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The Handbook of Project-Based Management
Improving the Process for Achieving Strategic Objectives
McGraw-Hill Companies, London, 1999:201-228
ISBN 0-07-709161-2

# 9 Managing time

## 9.1 Introduction

Let us now discuss the last of the five functions, managing time, by which the project manager coordinates the efforts of those involved, delivers the facility to meet market opportunities, and so ensures revenues are derived at a time which gives a satisfactory return on investment. All three of these purposes for managing time imply it is a soft constraint on most projects. Being late reduces the benefit; it does not cause the project to fail absolutely. There are only a few projects for which there is an absolute deadline. Project Giotto, the spacecraft which intercepted Halley's comet in 1986 was one: there was a very small time window in which to make the rendezvous, and if missed it would not reoccur for 76 years.[1] Another is the preparation for the Olympic Games. The start date is known six years in advance, to the nearest minute, and to miss the date would be very embarassing. Such projects are rare. Unfortunately many project managers treat time management as being synonymous with project management, and much of the project management software is written on this assumption.

In the next section, I consider the purpose of managing time, define the concepts and terminology of the time schedule, and introduce tools for communicating the schedule, including activity listings and bar charts. I describe how to calculate the duration of work elements, and how to use networks to calculate the overall project duration. I then show how to adjust the schedule by balancing resource requirements and resource availability, and end by describing the use of the schedule in controlling the duration of a project.

## 9.2 The time schedule

The time schedule is a series of dates against the work elements in the work breakdown structure, which record:

- when we forecast the work will occur
- when the work actually does occur.

### Purpose of the schedule

The purpose of recording these dates and times is:

- to ensure the benefits are obtained at a time scale that justifies the expenditure
- to coordinate the effort of resources
- to enable the resources to be made available when required
- to predict the levels of money and resources required at different times so that priorities can be assigned between projects
- to meet a rigid end date.

The first of these is the most important. It addresses the *raison d'être* of project management, achieving the overall purpose and mission. The second is the next most important as it enables the project to happen. The third and fourth are variations of this. It is the fifth item that gets most attention from project managers. They set a rigid end date, sometimes unnecessarily, and focus on this to the detriment of cost and quality. Indeed, part of the aims of managing the time is to optimize the cost and returns from the project. Figure 9.1 shows that the cost is made up of two elements:

- a work-dependent element; 100 man-days is the same whether 5 people take 20 days or 2 people take 50 days
- a time-dependent element; the project manager's salary for instance.

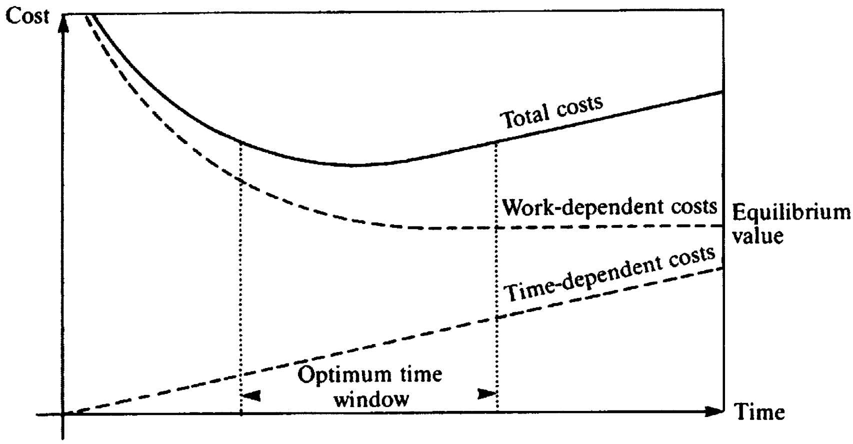


**Figure 9.1** Timing of minimum cost of a project

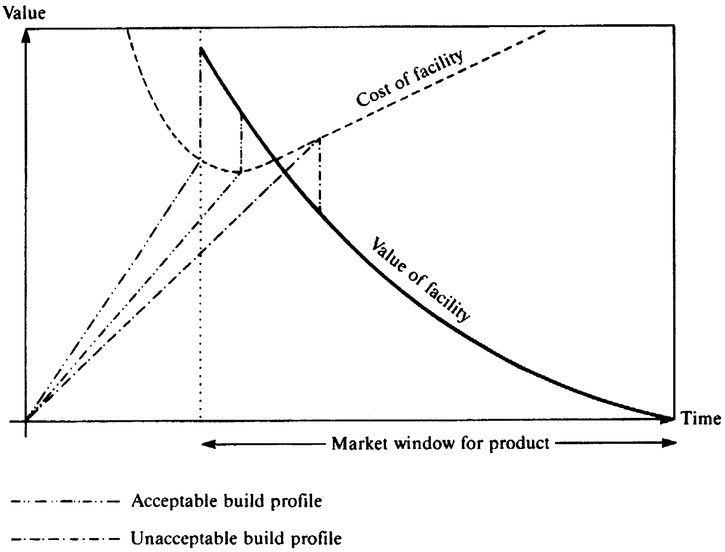


**Figure 9.2** Timing of optimum return from a project

However, the work-dependent element does actually increase as you try to shorten the project, and people interfere with each other, 10 people taking 12 days, and 20 people 8, perhaps. Adding the two together gives an optimum time window for the project in which cost is minimized. Figure 9.2 shows that maximum returns may not correspond to minimum cost. The value of the facility may decay with time, because of limited market window, and so on and hence highest profit may be made at a time earlier than minimum cost. Through the time schedule we must optimize cost and benefit.

## The schedule

On a simple level, the schedule records the planned and actual start date, finish date and duration of each work element. We may also record whether there is any flexibility in when each element may start without delaying the completion of the project. This is called the *float*. Sophisticated schedules record up to five versions of each of the start date, finish date, duration, and float; the early, late, baseline, scheduled and actual dates.

### THE DURATION

This is the time to do the work. It is common to treat a work element's duration as an immutable figure. For some, it is dependent on external factors beyond the control of the team. For others, it is a variable, which can be changed by varying the number of people working on the activity.

Methods of estimating durations are described in the next section and of balancing durations and resource levels in Section 9.5. For now we will assume they are fixed. Therefore, before work starts we have for each activity an estimated duration. Once work starts, but before it finishes, we can estimate a remaining duration. This may be equal to the planned duration less the time since the activity started, or we may re-estimate remaining duration based on the knowledge gained from doing the work so far. Once work is complete we can record an actual duration. It is useful to record actuals because a comparison of planned and actual figures may indicate trends which may be useful in the control process.

### EARLY AND LATE DATES

These can be forecast from estimated duration of all the activities. In Chapter 5, it was stated that the start or finish of an activity may be dependent on finishing other work. Therefore there is an earliest date by which a work element may start. This is known as the *early start date*. The early start date plus the estimated duration is the *early finish date*, the earliest date by which the work can finish. Similarly, other work may be dependent on the element's being finished, so there is a latest date by which it can finish and not delay completion of the project. This is known as the *late finish date*, and correspondingly the late start date is this less the estimated duration. If the late start date is different to the early start date, there is flexibility about when the element can start, the *float*:

Float = Late start date − Early start date.

If the duration is immutable, the difference between early and late start and early and late finish is the same, (and indeed this is the assumption made in most scheduling systems). However, it is not too difficult to imagine situations in which the duration is dependent on the time of year the work is done.

