MGT/PPM/1

WORLD HEALTH ORGANIZATION

PROJECT PLANNING METHODOLOGY

A REPORT

FROM

ADMINISTRATIVE MANAGEMENT

PROJECT PLANNING METHODOLOGY

MGT/PPM/3

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Administrative Management August 1974

PROJECT PLANNING METHODOLOGY

– with particular reference to the planning of environmental health country projects –

1 INTRODUCTION

11 General

The increased technical and administrative complexity of large-scale country projects in environmental health calls for planning, execution and monitoring techniques that will permit the accomplishment of project objectives despite pressure of time and scarcity of resources.

12 Approach

This paper is intended to offer guidance on the use of network analysis for planning and monitoring of comprehensive environmental health country projects.

The techniques outlined have general applicability and may be used whether the project under consideration is UNDP-supported or not. To the extend that this paper serves as a manual in project planning it is therefore completely separate from the UNDP Operational & Financial Manual.

The approach used is based on experience gained by MGT while collaborating with technical units in the planning and monitoring of projects. The most recent of these projects, WHO/UNDP project HUN 3101 : "Pilot Zones for Water Quality Management"[1] is that

[1] Management Survey Report No. 121, April 1974, WHO/HQ.

which is most relevant as far as subject area goes, and could be considered a case study on the topics contained in this paper.

To facilitate a complete understanding of this paper, the basic principles of network analysis are described in Appendix 1. It is recommended that readers unfamiliar with this technique consult this part of the paper at the outset.

2 PLANNING METHODOLOGY

Project planning methods are primarily aids in the control of a project and as such, to be effective, must have the full backing and support of both the Project Manager and co-manager. From the outset, there should be a clear understanding by all concerned of the objectives in using a formal planning methodology and of how it can be used in operating and controlling the project.

The reason for using one planning methodology rather than another is that it offers some particular advantage that makes its use preferable. For environmental health country projects which very often involve a high degree of complexity and uncertainty, it can be stated beyond doubt that the network planning technique gives the project executors the best means of ensuring continuous control over the various activities. The technique is ideally suited for projects which are unique and which have not been attempted previously.

The term "network planning" encompasses techniques such as PERT (Programme Evaluation and Review Technique) and CPM (Critical Path Method) and no attempt will be made in the following to make a distinction between these two similar techniques.

As will be seen, network planning may also be supported by other planning methodologies such as GANTT-charts (see Appendix 2) in the detailed follow-up and monitoring of activities and personnel.

Planning by networks is not, however, simply the drawing of diagrams on a piece of paper. It is part of a management system for the control of many aspects of project execution. Whereas it is primarily oriented towards the time aspect of a project, it can be extended to examine the relationships between time, money and other resources.

3 WHY USE NETWORKS?

The basis of network construction is simple and can be learnt quickly. With a minimum of ability for drawing and a questioning mind, the construction of effective networks is mainly a matter of experience gained on actual projects.

While the theory of network analysis is simple, its successful implementation requires that the project executors at the country level provide all the information necessary to enable the Organization through its Regional Offices and Headquarters to be able to assist in decision making. The effectiveness of the technique depends upon getting the right data upon which to operate, and upon the ability of the Project Manager/co-manager as well as the technical officers at Regional Offices and Headquarters to make use of the information which network analysis gives.

The reason for introducing network planning in a particular project may of course vary. Obviously, very few projects of the scale and complexity of those in which WHO/Environmental Health is engaged proceed without any problems, and it is far from suggested that network analysis represents any kind of panacea for such problems. On the other hand, there can be little doubt that there will be instances where network planning would provide the project co-ordinators both at the country level and in Regional Offices/Headquarters with a better tool for effective control of activities than that currently afforded.

The following represent a list of symptoms which may indicate a need for an improved system of control and where network analysis, properly applied, should be of assistance:

- Lack of clearly specified objectives
- Failure to predict potential problem areas
- Delays in decision-making
- Failure to predict realistic completion times of major activities
- Lack of adequate information for control
- Frequent crises during project execution
- Corrective action being taken too late
- Failure to complete project on time.

In these situations network analysis is extremely suitable because of its flexibility in meeting dynamic situations and the relative ease with which activities can be replanned and rescheduled quickly.

4 WHAT TO PLAN?

Network analysis is principally concerned with the logical inter-dependencies of the various activities which make up the project.

Before starting to construct a logic diagram, some thought should be given to the scope and level of detail required for the plan to be effective. This step is particularly important for those preparing a network for the first time, since lack of experience in the mechanics of network planning can divert attention away from the specific activities and content of the plan.

This pre-network stage should include considerations of the following factors:

- Review of the various main components of the project
- Decision on level of detail for the network
- Preparation of a list of activities.

For UNDP-supported environmental health country projects a complicating factor exists in that activities are carried out and input to the project provided both internationally by WHO/UNDP and nationally by the counterpart government. As the nature of each party's contributions to the project may be entirely different and the Project Manager may have no control over counterpart activities, it may be argued that two separate plans with different degrees of detail should be drawn up, one for WHO/UNDP activities and one for counterpart government activities. In instances where this may be warranted or necessary, however, it is essential that both plans be interrelated through a master network showing in broad outlines the main work involved in the project. This master network should then contain all important aspects of both international activities as well as those of the counterpart staff, and be sufficiently elaborate to show the inter-dependencies clearly.

Networks of the overall plan, whether they be in the form of a broad master network developed from more detailed sub-networks or constructed directly with a fair degree of detail, are very useful in that they provide the most effective means of communication between all parties involved as well as a basis for analysis of alternative approaches and assessments of progress.

5 WHEN TO PLAN?

In general the network plan should be drawn up as early as possible. For UNDP-supported country projects however, it is doubtful whether enough information about the logical relationship between activities is available at the time of project approval to enable a working diagram to be constructed.
In MGT's project experience it has been found that there is often a considerable time-lag between formal tripartite project approval and the actual initiation of the various project activities.

Two steps in the planning of UNDP-supported projects are therefore recommended:

- A preliminary network to be submitted together with the project documentation at the time of the contractual agreement.
- Detailed network(s) (as discussed in para. 4) to be submitted by the Project Manager for approval at the first tripartite review.[1]

51 <u>The Preliminary Network</u>

This should show in broad outlines the main work involved in the project and should replace the schedules of activities (of GANTT-chart type) often used at present in the contractual agreements.

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[1] An exception to this recommended procedure is pre-investment planning projects executed under subcontract. For such projects a preliminary network is incorporated into the project proposal and a detailed work-plan submitted to PIP/HQ and RO six weeks after the subcontractor arrives on site.

Such a network plan would have as its purpose clarification of the basic features of the project. It should highlight those aspects which are still uncertain and thereby assist in sorting out the priorities. The diagram should be simple, probably consisting of not more than, say, twenty activities.

52 The Detailed Network(s)

After initiation of project activities, the limitation of the preliminary network in the contractual agreement as a working model will quickly become apparent.

As the work progresses, the Project Manager/co-manager, alone or in collaboration with the technical officers at the Regional Offices and Headquarters, should therefore use their increasing knowledge of constraints and opportunities to refine and modify continuously the plan of operation as drawn up in the preliminary network.

It is suggested as a matter of procedure that the (first) detailed network, which will be sufficient to allow effective and timely control of the project to be exercised, be submitted by the Project Manager at the first tripartite review. (To MGT's knowledge, this would be approximately one year after the project became operational, by which time adequate knowledge of activities, their expected durations and inter-dependencies should have been gained.)

Whether this plan should consist of separate sub-networks for the international activities and those of the counterpart plus a master network combining the two, or of only one large and mixed network is a matter for the Project Manager to decide.

The dynamic nature of most country projects of some duration implies, however, that the preparation of work plans is not an isolated and one-time undertaking. At subsequent intervals (i.e. later tripartite reviews) there will be a need for review of the project and possible adjustment of both content and phasing of the network activities.

In this context it is worth noting a statement made by the UNDP Programme Working Group on 23 October 1973 to the 16th session of the UN Inter-Agency Consultative Board:

> "In on-going projects, project managers or team leaders in the case of large projects and the Agencies in the case of small ones, should be alert to the need for changes in the work plans and any consequent need for revision of the budgets. There should be appropriate decentralization of responsibility and authority to the field in this respect. Project managers should take the initiative in suggesting such changes whenever they appear necessary, and the periodic tripartite review of the project should also be used as an opportunity for identifying any need for change and for agreeing on it or if necessary recommending it to higher levels."[1]

6 SETTING OF OBJECTIVES

In theory the objectives of every project should be clearly defined in the project document. In practice, however, while statements about objectives are always present, these do not always appear to be sufficiently clear to permit evaluation as to what extent they are attainable within the project duration. In these instances, the development of a network, through the time-phasing of activities and events, will assist and sometimes enforce an explicit clarification of project objectives.

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1 UNDP Report of the Programme Working Group (PWG). CB.16/8 23 October 1973, para. 9.

Setting of concise objectives, although often difficult, can be a rewarding task if properly undertaken. In most programmes or projects there exists a hierarchy of objectives.

HIERARCHY OF OBJECTIVES

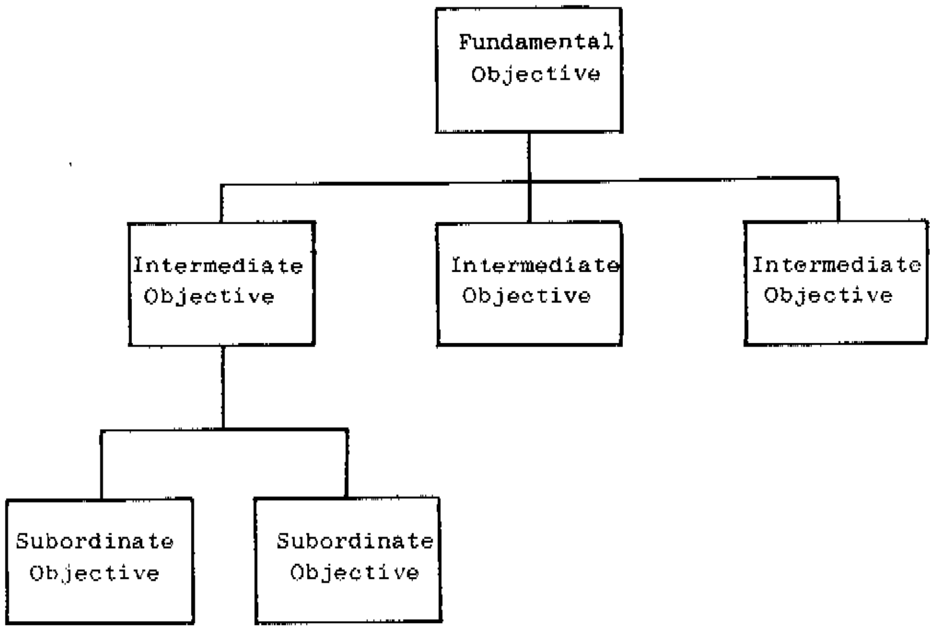


FIGURE 1

A hypothetical hierarchy of objectives for a typical water pollution

... project may be as shown in Annex 1.

At the top of the hierarchy there is a fundamental objective, often in the form of a general statement. The stated objective of WHO as a whole is a case in point: "The attainment by all peoples of the highest possible level of health". Although important in order to describe the nature and overall purpose of the project, general statements of objectives offer little help in monitoring the progress of project activities.

In projects with multiple objectives, which are the most frequent, as one descends the hierarchy, the intermediate or subordinate objectives become the means by which the fundamental objective is attained (ref.

... Annex 1).

A careful break-down of objectives has two very important aspects:

- The more carefully the layers of intermediate and subordinate objectives are formulated, the easier it is to see how the fundamental objective consists of clearly quantified targets which can be incorporated into the network as events and thereby effectively monitored.

- The time-span for the attainment of intermediate and subordinate objectives is progressively reduced as one moves down the layers, again facilitating exact identification in the detailed network(s).

In certain instances, the elaboration of a hierarchy of objectives will go hand-in-hand with the consideration of alternative ways of meeting the fundamental objective expressed. An illustration of this effect could be the case of a comprehensive national health plan (Fig. 2). Once the provision of basic sanitary services has been chosen as one means of attaining the fundamental higher level objectives, a further break-down (Fig. 3) can be made of each individual objective within this programme area.

7 MULTI LEVEL NETWORKS FOR COMPLEX PROJECTS

For large and complex environmental health projects involving several different pollution control aspects, i.e. water, air, soil and noise, it is doubtful if <u>one single</u> network can be constructed with sufficient detail to cover the operational control needs of all parties involved.

