The critical path activities are of prime concern, because uncorrected slippage will extend the project time. Of secondary importance are non-critical activities which possess small amounts of float. Slippage on these could cause them to go critical, and a whole new critical path develop. In this case, operations managers will need re-briefing on the changed status of later activities within their functional areas. The third level of importance are activities which contain considerable quantities of float. If independent float exists, for example, there will be scope to allow slippage and still operate the succeeding activity on the earliest time if required.

As part of this monitoring stage, regular management reports, prioritising activities which need to be done in terms of their float, will be required. Highest in the table are critical path activities which have no float, followed by those activities with ascending quantities of total float.

Simple projects can be drawn on to planning boards and progress can be recorded daily. If a computerised system is being used, the project manager must ensure that printed out material is intelligible to other managers and not in such copious quantities that it is set aside rather than acted on.

Figure 10 shows a further example of a Gantt chart.

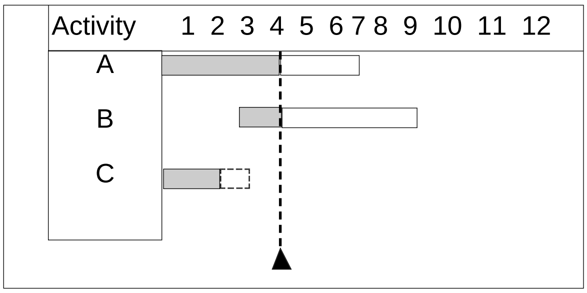


Figure 10: Gantt chart.

The following notation could be used:

Progress to date:

Work remaining:

Slippage or agreed extension:

Milestone dates: 

Gantt charts generated from computer packages have similar structures and are often based on the Lotus 1-2-3 spreadsheet package.

4.4 Project status reports

Project status reports are provided at both regular and pre-designated points in the life of the project so that corrective managerial action can be taken.

ACTIVITY 9

You are the project manager controlling the refurbishment of old shop premises into an up-market fashion boutique. A well-publicised grand opening is planned for 20 days ahead. It is apparent, however, that the builders have created a lot more dust, dirt and grime than was expected. The painters and decorators are due to start in three days time for their ten days of work. You reckon that there are six days of cleaning to be done. What possible actions can be taken so that the opening is not delayed?

Perhaps you could hire extra (contract) cleaners and possibly use them on a night shift.

You might consider cleaning up a particular area so the painters could make a start, allowing them to start on time. The cleaners would then move through ahead of the painters until the premises were clean. Some of the final tasks before opening could be approached differently; you apparently have a lot of float in the system, although perhaps you have 4 days' of carpet laying and shelf and rack building to schedule before the clothes can be displayed on the racks.

There are many options. A bar chart, with its associated network, allows 'What-if?' scenarios to be explored.

EXCEPTION REPORTING

Some projects are run on an exception-reporting basis. This only identifies activities on which managerial action is necessary to maintain scheduled progress. The management report shows the reference number of the activity, the amount of slippage, the effect upon overall project completion time, or the extent to which total, free or independent float can be used up.

Managerial accountability requires precise definition of the cause(s) of the delays so that other managers or customers can be accurately advised where necessary. A damage limitation process follows, led by the project manager. Ways need to be found to bring the project back into schedule by initially considering all the significant later activities. Challenging their resourcing and methods will often prove beneficial. This process is often a difficult one due to resistance from operational managers who know they may be required to execute an activity using new and untried methods. An alternative strategy when PERT principles have been used to determine the weighted average activity time, is to take steps over several sequential activities to pull the completion time towards the 'most optimistic' estimate.

4.5 Milestones

The term **milestone** is used in project control to describe events in the life of a project which signal the achievement of certain key stages.

ACTIVITY 10

You are using the project management approach to design a small business proposal which you aim to present to your bank manager. Can you list several key issues, or milestones, which would apply to this project?

Your milestones are likely to be:

- deciding your business idea by creative thinking process
- analysing your market research findings
- deciding on the location for the business
- carrying out your financial projections.

You probably included some different issues too. Notice how developments can often go in a number of directions after a milestone, depending upon your decision making.

Not all milestones need to be upon the critical path. Sometimes we can be dependent upon the efficiency of a contractor for the delivery of hire equipment, and have built in a margin to cope with late delivery through adverse weather conditions. The project manager is delighted to see the equipment arrive on time, happy to see it a day late, satisfied if it arrives two days late, when the network analysis shows there are five days of total float on the first activity which the equipment will be used for. Obviously, if the equipment arrives on time, it may be possible to pull activities forward and accomplish them early.

If a computer package is in use, it is possible to produce a management report consisting of a milestone listing. Various strategies can be employed to keep activities on schedule. One approach is to divide up the whole project into discrete phases and to ensure that every possible means is used to complete each milestone phase before the next phase begins. This is sometimes called **damming-up**.

4.6 Project cost scheduling

Cost control is necessary for a number of reasons. It assists in the financing of the project and recognises the points at which further finance needs to be injected. The project manager will be accountable for the on-going expenditure and this can be compared and reconciled against budgeted costs.

A cost schedule can be developed from the Gantt chart and milestone reporting intervals can be pre-determined. One approach which is used for control is to prepare a **cost-slope** for each activity. This can be used at the negotiation stage of project when a cost quotation is being prepared for the potential customer, as an overall project cost can be determined.

To undertake a cost-slope calculation for an activity requires the following factors:

- an agreed expected activity duration (in days/weeks/months)
- the budgeted cost of the activity, taking into account the costs of labour, equipment, materials and other resources.

