Indian Roads Congress
Special Publication 14

A MANUAL FOR THE APPLICATION OF THE CRITICAL PATH METHOD TO HIGHWAY PROJECTS IN INDIA

New Delhi 1980

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FOREWORD

The use of modern management techniques such as Programme Evaluation and Review Technique (PERT) and Critical Path Method (CPM) have been successfully employed in various Civ Engineering Projects in countries like the U.S.A., Canada and Australia with a view to achieving economy and efficiency. These techniques help management in efficient and economic use of resources in the accomplishment of programme objectives. They also help in effective planning, scheduling, evaluating progress and controlling of projects and programmes. Though PERT and CPM techniques are basically similar, the CPM technique is more widely used in the Civil Engineering industry. PERT is adopted in such projects where activities consuming time are considered uncertain and a probabilistic approach is resorted to. The main features of Critical Path Analysis have application to many programmes that do not warrant the complete PERT treatment.

CPM highlights minimum time required; gives an advance warning about future problems; helps predict the future time need, helps rationalising, optimizing and allocating and reshuffling resources and above all helps in completion of projects in time. Keeping in view the advantages of this technique, I am glad that the Indian Roads Congress have prepared this Manual for the Application of Critical Path Method to Highway Projects in India. In preparing the Manual, similar guides brought out by organisations like Canadian Good Roads Association, Bureau of Public Roads (USA), Department of Highways, Ontario, Department of Main Roads, Australia and some important text-books on the subject have been extensively consulted. The Manual is illustrated by examples of road and bridge projects so that the methodology described in the text can be comprehended easily in actual application.

I am sure, this Manual will not only serve as a useful guide to the Highway Engineering profession, it will also encourage the use of this modern technique in highway construction in our Country.

S.N. Sinha
Past President,
Indian Roads Congress

New Delhi,
September 4, 1973.

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APPENDICES

PLATES

1

Introduction

CHAPTER 1

1. INTRODUCTION

1.1. From the inception of a hignway or a bridge project to its completion, there is a vast expanse of management and admistrative tasks a modern Highway Engineer is called upon to fulfil in the present day. It is no more sufficient for him to be a good professional engineer. It is equally necessary for him to be competent in management in various fields such as planning, organising, staffing, directing, controlling and coordinating. He will have to take bold decisions, both on technical problems as well as management problems. Sound engineering management is an art, but luckily the art is backed by modern scientific tools. These tools can consider the complex problems of choice from various practical solutions. Linear Programming is one such tool which enables the engineer to arrive at an optimal solution to complete a project at the minimum cost for a specified construction time. The Critical Path Method, Known as CPM, has already proved its usefulness in many fields of Civil Engineering and is the natural answer to Highway Engineering Management of the present and the future. Because of its easy and effective applicability to Highway Engineering, the CPM has already replaced the old, familiar bar chart, which used to be the engineer's tool so far for controlling, planning and scheduling of sequences.

1.2. The CPM is the schematic representation of a project by means of a diagram or "net-work", depicting the sequence and interplay of the numerous component events that go to form the project and the utilisation of the data contained in the net-work for determining the most suitable programme for the implementation of the project. The final programme is so selected as to result in the lowest cost consistent with the time factor.

1.3. Though the CPM had its origin comparatively recently in the late 1950s, its demonstrated advantages as a management tool have already made it extremely popular in various branches of Civil Engineering in countries abroad, and large savings are reported in the time and cost of projects by its use. Its use in the highway departments has been widely accepted abroad, in areas such as planning, design, construction, research programmes and maintenance. In India, where there are a large number of constraints due to shortage of resources such as steel and cement, non-availability of skilled labour, seasonal availability of labour and climatic variations (the monsoon period, the season of floods in streams etc), the planning and execution of highway projects could be done in a more efficient manner by the application of CPM. Benefits can be reaped both by the Governmental Departments and the Contractors by its use and it is towards providing the concerned engineers with a ready manual of reference that this publication is directed.