OBJECTIVES AND ALTERNATIVES

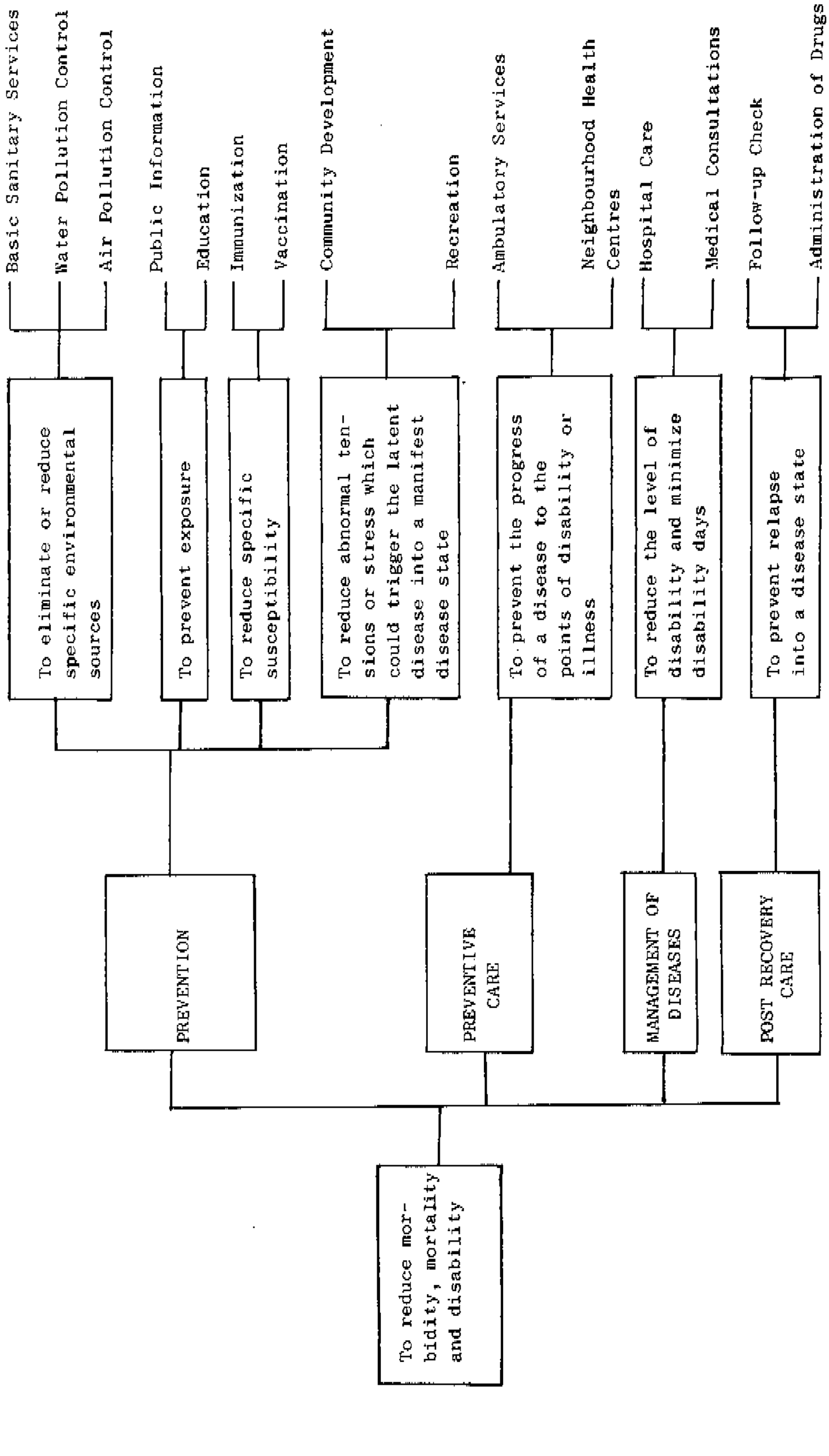


FIGURE 2

BASIC SANITARY SERVICES - HIERARCHY OF OBJECTIVES

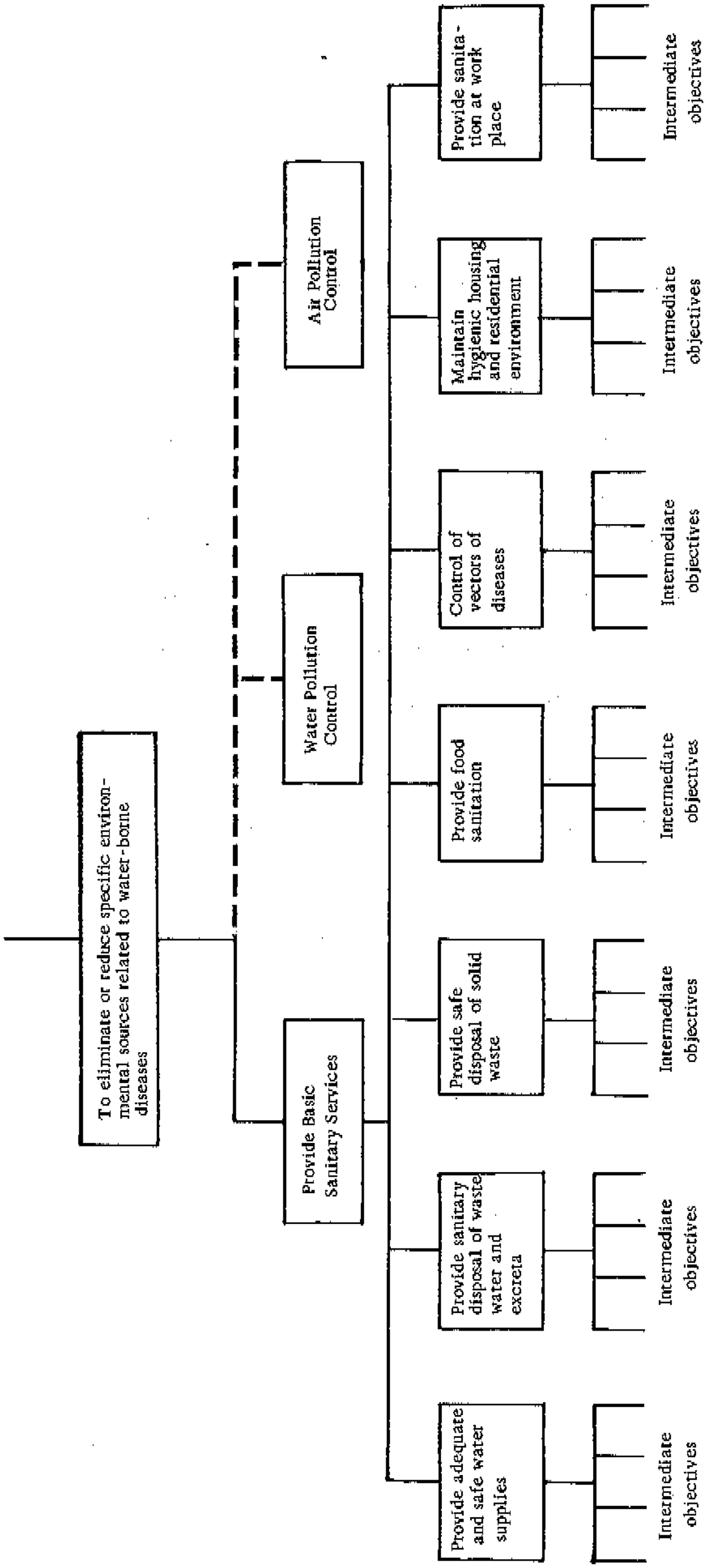


FIGURE 3

If the network is drawn in too great a detail, its complexity might tend to obscure the broad picture required by the co-ordinators in the Regional Offices and Headquarters. Also, the task of re-scheduling such a network in the light of imposed changes, unforeseen difficulties or mistakes made, would be excessively time-consuming. The dynamic setting of these projects implies that changes may occur in all components of the project and at all levels, and one should therefore try to avoid changes in the overall plan of the project owing to minor occurrences in each specific field. It should be the responsibility of the various scientists and case specialists to resolve problems wherever possible and only involve the Project Manager/co-manager when the difficulty is likely to affect other fields.

For such comprehensive projects, this complicating factor can be solved through the use of what are known as multi-level networks as illustrated in Fig. 4. This shows three levels of detail. At the top the overall project in the form of a master network is set out showing in broad outlines all important aspects of the project and the inter-relationships between the main activities within the various components (i.e. water, air, soil, noise).

The lower levels, or sub-networks, are then expansions of a single, or small group of activities on the higher level network. In Fig. 4, for example, if activities A and B in the master network represent, say, "self-purification studies of river X" and "studies on industrial emissions of CO_2 in province Y", then the second level networks would consist of a detailed elaboration of these two activities. The third level networks (corresponding to

MULTI-LEVEL NETWORKS

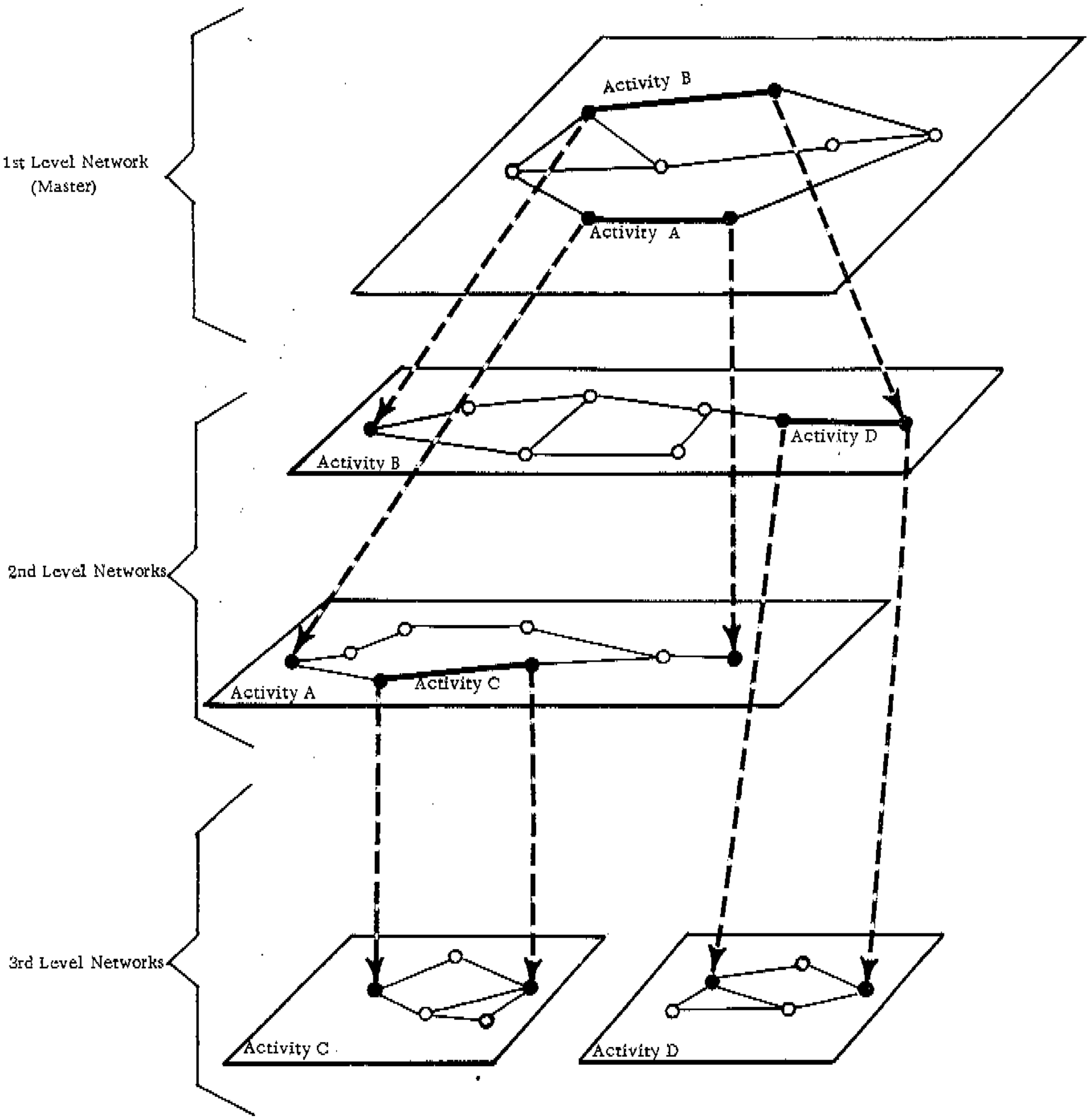


FIGURE 4

activities C and D) would similarly break down the plan into even greater detail, to the point where complete operational control by each responsible case specialist is achieved.

Another illustration of multi-level networks could be where the project is subcontracted by the Organization. The preparation of a master network may be stipulated by WHO as a contractual obligation. The contractor may in turn wish to sub-contract further parts of the project and in order to maintain some control over the progress of the sub-contracted part impose the requirement of a second-level network in the contract with his sub-contractor, and so on.

The points of contact between the different networks (denoted by dotted lines in Fig. 4) act as funnels through which the time analysis of one network is channelled to the next and higher-level network. This means that delay in any one sub-network need only be transmitted to higher-level networks, or to the overall master plan, if, in the view of the Project Manager/co-manager, the delay cannot somehow be made up within the network in which it occurred.

As progress on the project is recorded on lower-level networks by individual activities and events, the proportion of work outstanding can be assessed at intervals as work proceeds, and the progress information transferred, together with any forecast delays, from one level to the next via the events acting as contact points between the diagrams.

It is likely that for large projects involving more than one environmental component (air, water, soil, etc.) the application of multi-level networks will be necessary. The principle can of course equally well be applied to simpler projects and may in fact often be superior to other networking techniques.

In somewhat simpler projects therefore, where an option may exist, the Project Manager must weigh the intangible benefits derived through better control against the extra effort required and undoubtedly more work involved.

8 PROJECT PROGRESS CONTROL

The control of a project must be able to respond to changing conditions if the project is to be concluded successfully.

For control to be effective some form of progress reporting procedure is required. The nature of this will depend upon the size of the project as well as on the degree of control required. The need for control will again vary with the extent of direct involvement in the project:

- For the Project Manager/co-manager the most effective option may be progress meetings with the various responsible case specialists held either at regular intervals or when necessary.

- For technical officers in Regional Offices and at Headquarters a formal progress reporting system may be required, on an exception principle or on a regular basis as the need may be.

Progress meetings could be convened at different intervals depending upon the level of detail to be discussed. The following guidelines prepared by the Project Manager/co-manager of a current UNDP supported water pollution project illustrate how such staff meetings might be scheduled:

"Meetings should be organized:

(i) by the Project Office once a month (between the 25th and 30th) in order to follow up individual activities;

"(ii) by Department IV of /Institute X/ according to needs but not less than once every three months, in the form of a technical co-ordinating session to be attended by all key-persons responsible for major components of the project;

(iii) by the Scientific Council of /Institute X/ twice a year (for 1974 in June and in October/November) for the evaluation of reports, studies, etc. elaborated by the different units working in the project;

(iv) by the NWA Board of Directors once a year (February/March) for the evaluation of works already accomplished and the establishment of guidelines for further work."

The formal reporting system should be as simple as possible. An example, adapted from current UNDP procedures, would be the form as shown in Fig. 5:

PROGRESS REPORT FORM

PROGRESS REPORT		Submitted by:	Project Number:				Reporting Period: Date:
Activity Ref. (Network)	ACTIVITY DESCRIPTION	Scheduled Duration	PROGRESS				Major Factors Affecting Implementation of Activities
			Actual start	Expected finish	Actual finish		
REMARKS:							

FIGURE 5

This form permits registration of three basic information needs from a control point of view, viz:

. Information on activities completed.

. Information on activities just started.

. Information on progress of current activities.