The cost-slope is expressed in £/unit of time (e.g. £/day), by dividing the cost by the time. When all the activity cost-slopes are linked to the project calendar, a cost distribution graph can be drawn.

ACTIVITY 11

Calculate the activity cost-slopes for part of a project running between days 10 and 24 inclusively from the following data:

Activity reference	**Cost (£)**	**Duration (days)**	**C-S**
7-13	1875	15	
8-16	325	5	
9-18	1218	14	
10-19	873	9	
			Total cost per day £

Our calculations are

7–13	1875/15	=	£125/day
8–16	325/ 5	=	£65/day
9–18	1218/14	=	£87/day
10–19	873/ 9	=	£97/day
Total cost/day £		=	£374

This indicates the cash injection required over the 15-day period. A gross amount of £4291 will be required but spread differentially.

ACTIVITY 12

Develop this example further with this additional data:

Activity 7–13 begins at the start of day 1 and is completed by the end of day 15.

Activity 8–16 begins on day 2 and ends on day 7.

Activity 9–18 begins at the start of day 1 and ends on day 14.

Activity 10–19 begins on day 2 and ends on day 11.

Use a Gantt chart approach to calculate overall daily expenditure.

This is our Gantt chart and overall daily expenditures. We found that in this phase of the project the daily costs moved from £212 to £374 to £309 before returning to £212.

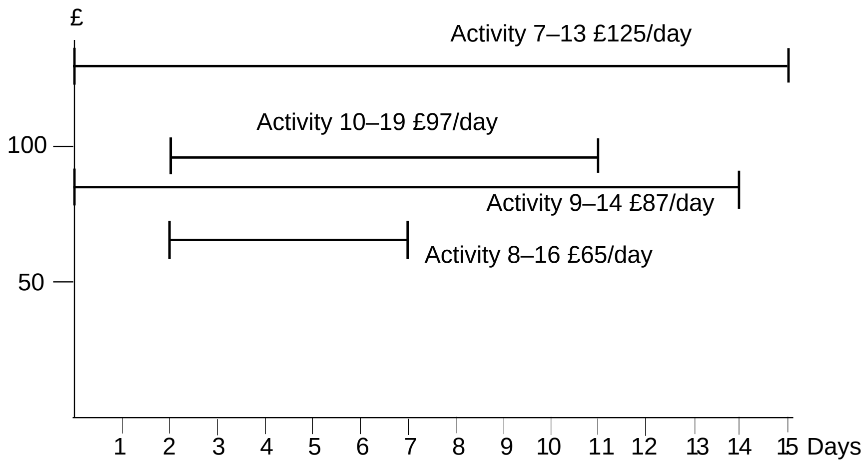


Figure 11: Gantt chart with costs

4.7 Crashing activities

The first overall project time established by a network may not be acceptable for a whole variety of reasons. There could be a commercial judgement relative to the acceptability to the customer or internal organisational reasons to do with resourcing or a clash with demands made by other projects.

If the duration is thought to be too long, the process of **crashing** the activities on a network is undertaken. More exceptionally, if the duration is rather shorter than the time available, **reverse crashing** can be used to open up activity times and reduce costs.

In order to reduce the overall project time the project manager will first identify the critical path activities and rank them in order of duration. The idea is that there would normally be greater scope for reducing time on an activity with a longer duration. The project manager would then examine the details of the activity at the top of the list and consult with the operational manager with whom the initial details had been agreed. If the PERT approach had been used there could have been later reflection on the estimates made and a revision is simply a matter of re-calculation. In most cases, however, the methods to be used, the resources involved and the relative costs will all need to be reconsidered. Other functional specialists from work study and finance may need to make inputs. Where a whole set of options develop it is possible to construct a cost/time curve and to make a selection in the light of the data produced.

4.8 Cost/time curve

The following data was produced whilst trying to crash an activity which involved sub-contracted printing and binding work:

Original
Printer 1 method ‘A’ £1200 8 days

Crashing Data
Printer 2 method ‘A’ £1150 7 days
Printer 2 method ‘B’ £1300 5 days
Printer 3 method ‘B’ £1620 3 days.

Plotting this data gives the curve as in Figure 12.

The project manager can then decide how much time reduction is needed on the project in the knowledge of the cost implications.

If a computer package is being used for this process it is then possible to revise the network data to take account of the new activity duration. This needs to be done for two reasons:

- to see when the target amount of reduced overall project time has been reached.
- to continually check which activities now lie on the critical path.

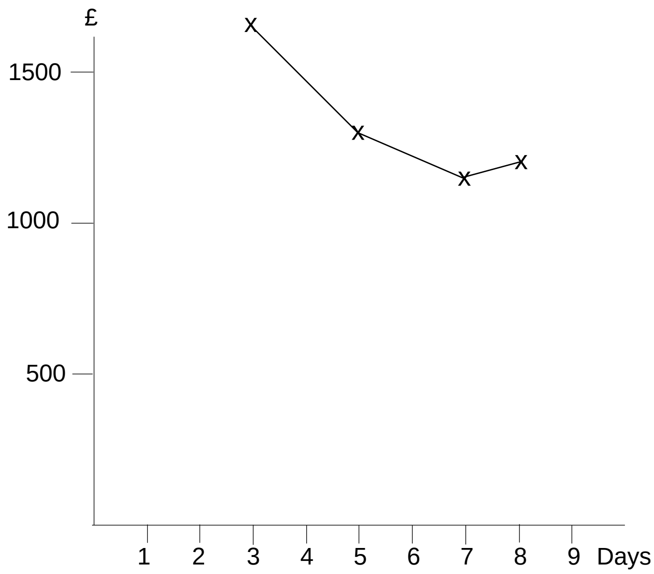


Figure 12: Cost/time curve.