A work element with zero float is said to be critical, its duration determines the project's duration. If a project is scheduled with minimum duration, then running through it will be a series of work elements with zero float. This series is known as the *critical path*. Work elements with a large float are known as *bulk work*. They are used to smooth forecast resource usage, by filling gaps in the demands made by the critical path. There are also work elements with a very small float. These are *near critical*, and should receive as much attention as the critical path. In Section 9.4, CPM (critical path method) networks are described, which are mathematical tools for calculating early and late start and finish and float.

### PLANNED, BASELINED AND SCHEDULE DATES

These are dates between the early and late dates when we choose to do the work. These are *planned dates*. However, the date we planned to do a work element at the start of the project may be different to our current plan. It is important to record the original plan, because that is the measure against which we control time. This original measure is commonly known as the *baseline date*, and the current plan as the *scheduled date*. If the baseline start is later than the early start, then the planned or baseline float will be less than the available float. Likewise, as a project progresses, if the start or finish of a work element is further delayed, then the remaining float will be less than the original float.

THE TOTAL SCHEDULE

Hence in a full scheduling system, there are up to 15 dates and times associated with a work element (Example 9.1). The process of scheduling the project is the assignment of values to these dates and times. The first step is to estimate the duration and the second is to assign start and finish dates. This is usually done by calculating the early start and late finish dates and then assigning baseline dates somewhere between these, after taking account of other factors such as resource smoothing. It is sometimes necessary to assign a finish date after the late finish and thereby delay the project. If the logic is correct it will be impossible to schedule the start before the early start.

| | | |
|---|---|---|
| Early start | Duration | Early finish |
| Late start | Float | Late finish |
| Baseline start | Baseline float | Baseline finish |
| Schedule start | Remaining float | Schedule finish |
| Actual start | Remaining duration | Actual finish |

where:

Planned duration = Planned finish − Planned start;
Planned float = Late finish − Planned finish.

**Example 9.1** Scheduled dates associated with a work element

For some projects with a well-constructed WBS, it is possible to schedule the project manually, by nesting the schedule at lower levels within that at higher levels. To be able to do this it must be possible to break the project into discrete work areas and work packages, with few logical links between them and little sharing of resources. The four large multi-disciplinary projects described in Section 5.7 were four such projects. In the Regional Health Authority warehouse and the Norwegian Security Centre projects, the project managers positively resisted computer systems because they felt they retained greater visibility without them. Where there are complex interdependencies and multiple shared resources, it may be necessary to use computer-aided support tools.

The processes of estimating durations and calculating and assigning dates, including the use of computer-aided network planning systems will be described in the next sections. However, first it is appropriate to describe tools by which the schedule is communicated.

## Communicating the schedule

There are two accepted ways of communicating a project's schedule:

### ACTIVITY LISTING WITH DATES

This is a list of some of the work elements at a given level of the WBS, with some or all of the dates and times above listed beside them. This method of communicating the schedule can give a comprehensive checklist, but is not very visible. Figure 9.3 is an activity listing for a simple project to erect a statue by early start/early finish. Although this list shows the float, I believe it should not be shown as it tends to be consumed.

### BAR CHARTS

The schedule can be more visibly represented by the use of bar charts (sometimes called Gantt charts, after Henry Gantt who pioneered their use). Figure 9.4(a) is a simple bar chart for the project in Figure 9.3. Figure 9.4(b) is the same bar chart with the float shown. It is also possible to show the logic in a bar chart (Figure 9.4(c)).

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**ACTIVITY LISTING**

**PROJECT NAME: ERECT STATUE**

| Activity No | Name | Duration (days) | Early start (day) | Early finish (day) | Float (days) |
|---|---|---|---|---|---|
| A | Grade site | 3 | 0 | 3 | 0 |
| B | Cast plinth | 2 | 3 | 5 | 0 |
| C | Plant grass | 3 | 3 | 6 | 1 |
| D | Set concrete | 2 | 5 | 7 | 0 |
| E | Place statue | 1 | 7 | 8 | 0 |

**Figure 9.3** Activity listing

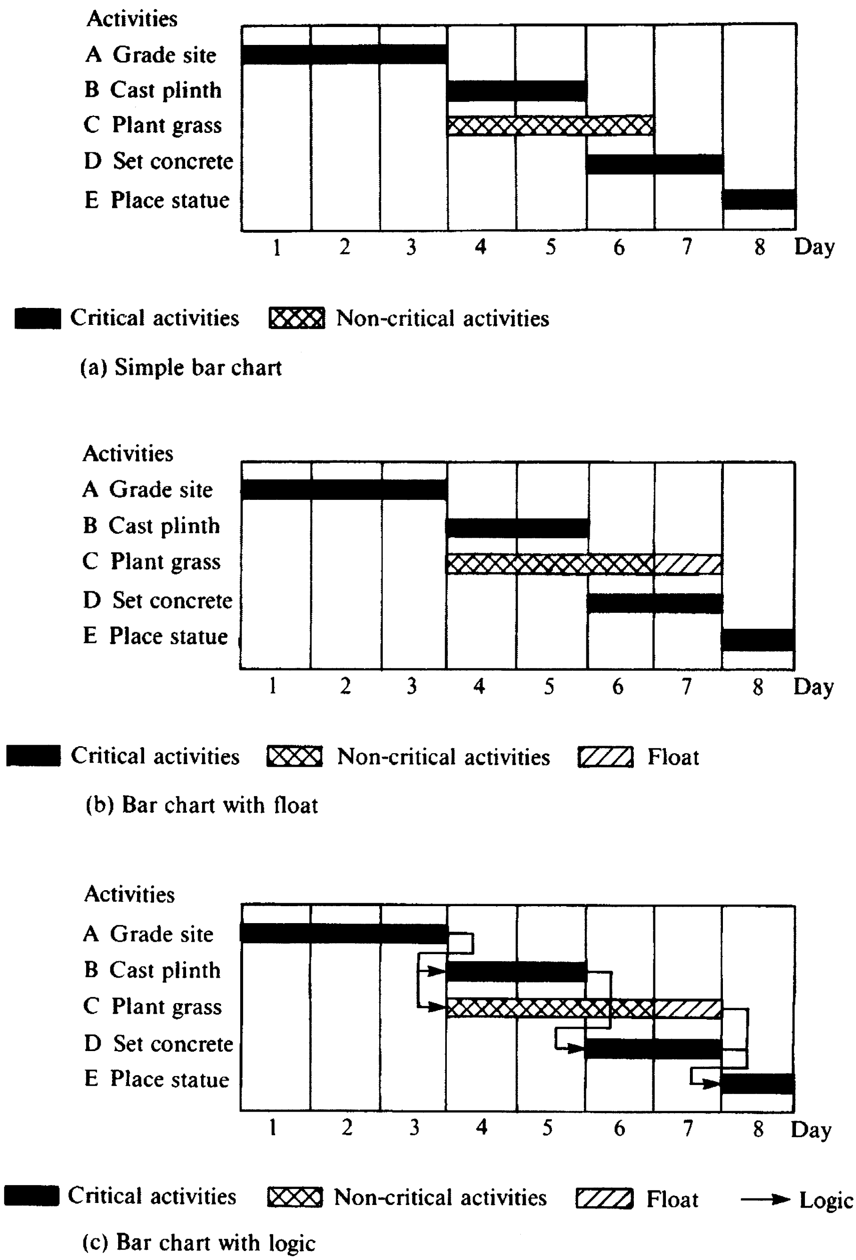


**Figure 9.4** Bar charts for the activity listing in Figure 9.3

## 9.3 Estimating durations

The duration of work elements is central to the scheduling process, not only in relating the start and finish of a given work element, but in calculating its earliest start from the cumulative duration of the preceding activities, and the latest finish from the cumulative duration of the succeeding activities. The duration of a work element is dependent on one of three things:

- the amount of time it physically takes to do the work involved, which in turn is dependent on the number of people available to do it
- the lead time, or waiting time, for the delivery of some item, which is independent of the number of people doing the work
- some mixture of the two.

