project planning and management series

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ACKNOWLEDGEMENT

The Project Planning and Management Series consists of a set of manuals and associated modules presenting practical approaches, tools and techniques for project planning and management. (See list on back cover). A product of the Government of Jamaica/USAID National Planning Project (1976-1980), the series was developed by the Project Development Resource Team (PDRT) of PAMCO for use in "action-training" workshops and reflects extensive experience in training and project development. All present PDRT members are contributing authors and have worked together in writing, revising and publishing the series. Special credits are due to Dr. Merlyn Kettering for design and development of the series; Dr. Bruce Brooks for writing final versions of many modules; Mrs. Marjorie Humphreys for assuming primary editing and production responsibility and for organizing draft papers into more useful materials; Mr. Lascelles Dixon, head of PDRT since 1979, for designing the cover and improving many of the illustrations; and Mrs. Christine Hinds and Miss Linette Johnson for typing the drafts and final manuscripts. Any comments on the series and its usefulness are welcome.

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MODULE 9

PROJECT SCHEDULING - NETWORK ANALYSIS

Bruce Brooks

A. *PREREQUISITES:* MODULE 3 - Work Breakdown Structure
MODULE 4 - Activity Sheets

B. *INTRODUCTION:*

There are a number of scheduling techniques that rely on network models which have been developed and widely used in programme and project management over the past fifteen years. These methods are often referred to as precedence diagramming and arrow diagramming which are two different techniques used in summarizing the same general aspects of project network analysis.

The Project Evaluation Review Technique (PERT) uses the arrow diagramming technique.

Arrow diagramming depicts activities by the use of arrows, and events by the use of nodes that are placed between the connecting arrows. The arrow diagram below is the format used for PERT scheduling, with events depicted by nodes and activities represented by arrows:

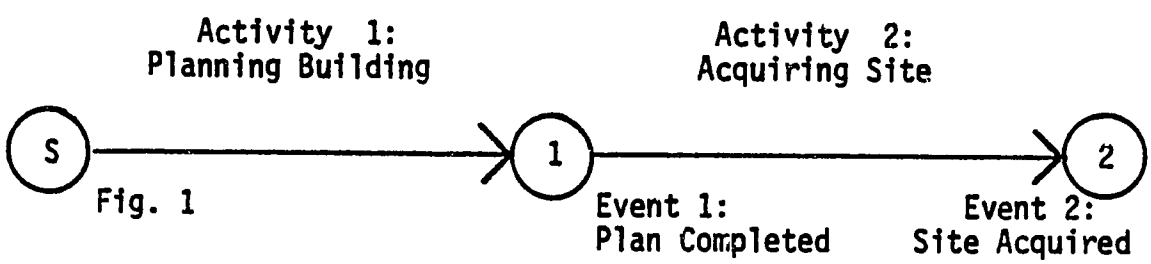

Fig. 1

The form of network analysis which will be described in greater detail in this module is precedence diagramming. The nodes of the diagram are the activities rather than events and the arrows are used only to connect the activities. An activity can be represented by a circle ◯ or a box □, the latter being preferred.

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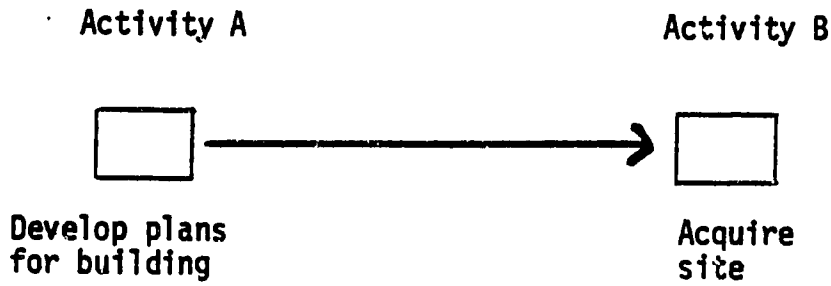
Fig. 2



The activity from which the arrow originates takes precedence over, or must be undertaken before the activity to which the arrow flows. In both PERT and PDM precedence diagrams the network diagrams are time-scaled.

The length of the arrows are not usually related to the time-scale but they can be. The time-scale is determined by the estimated completion times for each activity. The total of the completion times will give the time frame for the entire project. This total time frame of the project is divided into segments of days, weeks, or months, and the project activities are superimposed, resulting in a PERT or PDM network diagram.