In the sense that the form may contain all activities which are currently going on, as well as activities which are due to begin, it can be used both as a progress report and a plan of activities for the immediate future.

It is of course important that this form, or any other formal progress reporting system, should be related to the frequency of progress meetings convened by the Project Manager/co-manager (see (i) to (iv) above) so that the information to the technical officers in the Regional Offices or at Headquarters is as up-to-date as possible.

9 SCHEDULING

Once a network (or set of networks) has been agreed which satisfies the hierarchy of project objectives, and an effective progress control system exists, the final step is to elaborate schedules of project inputs and outputs whose time-phasing cannot be accurately assessed from the network diagram.

For UNDP-supported environmental health projects the terms "inputs" and "outputs" refer to:

. Timing and duration of consultants . Timing and duration of fellowships . Procurement of equipment	Inputs
. Timing of WHO/UNDP reports . Timing of reports by counterpart staff	Outputs

Scheduling of these elements would normally be in the form of GANTT-charts as explained in Appendix 2. An example of this, taking the fellowship component, is shown in Fig. 6:

FELLOWSHIP SCHEDULE

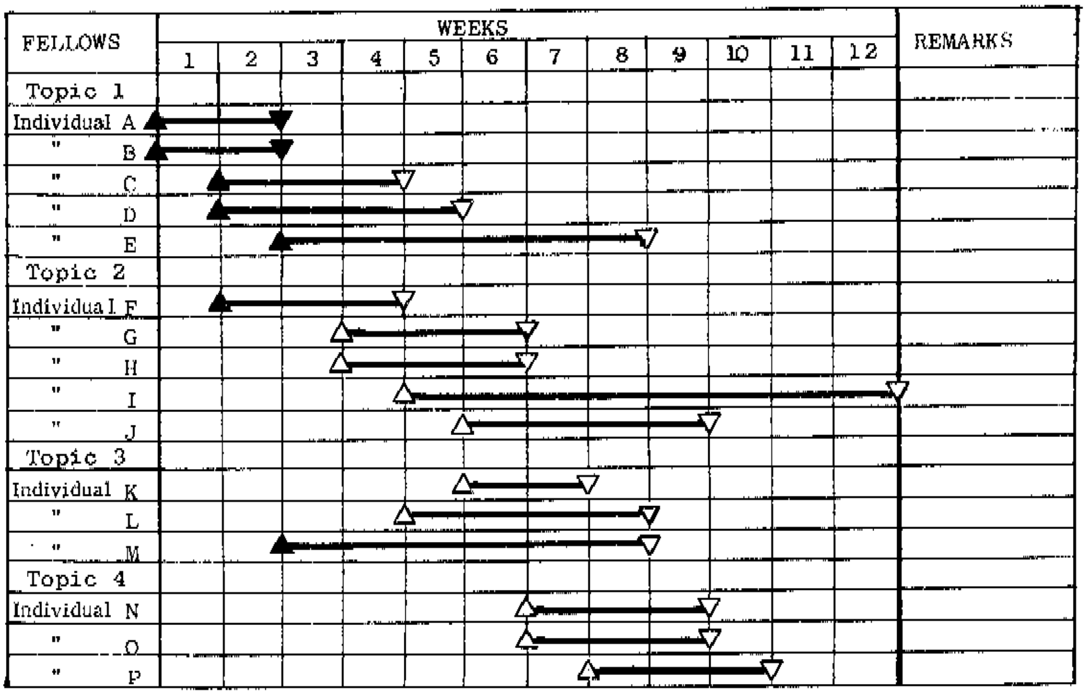


FIGURE 6

Guidelines for the preparation of schedules in environmental health country projects could be as follows, in order that a proper review of these can be made at Regional Offices or at Headquarters:

. The consultant schedule should be planned six months in advance.

. The fellowship schedule should be planned three months in advance.

. The equipment schedule should be planned six months in advance.

It is important to keep in mind that the schedules of inputs and outputs is in no way superseded by the use of network analysis. These still have an important function to perform in the planning and control of project work and the network(s) should not be regarded as the one and only way to plan. The two are complementary in that they contain different information and serve different purposes.

10 A FINAL NOTE

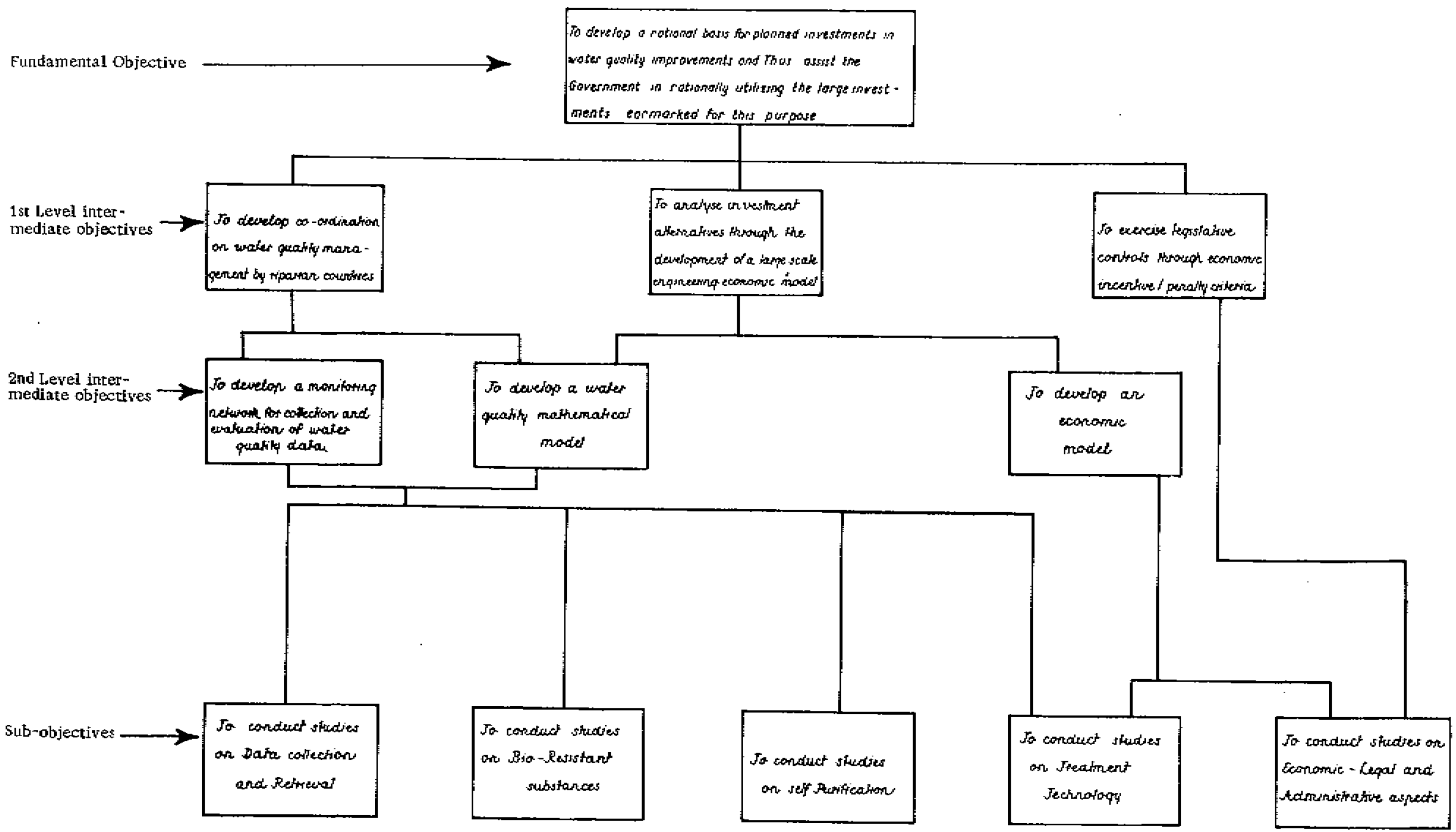
Network planning and analysis is an addition to existing procedures, i.e. UNDP-reporting system, tripartite project reviews, etc., and do not, of course, represent a substitute for these.

The existence of a network does not relieve the Project Manager/ co-manager of their responsibilities for planning and organizing their own work which can never be represented in a diagram.

While it may be argued that systematic planning places a restriction on the Project Manager's freedom of action, network planning on the other hand certainly forces all involved in a project to consider their decisions more systematically and, having agreed upon the formal plan, to operate within it.

ANNEX 1

HIERARCHY OF OBJECTIVES



NETWORK ANALYSIS

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ANNEXES

1 INTRODUCTION

10 <u>Objective</u>

The objective of this Appendix is to present and discuss the basic principles of network analysis. The knowledge of these principles will enable one to:

(i) determine if and when network analysis should be applied to support project management;

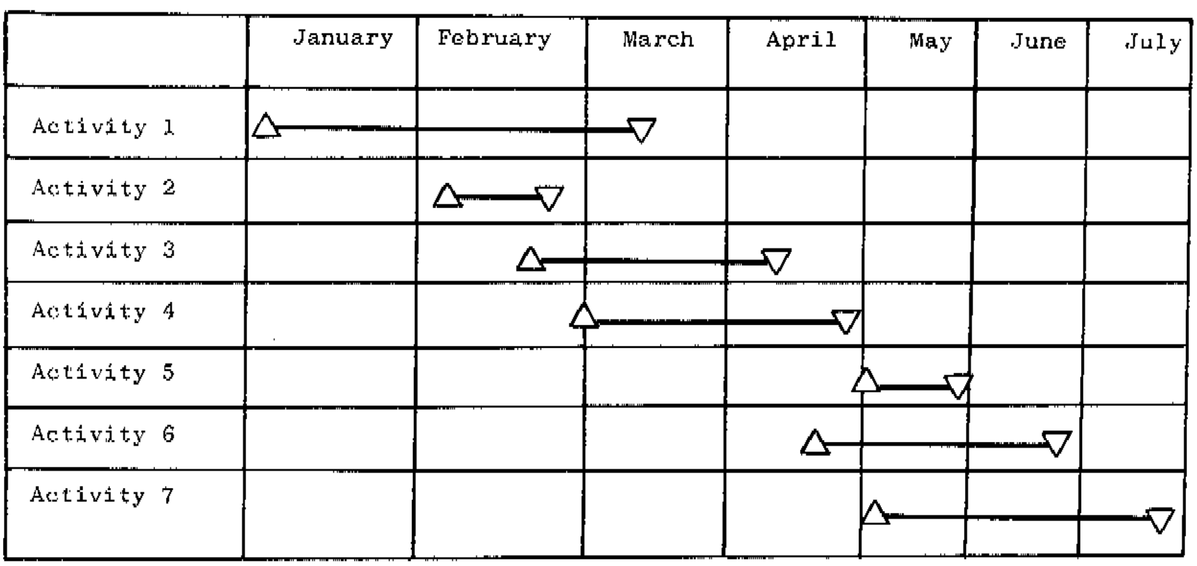
(ii) read, interpret and make appropriate managerial decisions from a network or a network analysis sheet; and

(iii) construct a simple network.

11 <u>History</u>

For many years the "Gantt Chart" (see Figure 1) has been one of the most advanced project scheduling techniques available to management. Its advantages are that it is simple, can be constructed without difficulty, and is easily interpreted.

Figure 1: Gantt Chart



The Gantt Chart, however, has various disadvantages. For example:

(i) it does not show the interrelationship between activities. In other words, it fails to show which activities precede and follow an activity in question;

(ii) it does not indicate those activities which are "critical", i.e. those activities on which management's attention and effort should be focused.

To answer the basic need for a project management tool, the following two "Project Planning and Control Techniques" were developed in the late 1950's:

CPM (Critical Path Method)

PERT (Programme Evaluation and Review Technique)

CPM had its inception in 1957 on a job that the Sperry Rand Corporation did for E.I. du Pont de Nemours & Co.

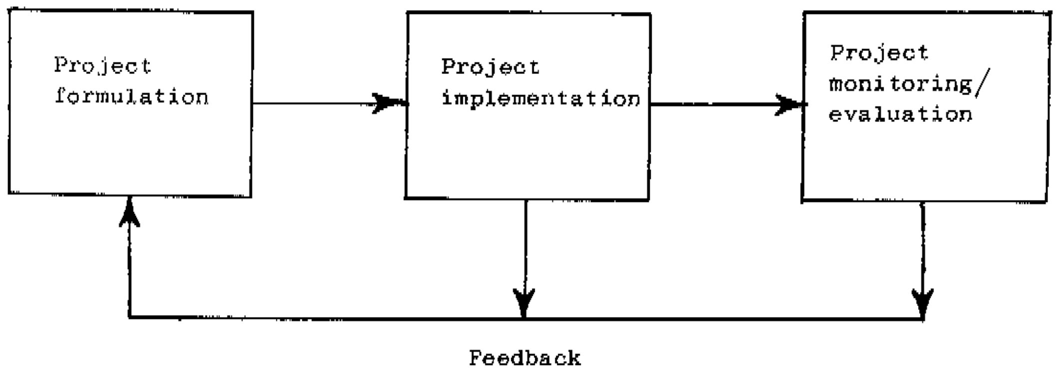
PERT was developed in 1958 by a project team at the US Navy Special Projects Office. The project team consisted of personnel of the US Navy Projects Office, the firm Booz, Allen and Hamilton, and Lockheed Missile Systems Division.

It is important to note that the two pioneer applications of network analysis at du Pont and the Navy Special Projects Office had somewhat different objectives. The Navy was concerned primarily with monitoring and co-ordinating the work of many contractors and comparing overall performance with established project criteria. At du Pont management was responsible for allocating resources to various activities so as to achieve the most economical schedule. As a result, PERT was more "event oriented" and CPM more "activity oriented". With the passing of time, the two techniques have lost their individual identity and have been absorbed into what is now called Network Analysis.