### Duration dependent on work content

It is often assumed the duration of a work element depends on the amount of work to do and the number of people available to do it. Nominally:

$$\text{Duration (days)} = \frac{\text{Work content (man-days)}}{\text{Number of people available}}$$

I described the role of work content in negotiating the contract between project manager and resource providers in Chapter 6 and how to estimate it as a labour cost in Chapter 8. It is always necessary to add allowances to this raw estimate of duration, to calculate the actual duration. These allowances are to account for various factors, which include:

LOST TIME

Somebody nominally working full time on a project is not available 5 days per week, 52 weeks per year. They lose time through holidays, public holidays, sickness, training, group meetings, etc. It was suggested in Section 6.5 that for the average project worker these consume 80 days per year; somebody assigned full time to a project does on average 180 days of project work a year, equivalent to 70 per cent availability. To allow for this 40 per cent is added to the nominal duration (1.4 = 1.0/0.7). A smaller ratio will be added if the project's resource calendar allows for some lost time.

PART-TIME WORKING

Individuals may be assigned to a project part time. Therefore the number of people should be based on the number of full-time equivalents (FTE). However, you must be careful not to double account. If somebody is assigned two days per week to a project (40 per cent), you must be clear whether those two days include or exclude a proportion of the lost time above before adding the 40 per cent allowance.

INTERFERENCE

Doubling the number of workers does not always halve the duration, because people doing work can restrict each other's access to the work face, and so reduce their effectiveness. For instance, if the task requires access to a limited space with room for just one person, adding a second person will not double the rate of working. Two will work faster than one, because they can step each other off, but only one can work at a time. Adding a third person will not increase the rate of working, and may even reduce it by distracting the other two. A third person would be most effectively used to extend the working day through a shift system.

COMMUNICATION

Where more than one person works on a job, they need to communicate details of the work to each other to make progress. This is especially true of engineering design and writing software. With two people there is just one communication channel, so they may work almost twice as fast as one. With three people there are three channels, with four people six, and as the number of people grow, the channels grow exponentially. Hence, you reach a point where adding another person in fact reduces the amount of effective work (Example 9.2). The way to overcome this is to find ways of reducing the channels of communication, by using a central administrator or Project Support Office (Chapter 14). In the office in Example 9.2, the pool was split into four pools of three secretaries. It is commonly believed that in a professional office, three is the optimum team size, balancing the additional motivation from working in a team, with the added levels of communication.

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In an office in which I worked, there were three managers each with a secretary. As the office grew, and new managers joined, the numbers of secretaries grew, until there were about twelve working in the same pool. We reached a point where adding a new secretary seemed to make no difference to the amount of work done in the pool. If we assume a new secretary spends a quarter of an hour each day talking to each of the others, (not an unreasonable amount of time for social interaction), then each conversation consumes half an hour's work, and since she has twelve conversations, six hours are lost, equal to the effective working day.

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**Example 9.2** Communication consumes time

ESTIMATING DURATIONS

Hence the estimate of duration for a work element is based on the formula above, but adjusted taking account of all the factors discussed, which may indeed dominate. This reinforces the fact that project management is not a mathematical exercise, but much more of a social science one.

### Duration dependent on lead time

For some work elements the duration depends on the lead time or waiting time to obtain some item of material or information or to wait for some change to take place. This may include:

- delivery time for materials in procurement activities
- preparation of reports
- negotiations with clients or contractors
- obtaining planning permission or financial approval
- setting of concrete or watching the grass grow.

In these cases the likely duration will be known from historical data or the known cycle of events.

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The work package, *05: Redeployment and Training*, from the CRMO Rationalization Project, may consist of the following activities:

- identify training needs of staff
- develop training material
- conduct courses
- transfer staff to new posts.

The first two of these are work-content dependent. The number of trainers assigned will depend on the number of people requiring training and the amount of material to be developed. However, two people will not work twice as fast as one because they will need to keep each other informed of progress. The duration of the third activity depends on the availability of the training facilities, and the fourth on how quickly people can be assimilated into new work environments.

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**Example 9.3** A work package from the CRMO Rationalization Project containing activities of mixed type

### Duration dependent on work content and lead time

In some instances a work element contains lower level activities, some of which are work-content dependent and some lead-time dependent (Example 9.3). The duration of the work package must be calculated from the duration of each of the activities and their logical dependence, perhaps using the networking techniques described in the next section in more complex cases. (If you are adopting a rolling-wave approach to planning, at the start of the project you will estimate the duration of the work package as a whole working from a work-package scope statement and making use of previous experience, and only do the more detailed analysis when you are about to start the work.)

### Estimating sheets

The estimating sheet (Figure 6.12) was introduced as a tool for estimating work content. The same sheet can be used for estimating durations (Figure 9.5). Example 9.4 provides a rationale.

1. The person with the most work to do is the project control officer, with 24 man-days.
2. Therefore the duration of the work package will be determined by their availability.
3. It is assumed that during Project Definition control officer will not take holiday. Therefore his or her availability will be greater than the average 70 per cent. A figure of 80 per cent is assumed.
4. The duration is therefore 30 (24/0.8) days.

**Example 9.4** Rationale for the duration of the work package *P1: Project Definition*

## 9.4 Calculating the schedule with networks

Having estimated duration, we assign dates to work elements. In the distant past, that was done manually using bar charts (Section 9.2). With the increasing size and complexity of projects this became more difficult, until computer-aided tools were introduced in the 1950s. Since then, these have grown in power. The mathematical technique on which they are based is the critical path method (CPM), sometimes called critical path analysis (CPA), or the programme evaluation and review technique (PERT). The initials CPM, CPA and PERT are used interchangeably by many people, although they do mean something slightly different. Networks are a mathematical technique used to calculate the schedule. They are seldom useful for communicating the schedule. Bar charts or activity listings (Section 9.2) are best used for that. Networks will only be used where the project is too complex to be scheduled manually through the WBS and so will only be used in conjunction with computer-aided systems. In this section I describe the mathematical technique of networking. Computer-aided project management information systems (PMIS) are described in Chapter 15.

### Types of network

There are three types of network:

PRECEDENCE NETWORKS

In precedence networks, work elements are represented by boxes, linked by logical dependencies, which show that one element follows another. Figure

| ESTIMATING SHEET | | TRIMAGI COMMUNICATIONS BV | | | 02-Jan-9X |
|---|---|---|---|---|---|
| PROJECT: | CRMO Rationalization | CODE: | C1 | ISSUE: | A |
| WORK AREA: | Project | CODE: | C1P | AUTHOR: | LJN |
| WORK PACKAGE: | Project Definition | CODE: | C1P1 | APPRVD: | JRT |
| ACTIVITY: | ........................................ | CODE: | .................. | DATE: | 02-Jan-9X |