THE PRECEDENCE DIAGRAM METHOD

C. PURPOSE:

The Precedence Diagram Method (PDM) of project network analysis is a diagrammatic presentation for planning and controlling sequenced project activities, so a project can be completed in a pre-determined time frame.

D. USES:

When the project activities must be performed in a specific sequence, the PDM method can aid in planning and controlling these activities and thus:

1. enables management to identify the activities that have critical time constraints and therefore must be closely controlled;
2. gives an approximation of the minimum total time needed for completing the project;
3. shows the time that activities must be completed in order to minimize the time in which a project is completed;

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4. facilitates communication to others interested in the project about time constraint problems that can develop if specific objectives fall outside their estimated time-frames; and

5. directs timely attention and resources to the performance of critical activities during implementation so that corrective measures can be taken if necessary to keep the project on schedule.

E. *DEFINITION OF TERMS:*

The clarification of some of the terms used in PDM network scheduling for projects may be needed.

Activities are specific actions taken that have a definite beginning and ending time and are performed to accomplish specific tasks.

A critical activity is a specific task that will delay the entire project if it is not finished on schedule.

The critical path is the sequence of specific activities that must start and finish on time to prevent time sequencing and resource-use problems causing delay of the project. Each activity on the critical path makes use of all the available time scheduled for it. Each activity on the critical path has zero slack time, which means that there is no scheduling leeway for starting or finishing these activities. All of the activities that *are not* on the critical path can be delayed somewhat without causing a completion delay for the entire project. The "time slippage" that is allowed for non-critical activities is called "slack" or "float time".

F. *LIMITATIONS:*

G. *ASSUMPTIONS:*

If a network analysis is to be done, it is assumed that:

1. the project can be segmented into activities that are identifiable during the planning phases;

2. the time for each activity can be reasonably estimated;

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3. signal difficulties to the manager, and delays in making decisions.

I. *STEPS FOR:*

STEPS IN CONSTRUCTION OF A PROJECT NETWORK

Step 1 *Enumerate the activities* needed to complete the project. Each activity is listed by describing it, e.g., complete plans, obtain site, develop site, etc. An alphabetical letter or number is assigned to each activity.

Step 2 Estimate the *time necessary to complete each activity* giving consideration to the available resources and the performance specifications for the activity, i.e., an activity requiring six days to complete with six men and one truck, requires additional resources if the time estimate is reduced to three days. If the specifications for an activity, such as "complete foundations of building", require that the concrete be cured for 72 hours before beginning erection of the superstructure, it is obvious that the three days (3x24) hours) for curing the concrete must be included in the time estimate for the activity.

Step 3 *Arrange the activities in a network* showing their logical sequence from beginning to end of the project. (SEE ILLUSTRATION 1., ABBREVIATED PROJECT NETWORK OF THE ACTIVITIES NECESSARY TO CONSTRUCT A SMALL MANUFACTURING PLANT).

Step 4 *Compute the critical path* through the network to determine which activities are critical to the completion of the project within the total time constraint. (SEE ILLUSTRATION 2. ACTIVITIES TABLE FOR ABBREVIATED NETWORK OF ACTIVITIES FOR CONSTRUCTING A SMALL MANUFACTURING PLANT). Those activities which have no slack time or zero slack time are on the critical path. There can be more than one critical path in a sequenced series of planned activities.

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Examples of Construction of PDM Network Schedule

Definition of other terms that need to be understood.

(a) *Duration of an activity* is the estimate for completing an activity.

(b) *Precedence activities* are those activities that must be completed before another activity can start.

(c) *Earliest start* (ES) for an activity is the earliest time that an activity can begin if all precedence activities are completed. The earliest start time is measured from the beginning of the project.