12 Context

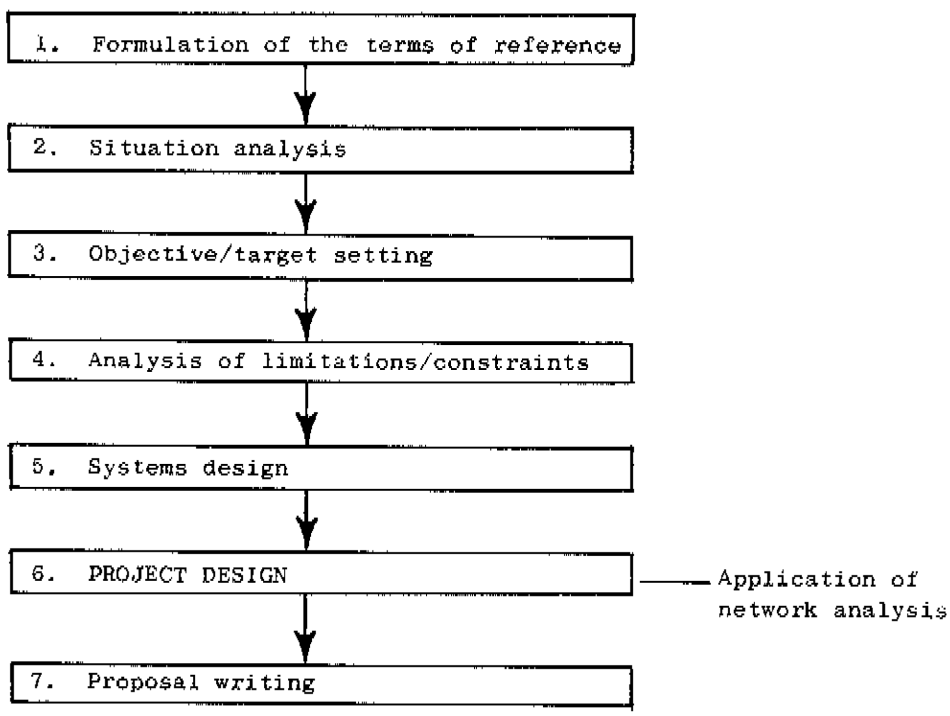
Network analysis is a management tool used in support of project management which has three main elements as shown in Figure 2.

Figure 2: Main elements of project management



Network analysis is most useful for project formulation and particularly for project design which is one crucial phase in the project formulation process as shown in Figure 3. However, network analysis is also useful in project implementation and project monitoring.

Figure 3: Project formulation phases



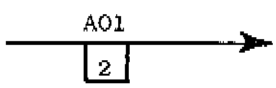
Project design encompasses all aspects of modifying an old or creating a new system, e.g. a health service system, health education system, health research system, etc. Project activities are listed in detail, put in sequence and scheduled in a network format. Other details of the project, such as its organizational structure, operating procedures, resources, requirements, etc., are specified.

2 CONSTRUCTION OF A NETWORK

To design a network one does "arrow diagramming". In the process four basic symbols are used to represent activities, events, milestones and dummies.

20 Activity

An activity is represented by an arrow:



an activity with its code and time consumption indicated

. The arrowhead orients the activity, showing that it proceeds from beginning to end, generally, in the direction left to right.

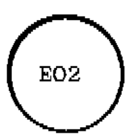
. Arrow length is for convenience.

. Arrow direction has no vectorial significance.

. Activities consume resources, e.g. time, money, manpower, etc.

21 Event

The start or termination of an activity is called an event. An event is represented by a circle.



an event with its code

22 Milestone

A milestone is represented by a square:

a milestone with its code

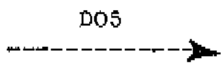
A milestone is employed to indicate:

(i) the termination of an important activity, or

(ii) an event which is significant in monitoring the project.

23 Dummy

A dummy is represented by a dotted arrow:

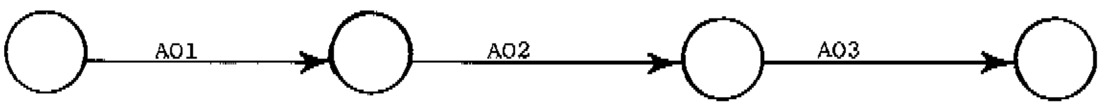


a dummy with its code

The dummy is employed to keep the logical sequence of activities and their interrelationship correct; it consumes no resources

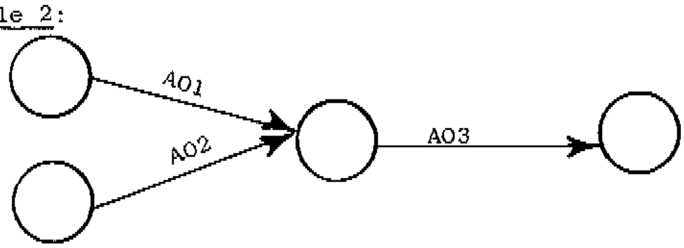
24 Examples

Example 1:



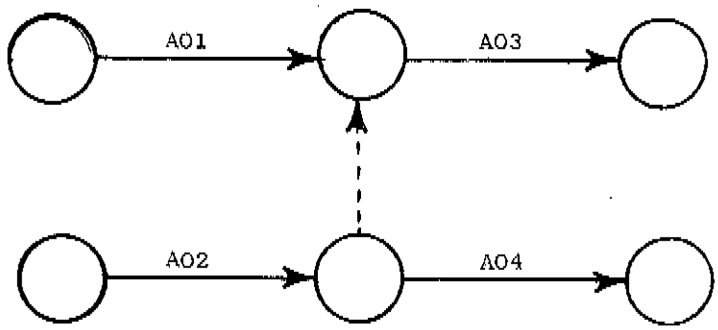
The above diagram illustrates a three-activity project wherein activity A01 is a starting activity and must be completed before A02 may be started. Activity A03 is a final activity and may not be started until activity A02 has been completed.

Example 2:



The activity A03 may not begin until the two activities A01 and A02 are completed; activities A01 and A02 are independent of each other.

Example 3:



The activities A01 and A02 must be completed before activity A03 may start, but only activity A02 must be completed before activity A04 can start.

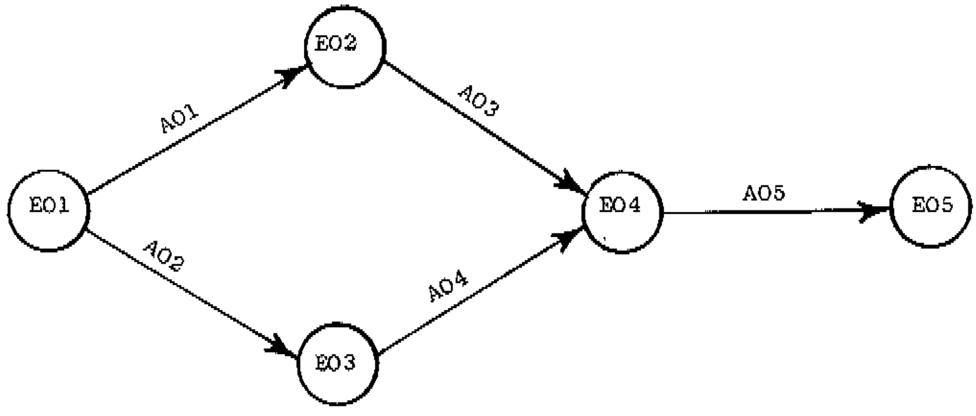
25 Three rules for placing activities in a network

In drawing a network, three rules must be followed:

- rule 1: in placing any activity in the network, identify the preceding activity, if any.
- rule 2: be sure you show any activities that occur at the same time as the activity you are placing in the network.
- rule 3: identify the activity that follows the one you are placing in the network, if any.

26 Event numbering

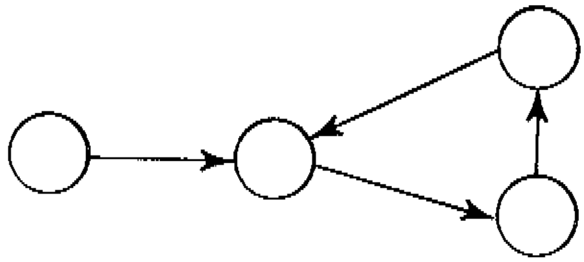
Networks are more easy to read and more meaningful if, in addition to the activities, events are labelled or numbered. As a general rule the numbers must be placed in a network in a particular sequence: each event is numbered only after all of the preceding events have been numbered. The following example illustrates the use of event numbers.



27 Loop and dangle

In constructing a network, two basic mistakes may occur:

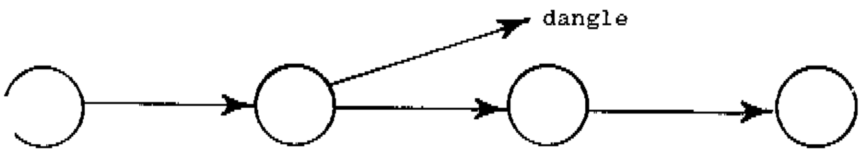
Loop



A loop is an activity sequence which leads back to some preceding activity.

A loop arises if an illogical dependency exists.

Dangle



A dangle is an activity with no apparent succeeding activity. The dependency conditions of this activity must be examined to determine the point at which the activity should be joined.

28 Listing of activities

The first step in network analysis is to identify the activities needed in order to complete the task or project. As the activities are identified in random order they are compiled into a list.

In a highly simplified and hypothetical example of a feasibility study on water pollution control this random listing might be as follows:

- Construction of Water Quality Monitoring System
- Assessment of Polluting Sources
- Hydrological Studies
- Determination of Toxic Concentrations
- Self-Purification Studies
- Elaboration of Alternative Treatment Solutions
- Generation of Alternative Treatment Operating Costs
- Cost-Effectiveness Studies on Waste Treatment
- Elaboration of Regional Water Quality Plan
- Development of Discharge Criteria.

When the list has been developed, the activity codes are assigned in their correct sequential order:

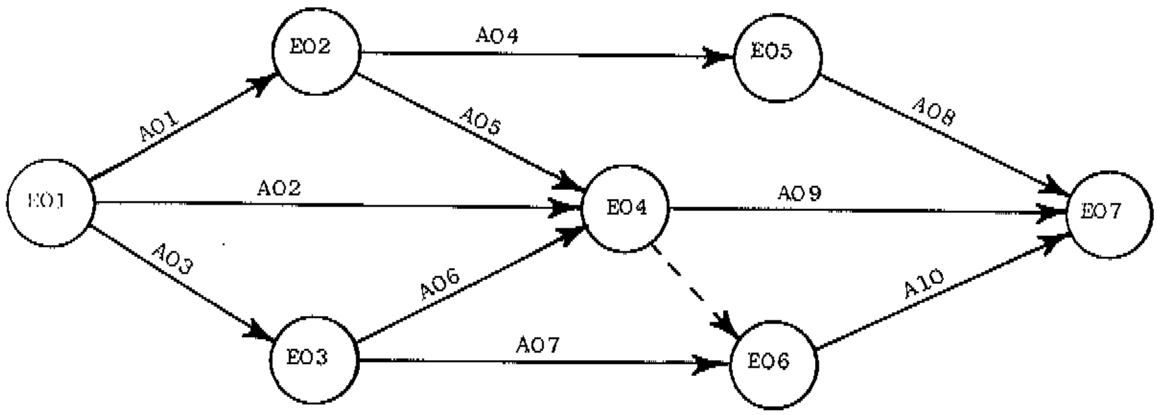
Activity Code	Activity Description
A01	Construction of Water Quality Monitoring System
A04	Assessment of Polluting Sources
A03	Hydrological Studies
A05	Determination of Toxic Concentrations
A02	Self-Purification Studies
A06	Elaboration of Alternative Treatment Solutions
A07	Generation of Alternative Treatment Operating Costs
A10	Cost-Effectiveness Studies on Waste Treatment
A08	Elaboration of Regional Water Quality Plan
A09	Development of Discharge Criteria

29 Interrelationships between activities

When the appropriate codes have been assigned to the activities, the list is re-arranged to show the activities in ascending order. At the same time the interrelationships of each activity with preceeding activities are identified, as shown:

Activity Code	Activity Description	Preceding Activity
A01	Construction of Water Quality Monitoring System	-
A02	Self-Purification Studies	-
A03	Hydrological Studies	-
A04	Assessment of Polluting Sources	A01
A05	Determination of Toxic Concentrations	A01
A06	Elaboration of Alternative Treatment Solutions	A03
A07	Generation of Alternative Treatment Operating Costs	A03
A08	Elaboration of Regional Water Quality Plan	A04
A09	Development of Discharge Criteria	A02, A05, A06
A10	Cost-Effectiveness Studies on Waste Treatment.	A06, A07

Once the interrelationships between the activities have been determined the network can be drawn with relative ease:



Exercises

To provide some practice in constructing networks, it is recommended that the following two exercises be attempted. The solutions are attached (see Annexes A and B).

Exercise 1: to draw a network and to number the events:

- Activities A01, A02 and A03 may be started at the beginning of the project
- When activity A02 is complete, A05 and A06 may start.
- When activity A01 is complete A04 may start.
- A07 can only start when both A04 and A05 are complete and is a final activity.
- A08 can start after A06 is complete and is a final activity.
- A09 must follow the finish of A03 and should not end in the event where A06 ends.
- A10 cannot start until both A06 and A09 are complete.
- A-11 can start when A10 is complete and is a final activity.
- All final activities end in one final event.

Exercise 2: to draw a network and to number the events

- Activities A01 and A02 may be started at the beginning of a project.
- When activity A01 is completed activities A03, A04 and A05 may be started.
- When A03 is completed A06 may be started.
- A07 and A09 may start when A04 is complete.
- A10 may start when A06 and A07 are complete.
- When A10 is complete A12 may start.
- A13 may start when A09 and A12 are complete.
- A08 depends for its start on the completion of A05.
- When A09 is completed A-11 may be started.
- A14 may start when A08 and A-11 are complete.
- When A02 and A14 are complete A16 may start and is a final activity.
- A15 may start when A14 and A13 are complete and is a final activity.

3 TIME ANALYSIS

Thus far we have described how to construct a network irrespective of time and resources. We shall now explain how to relate "time" to each activity and how to compute various types of network times.

30 Activity time

Since activities consume time one has to make an estimate of how much time will be needed to complete each activity. The unit of time does not matter so long as there is consistency throughout the network. But how does one estimate activity times? The best place to go for activity time information is directly to the person who will be responsible for the completion of the activity.

In practice, there are two different ways to determine activity times: (i) with only one time estimate, or (ii) with three time estimates.