| ACTIVITY/TASK | | WORK CONTENT | | | RESOURCES | | | | | 9 People |
|---|---|---|---|---|---|---|---|---|---|---|
| | | No of steps | Effort/ step | Total effort | Prjct Mgr | Prjct Offc | CRMO TL | CRMO Mgrs | Ops Direct | Other Mgrs |
| Number | Description | | (days) | (days) | 1 | 1 | 1 | 2 | 1 | 3 |
| 1 | Produce project proposal | 1 | 4 | 4 | 1 | 2 | 1 | | | |
| 2 | Hold project definition workshop | 1 | 4 | 4 | 1 | 1 | 1 | | 1 | |
| 3 | Define required benefits | 1 | 2 | 2 | 1 | | 1 | | | |
| 4 | Draft Project Definition Report | 1 | 8 | 8 | 2 | 6 | | | | |
| 5 | Hold project launch workshop, 1.5 day duration | 1 | 12 | 12 | 1.5 | 1.5 | 1.5 | 3 | | 4.5 |
| 6 | Finalize milestone plan | 1 | 2 | 2 | 1 | 1 | | | | |
| 7 | Finalize project responsibility chart | 1 | 2 | 2 | 1 | 1 | | | | |
| 8 | Prepare estimates - time | 20 | 0.1 | 2 | | 2 | | | | |
| 9 | Prepare estimates - cost | 20 | 0.1 | 2 | | 2 | | | | |
| 10 | Prepare estimates - revenue | 1 | 1 | 1 | | 1 | | | | |
| 11 | Assess project viability | 1 | 1 | 1 | 1 | | | | | |
| 12 | Assess risks | 1 | 3 | 3 | 1 | 1 | 1 | | | |
| 13 | Finalize Project Definition Report | 1 | 5 | 5 | 2 | 3 | | | | |
| 14 | Mobilize team | 1 | 3 | 3 | 0.5 | 0.5 | 0.5 | | | 1.5 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | SUB-TOTAL: | 51 | 13 | 22 | 6 | 3 | 1 | 6 |
| TOTAL EFFORT: 56 DAYS | | | | | | | | |
| TOTAL COST: £K 22.22 | ALLOWANCE % | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| DURATION: 30 DAYS | | | | | | | | |
| TARGET START: 01-Feb-9X | TOTAL EFFORT: | 56 | 14 | 24 | 7 | 3 | 1 | 7 |
| TARGET FINISH: 15-Mar-9X | | | | | | | | |
| | UNIT RATE: | £K/day | 0.5 | 0.3 | 0.3 | 0.5 | 0.8 | 0.5 |
| | COST: | £K | 7.15 | 7.26 | 1.98 | 1.65 | 0.88 | 3.30 |

**Figure 9.5** Estimating sheet with durations entered for the milestone *P1: Project Definition* from the CRMO Rationalization Project

9.6 is a simple precedence network with four activities A, B, C and D. B and C follow A and D follows B and C. Four types of logical dependency are allowed (Figure 9.7):

- *end-to-start*: B cannot start until A is finished
- *end-to-end*: D cannot finish until C is finished
- *start to-start*: D cannot start until C has started
- *start-to-end*: F cannot end until E has started.

End-to-start dependency is usually used (a hangover from IJ networks). End-to-end and start-to-start dependencies are the most natural and allow overlap of succeeding work elements in time. It is not uncommon to build ladders of activities like C and D. It is the use of end-to-end and start-to-start dependencies which allows fast track or fast build construction (Section 4.4). Start-to-end are only defined for mathematical completeness. I have never come across a case where it might be used. I will introduce later leads and lags on dependencies. It is now increasingly common to use only end-to-start dependencies, and use leads to overlap

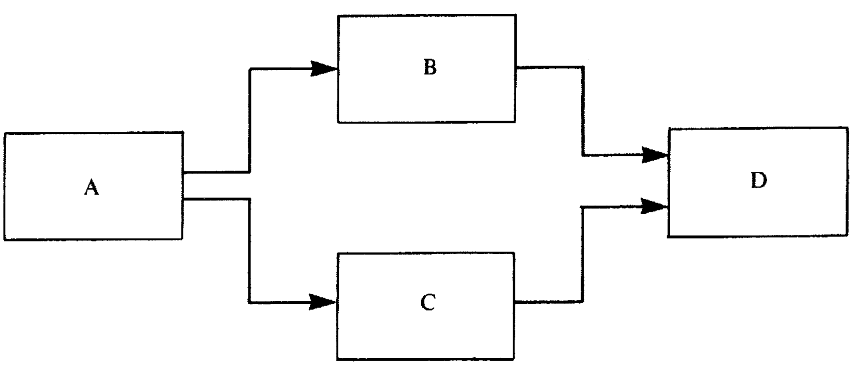


**Figure 9.6** A simple precedence network

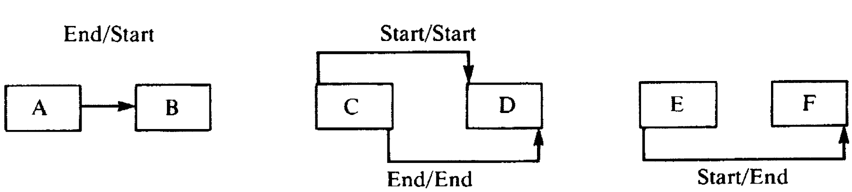


**Figure 9.7** Four types of logical dependency

activities. This greatly simplifies the network, and is to be recommended for that reason.

The milestone plan (Section 5.5) is a precedence network. The circles, (nodes), represent the work. The lines are end-to-end dependencies, linking the milestones.

ACTIVITY-ON-ARROW NETWORKS

These are often called IJ networks, because each activity is defined by an IJ (start/finish) number. In this type of network a work element is represented by an arrow between two nodes. The activity is known by the number of the two nodes it links. Figure 9.8 is Figure 9.6 drawn as an IJ network. Activity A becomes 1–2, etc. Because activities must be uniquely defined two cannot link the same two nodes. Therefore B and C finish in nodes 3 and 4 respectively and these nodes are linked by a dummy activity. Because activities are linked through nodes, end-to-start logic is imposed. However, it is possible to introduce dummy activities to represent the other three logical links.

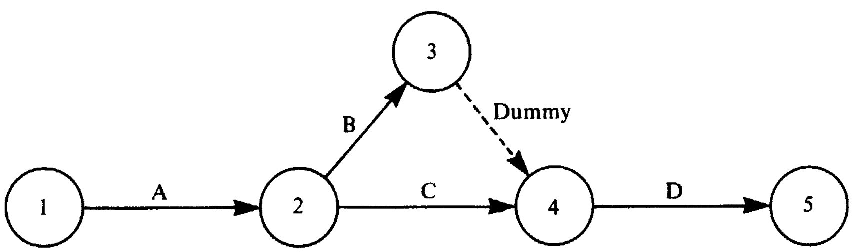


**Figure 9.8** Activity-on-arrow network

HYBRID NETWORKS

These mix the two previous types. Work is represented by either a box (node) or a line (arrow). Furthermore there may be boxes and lines which do not represent work, just events in time and logical dependency. A line need not join a box at its start or finish, but at any time before, during or after its duration. In advanced hybrid networks, even the distinction between nodes and lines disappears. The mathematics of hybrid networks is fairly new so they will not be discussed further.

PRECEDENCE VS ACTIVITY-ON-ARROW NETWORKS

You will find some people fervently committed to one or the other. The early work in the 1950s was done with arrow networks, whereas precedence networks were not introduced until the 1960s. Therefore arrow networks tend to be the more widely used. However, precedence networks are gaining wider preference with practising project managers. There are several reasons for this:

1. It is more natural to associate work with a box.
2. It is more flexible for drawing networks. All the boxes can be drawn on a page and the logical dependencies put in later. In Section 6.5, I described how to develop a precedence network (milestone plan) by moving Post-It notes around a flip chart or white board. The same is not possible with an activity network because the activities are only defined by two nodes and that imposes logic.
3. It is easier to write network software for precedence networks. Most modern software is precedence only or both. That which is both has an algorithm to convert from precedence to IJ.
4. It is easier to draw a bar chart showing precedence logic with the bars representing the activity boxes and vertical lines showing the logical dependencies (Figure 9.4(c)). With an arrow network either more than one activity must be drawn on a line or dummies must be used to show logic, which virtually gives a precedence network. (This last statement reintroduces hybrid networks, and shows that the distinction between precedence and IJ networks really is slight.)
5. The work exists independently of the logic, and so you can draw a work breakdown structure and overlay the logic later. If you use the C/SCSC methodology and the approach described in this book, where you define the work of the project first, then you are almost forced to use precedence networks. (People who use IJ networks have to draw the network before developing the work breakdown structure.) For this reason precedence networks are treated more fully here.