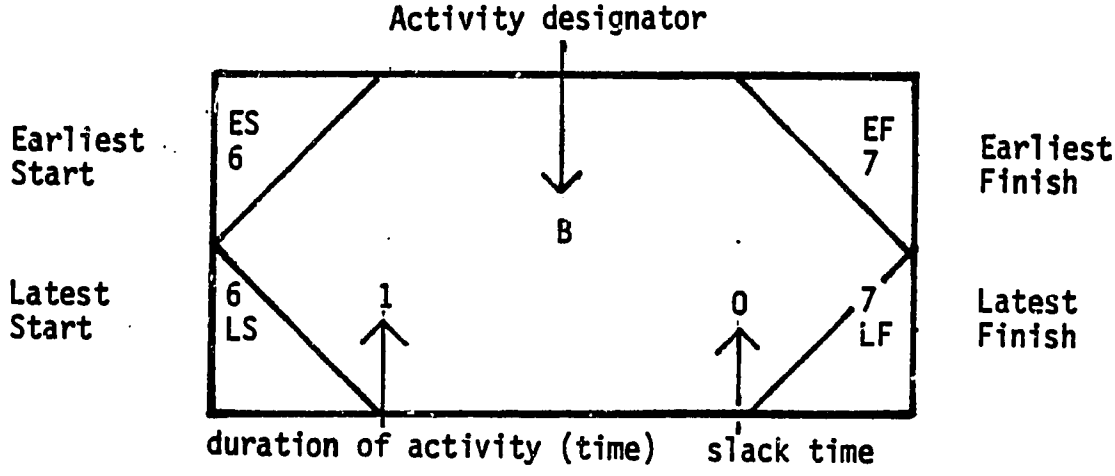
(d) *Earliest finish* (F) for an activity is the earliest start time plus the duration time of the activity.

(e) *Latest finish* (LF) of an activity is the latest time that an activity can be completed (time measured from beginning of the project) without causing a delay in finishing the project.

(f) *Latest start* (LS) is the latest finish time minus the duration of an activity.

(g) *Slack time* for an activity is the additional time available in which the activity can be started or finished. It can be determined in two ways (1) by subtracting the EF (Earliest Finish) from the LF (Latest Finish) i.e., LF - EF = Slack or (2) by subtracting the Earliest Start from the Latest Start, i.e., LS - ES = Slack.

An Illustration of an Activity diagram as it would appear in a PDM Network Diagram is shown below:



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ES or Earliest Start is determined by the EF (Earliest Finish) or the previous activity or predecessor activity.

B is the symbol used to designate this activity. Sometimes a number is used such as 20 or 40.

I is the number one, and represents, the unit of time (one day, week, month) of the estimated duration of the activity.

EF is the earliest finish of this activity and in this case EF is 6(ES) + 1 (duration) or 7.

LS is the Latest Finish minus the duration, i.e., 7 - 1 = 6.

0 is the slack. There is no leeway in the time for this activity. It must be finished within the estimated time frame.

The slack time is computed by:

LS - ES = Slack (6 - 6 = 0)
LF - EF = Slack (7 - 7 = 0)

The manager knows immediately that this activity lies on the Critical Path because it has 0 slack time.

Constructing a Project Network Analysis Using PDM

1. *Identify all the needed activities to complete the project* by listing them on a sheet of paper. Avoid too much detail and duplication (SEE ILLUSTRATION 1).

2. *Give each activity an identifying letter* (A, B, C) *or number* (10, 20, 30). If there are more than 26 activities, use numbers to identify them. If activities are added later, use subscripts on letters (A_1, A_2) or a number between your original numbers, such as 11, 12, 13. When using numbers for identifying activities, it is advisable to start with numbers that have 5 or 10 intervening numbers, e.g., 5, 10, 15, so you can easily add other activities when they are identified.

3. *Estimate the time needed for each activity giving due consideration* to the amount of resources and the level of the specifications that have to be met in order to complete the proejct. (SEE ILLUSTRATION 1).

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4. *Draw the Project Network* with a pencil on a large enough sheet of paper to permit boxes 1½" x 1" to be drawn with the activity identifying letters or numbers of the activities centred in each box. (SEE ILLUSTRATION 2). Arrange the activities in logical sequence from left to right. The sequence followed is taken from the activity list and may need to be altered. Those activities that can be done wholly or in part at the same time are arranged one under or over the other, vertically on the page. Those that must be completed before other successor activities are arranged horizontally across the page (SEE ILLUSTRATION 3). Use arrows to connect each of the boxes (activities) with its immediate successor. All activities must be connected with one or more successor activities except the last or Stop.

5. *Identify the project Start and Stop* by using boxes just like those used for other activities. Each of these activities have zero duration. The starting time of the project has a reference time of zero.

6. Determine each activity's Earliest Start (ES) and Earliest Finish (EF) by:

   (a) beginning with the project start of zero and working from left to right through the network;

   (b) computing the EF for each activity by adding the duration time to its ES;

   NOTE: that the ES for any successor activity is the EF of any predecessor activity which is larger than the EF of any other predecessor activity. But, if there is only one predecessor activity the ES for the successor activity is the EF of the single predecessor activity.