2

Definitions

CHAPTER 2

2. DEFINITIONS

Before the procedure of constructing the network is discussed, it will be necessary to be conversant with the terms commonly used. The definitions of these terms with suitable examples are as follows.

(i) Network or Flow Diagram

It is diagrammatic representation of the entire project, wherein the order in which the various items of works must be performed is shown. A typical network is shown in Fig 1. Generally, in a network, the general flow of events is from the left to the right.

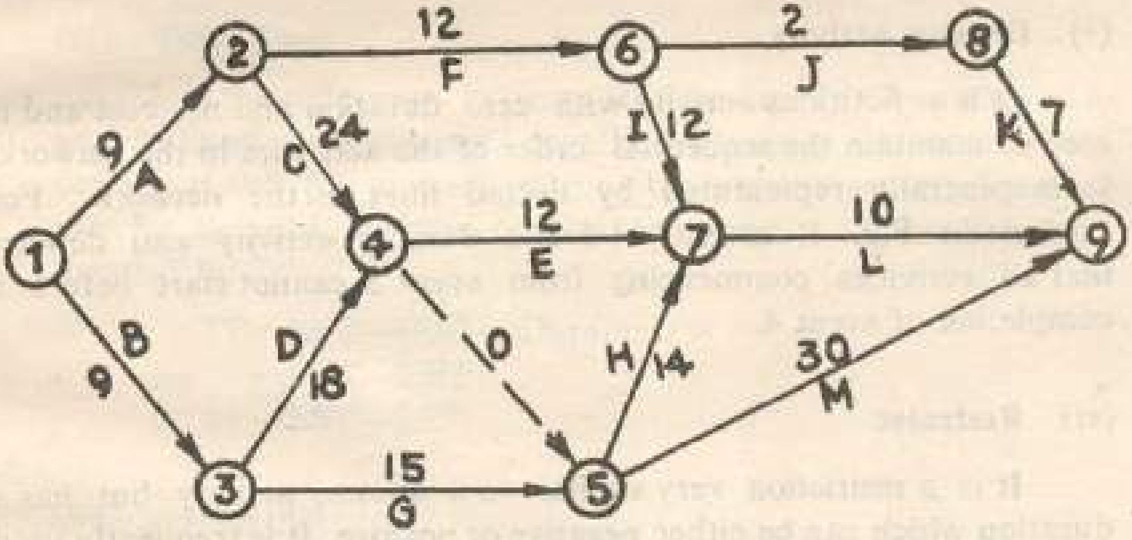


Fig. 1

(ii) Activity

An activity is a part of the project denoted by an arrow on the network, the tail representing the start of the activity and the head the end of the activity. One and only one arrow can be used to represent one activity or operation. Each activity has to have a given time. However, length and direction of the arrow have no significance. For example in Fig. 1, an activity can be represented as 1-2 or by 'A'.

(iii) Event

An event is a stage or a point where all previous jobs are complete and the succeeding ones are to start. The event is represented on the network by a circle (node) at the junction of arrows. An event cannot occur until all the activities leading to it are completed. Similarly, no activities emanating from an event can start until the event has occured. These events are numbered in their sequential order on the network.

(iv) Durations

Duration is the estimated time required to complete an activity and is denoted on the activity in the network. For example the duration for activity 1-2 (A) is 9 days in the network shown in Fig. 1 The duration can be expressed in any convenient unit such as hours, days, weeks, months, etc.

(v) Dummy Activity

It is a fictitious activity with zero duration and no cost and is used to maintain the sequential order of the activities in the network. It is generally represented by dotted lines on the network. For example in Fig. 1, activity 4-5 is a dummy activity and denotes that all activities commencing from event 5 cannot start before a completion of event 4.

(vi) Restraint

It is a restriction very similar to a dummy activity but has a duration which can be either negative or positive. It is frequently used to fix intermediate dates within the network and thereby fix the relative start or finish of the parallel activities, when these activities are not coincident.