**Networking technique**

All networks do is to calculate the early start and finish, the late start and finish and the float of work elements in a project given their duration and logical dependency. The reason this is so powerful is it allows you to explore many different options, called conducting a *what-if* analysis, assuming different durations and logical dependencies of the work elements. As I introduce networking technique, I will illustrate it by scheduling a simple project, represented by the network in Figure 9.6. An activity listing for the network is given in Figure 9.9. This is modified Figure 9.3 and you will see shortly that the activity, 'set concrete' has been replaced by a lag on the logical dependency from B to D.

NOTATION

In a precedence network, each work element is represented by a box with seven segments (Figure 9.10). The top three segments contain the early start, duration and early finish respectively. The bottom three contain the late start, float and late finish. The central one contains a description of the activity. Figure 9.11 is Figure 9.6 with durations entered. In an arrow network the node has four segments, the identifier, the early and late time and the float. The time is the start of the succeeding activity and the finish

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**ACTIVITY LISTING**

**PROJECT NAME: ERECT STATUE**

| Activity No | Description | Duration (days) | Preceding activities | Lead/Lag (days) |
|---|---|---|---|---|
| A | Grade site | 3 | — | 0 |
| B | Cast plinth | 2 | A | −2 |
| C | Plant grass | 3 | A | 0 |
| D | Place statue on plinth | 1 | B, C | +2,0 |

**Figure 9.9** Activity listing for a project to erect a statue

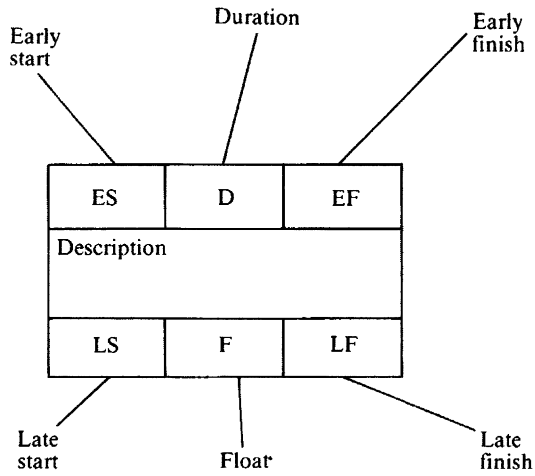



**Figure 9.10** Activity in a precedence network

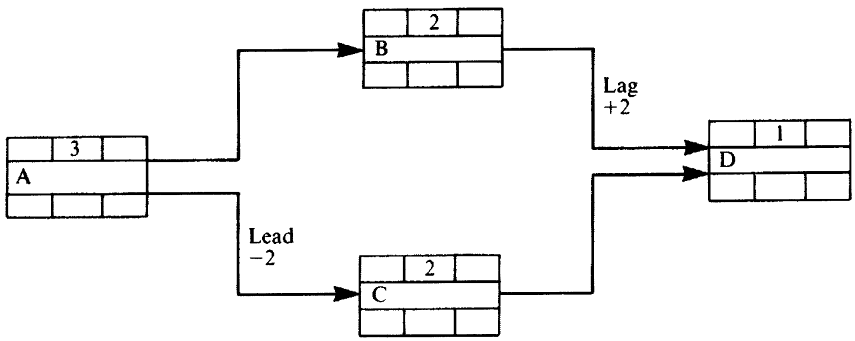



**Figure 9.11** Precedence network: durations entered

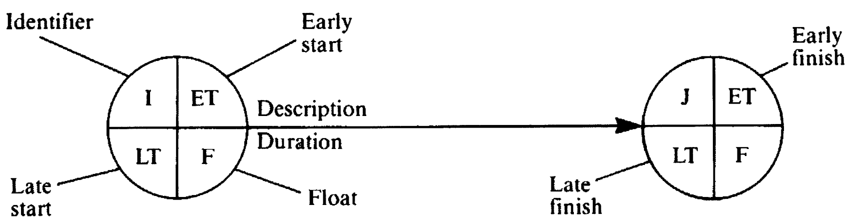



**Figure 9.12** Activity in an IJ network

of the preceding activity. The duration is still associated with the activity (Figure 9.12).

LEADS AND LAGS

The dependencies connecting the activities in a precedence network usually have zero duration. However, they can be given positive or negative duration, and this is called *lag* or *lead* respectively. In Figure 9.9 the concrete must be left for two days to dry before erecting the statue. These two days can either be added to the duration of B (taking it to 4 days) or shown as a lag on the dependency. Similarly it might be possible to start planting grass on the second day after the first third of the site has been graded. This can be shown as a start-to-start dependency with a lag of 1 or a finish-to-start with a lead of −2. The latter is chosen. The leads and lags are also shown in Figure 9.11.

FORWARD PASS

Early start and finish are calculated by conducting a *forward pass* through the network. The early start of the first activity is zero and the early finish is calculated by adding the duration. The early finish is transferred to subsequent activities as the early start, adding or subtracting any lead or lag, assuming a finish-to-start dependency. For a start-to-start dependency it is the start time which is transferred to the start, for a finish-to-finish dependency the finish time is transferred to the finish, and for a start-to-finish the start time is transferred to the finish. Where an activity has two or more preceding activities the largest number is transferred. The process is repeated throughout the network. Figure 9.13 shows the example network after a forward pass.

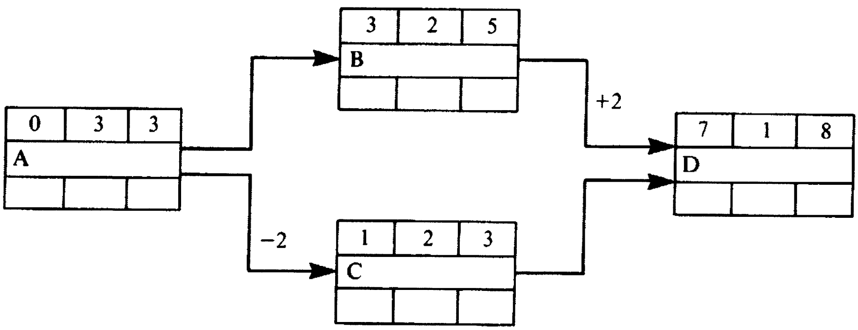



**Figure 9.13** Network after forward pass

BACK PASS

The late start and finish and float are calculated by conducting a *back pass*. The early finish of the last activity becomes its late finish. The duration is subtracted to calculate the late start. The late start is transferred back to the late finish of preceding activities. Again it is the start or finish time which is transferred to become the start or finish time depending on the type of dependency. Where an activity has two or more succeeding activities it is the smallest number which is transferred, (after adding lags or subtracting leads). The process is repeated throughout the network. The float of each activity is calculated (Section 9.2). (This should be the same for both start and finish.) The float of the first and last activities should be zero. Figure 9.14 shows the network after the back pass.