   Repeat (a) or (b) above until the project *Stop* is reached. The ES for an activity *cannot* be computed until all of the preceding activities EF's have been completed. This is true because the ES of any successor activity can be no earlier than the latest finish of any predecessor activity.

7. Determine each activity's latest start (LS) and latest finish (LF) by:

   (a) *beginning at the project stop and working backward through the network.*

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(b) setting the LF of the project stop equal to its EF,

(c) computing the LS for each activity by subtracting the duration from the LF,

(d) noting that the LF for each activity with only one immediate successor is the LS of that successor.

(e) observing the LS of all of the activities that are connected to other activities by an arrow when there is more than one activity, setting the LF equal to the minimum LS of the connected activities. For example, if activity C is immediately after (on backward pass through network) D and E then the LF of C is the same as the LS of D or E whichever is the smaller of the two LS's.

The dotted lines on ILLUSTRATION 2 are two examples of the smaller LS being used as the LF for the next activity, moving from right to left through the network or backward through it. Note that the LF for an activity which follows is the same as the LS of the activity that follows it. The LF of an activity cannot be entered until all of the LS's of the activities to which it is connected have been completed.

8. *The Slack Time* for each activity *is computed* by subtracting the ES from the LS (LS - ES = Slack) or the LF from the EF (EF - LF = Slack). If, when these subtractions are made, the result is 0, then there is no slack for an activity. If, when the subtraction is made, there is a remainder then there is slack time for an activity.

The slack is entered in the activity box underneath and to the right of the activity designator (SEE ILLUSTRATION 3). The slack calculations for each activity can be checked by adding the duration and the calculated slack to the ES. If they equal the LF then the slack calculation is correct.

9. *The critical path* for the project *is identified* by each activity that has zero slack. The activities with zero slack are critical activities. The sequence of the activities that are critical from start to finish of the network is the critical path. There may be more than one critical path in a network. The critical path(s) is marked with a double line or a heavy line as shown in ILLUSTRATION 3.

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10. The duration of the project *as planned is determined* by the EF of the last activity in the project. As *shown in ILLUSTRATION 3*, the duration of this project is 80 weeks.

After the diagram is complete, consideration should be given to shortening some of the activity duration times along the critical path by the use of additional resources or perhaps review of the specifications for performing the activity to determine if some of them might be changed to permit a shortening of the total project duration.

Construction of an Activity Table

Previous to construction of the network the completion of a Project Activity Table is recommended. This table is necessary for doing the PDM network. An example of a network activity table has been worked out in ILLUSTRATION 2 shown on PAGE 14. It contains the activities and duration times for activities shown in ILLUSTRATION 1 on PAGE 13.

REASONS FOR USING CPM PROJECT NETWORK ANALYSIS

There are several reasons why a project manager will find it advantageous to use this project management tool.

1. project progress can be continually and concisely reviewed and communicated to the staff and co-operating and funding agencies;

2. project planning in advance of implementation is encouraged;

3. CP identifies those activities that must be completed on schedule if the project is to be completed on time. The advantage lies in the signals that this tool gives the manager that enable him to devote more attention and/or resources to those activities that are along the critical path;

4. avoidance of unnecessary delays is a frequent result of the PDM of network planning because the manager has previous knowledge about which activities must precede others and the planned activity duration for each activity; and

5. the total time taken for the project can be reduced considerably because the CP makes it evident to the project manager which of the specific activities can proceed simultaneously (not necessarily beginning and ending at the same time, but the time period devoted to the activities may overlap.

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ILLUSTRATION 1

LIST OF LOGICALLY SEQUENCED ESTIMATED ACTIVITIES WITH DURATION TIME OF EACH ACTIVITY FOR BUILDING A SMALL MANUFACTURING PLANT

A.	Develop Plans	6
B.	Acquire Funds	2
C.	Clear Legal Issues	1
D.	Acquire Site	2
E.	Hire Contractor	3
F.	Develop Site	6
G.	Order Building Materials	3
H.	Order Plant Machinery & Equipment	4
I.	Construct Plant	40
J.	Receive and Install Machinery	20
K.	Plant Inspection and Turnover	2

Earlier PDRT working papers relevant to this topic include "Managing Project Plan Preparation, Appendix A: Network Planning", M. Kettering and J. Kristiansen, 1977. (3 pages).