301 One time estimate

One time estimate is sufficient in the case of activities where (i) standard times are available, and (ii) there is little uncertainty as to how long it will take for the activities to be completed. One time estimates are usually made in the construction industry.

302 Three time estimates

There are, however, many projects for which no reliable standard times exist, and the uncertainty as to the project completion time is large. To offset partly the bias that may be present in the first time estimate (one time estimate) a technique using three time estimates has been developed. Before a person is asked for three time estimates, he should be given a careful explanation of the basis for making each time estimate.

Most likely time (m)

Of the three time estimates, the first estimate one will ask for is the

Most likely time (m)

an estimate of the "normal" time an activity will take; a time which would occur most often if the activity were to be repeated frequently under similar circumstances.

Optimistic time (a)

an estimate of the minimum time an activity will take; a result which can occur if good luck is experienced and everything "goes right".

Pessimistic time (b)

an estimate of the maximum time an activity will take; a result which can occur if bad luck is experienced.

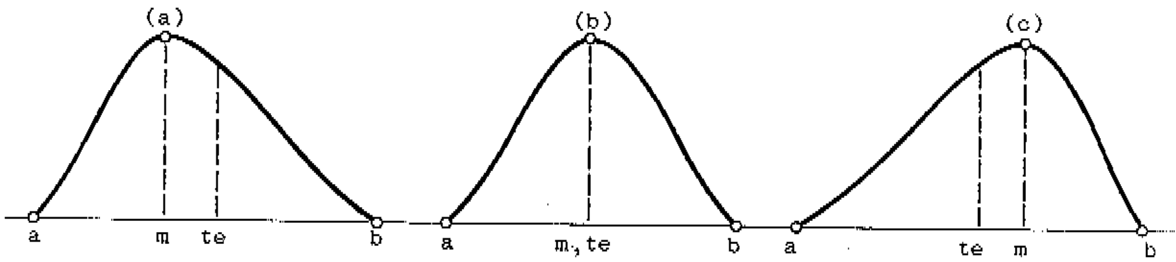
Expected time (te)

The aim now is to convert the three time estimates, m, a and b, to a single time called the expected time (te). Assuming that the values resulting from repeating an activity "x" number of time are distributed according to the beta distribution, the following formula is used to calculate te:

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

The characteristics of the beta distribution curve and the relationship of te, a, m and b are shown in Figure 4 (a, b, c).

Figure 4: Interrelationship of te, a, m and b



Key:

a = optimistic time

m = most likely time

te = expected time

b = pessimistic time

Example:

most likely time (m) : 30 days

optimistic time (a) : 20 days

pessimistic time (b) : 70 days

$$te = \frac{a + 4m + b}{6} = \frac{20 + 4 \times 30 + 70}{60} = \underline{\underline{35 \text{ days}}}$$

31 Event times

In the preceding section 30 we showed how to estimate the time needed to complete each activity. In this section we will explain how to calculate the earliest event time (TE), the latest event time (TL) and the total time it will take to complete the entire project.

Earliest event time (TE)

The earliest event time (TE) is the earliest time that an event can occur. It is calculated by determining the time between the start of the project and the completion of the event in question. This is done by adding the time of each activity to the TE of the preceding event. In the case of two or more paths leading to the event, use the path requiring the longest time. The TE is recorded at each event on the project. The TE of the final event is the earliest completion time for the project.

Latest event time (TL)

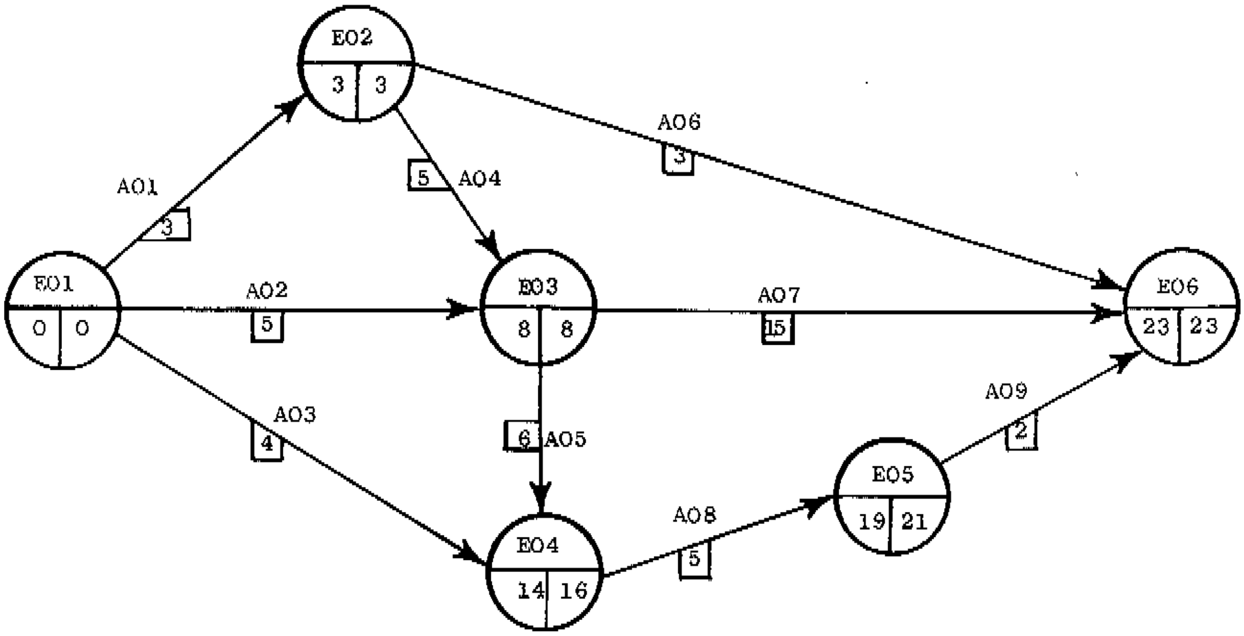
The latest event time (TL) is the opposite of the TE. It is the latest time at which an event must be completed. Failure to complete an event by this time will extend the time of the project.

To calculate the TL, one begins at the final event and subtracts the time of the activities leading to it; the result is the TL of the event preceding the final event. One continues backwards through the network, subtracting the time of each activity from its succeeding event. In the case of two or more paths leading backwards to an event, one uses the shortest time.

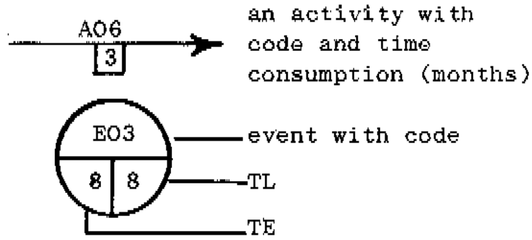
Example:

The following example will illustrate the computation of the TE and TL.

Figure 5: Network (computation of TE and TL)



Key:



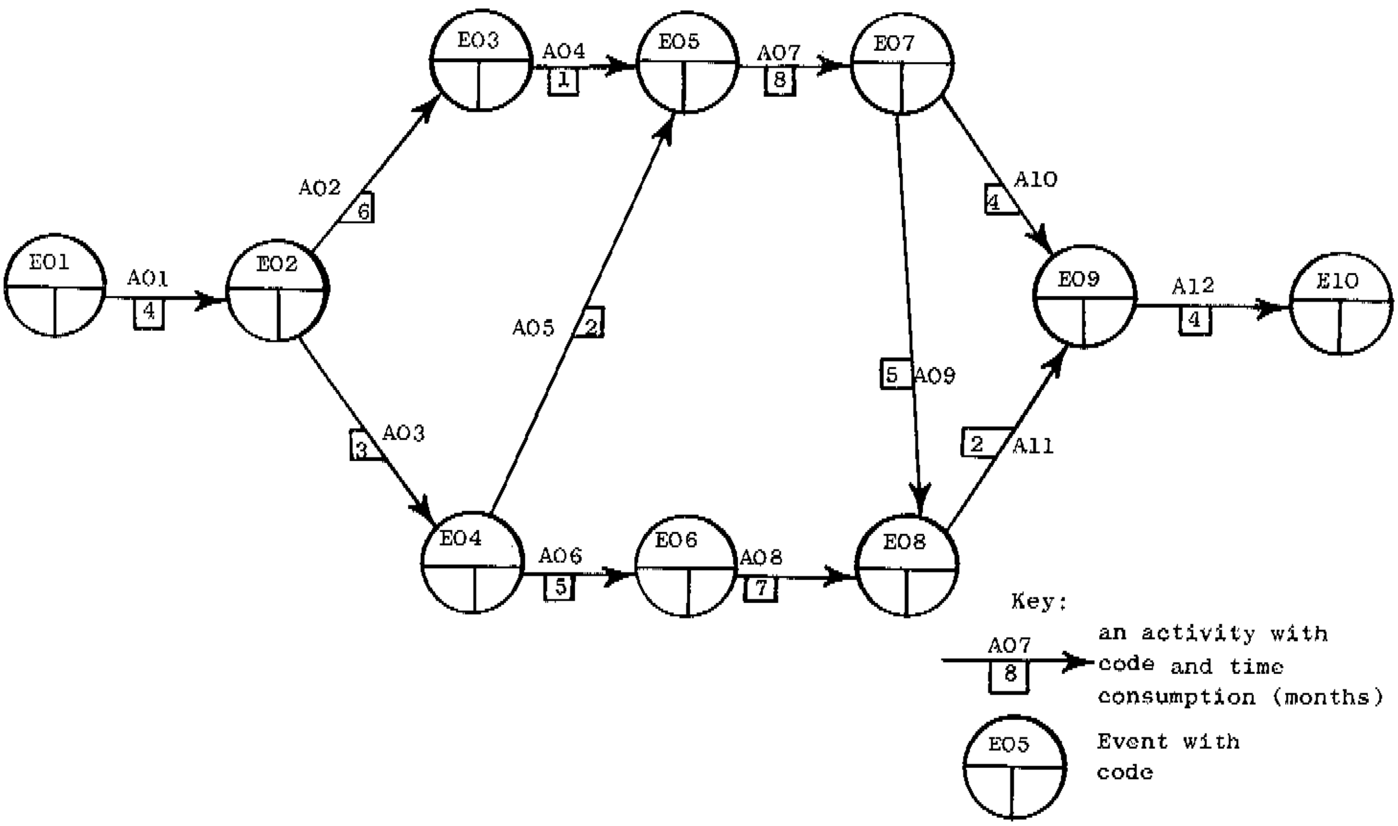
Explanation:

First one computes the TE. No time has been expended prior to event E01, so TE = 0 at event E01. The time to reach event E02 is the time to complete activity A01, or 3 months. In the case of event E03, there are 2 activities leading to it; therefore TE is determined by the longest activity time : 3 + 5 = 8 months. Now one computes the TE of event E04. There are again 2 arrows running into this event. One arrow starts at event E01, the other starts at event E03. We use the longest activity time, which is:

TE at event E03 + time of activity A05, or 8 + 6 = 14 months. Event E05 is a simple situation : the TE is the 19th month. Now for event E06; there are 3 arrows leading directly to this event. We retain the longest activity time which is: TE at event E03 + time of activity A07, or 8 + 15 = 23 months.

In this example it is implied that the project should be completed not later than the earliest completion date. This means that TL and TE of the final event E06 will be the same, or the 23rd month. The TL of event E05 is TL of event E06 - time of activity A09, or 23 - 2 = 21 months. For event E04 the TL = 16th month (21 - 5). For the case of event E03, there are 2 paths between event E03 and event E06: one path comprising activity A07 and the other comprising activities A09, A08 and A05. The longer path is 15 months. Thus event E03 must occur no later than the 8th month of the project. Now one moves back to event E02. As in event E03, there are 2 activity arrows leading from it. Again, we retain the smaller result of the 2 paths which is: TL of event E03 - time of activity A04, or 8 - 5 = 3 months. For event E01 the smallest result is zero.

Exercise 3: compute the TE and TL of the following network; the solution is attached, (see Annex C)



32 Activity float time

Activity float time is the extra time available to complete an activity. By using part or all of the float, an activity may be extended or delayed without affecting the project time. The float time provides time flexibility within the project.

There are two kinds of activity float: total float and free float.

Total float:

This is defined as the amount of time an activity can be delayed without affecting the overall finishing time for the project (TL of final event).

total float = latest event time at event j - duration of activity ij - earliest event time at event i

$= TLj - Dij - TEi$

Free float:

This is defined as the amount of time an activity can be delayed without affecting the earliest start of any following activity.

free float = earliest event time at event j - duration of activity ij - earliest event time at event i

$= TEj - Dij - TEi$

Example:

In the case of the network as shown in Figure 5 on p.14 total float and free float are calculated as follows:

Activity	Total float	Free float
A01	0	0
A02	3	3
A03	12	10
A04	0	0
A05	2	0
A06	17	17
A07	0	0
A08	2	0
A09	2	2

Exercise 4: calculate total float and free float of the network in exercise 3; the solution is attached (see Annex D).

33 Event slack

Event slack is the time period over which the event could occur, without affecting the overall time of the project, or the difference between TL and TE of an event.

Example:

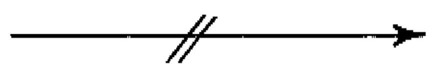
In the case of the network as shown in Figure 5 on p.14 only the events E04 and E05 have an event slack, each of 2 months.

34 Critical path

Within each network there exists a path composed of activities and events which, if delayed, would affect the overall project time. These activities are called critical activities and make up the critical path. Critical activities are activities which have no float time.

In some networks, the critical path may split into two or more branches, i.e. there may be more than one critical path.