(vii) Early Start Time

It is the earliest possible time an activity can start without changing the sequence of activities in the network. It is denoted as EST. EST of an activity is also the Early Finish Time of the event preceding it, i.e. the event at the tail of the activity arrow.

(viii) Early Finish Time

It is the earliest time by which an activity can be completed. It is denoted by EFT.

EFT of an activity = its EST + duration of activity

(ix) Late Start Time

It is the latest time by which an activity can start without delaying the project. It is denoted as LST.

LST of an activity = its own LFT — its duration

(x) Late Finish Time

It is the latest time by which an activity can be completed without delaying the project. It is denoted as LFT. The LFT of an activity is also the LFT of the event at the head of the activity arrow.

(xi) Total Float

It is the difference between the maximum time allowed for an activity and its estimated duration. It can, in other words, be defined as the full amount of time by which the start of an activity can be delayed without causing the project to last longer. It is denoted by TF.

$$\begin{aligned} TF &= LFT - (EST + \text{Duration}) \\ &= LFT - EFT \\ \text{or } TF &= LST - EST \end{aligned}$$

(xii) Free Float

The free float of an activity is the amount of time by which the activity can be delayed without interfering with the start of succeeding activities. It is denoted as FF.

FF = EST of its following activity — its own EFT

(xiii) Interfering Float

It is the difference between the total float and the free float. Consumption of any of the interfering float time in a delayed start of an activity will necessarily retard some of the following activities, but will not delay the overall project time. Interfering float is denoted by IF.

$$IF = TF - FF$$

(xiv) Critical Path

The events which have no float are the critical events, i.e. they have the same EFT and LFT or in other words no leeway. These events must be completed on schedule if the project is to be completed in the minimum total time. The path joining such critical events is called the critical path of the network.

(xv) Critical activities

The activities lying on the critical path are called critical activities. Critical activity has a zero float.

3

Network Construction

CHAPTER 3

3. NETWORK CONSTRUCTION

3.1. The basic step in analysing a project by the CPM technique is to draw up the net-work, which schematically represents the entire project after it is split up into a number of activities. The procedure involved in drawing up the network is detailed in the succeeding paragraphs.

3.2. As a first step, the activities involved in the project are carefully listed out without regard to their order of occurrence. Care must be taken to see that none of the activities involved are left over, as an error at this stage would be a basic one and consequent to which the network would be entirely wrong. It should, however, be noted that the number of activities into which a project is to be split will depend entirely upon the extent of detailed control and information feed back desired. The Bill of Quantities for the work will give a very good idea of the various feasible activities involved, but some of the items included in the Bill of Quantities may themselves have to be broken down further into smaller activities, depending upon the degree of refinement needed.

3.3. The next step is to establish a logical sequence of the activities. In arranging the order of the activities, the following should be kept in mind':

(a) Which are the activities that must be completed before the start of each activity?

(b) Which activities can occur simultaneously?

(c) Which activities must succeed each activity?

3.4. Necessary constraints in the project should be identified at this stage. The constraints may be materials, equipment, labour, variations in season etc. For example, in a road construction job, the bitumen might be available only at a specified date. While all activities not requiring bitumen can be done prior to this date, the mixing and laying of the bituminous pavement can be done only after that date. Labour might not be available in the harvesting season, and this factor is a major restraint in the project scheduling. Heavy rains in monsoon period rule out the possibility of bituminous work and this is a seasonal limitation.

3.5. The actual drawing up of the flow diagram can now be possible. The following simple illustrations indicate how a net-work can be constructed.