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ILLUSTRATION 2

COMPLETED ACTIVITY TABLE FOR BUILDING
A SMALL MANUFACTURING PLANT

Letter or Number	Activity	Duration	Immediate Predecessors	Immediate Successors	START		FINISH			
					Earliest	Latest	Earliest	Latest	Slack	Status
Start	Start	0	None	A	0	0	0	0	0	
A	Develop Plans	6	Start	B	0	0	6	6	0	Critical
B	Acquire Funds	2	A	C	6	6	8	8	0	Critical
C	Clear Legal Issues	1	B	D,E	8	8	9	9	0	Critical
D	Acquire Site	2	C	G,H	9	10	11	12	1	
E	Hire Contractor	3	C	F	9	9	12	12	0	Critical
F	Develop Site	6	E	1	12	12	18	18	0	Critical
G	Order Materials	3	D	1	12	15	15	18	3	
H	Order Machinery	4	D	1	12	14	15	18	2	
I	Construct Plant	40	F,G,H	J	18	18	58	58	0	Critical
J	Receive and Install Machinery	20	1	K	58	58	78	78	0	Critical
K	Inspect and Turnover	2	J	Stop	78	78	80	80	0	
Stop	Stop	0	K		80	80	80	80	0	

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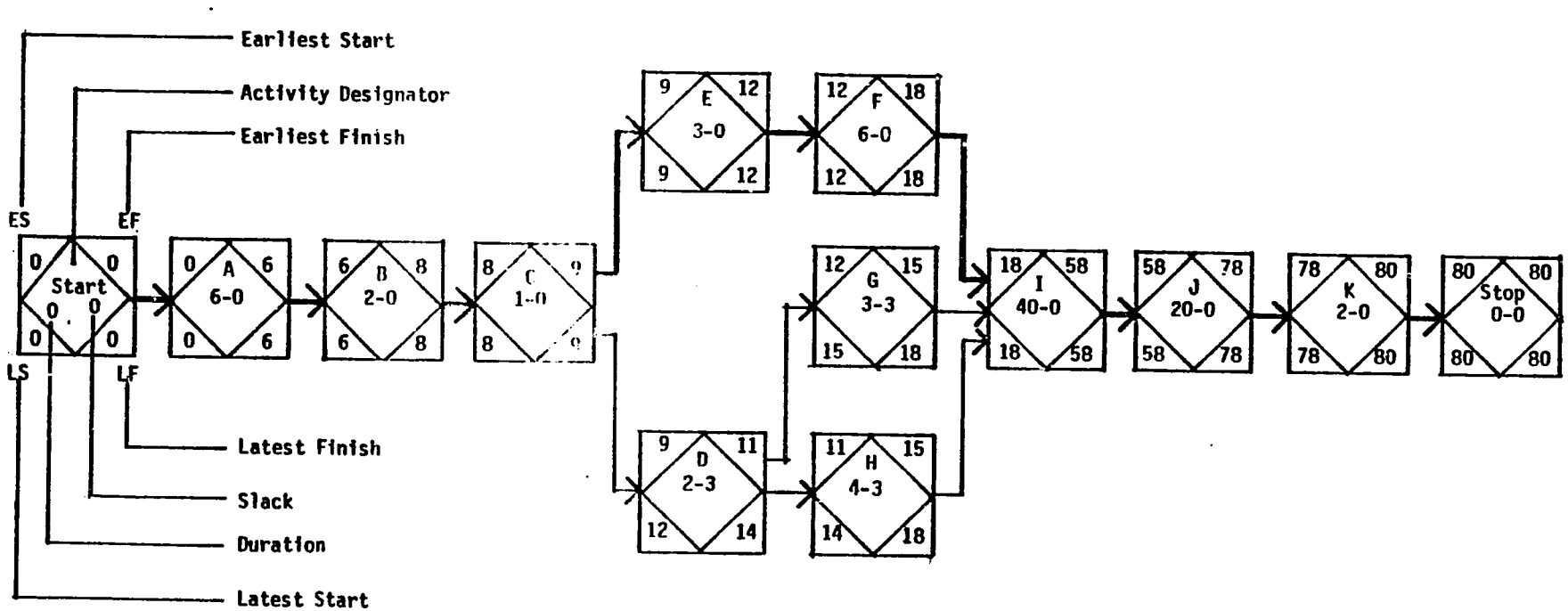
ILLUSTRATION 3

AN EXAMPLE OF CPM NETWORK SCHEDULING FOR BUILDING A SMALL MANUFACTURING PLANT
USING ACTIVITIES AND DURATION TIMES FROM ILLUSTRATION 1



CRITICAL PATH

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