On a network diagram, the critical activities may be marked in one of two ways. The quickest way is to draw two short diagonal lines across the critical activity, e.g:

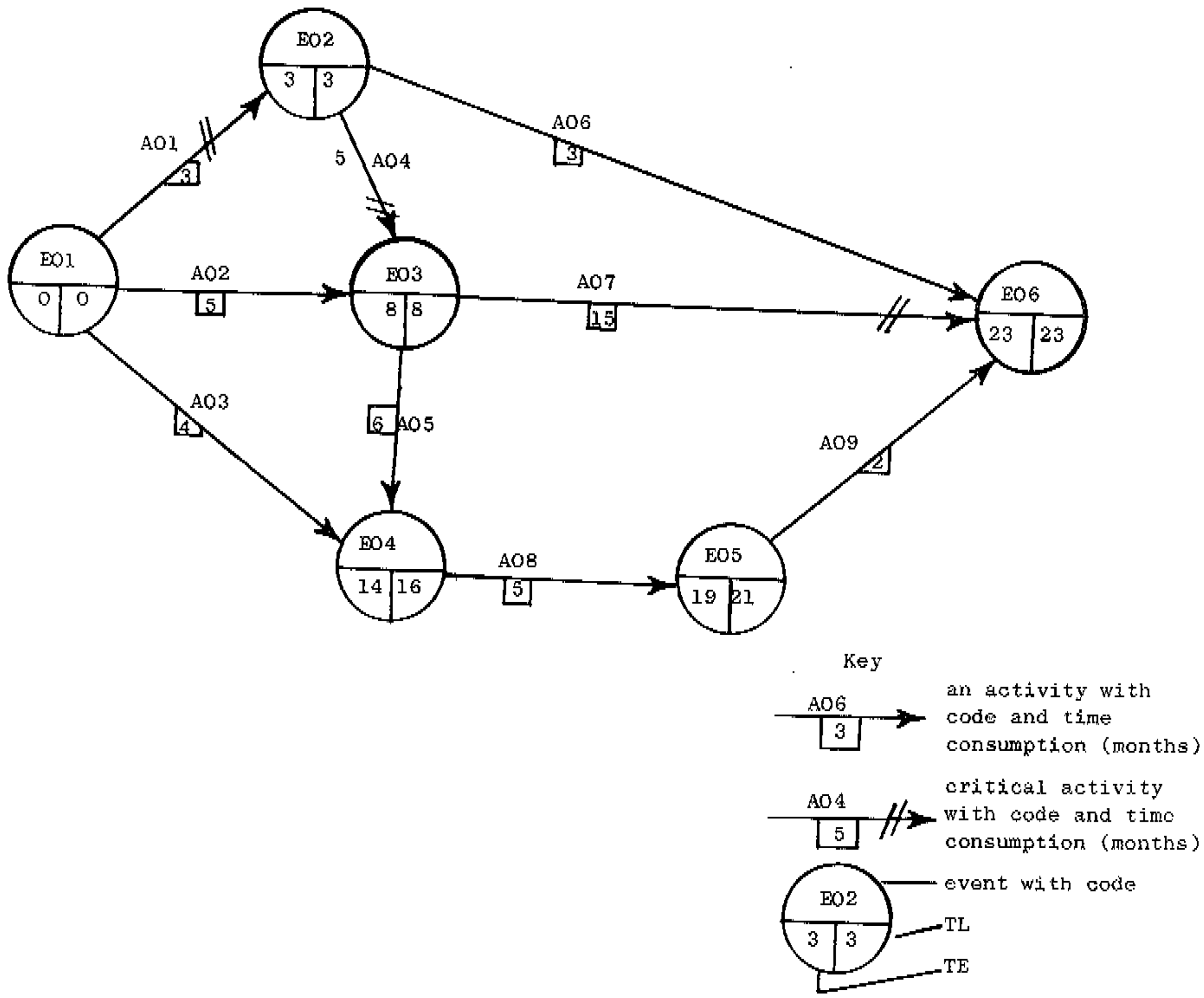


Another way is to draw the critical activity arrows heavier.

Example:

In the following network the critical activities are marked:

Figure 6: Network with critical activities marked



Exercise 5: mark the critical activities of the network in exercise 3; the solution is attached (see Annex E).

35 Project probability

Often, for external reasons, an arbitrary date will be set for project completion. Consequently, the question arises: Will the project be completed on schedule?

In the case of three time estimates (m, a, b) the following formula can be applied to any event to determine the probability of meeting the scheduled completion time:

$$Z_j = \frac{TS_j - TE_j}{\sigma\ TE_j}$$

Z_j = Z value in the table of the standard normal distribution function

TS_j = imposed completion time at event j

TE_j = earliest event time at event j

σTE_j = standard deviation on TE_j

$$= \sqrt{\text{sum of } \sigma te^2 \text{ for all activities from first event to event } j \text{ that affect the calculation of } TE_j}$$

It has to be noted that this formula should be used only if at least 8 - 10 activities preceed the event for which a completion time has been imposed.

Example:

For illustration purposes only the following example of a project consisting of two activities is given:

Activity	Most likely time (m) (months)	Optimistic time (a) (months)	Pessimistic time (b) (months)
A01	6	10	20
A02	12	15	30

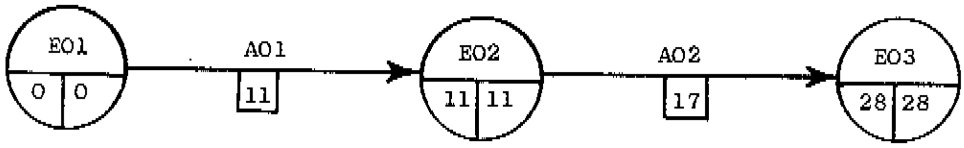
The imposed completion time for the project is 25 months.

Calculation of te

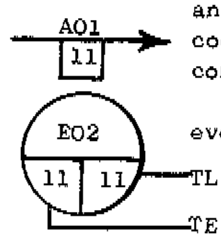
te for activity A01 $= \frac{a + 4m + b}{6} = \frac{6 + 4 \times 10 + 20}{6} = 11$

te for activity A02 $= \frac{a + 4m + b}{6} = \frac{12 + 4 \times 15 + 30}{6} = 17$

Network



Key:



an activity with code and time consumption (months)

event with code

Calculation of the standard deviation

$$\sigma_{te} \text{ for activity AO1} = \frac{b-a}{6} = \frac{20-6}{6} = \frac{14}{6} = \frac{7}{3}$$

$$\sigma_{te} \text{ for activity AO2} = \frac{b-a}{6} = \frac{30-12}{6} = 3$$

Calculation of σ_{EO3} and Z

$$\sigma_{EO3} = \sqrt{(\sigma_{te}) \text{ for AO1 and AO2}} = \sqrt{(\tfrac{7}{3})^2 + (3)^2} = 3.8$$

$$Z = \frac{TS_{EO3} - TE_{EO3}}{\sigma_{EO3}} = \frac{25-28}{3.8} = -0.789$$

According to the table of values of the standard normal distribution function there is a mere 21% probability of completing the project at the 25th month (see Annex F)

4 RESOURCE ALLOCATION

The planner is not only concerned with estimating the optimum project duration, but he will also try to avoid peaks and troughs in resource consumption. How the planner can strive toward this objective is shown by the following charts.

The planner will first determine the resource requirements over the period of the project (see Figure 7)

Figure 7: Resource requirements

Activity	Time	Earliest		Latest		Total	Resources	
	(months)	Start	Finish	Start	Finish	Float	Type I	Type II
A	2	0	2	0	2	0	1	–
B	1	0	1	5	6	5	–	2
C	4	2	6	2	6	0	3	3
D	2	2	4	8	10	6	1	–
E	2	6	8	8	10	2	1	1
F	5	6	11	6	11	0	2	3
G	1	8	9	10	11	2	–	1
H	2	8	10	12	14	4	1	2
I	3	11	14	11	14	0	2	2

Figure 8 shows the activities in the form of a bar-chart on the assumption that they should be commenced at their earliest possible start time. Over the bar-chart a resource histogram is constructed for the resources type I and type II. The histogram shows the expected peaks and troughs in resource consumption.

Figure 9 shows the result of smoothing the peaks of resource consumption in delaying activities D and H within their "float".

Figure 8: Allocation of resources (on the assumption that all activities should be commenced at the earliest starting times)

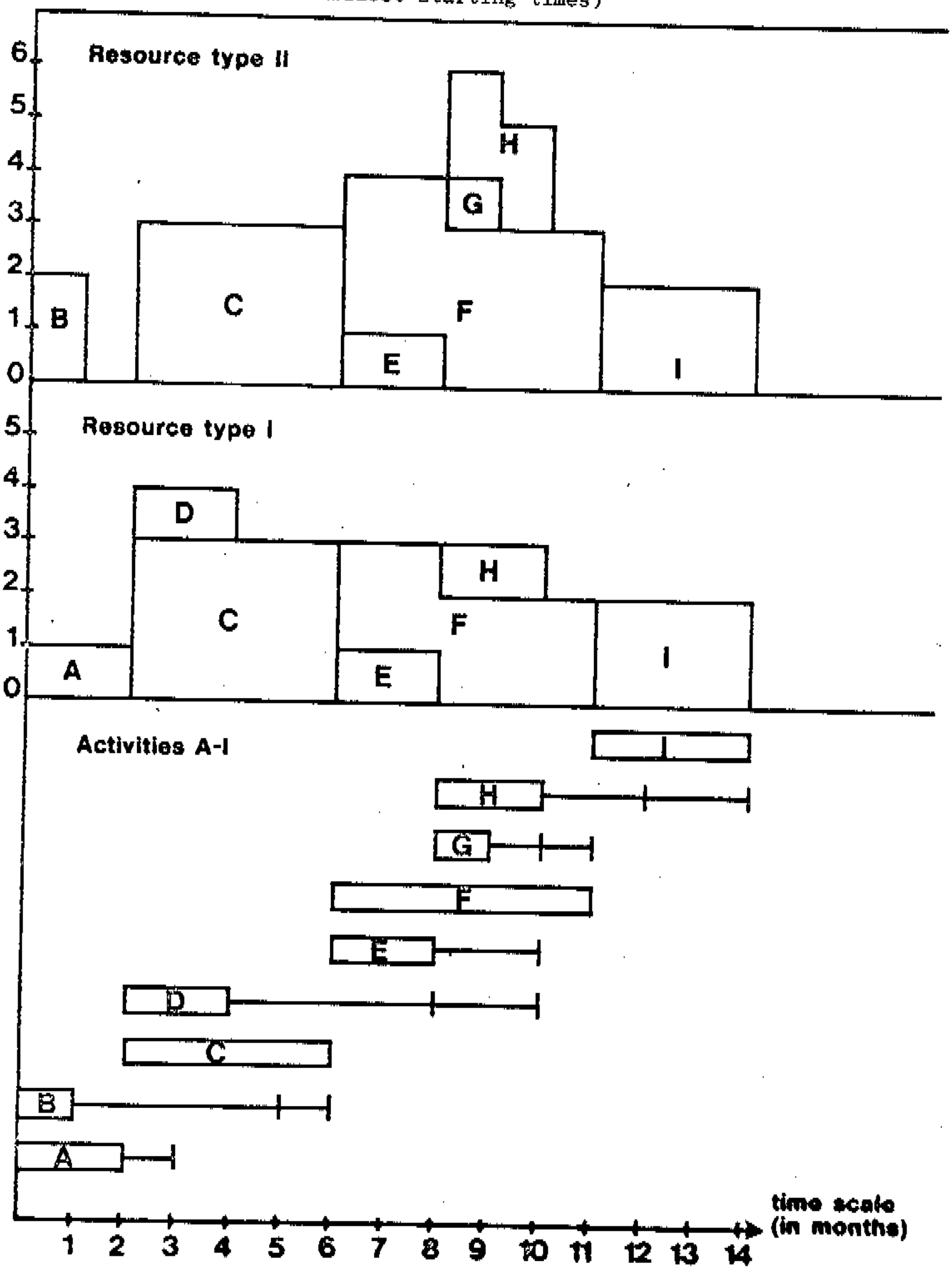
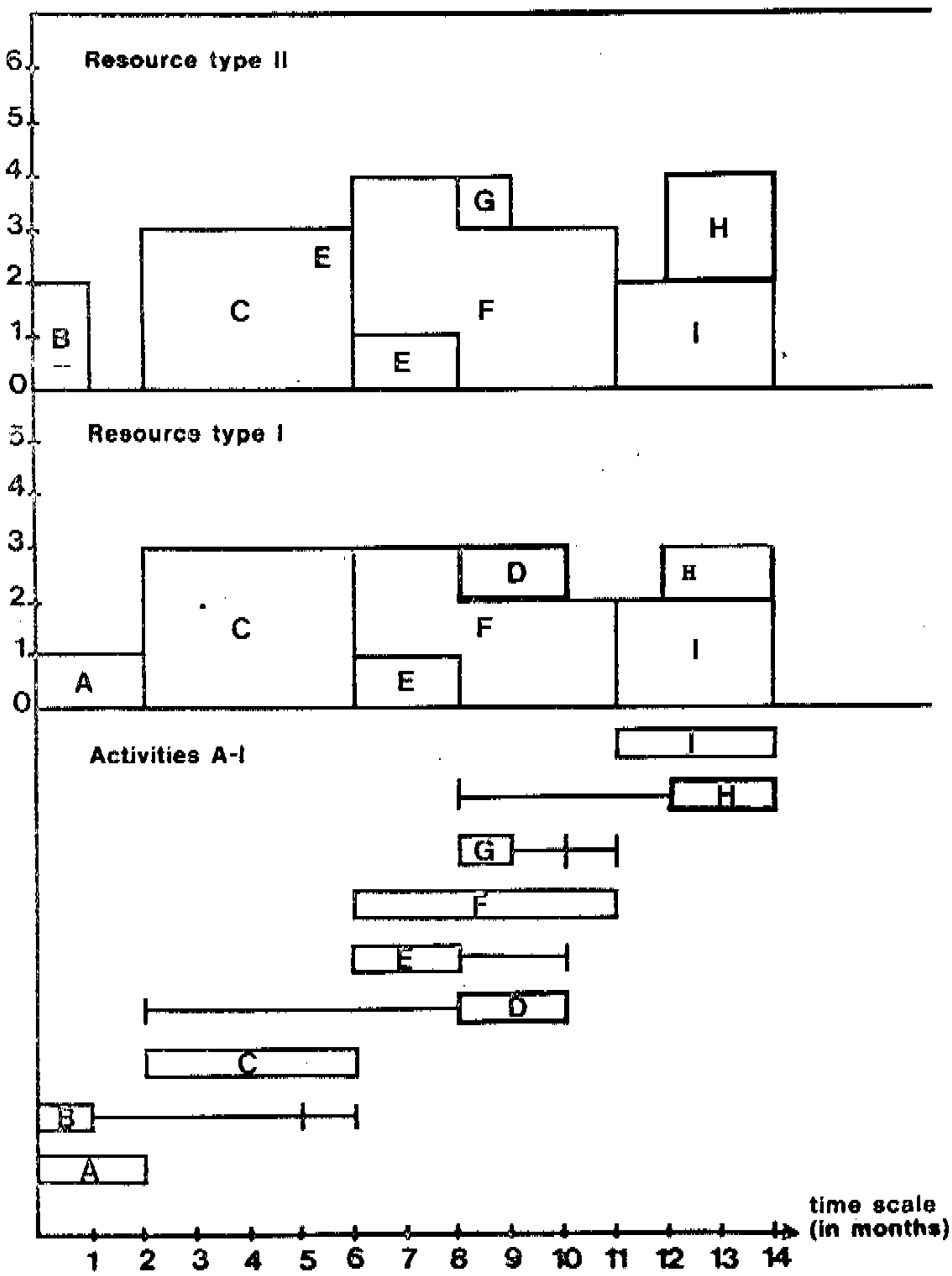
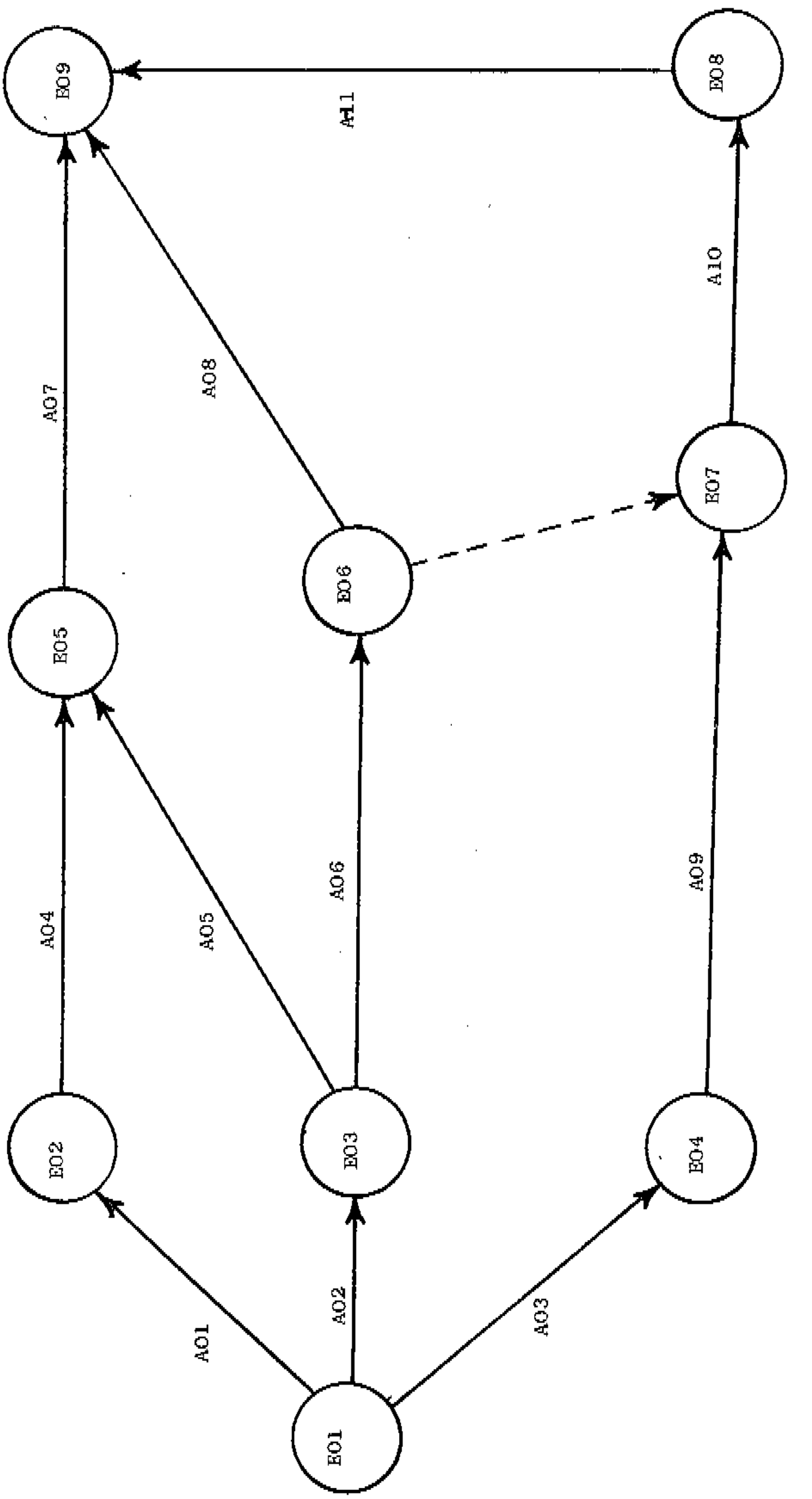