Logic behind the diagram

FIG. 2

Activity C can start only after activity B ends. Activity B can start only after activity A ends

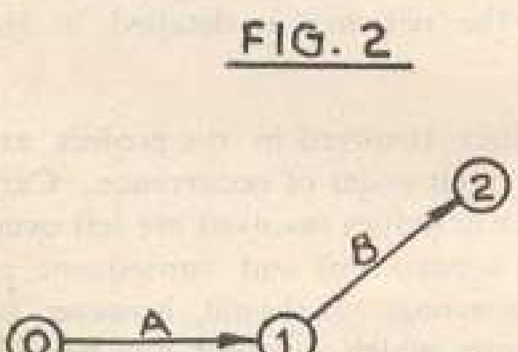


FIG-3

Neither activity B nor C can start unless activity A ends

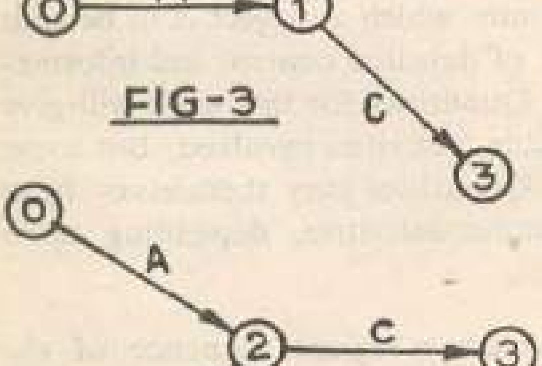


FIG-4

Activity C can start only after both activities A and B end

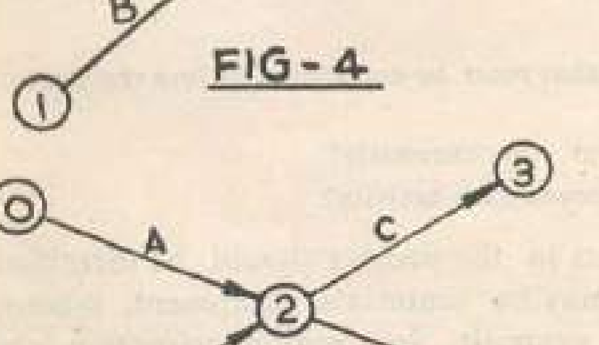
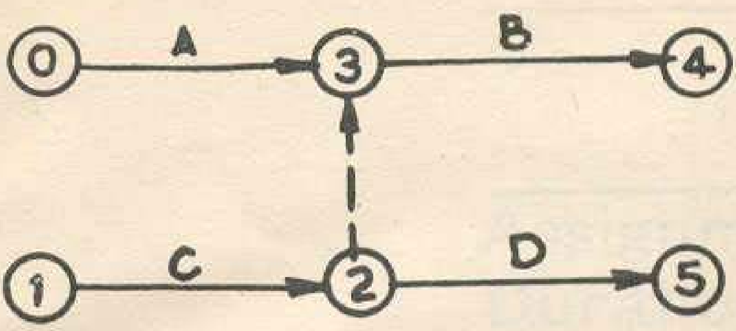


FIG-5

Activities C and D cannot start unless activities A and B are completed, but activity C can be started independent of D and *vice-versa*



Activity B cannot begin until both activities A and C are completed, but activity D can start after activity C is completed. The dashed arrow here represents a dummy activity to maintain the logical sequence of activities and their inter-relationships.

Fig. 6

3.6. After the net-work is completed, it should be checked for accuracy of logic by beginning at the final event and working backwards towards the start, going from event to event and checking whether (i) each activity beginning at an event depends upon all activities leading to the event, and (ii) all activities upon which the one in question must depend, lead into the event.

3.7. The following data leads to the preparation of the network diagram given in Fig. 1.

(1) Activities A and B, which occur at the start of the Project, can be performed concurrently.

(2) Activities C and F are preceded by Activity A

(3) Activities D and G are preceded by Activity B

(4) Activity E follows activities C and D

(5) Activities H and M both cannot start till Activities C, D and G are completed

(6) Activities J and I follow Activity F

(7) Activity L is preceded by Activities I, E and H

(8) Activity K follows Activity J

(9) Activities K, L and M can occur simultaneously to take the project to completion

3.8. It will be seen from the net-work in Fig. 1, that each node is numbered. The numbers are chosen in a purely arbitrary way, generally proceeding from lower numbers at the start of the project and having higher numbers as the project advances.