You must appreciate that a degree of iteration is necessary and the project manager must ensure that time and energy are not being expended in attempts to crash activities which are no longer of critical importance.

Some computer packages are capable of producing a graph showing the overall project cost plotted against the duration. As changes are being made to activity times and costs, a decision can be taken about the whole project, to gain optimum economic advantage.

4.9 Controlling variances

Many projects are now agreed on the basis of either a fixed price or cost reimbursement contract. A **fixed price** contract contains a statement of the total agreed price, the delivery date and an identification of penalties which will come into operation should late delivery occur. Obviously it is possible for technical or political factors, which are beyond the control of any involved party, to arise during the life of a lengthy project. In such circumstances, further negotiations between clients, suppliers, contractors and sub-contractors have to be undertaken. The outcome is usually the production of a **change-order** which then forms that part of the overall contract. Note that many projects, particularly technological, creep up incrementally in cost due to a series of change-orders which become necessary. The final extra cost, whilst regrettable, is today usually a function of unforeseen factors outside of the control of the parties to the contract, rather than of poor planning.

The **cost reimbursement** (or cost-plus) approach requires the client to pay the costs incurred by a supplier or contractor plus an agreed profit margin percentage. This is probably what a householder enters into when a tradesman is employed to undertake a domestic job, for example, fit a new window. There is very little real control over what the tradesman actually does with his time, and even where an estimate has been given, it is difficult for the client to counter a demand for extra payment. In a more complex project, the client can receive extra payment demands which seem authentic, but which are retrospective and say nothing about the level of efficiency achieved.

4.10 Project success

We can consider a project as a success if it fulfils the objective criteria which were set. In reality, there are many criteria, and overall success is usually achieved as a result of numerous trade-offs. Some aspects of the project work out better than expected, and more than compensate for those aspects which were difficult to achieve. Typical success criteria would be time, cost, quality, profit and client satisfaction.

FACTORS WHICH LEAD TO PROJECT SUCCESS

A number of factors help to lead to project success:

- An initial careful definition of the objectives of the project, agreed by all the participants is essential.
- There should be commitment and involvement from all participants in the project. This will involve communication and information flows using appropriate channels such as: meetings, written reports, computer printouts on progress and cost, personal conversations, faxes, e-mails, video-conferencing.
- Appropriate planning and control systems must be used. Detailed provisioning and scheduling of resources will be essential to achieve optimal project conditions. A proactive stance can help in forestalling some potential problems, and feedback is vital to keep all participants fully informed on progress and modifications.

What can go wrong if clearly defined project objectives are not agreed between the project manager and the client? Any of the criteria could be emphasised wrongly, for example, the project manager wants to minimise time, but the client is much more concerned about cost; the project manager is concerned about the safety of staff. The client is unaware of the hazards of the job. The end result may not satisfy either party, for example a restaurant is built when a coffee bar is required. There are many more issues. How would you handle the actual specification process to ensure there were no misunderstandings?

4.11 Project failure

We can look at all project failures as the failures of systems. In Unit 1, we learned that a system can be viewed as an input of resources, a transformation to add value, and an output of goods or services. When a project fails to reach a successful conclusion, the cause could lie within any of the three aspects. Inadequate resourcing, poor planning and control, and an indifferent quality of output could all result in failure or non-acceptability.

Sometimes the project itself achieves a conclusion which is perfectly satisfactory in its own right, but which is unsatisfactory to the client. For example, the shop premises are built, but the late completion date has messed up all the plans the client had for new staff recruitment and the opening promotion.

Factors which lead to project failure

The reasons for a failed or unsatisfactory project can be due to personnel, technical, financial, operational, legal or environmental factors such as:

- lack of support from senior management
- inadequate project management skills or experience
- poor communications
- rushed decision making
- inaccurate time estimations
- ignorance of legal or environmental stipulations
- too many ill-fitting significant changes during the project
- lack of managerial control.

Summary

In this section, we discussed the allocation of resources to the network. We highlighted the use of histograms and Gantt charts by project planners and considered project control, project status and exception reporting. We introduced the term milestone and looked at project cost scheduling. We described the process of crashing activities on a network and briefly mentioned the control of variances. Finally, we listed the factors which can lead to project success or failure.

SECTION 5

Activity-on-Node (AON) Technique

Introduction

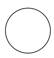
In this section, we will describe the activity-on-node approach to project management. The development of increasingly sophisticated computer packages has led to increasing use of this technique. There are similarities in methodology to the work-balancing technique known as **precedence diagrams**, so these will be a good starting point.

5.1 Precedence diagrams

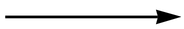
Precedence diagrams use the network planning symbols but the model produced shows the activities and their times on the node or event (activity-on-node). The arrows simply identify the relationships between the activities in terms of their logical sequences. The fundamental rule in scheduling the activities of the project is that no later activity can be undertaken before all the activities which lead into it by arrow have been completed.