Figure 9 : Allocation of resources (on the basis of delayed activities D and H)

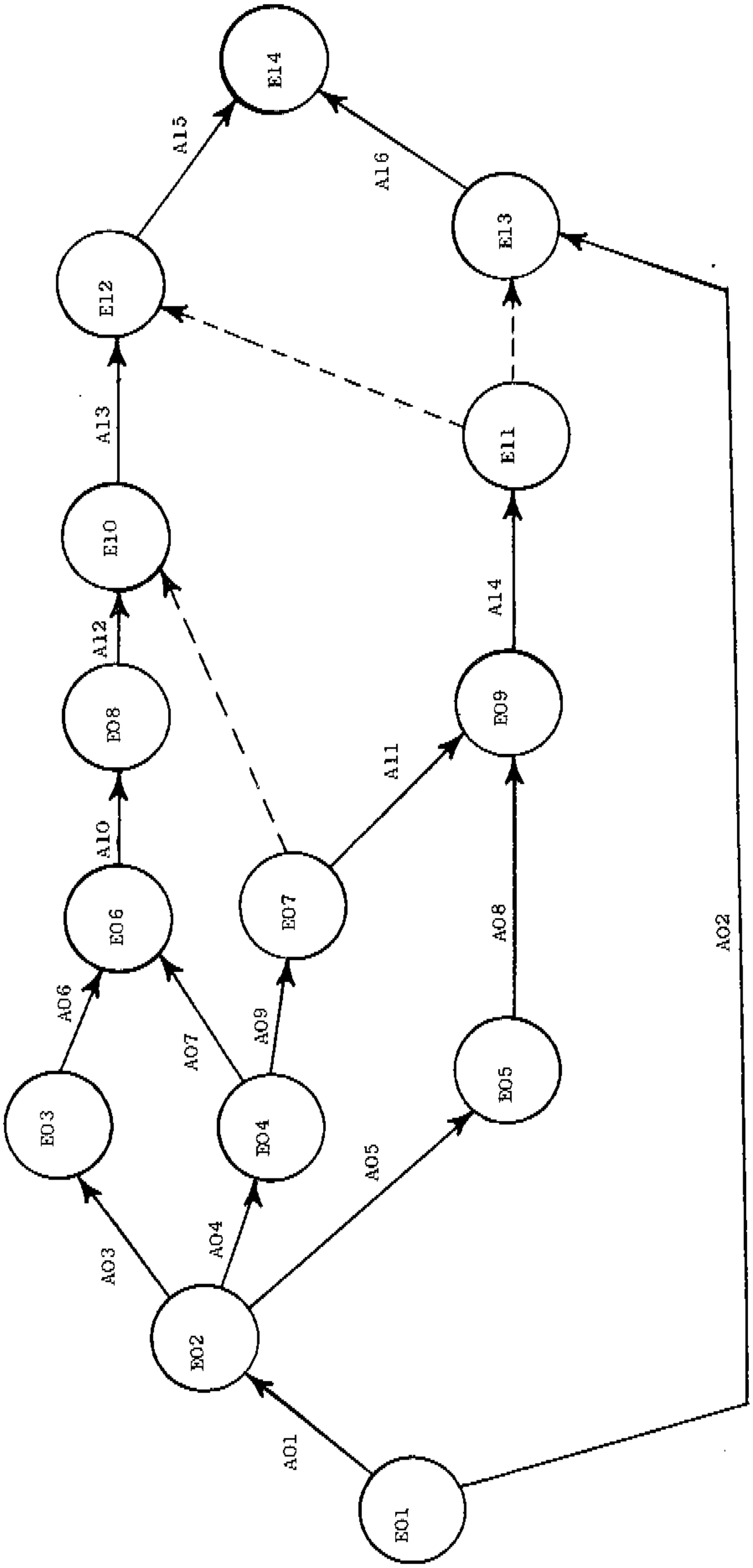


Solution to exercise 1

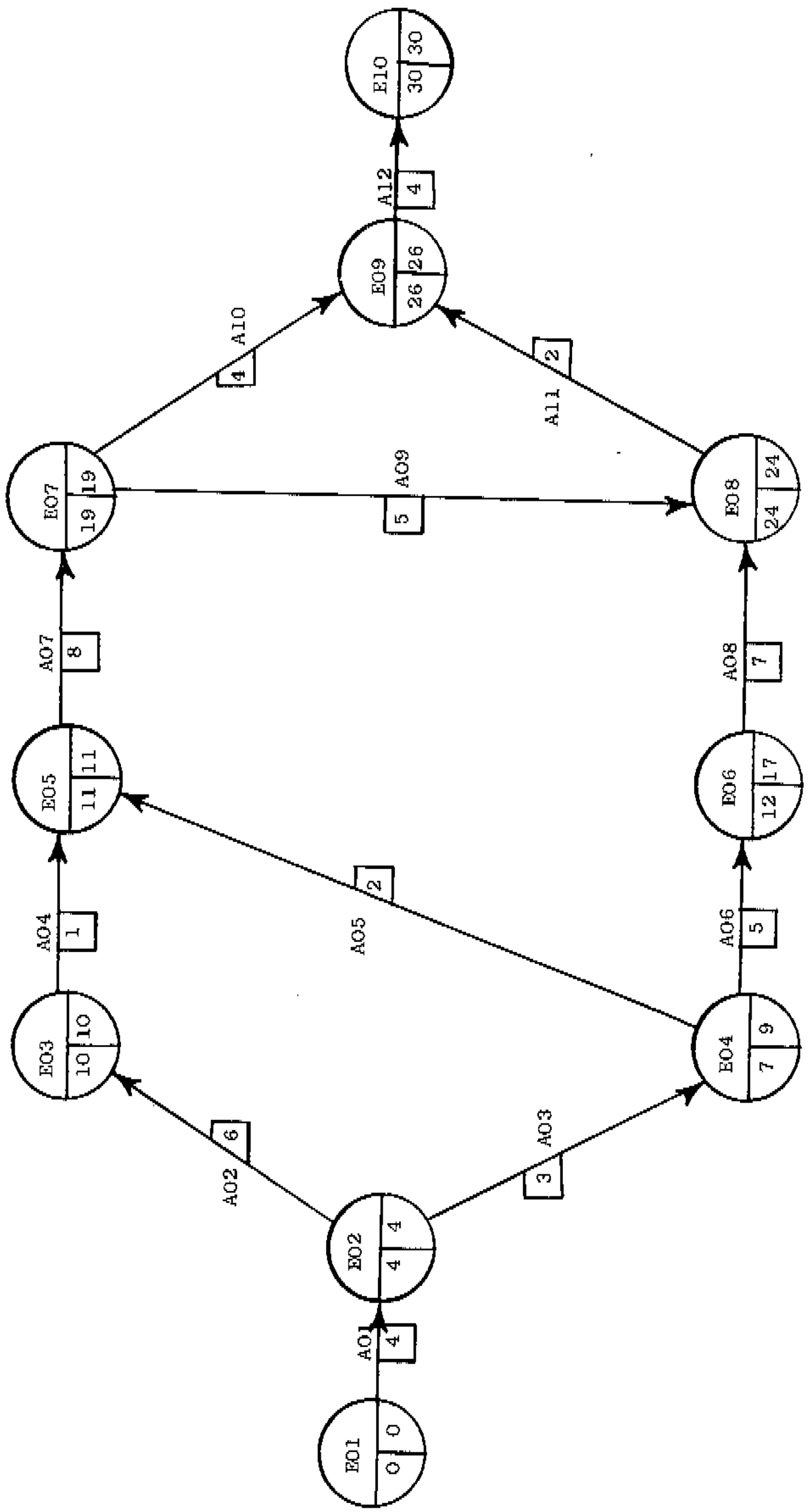


ANNEX B

Solution to exercise 2



Solution to exercise 3



Solution to exercise 4

Activity	Total float	Free float
A01	0	0
A02	0	0
A03	2	0
A04	0	0
A05	2	2
A06	5	0
A07	0	0
A08	5	5
A09	0	0
A10	3	3
A11	0	0
A12	0	0