4

Assignment of Durations for Activities

CHAPTER 4

4. ASSIGNMENT OF DURATIONS FOR ACTIVITIES

When the network has been completed, it is necessary to assign duration to each activity. Duration is the time required to complete the activity. Duration is assigned to each activity entirely on its own without considering the effects and delays caused from the adjoining activities. Such influences are taken care of in calculating the critical path itself and need not enter at this stage. The duration should be established by individuals having thorough familarity with the details involved in the project. Previous history of similar projects will be valuable guides, provided the information is updated and is not old. The time initially assigned is the normal time or average time assuming that all available resources can be applied for the completion of each activity. The time estimates are later on refined, considering all the activities in progress during the same period and optimising the available equipment and other resources. The unit of time used in the network for assigning duration could be hours, shifts or days as can be convenient for a particular case but the unit should be the same for all the activities in a particular network. The duration is written above or below the arrow line representing the activity, vide Fig. 1.

5

Determination of Project Schedule and Critical Path

CHAPTER 5

5. DETERMINATION OF PROJECT SCHEDULE AND CRITICAL PATH

5.1. The next objective is the preparation of the project schedule and the critical path. In order to accomplish this, it is necessary to run through the events in the network and determine the Early Finish Time (EFT) and Late Finish Time (LFT) of each activity. In this procedure, the node at the start of the network is assigned a value of zero. As one progresses, the duration of each succeeding activity is added to the Early Finish Time of an event to determine the Early Finish Time of the next event. In doing so it, will be seen that the earliest finish time of each event is one which is arrived at by the longest path. In the example of Fig. 1 the early finish time for event (4) works out to 33 days via activities 1-2 and 2-4 and 27 days via activities 1-3 and 3-4. In this case, the EFT is the greater of the two values i.e. 33 days. All the EFT thus calculated are marked on the left half of the 'oval time space' on the net-work. After proceeding in this manner, through the net-work, EFT of the last event is known i.e. the earliest possible time by which the project can be completed which is the sum of the duration of the longest time path through the network. It will be seen that in the example shown in Fig. 7, the EFT of the last event is 63 days. Accepting this as the project duration time, the latest finish time (LFT) of the final event becomes 63 days. This is entered in the right half of the "oval time space" of the final event. From the LFT of the final event, one works backwards to find the LFT of each event. The LFT is controlled by all the activities starting from the event concerned and is the minimum figure so obtained. For instance consider event (4). Its LFT considering activity 4-7 would be 53-12=41 days but as there is a dummy activity 4-5 of zero duration, the LFT comes to 33—0=33 days. As such the LFT of event (4) will be the minimum value i.e. 33 days. It is thus possible to work out the LFT of each event which have been shown in the right half of the "oval time space" on Fig. 7.