NOTATION

We use the following notations:

A circle represents an activity 

The upper half is used to identify the activity with the order of operation reference number. The activity time can be shown either in the bottom half of the circle or outside the circle as in Figure 13.

 directional arrows which link the circles

Probably the major use of precedence diagramming is to solve efficiency problems in the setting up of work stations on product assembly lines. We look at a brief outline in this unit; other heuristical approaches are investigated elsewhere in this module.

METHODOLOGY

We follow a series of steps in creating the model as we did before:

- identify the number of activities in the project or process

- define the relationships between these activities in terms of what follows what, the precedences.
- investigate which activities can be undertaken using the same skills and resources in the same locations
- determine the standard times, known as SMs or SHrs (see Glossary)
- construct the precedence diagram model, building in the logic.
- establish any or all of the following factors from management:

  output required per period of time

  number of work stations desired

  target cycle time per unit of output

  if there are zoning constraints, for example, due to dust.
- discuss with operational staff the possibility of the splitting of activities into smaller components; the use of this data will be a secondary phase strategy.
- develop further managerial debate on objectives and the extent to which a **balancing loss** is acceptable. We cover balancing loss later in this module.

Let's look at an example!

On an assembly line, 11 activities need to be performed to assemble a domestic product.We want to construct the precedence diagram and then use it to look at the best way of using the work stations for maximum efficiency and productivity.

Activity:	1	0.27 SMs (precedes)	2,5,6,7,8,9,10,11
	2	0.12	4,5,6,7,8,9,10,11
	3	0.06	5,6,7,8,9,10,11
	4	0.16	5,6,7,8,9,10,11
	5	0.05	6,7,8,9,10,11
	6	0.13	8,10
	7	0.25	8,9,10,11
	8	0.35	10
	9	0.11	10,11
	10	0.21	11
	11	0.16	none

The following are key factors:

no zoning constraints

5 work stations required each staffed with one person, all of which can perform any activity

maximum work station time = 0.40 SMs

no subdivision of activities permitted.

PRECEDENCE DIAGRAM

We can now draw the precedence diagram as shown in Figure 13.

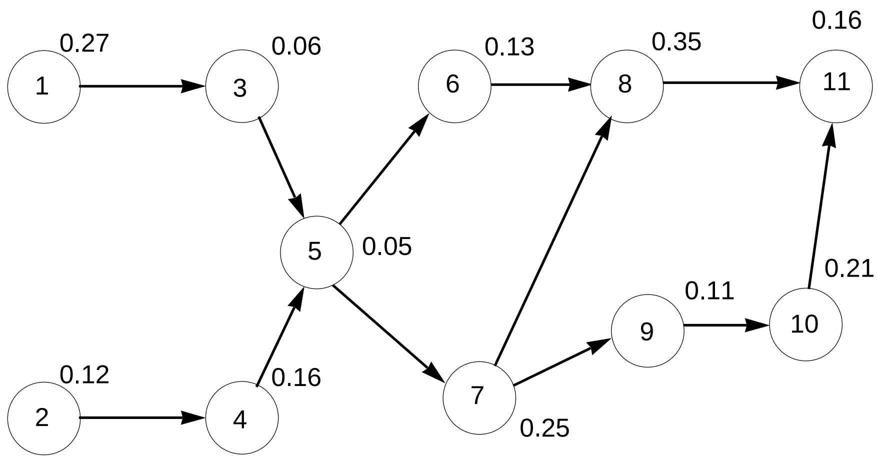


Figure 13: Precedence diagram for assembly line

Possible solution

We then need to break down the activities into the number of work stations, that is, 5.

work station	A activities	1,2	0.39 SMs
	B	3,4,5,6	0.40
	C	7,9	0.36
	D	8	0.35
	E	10,11	0.37

We can then calculate the output per hour, as the maximum work station time is 0.40SMs:

Output/hour $\frac{60}{0.40}$ = 150 appliances

Direct labour cost per hour: 5 staff @ £6/hr = £30

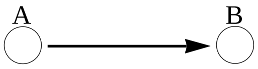
Our productivity will be the output per hour, divided by the cost of that output:

Productivity index $= \frac{\text{output}}{\text{input}} = \frac{150}{30}$

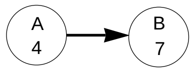
= 5 appliances/£1 direct labour cost.

5.2 Networks using AON

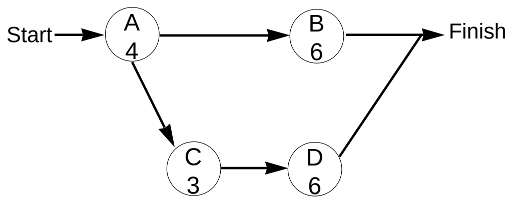
Different notation will be required within the nodal segments in order to calculate through the AON network.

Initially the nodes can be shown as 

They are then evaluated according to the times determined for the activity.

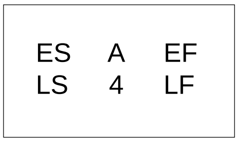


We need to identify a starting point for the project and a finishing point:



Then we need to further sub-divide the node to enable calculation of the float time and to identify the critical path.

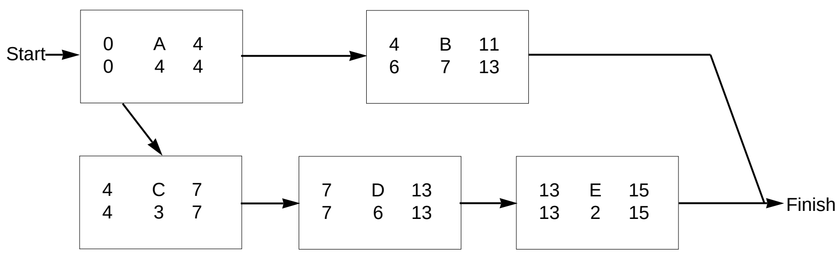
A typical convention is as follows:



where: ES is the Earliest Start time EF is the Earliest Finish time
LS is the Latest Start time LF is the Latest Finish time

All this data can be contained in a box shape or a large circle.