IDENTIFYING THE CRITICAL PATH

This is the series of activities with zero float, here A–B–D. Some text books suggest you find the critical path, not by conducting a forward and back pass, but by identifying every possible path and finding that with the longest duration. This works with small networks, but it does not take many activities before this becomes an impossible task. The method of forward and back

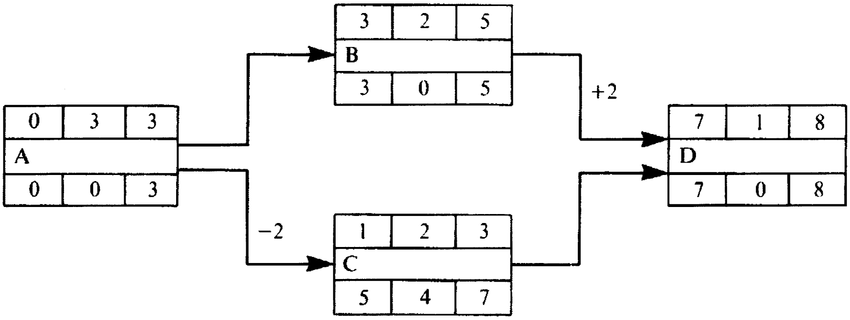



**Figure 9.14** Network after back pass

pass is designed to cope with networks of limitless size. Since you only need to use networking on large projects, it is the approach recommended.

ARROW NETWORKS

Figure 9.15 shows figure 9.14 drawn as an arrow network after forward and back pass.

CASE STUDY PROJECT

Figure 9.16 is the precedence network (at work-package level) for the CRMO Rationalization Project.

SOFTWARE PACKAGES

Some software packages assume that if an activity has a start date of day 6

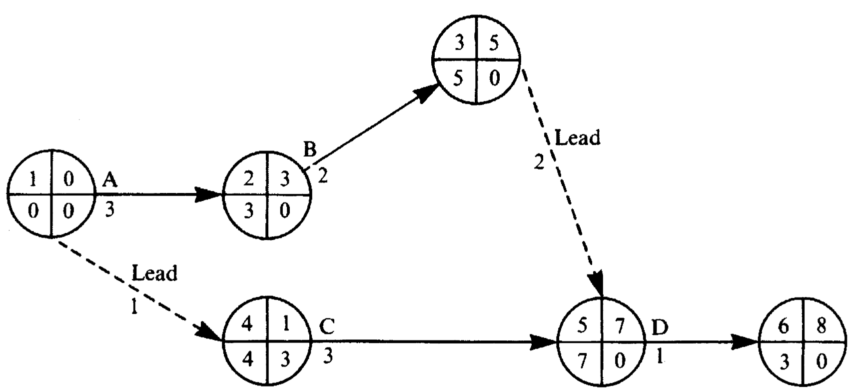
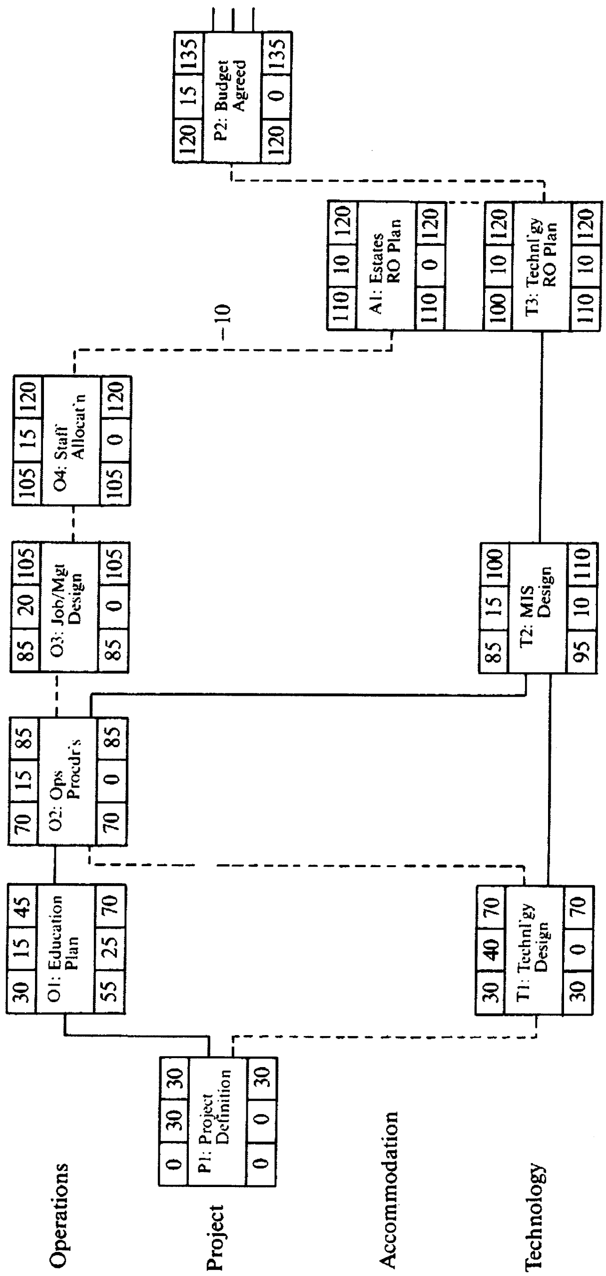



**Figure 9.15** Arrow network after forward and back pass


Operations
Project
Accommodation
Technology
P1: Project Definition
O1: Education Plan
O2: Ops Procdr's
O3: Job/Mgt Design
O4: Staff Allocat'n
A1: Estates RO Plan
T1: Technl'gy Design
T2: MIS Design
T3: Technl'gy RO Plan
P2: Budget Agreed
−10

(a)

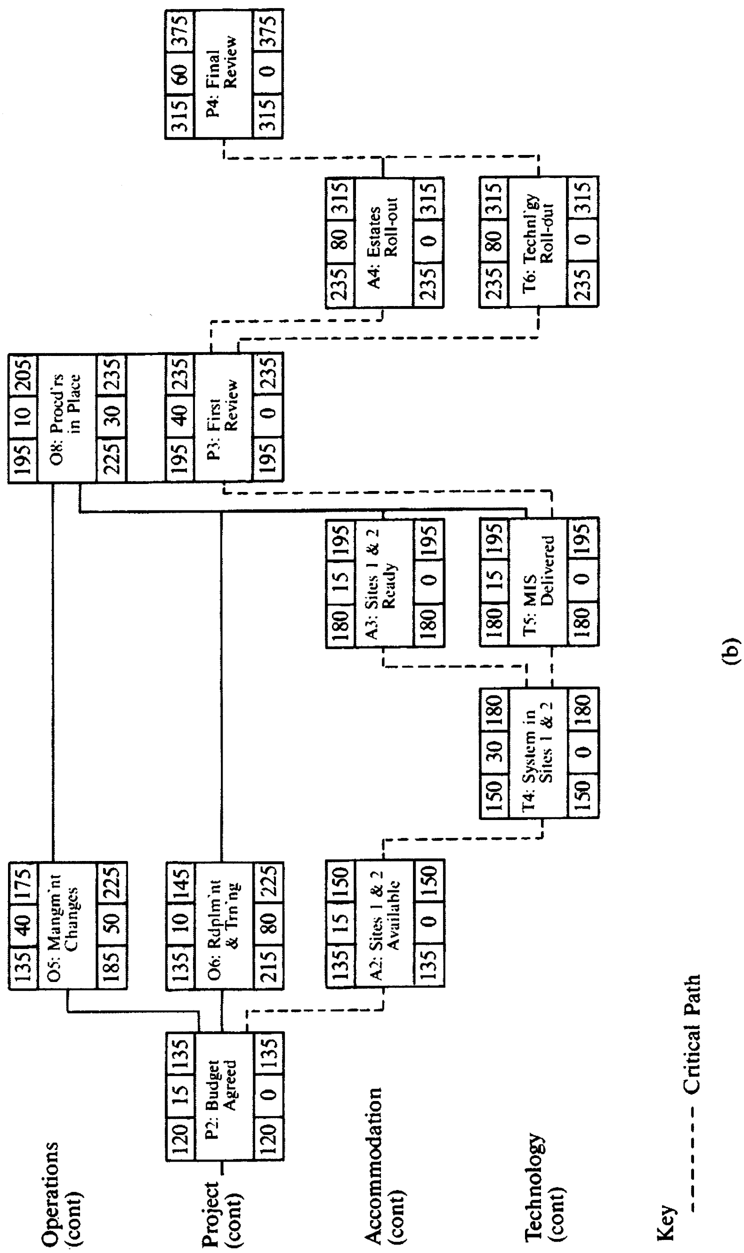



**Figure 9.16** Precedence network at work-package level for CRMO Rationalization Project

(Monday, say) and duration 3, then it will finish on Wednesday evening, day 8. Therefore the finish is:

$$\text{Finish date} = \text{Start date} + \text{Duration} - 1.$$

However, if there is no delay to the start of the next activity, it starts on Thursday morning, day 9. Therefore a day is added as the finish date is transferred to the start of the next activity. The start date of the first activity is taken as day 1, Monday morning, rather than zero as used above. The overall effect is just to add one to all the start dates you would obtain using the method proposed above.

### Scheduling the project

The network only calculates early and late dates. The baseline or scheduled dates must be chosen taking account of other factors. Hopefully they will be between the early and late dates. There are three options:

- *schedule by early start, (hard-left)*: used to motivate the workforce
- *schedule by late finish, (hard-right)*: used to present progress in the best light to the customer
- *schedule in between*: done either to smooth resource usage (Section 9.5) or to show management the most likely outcome.

### Using networks

Networks are a mathematical tool to be used as appropriate. This does not depend on the size of the project. In Section 5.6, I gave examples of multi-million pound projects where they were not used. It depends on the complexity of the interdependencies and resource sharing and the manager's ability to analyse these without computer support. As a mathematical tool, they help the manager calculate the schedule and analyse the impact of changes (what-if analysis). However, except as a milestone plan, networks should not be used to communicate the plan or schedule: bar charts should be used for that purpose.

## 9.5 Resource histograms and resource smoothing

Using a network, you can calculate the early and late start and finish for work elements. However, in order to set the baseline or scheduled dates, it is necessary to take account of other constraints. Resource constraints are the most common. If the resource requirements for all activities are known, once the project has been scheduled you can calculate a resource profile for the project as a whole. This is known as the resource schedule and is either listed as a table of resource levels with time or is drawn as a resource histogram. This resource schedule can be compared to the known availability of each type of resource, and if the requirement exceeds availability it may be necessary to adjust the schedule to reduce the requirement. It may be possible to do this by consuming some of the float on non-critical activities. Alternatively, it may be necessary to extend the duration of the project.

The method of calculating the duration of an activity was given in Section 9.3. Although no mention was made at the time, this calculation assumed either a constant or stepped resource usage during the activity. Figure 9.17 illustrates four possible resource profiles for an activity: constant, stepped, triangular and normal. Constant or stepped profiles are almost always used at the activity level, and indeed the errors introduced by these simplifying assumptions cancel out at the work package or project level. Using triangular or normal profiles is something which is quite easy with modern computer systems.

Figure 9.18 is an activity listing for a small project which I will use to illustrate the concept of resource scheduling. There are two resource types: analysts and programmers. Figure 9.19(a) shows the bar chart and resource histogram for both resource types with the project scheduled by early start. This produces quite wildly varying resource levels. If there were only one analyst available to the project, he or she would be overloaded during the first two months of the project. One person can work up to 22 days in a month without overtime. To overcome this problem we can try to use the float associated with some of the work elements to smooth the resource

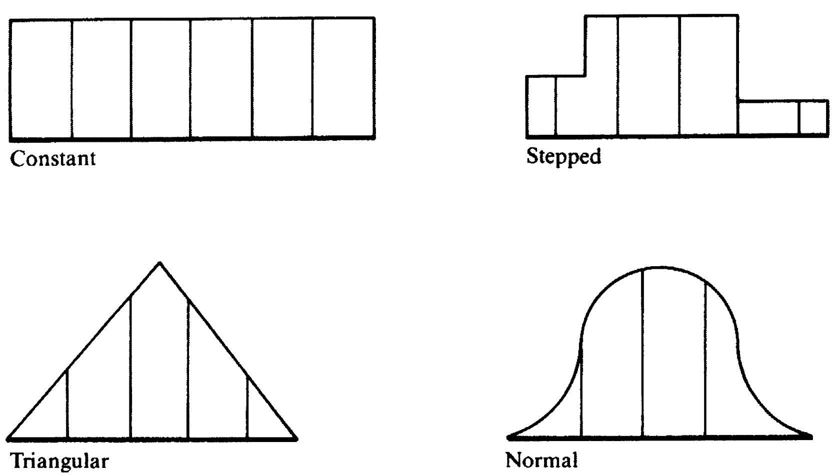



**Figure 9.17** Resource profile for an activity

**TRIMAGI COMMUNICATIONS BV**
**ACTIVITY LISTING**

**PROJECT NAME: CRMO RATIONALIZATION**
**WORK AREA: MIS DESIGN AND DELIVERY**

| Acty | Durn (mths) | Early start (mth) | Late start (mth) | Early finish (mth) | Late finish (mth) | Resource requirement Analyst (days) | Programmer (days) |
|---|---|---|---|---|---|---|---|
| A | 3 | 0 | 1 | 3 | 4 | 24 | — |
| B | 2 | 0 | 2 | 2 | 4 | 24 | — |
| C | 2 | 0 | 2 | 2 | 4 | 16 | 16 |
| D | 1 | 3 | 4 | 4 | 5 | — | 12 |
| E | 1 | 0 | 3 | 1 | 4 | — | 4 |
| F | 4 | 0 | 0 | 4 | 4 | 16 | — |
| G | 1 | 4 | 4 | 5 | 5 | 12 | 8 |
| H | 1 | 5 | 5 | 6 | 6 | 4 | 8 |

**Figure 9.18** Activity listing for an IT project

profiles. Figure 9.19(b) shows the bar chart and resource profiles for the project scheduled by late start. This is no better as the analyst is still overloaded, but now in months 3 and 4.

Concentrating on the analyst, Figure 9.19(c) shows a schedule which gives the least variability of the analyst's utilization, giving a maximum level of 24 days in month 3. This can be easily met by overtime. It also illustrates two further points:

- the danger of imposing a rigid resource constraint of 22 days which would delay the project
- the need to encourage the analyst to take his or her annual holiday in months 5 and 6 rather than months 1 to 3.

Alternatively you can take the programmer as priority. Figure 9.19(d) shows the schedule and resource profiles in that case. However, this overloads the analyst again.