ANNEX E

Solution to exercise 5

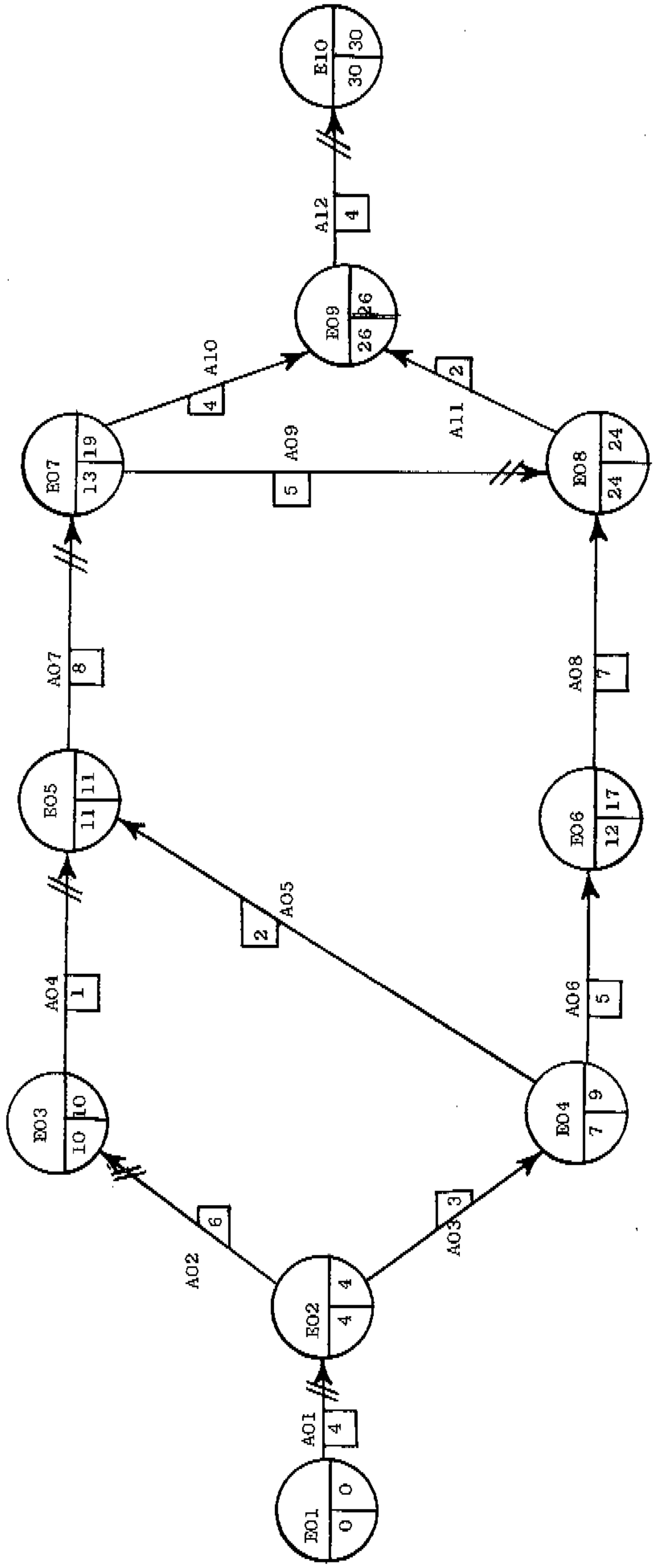


Table of values of the standard normal distribution function:

z	0	1	2	3	4	5	6	7	8	9
.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
.7	.7580	.7611	.7642	.7673	.7703	.7734	.7764	.7794	.7823	.7852
.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9278	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9430	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9648	.9556	.9664	.9671	.9678	.9686	.9693	.9700	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9762	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9874	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.	.9987	.9990	.9993	.9995	.9997	.9998	.9998	.9999	.9999	1.0000

Table of values of the standard normal distribution function (concluded):

z	0	1	2	3	4	5	6	7	8	9
-3	.0013	.0010	.0007	.0005	.0003	.0002	.0002	.0001	.0001	.0000
-2.9	.0019	.0018	.0017	.0017	.0016	.0016	.0015	.0015	.0014	.0014
-2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
-2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
-2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
-2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
-2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
-2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
-2.2	.0139	.0136	.0132	.0129	.0126	.0122	.0119	.0116	.0113	.0110
-2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
-2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
-1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0238	.0233
-1.8	.0359	.0352	.0344	.0336	.0329	.0322	.0314	.0307	.0300	.0294
-1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
-1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
-1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0570	.0559
-1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0722	.0708	.0694	.0681
-1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
-1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
-1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
-1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
- .9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
- .8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
- .7	.2420	.2389	.2358	.2327	.2297	.2266	.2236	.2206	.2177	.2148
- .6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
- .5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
- .4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
- .3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
- .2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
- .1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
- .0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

GANTT CHART

1 Key Activities and Personnel Information (Figure 1)

The major significant activities for the project are listed with "hollow" triangles denoting scheduled start △ and scheduled stop ▽ dates. These triangles are left unfilled until the activity is completed, at which time the actual start is shown by a filled-in triangle ▲, and the actual stop is shown by a filled-in inverted triangle ▼. A circle surrounding a triangle (△) indicates that an action is required at this scheduled time, e.g. a monthly report. Completion of action is shown by filling in the triangle (▲).

Key personnel activities are shown through use of the triangle code, e.g. △ start, and ▽ stop along a weekly time line, e.g. △ leave ▽. Information that cannot be shown on the connecting line is shown by a number, assigned by project manager, e.g. △ ⑥ ▽ which is then amplified in paragraph IV "Programme Problems".

2 Project Status Board (Figure 2)

The information available in Figure 1 can be further reduced visually on the Project Status Board (Figure 2) through the use of colour keys.

(G) Green coding is used when performance is proceeding in accordance with objective(s) and is normally the colour for a "yes" response.

(Y) Yellow indicates a qualified answer, warns of potentially serious trouble, and suggests that careful attention is warranted.

(R) Red reflects "out of control" situations such as a cost over-run, a schedule delinquency, or technical problems which are influencing the project objectives.

Yellow and Red situations require an explanation under "Programme Problems" (on Figure 1).

Figure 1

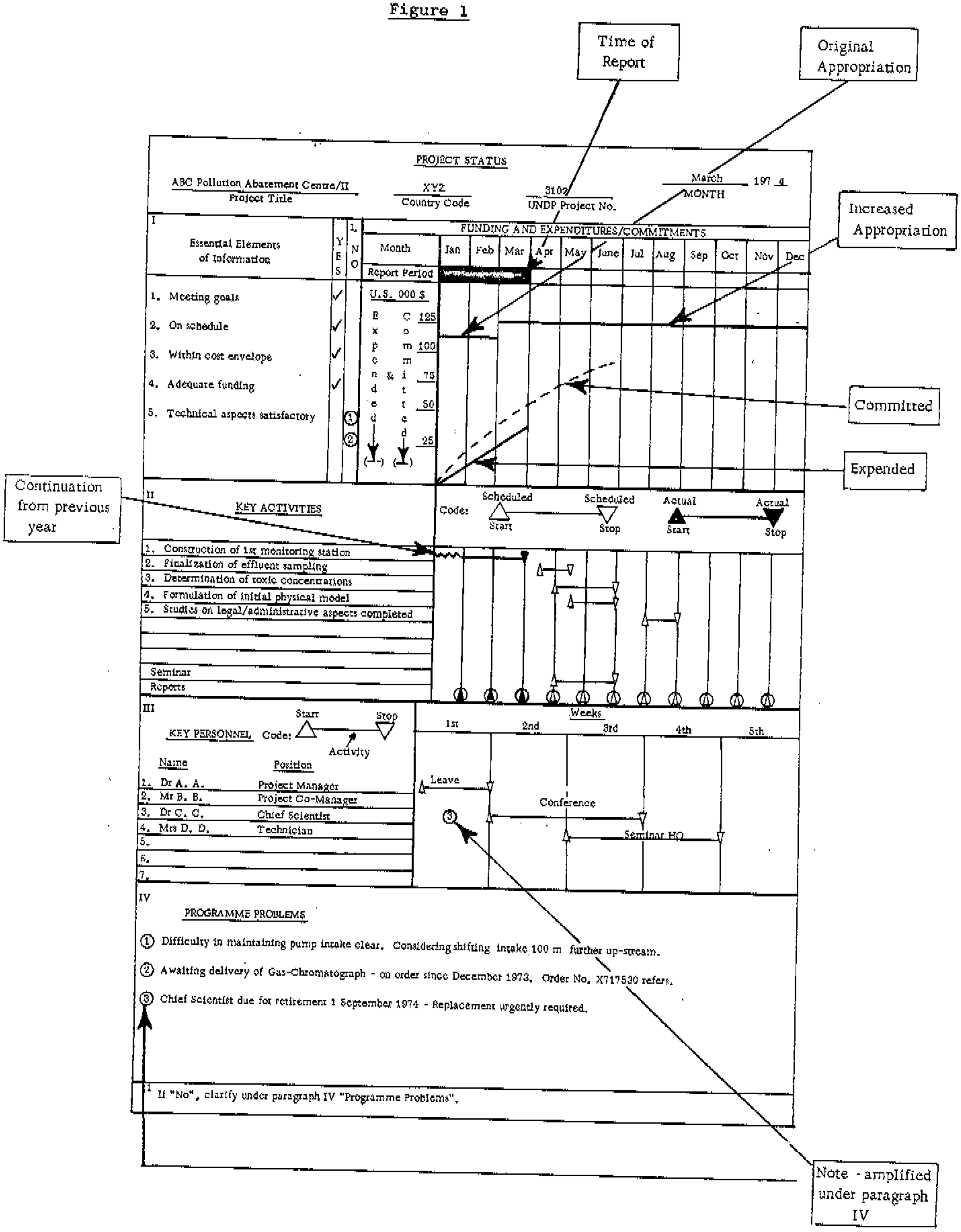
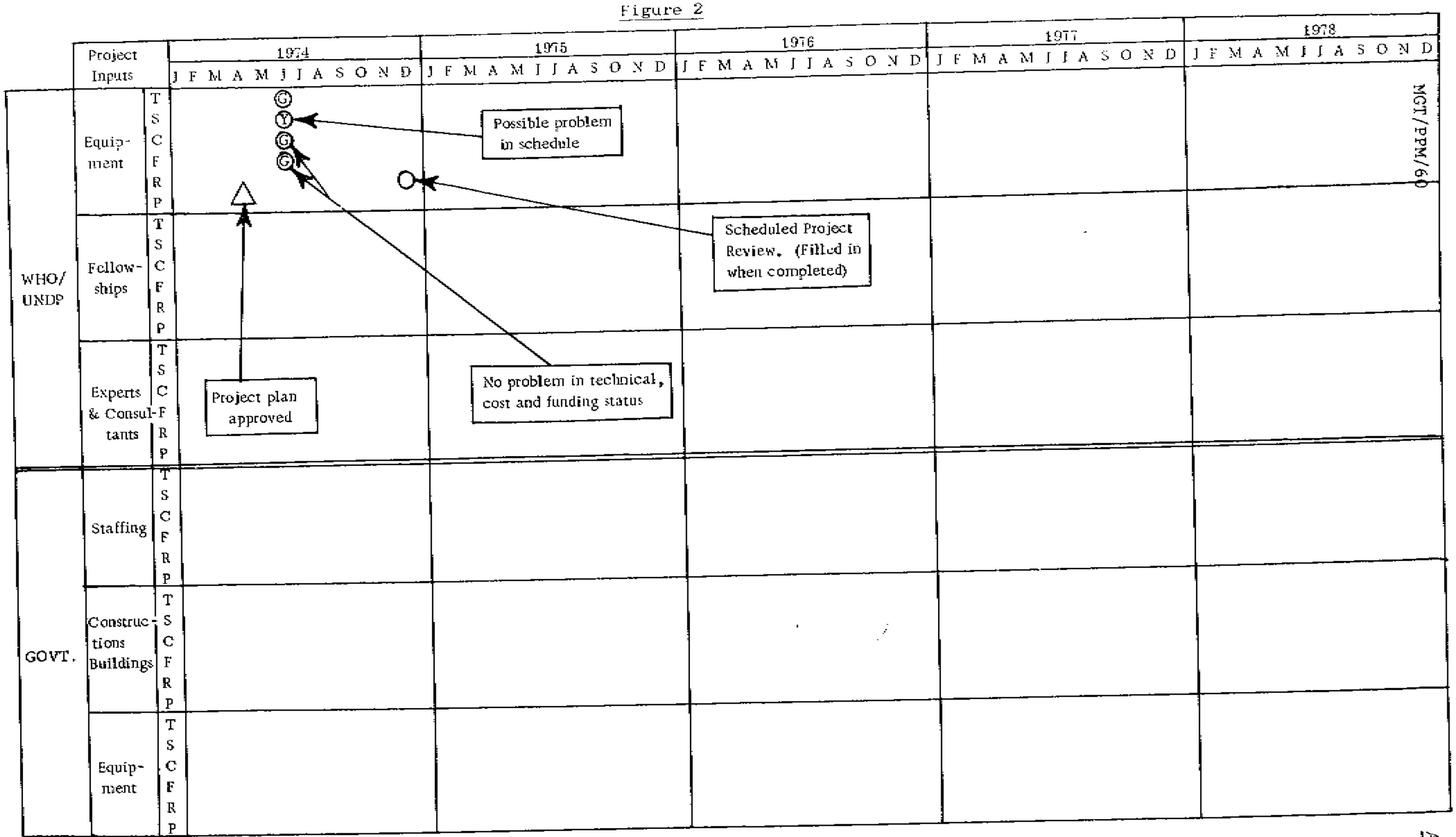

Time of Report
Original Appropriation
PROJECT STATUS
ABC Pollution Abatement Centre/II
Project Title
XYZ
Country Code
3102
UNDP Project No.
March 1974
MONTH
Increased Appropriation
I
Essential Elements of Information
YES
NO
FUNDING AND EXPENDITURES/COMMITMENTS
Month
Jan Feb Mar Apr May June Jul Aug Sep Oct Nov Dec
Report Period
1. Meeting goals
2. On schedule
3. Within cost envelope
4. Adequate funding
5. Technical aspects satisfactory
U.S. 000 $
Expended
Committed
125
100
75
50
25
Committed
Expended
Continuation from previous year
II
KEY ACTIVITIES
Code: Scheduled Start Scheduled Stop Actual Start Actual Stop
1. Construction of 1st monitoring station
2. Finalization of effluent sampling
3. Determination of toxic concentrations
4. Formulation of initial physical model
5. Studies on legal/administrative aspects completed
Seminar
Reports
III
KEY PERSONNEL
Code: Start Stop Activity
Weeks
1st 2nd 3rd 4th 5th
Name Position
1. Dr A. A. Project Manager
2. Mr B. B. Project Co-Manager
3. Dr C. C. Chief Scientist
4. Mrs D. D. Technician
5.
6.
7.
Leave
Conference
Seminar HQ
IV
PROGRAMME PROBLEMS
① Difficulty in maintaining pump intake clear. Considering shifting intake 100 m further up-stream.
② Awaiting delivery of Gas-Chromatograph - on order since December 1973. Order No. X717530 refers.
③ Chief Scientist due for retirement 1 September 1974 - Replacement urgently required.
1 If "No", clarify under paragraph IV "Programme Problems".
Note - amplified under paragraph IV

Figure 2



Code

T = Technical status
S = Schedule status
C = Cost status
F = Funding status

(G) "Green" status
(Y) "Yellow" status
(R) "Red" status

R = ○ Project review
P = △ Project plan approved.