If we develop our simple example further:



where: ES = earliest possible start time for an activity

EF = ES plus activity duration
LS = Latest finish time – activity duration
LF = Cumulative total – activity duration time.

The usual rules regarding situations where more than one path leads into a node apply (see Section 2). Float is calculated in the normal way.

ACTIVITY 13

This is a practice network for you to calculate using activity-on-arrow technique.

The directors of Sunrise Engineering Co Ltd are currently considering the feasibility of computerising the stock control procedures at their regional depots. It is likely that one depot at a time will be computerised and linked to the head office mainframe computer. The directors have decided to use network planning in this feasibility study.

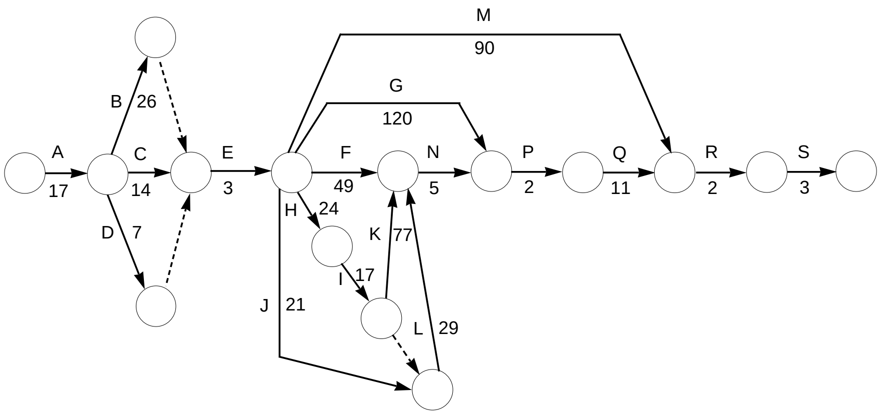
Use the following data to: construct the network
calculate the project duration
identify the critical activities
calculate the float (T/F/I)

	Activity details	**Duration (days)**	**Must precede**
A	Pilot study of total needs	17	All
B	Pilot study of likely costs	26	E
C	Pilot survey of depot buildings	14	E
D	Arrange staff discussions	7	E
E	Project decision meetings	3	M, G, F, H, J
F	Appoint project leader consultant	49	N
G	Train depot staff	120	P
H	Appoint building contractor	24	I
I	Obtain building materials	17	K, L
J	Appoint electrical contractor	21	L
K	Alter depot buildings	77	N
L	Install cabling and power	29	N
M	Customise software, design forms	90	R
N	Install computer terminals	5	P
P	First test run	2	Q
Q	De-bug the system faults	11	R
R	Second test run	2	S
S	First commercial run	3	–

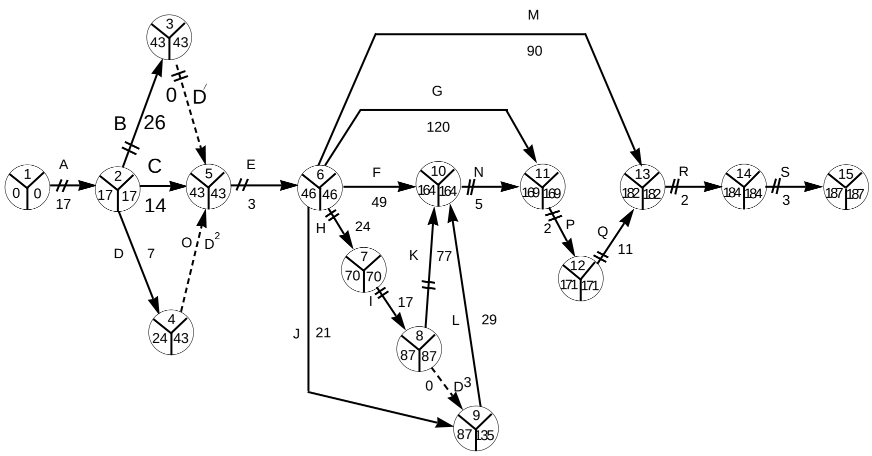
Why do the directors need to exercise rigorous managerial control of critical path activities?

Assuming a five-day working week, if the final managerial decision to proceed (activity E) was made on 20 May, and normal progress was maintained each seven-day week thereafter, when would the new system start?

First build the logic diagram:



Then calculate the activity times and insert in the diagram, include dummy activities, identify the critical path:



Critical path route is ABD′EHIKNPQRS, duration is 187 days.