## 9.6 Controlling time

Up to this point, I have explained how to calculate and communicate the schedule. I conclude by discussing how to use the schedule to control the project's duration, which is the primary purpose of setting the schedule. There are four steps in the control process, (Section 8.2):

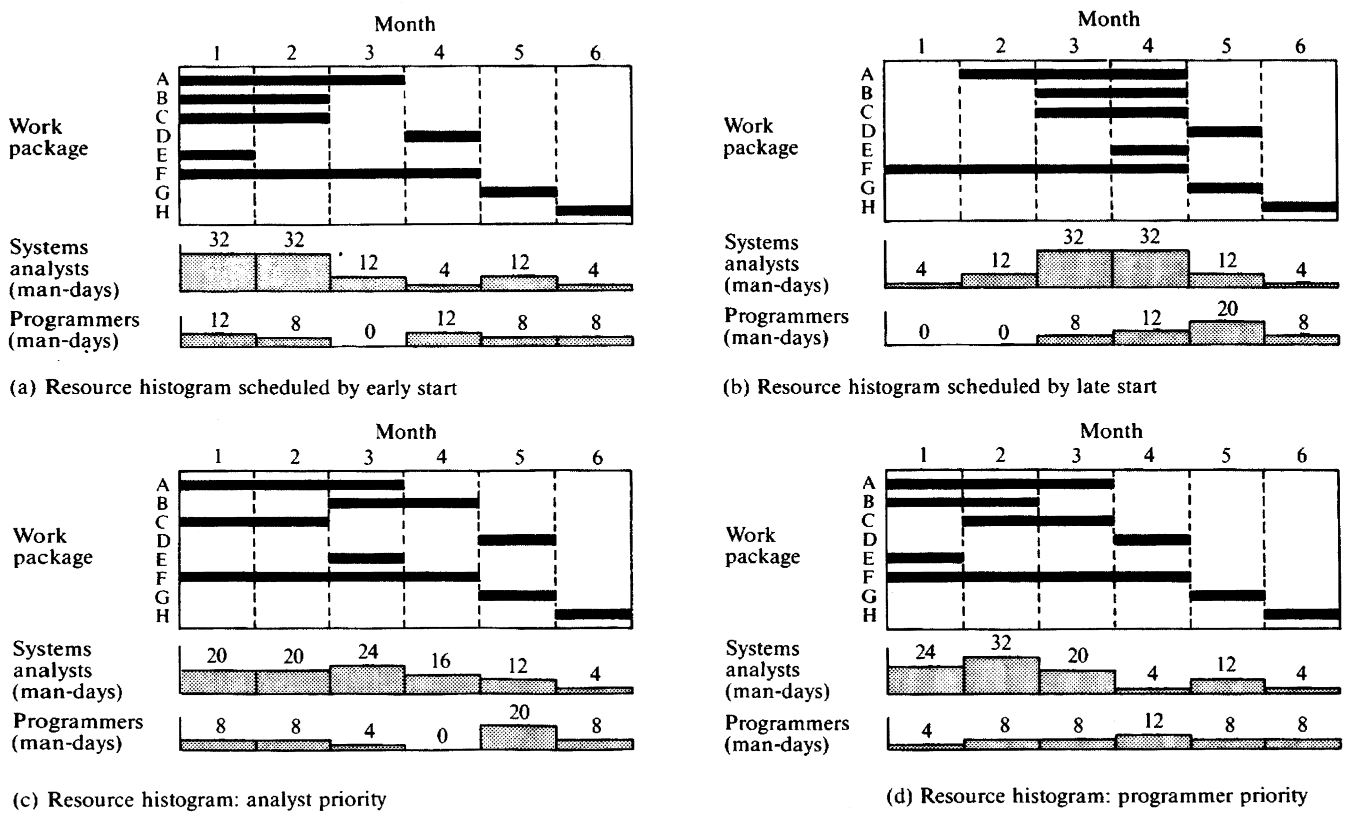



**Figure 9.19** Resource smoothing

– set a measure
– record progress
– calculate the variance
– take remedial action.

I describe for now only the first three of these, and the use of S-curves to produce a visual representation of progress. I leave the taking of remedial action to Chapter 12.

SET THE MEASURE

The planned, or baselined, dates set the measure for control of time. It is vital to measure progress against a fixed baseline. If you measure progress against the most recent update of the plan, you lose control. It is not uncommon to come across projects which are always on time because the schedule is updated at every review meeting, and people very quickly forget what the original schedule was; they can remember that the schedule has been updated, but not by how much.

RECORD PROGRESS

Progress is recorded by reporting actual start and finish dates. It is common to measure progress against start and finish dates only, as opposed to trying to assess percentage completion part way through a work element, at a level of the WBS and on a frequency to provide adequate control. Typically, on a project of a year's duration, progress is measured fortnightly against activities of two week's duration, (Section 5.2). Progress is fed up to higher levels of the WBS on a longer frequency.

CALCULATE THE VARIANCE

The variance is calculated either in the form of delays to completion of critical or near-critical work, or as the remaining float of subsequent activities. There is a tenet of project management that you cannot do anything about the past; you can only affect the future. Therefore it is better to focus on the remaining float of subsequent work, or on future delays to the start of critical or near-critical work. Delays to critical or near-critical work have an impact on the remaining float of subsequent work, and when the remaining float of a subsequent work element becomes negative, that extends the forecast completion date of the project. It is important to monitor near-critical work, and not focus solely on the critical path. The mathematical exactitude of the network can produce an undue focus on one area of the project, whereas it may be one of several other near-critical paths which determines the duration of the project, and it was only estimating error that caused one of these to be identified as the critical path. Indeed, if you focus all your management attention on one path, you can guarantee another will determine the duration.

Where delays occur to bulk work, it will have little effect on the remaining float of future activities, until it has been delayed so much that it is itself critical. Indeed resources may be switched from bulk work to critical work to maintain progress on the latter.

In order to determine the impact of any delays on the project, and any proposals for eliminating them, it is necessary to analyse the effect of each on the overall project. This is a repeat of the what-if analysis described above. If the WBS has been well constructed this analysis can often be conducted manually, by analysing the effect of the delay on the work package within which it occurs and then the effect of the work package on the overall project. The milestone plan is a powerful tool for determining whether a work package is critical and its effect on the project. This approach gives greater management control. Alternatively, where there are complex interdependencies and multiple shared resources, the analysis can be performed using the network. This provides a more accurate picture of the effect of changes, but it is difficult to determine the appropriate changes in the first place. The network does provide a valuable support to the manual approach, avoiding oversights.

**S-curves**

S-curves (Section 8.7) provide a pictorial representation of whether the project is on average, ahead of or behind schedule. The volume variance introduced in that section is another time variance, in addition to the remaining float on critical activities.

## 9.7 Summary

1. The purpose of scheduling time on a project is:
   - to obtain timely benefits which justify the expenditure
   - to coordinate resource inputs
   - to schedule resource availability
   - to assign priority for resources between projects
   - to meet a specified end date.
2. The schedule specifies the duration, start and finish date, and float of the activities in the project. There are several dates recorded against each activity:
   - early date
   - late date, and float
   - baseline date, and baseline float

- most likely date, and remaining float
- actual date, and remaining duration.

3. The schedule can be communicated as:
   - an activity listing
   - bar charts.
4. The duration is calculated by comparing the work content to the number of people available, and allowing for:
   - lost time
   - part-time working
   - interference
   - communication
   - lead times
   - sequencing of tasks within activities.
5. The early and late dates can be calculated from the durations and logical sequence of the activities using a critical path network. The are two types of network:
   - precedence network
   - activity-on-arrow network.
6. Given the initial schedule and resource requirements for each activity, a resource schedule can be calculated showing the requirements for each type of resource with time. This can be smoothed by delaying bulk work to fill peaks and troughs, or by extending the duration of the project. Then resulting schedule is frozen as the baseline.
7. Progress against the schedule can be monitored by:
   - recording progress on the critical or near critical paths
   - recording progress on S-curves.

## Reference

1. Morris, P.W.G. and Hough, G.H., *The Anatomy of Major Projects: The reality of project management,* Wiley, 1987.