Here are the float calculations:

Activity	Durn	ES	LS	EF	LF	TF	FF	IF
1–2	17	0	0	17	17	0	0	0
2–3	26	17	17	43	43	0	0	0
2–4	7	17	17	24	43	19	0	0
2–5	14	17	17	43	43	10	10	10
3–5	0	43	43	43	43	12	12	12
4–5	0	24	43	43	43	19	19	0
5–6	3	43	43	46	46	0	0	0
6–7	24	46	46	70	70	0	0	0
6–9	21	46	46	87	135	68	20	20
6–10	49	46	46	164	164	69	69	69
6–11	120	46	46	169	169	3	3	3
6–13	90	46	46	182	182	46	46	46
7–8	17	70	70	87	87	0	0	0
8–9	0	87	87	87	135	48	0	0
8–10	77	87	87	164	164	0	0	0
9–10	29	87	135	164	164	48	48	0
10–11	5	164	164	169	169	0	0	0
11–12	2	169	169	171	171	0	0	0
12–13	11	171	171	182	182	0	0	0
13–14	2	182	182	184	184	0	0	0
14–15	3	184	184	187	187	0	0	0

If critical path activities are not completed according to schedule, the overall project completion time will not be achieved. Any slippage which occurs early in the life of the project may be able to be clawed back if the directors crash activities later on in the network. Continual reporting, monitoring and appropriate cost-effective decision making by the directors is essential.

The system can start after 5 October. Did you calculate this, too?

The end of ‘E’ is 46 days into the project so your 141 remaining days begin on 21 May. The last day of ‘S’ is on 8 October, but this is the commercial run which began on 6 October!

Summary

In this section, we discussed the AON approach to project management. We began with precedence diagrams, which have similarities in methodology, then looked at networks using AON.

SECTION 6

Line of Balance Technique

Introduction

In this section, we will discuss **line of balance (LOB)**, a technique which extends the scope of network analysis. It is particularly suited to the scheduling and control of projects which are made in either fluctuating or repetitive batches. We study all activities which make up the final product and this is translated into an arrow diagram. A programme showing the quantities to be produced every week or month is also required.

Once we have constructed the LOB chart we can see where all phases of production should be at a particular review period, and the likelihood of the delivery programme being met. Current levels of production of each activity can also be compared with planned levels and corrective action can obviously be taken when imbalance is observed. Production levels above the LOB are regarded as safety stock or economic order stock but may indicate that greater than necessary costs have accrued.

6.1 Deriving the line of balance

We follow a series of steps in deriving the LOB:

- Draw a logic diagram of the process but show as many single event starts as there are separate departments.
- Number the events. It is advisable to work backwards. **The number of the last event will be the number of activities plus one**.
- Enter the activity times.
- Proceed to determine the number of weeks that each event is behind the finish of the last activity. This is done by taking the last event as 0 and working backwards, adding the duration of each activity cumulatively.
- Draw up a cumulative delivery schedule.
- Plot cumulative delivery against week number on the LOB chart and enter the departmental activities.

Consider the following example. A vacuum cleaner is being introduced in a new export market. An analysis of the activities shows:

Motor division

Purchase parts	1 week
Sub-assembly	3 weeks
Final assembly	1 week

Casting division

Purchase raw material	1 week
Cast	1 week
Fettle	1 week
Paint	1 week

Manufacture and assembly division

Purchase raw material	2 weeks
Internal manufacture	4 weeks
Purchase sub-assembly components	6 weeks
Assemble sub-assemblies	1 week
Final assembly	2 weeks
Purchase cartons	2 weeks
Pack for shipment	1 week

A manufacturing schedule was devised and actual output levels plotted against planned levels:

Week	Planned	Actual	Cumulative Planned	Actual
1	100	100	100	100
2	100	100	200	200
3	150	150	350	350
4	150	150	500	500
5	300	300	800	800
6	500	500	1300	1300
7	400	400	1700	1700
8	300	300	2000	2000
9	300	300	2300	2300
10	200	nil	2500	2300
11	200	300	2700	2600
12	100		2800	
13	100		2900	
14	50		2950	
15	50		3000	

The tabular analysis and the graph show that up to week 9 there was no deficiency. However, from week 10–11 deficiencies arise. The graph is quicker to interpret and shows the trend clearly.The chart does not show which division is responsible for the deficit, nor does it provide an early warning system. Line of balance is designed to provide these facilities (see Figure 14).

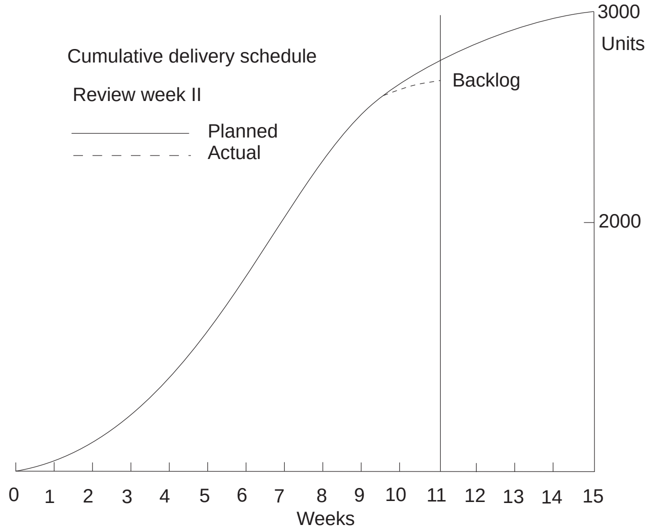


Figure 14: Cumulative delivery schedule (from information held by Bolton Business School and used by the author of this unit with permission)

We now draw a logic diagram (Figure 15) of the situation with as many single event starts as there are departments. Events are numbered and activity times inserted. It is then necessary to determine the number of weeks that each event is behind the finish of the last activity. Make the last event (15) as B = 0 and work backwards adding the duration of each event cumulatively.

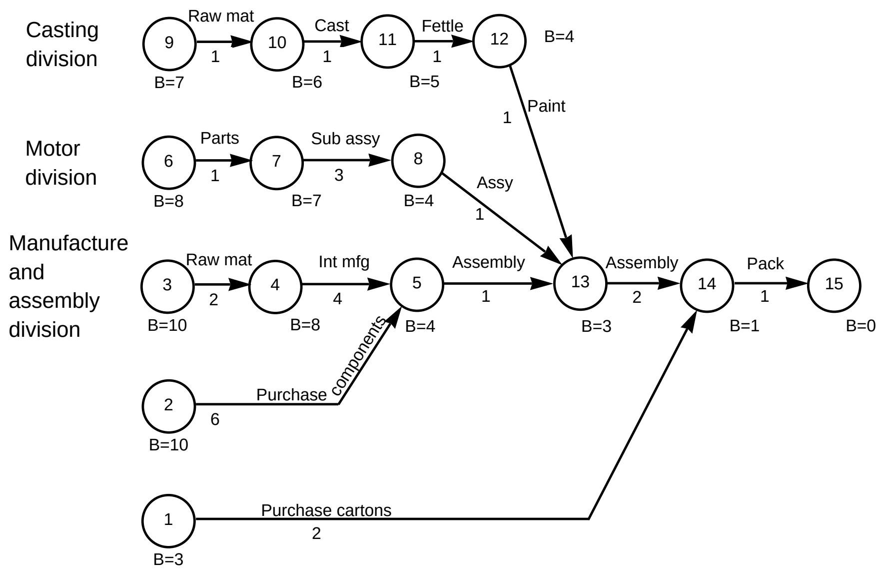


Figure 15: Logic diagram

The chart (Figure 16) shows that the planned output for week 10 will be short of units unless action is taken in the painting department in week 7. The LOB chart is here being used as an early warning system.

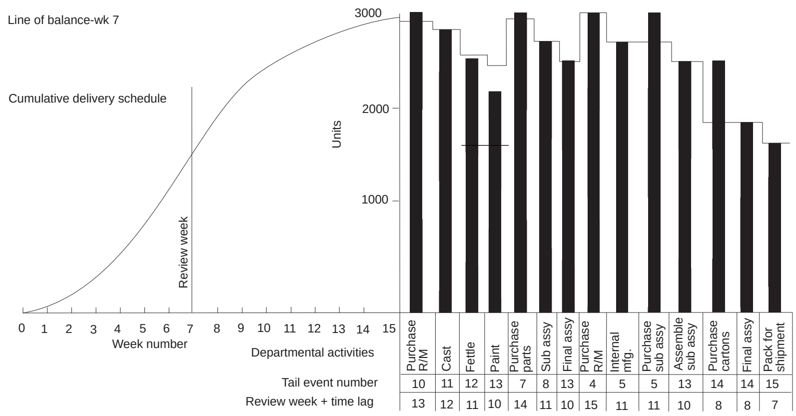


Figure 16: LOB chart (from information held by Bolton Business School and used by the author of this unit with permission)

The chart can also be represented functionally. The purchasing department's responsibilities are shown in Figure 17.

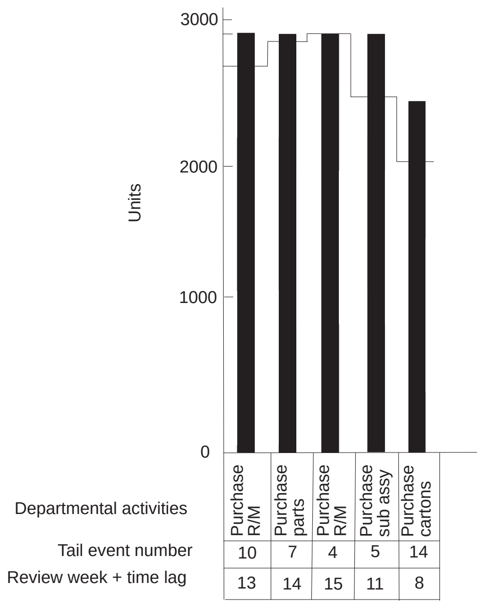


Figure 17: Functional version of LOB chart (from information held by Bolton Business School and used by the author of this unit with permission)

In effect, we can say that any work which has been fettled will be ready for shipment in four weeks' time.

A cumulative delivery schedule is then drawn up. The cumulative delivery is plotted against the week number on the LOB chart (Figure 18).

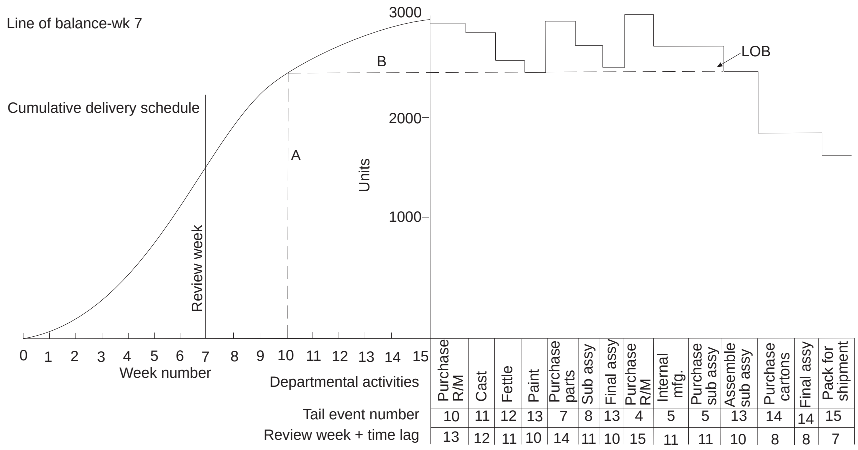


Figure 18: LOB chart for week 7 (from information held by Bolton Business School and used by the author of this unit with permission)

Consider the LOB chart for week 7 (Figure 18). The schedule demands a cumulative output of 1,700 units. The finished units produced in week 7 would have passed through the painting department in week 4. The logic diagram shows that it takes a further 3 weeks to complete the vacuum cleaner after painting. At the end of week 7 any finished units in the painting department should be ready for shipment at the end of week 10. The production level of each department can be determined.

Enter the review week on the chart. Consider week 7, and add for each department separately the number of weeks by which that department is lagging behind the finished product.

For each department erect a perpendicular (A) corresponding to that department's relative time-lag. The level at which the perpendicular meets the curve will indicate the planned cumulative level of that department, and it is recorded by drawing a horizontal line (B). This has been shown for the painting department.

Thus, a line of balance has been determined for all departments for week 7.

Enter in the actual units in each department by drawing bar charts. The number of units over the LOB is the extent of over-production. Any less is under-production. Computer programs are available for LOB. Once set up they can be easily manipulated to control production effectively. The table, over page, is what a sample print out might look like.

Departmental Activity	LOB	Actual	Difference	Action
Purchase R/M	2900	3000	+100	Inform mgr
Cast	2800	2800	–	–
Fettle	2700	2600	–100	Inform mgr
Paint	2500	2200	–300	Inform mgr
Purchase parts	2950	3000	+50	Inform mgr
Sub-assy	2700	2700	–	–
Final assy	2500	2500	–	–
Purchase R/M	3000	3000	–	–
Internal mfg	2700	2700	–	–
Purchase sub-assy	2700	3000	+300	Inform mgr
Assembly sub-assy	2500	2500	–	–
Purchase cartons	2000	2500	+500	Inform mgr
Final assy	2500	2500	–	–
Pack for shipment	1700	1700	–	–

Summary

In this section, we discussed line of balance, a technique particularly suited to the scheduling and control of projects which are made in either fluctuating or repetitive batches. We looked in particular at the development and construction of LOB charts.

Unit Review Activity

Answer the following questions:

1 Detail the three factors which need to be balanced when planning a project.

2 List some of the reasons why projects are increasingly being handled using network planning techniques.

3 List the basic steps discernible in project planning.

4 Describe the three symbols used in critical path method.

5 How are activity times determined?

6 What are the three measures of float and how is each calculated?

7 How can a Gantt chart which highlights slippage on agreed stage dates be used for a project progress meeting?

8 What are precedence diagrams?

9 List some of the reasons why projects fail, either entirely or in part.

10 Detail some of the features you would look for when purchasing a computer network planning package.

Unit Summary

In this unit we examined the logic principles underpinning the techniques used in project management and emphasised the use of the network planning approach for the effective control of resources during the planning and execution phases of projects. We examined the role of operations managers, and the importance of operational management techniques was discussed in relation to cost/time aspects of a project.

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Answers to Unit Review Activity

1 Quality, time and cost. It is vital to identify customer expectations early in the process to draw up the terms of reference and contractual obligations. A high quality specification will require more resourcing time and cost.

2 Here are five major reasons:

- work effort is co-ordinated across functional areas
- a single comprehensive plan can be produced
- optimal resource utilisation is targeted
- an agreed completion date is established
- sophisticated scheduling and progress monitoring is possible.

3 You should have included:

- define the project
- determine the essential activities and their times
- build the network model
- use the model to optimise resource usage
- produce a master plan with scheduled dates
- monitor progress, make changes to meet deadlines.

4 Activities are drawn as ——————► and require resources.

Events are shown as ○ . They do not use resources, and separate activities.

Dummy activities are logic devices to show linkages and take no resources. They are drawn as –·–·–·–·►

5 Activity times are determined by analysis, measurement and discussion.

Past records, estimates and synthetic data may be available.

Work measurement may be required.

Comparative or analytical estimating can be used.

PERT three-time estimating may be advisable.

6 **Total float**: is the longest possible time in which an activity which is not on the critical path can be completed.

TF = Latest finish time – Earliest start time – Activity duration

Free float: is used to run a project on an earliest possible time basis even with activities which do not lie on the critical path.

FF = Earliest finish time – Earliest start time – Activity duration

Independent float: is used to calculate slippage on non-critical activities when an earliest time plan is in operation.

IF = Earliest finish time – Latest start time – Activity duration.

7 Construction of a Gantt chart, by hand or from computer sources, will identify activities which are running behind (or ahead of) schedule. Decisions can be made about their significance and the technique of crashing is used, where appropriate, to recover lost time. Extra resources or new methods can be employed to advantage.

8 Precedence diagrams identify the sequence of occurrence of activities. They are widely used to undertake efficient balancing of work stations on a product assembly line to minimise time loss. A circle is used to denote an activity. Arrows are linkages.

9 You may have included these five reasons:

- lack of support from senior managers
- inaccurate activity time estimations
- poor project control
- unforeseen factors, for example, severe weather
- too many fragmented changes during the project.

10 You may have included these features:

- able to handle an adequate number of activities
- user-friendliness
- choice of CPM and precedence diagram modelling
- reasonable cost
- able to produce management reports and charts.