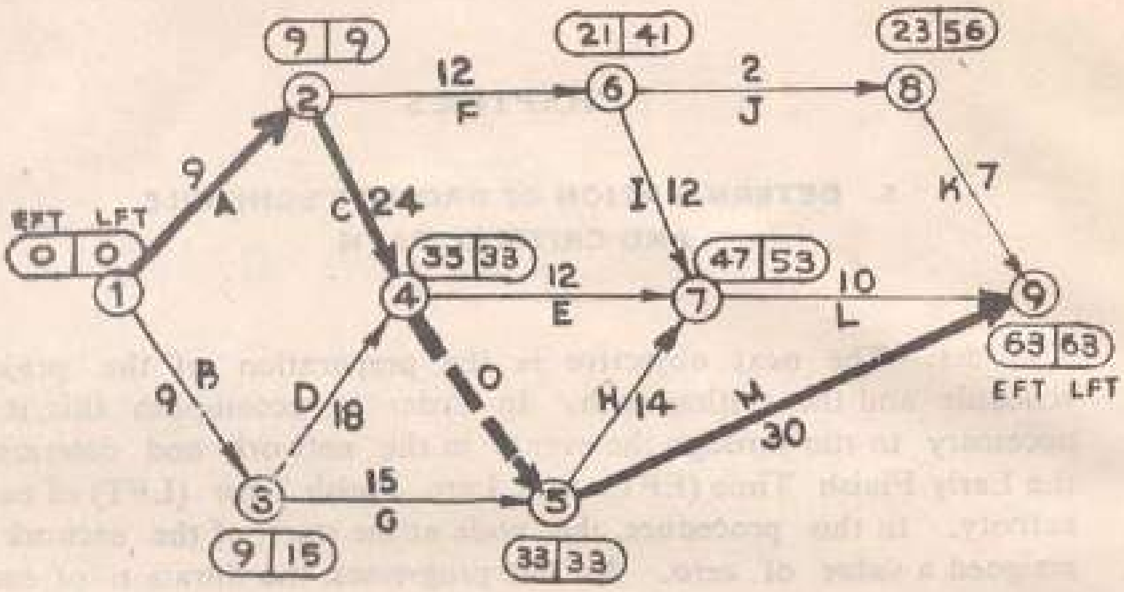


Fig. 7

5.2. The events in which the EFT and LFT are the same or in other words there is no leeway, fall on the critical path. The critical path is shown in heavy lines on the network in Fig. 7 and passes through the events 1, 2, 4, 5 and 9. It may be noticed that for any particular project, there may be more than one critical path. The critical path will be a continuous line beginning from the start of the project and ending at its completion. All activities on the critical path must be completed on schedule and cannot be prolonged. On the other hand, the activities outside the critical path, can be prolonged within the limits indicated by their floats, without prolonging the total project time.

5.3. Activity times, Floats and Bar graph

After having derived the earliest and latest finish times for all the events in the project, the next step is to find the activity times and the floats. In Fig. 7, activity 6-8 has a duration of 2 days and it is apparent that event 6 could occur as early as the 21st day; whereas event 8 could be as late as the 56th day, so there might be 35 days available in which this "2 days" activity could be done. This activity therefore, has a total leeway of 33 days and is not a critical activity. On the other hand, activity 2-4 is critical having no float at all. The EST, LST, EFT, LFT and floats have been calculated in respect of all the activities and are shown in Table 1.

TABLE 1

Activity Item	Activity Arrow	Duration in days	EST	LST	EFT	LFT	TF	FF	IF	Remarks
A	1-2	9	0	0	9	9	0	0	0	Critical
B	1-3	9	0	6	9	15	6	0	6	—
C	2-4	24	9	9	33	33	0	0	0	Critical
F	2-6	12	9	29	21	41	20	0	20	—
D	3-4	18	9	15	27	33	6	6	0	—
G	3-5	15	9	18	24	33	9	9	0	—
Dummy	4-5	0	33	33	33	33	0	0	0	Critical
E	4-7	12	33	41	45	53	8	2	6	—
H	5-7	14	33	39	47	53	6	0	6	—
M	5-9	30	33	33	63	63	0	0	0	Critical
I	6-7	12	21	41	33	53	20	14	6	—
J	6-8	2	21	54	23	56	33	0	33	—
L	7-9	10	47	53	57	63	6	6	0	—
K	8-9	7	23	56	30	63	33	33	0	—

The essential time relationships between the various activities can now be analysed and decisions taken concerning the scheduled timing of the activities in the construction works. To appreciate the scheduling of time better, often the CPM bar graphs are drawn. The CPM bar graph for the activity times and floats shown in Table 1 is given in Fig. 8.

Study of Fig. 8 will reveal that this chart is identical to the conventional construction programme, but in addition it shows the critical activities and the float times. Hence one can see just at a glance which are the activities which cannot be delayed and also in which activities delay can be tolerated and by how much. Thus the planner has a better tool in hand to know exactly the repercussion of any delay in the entire project and hence can undertake the necessary remedial measures in time.

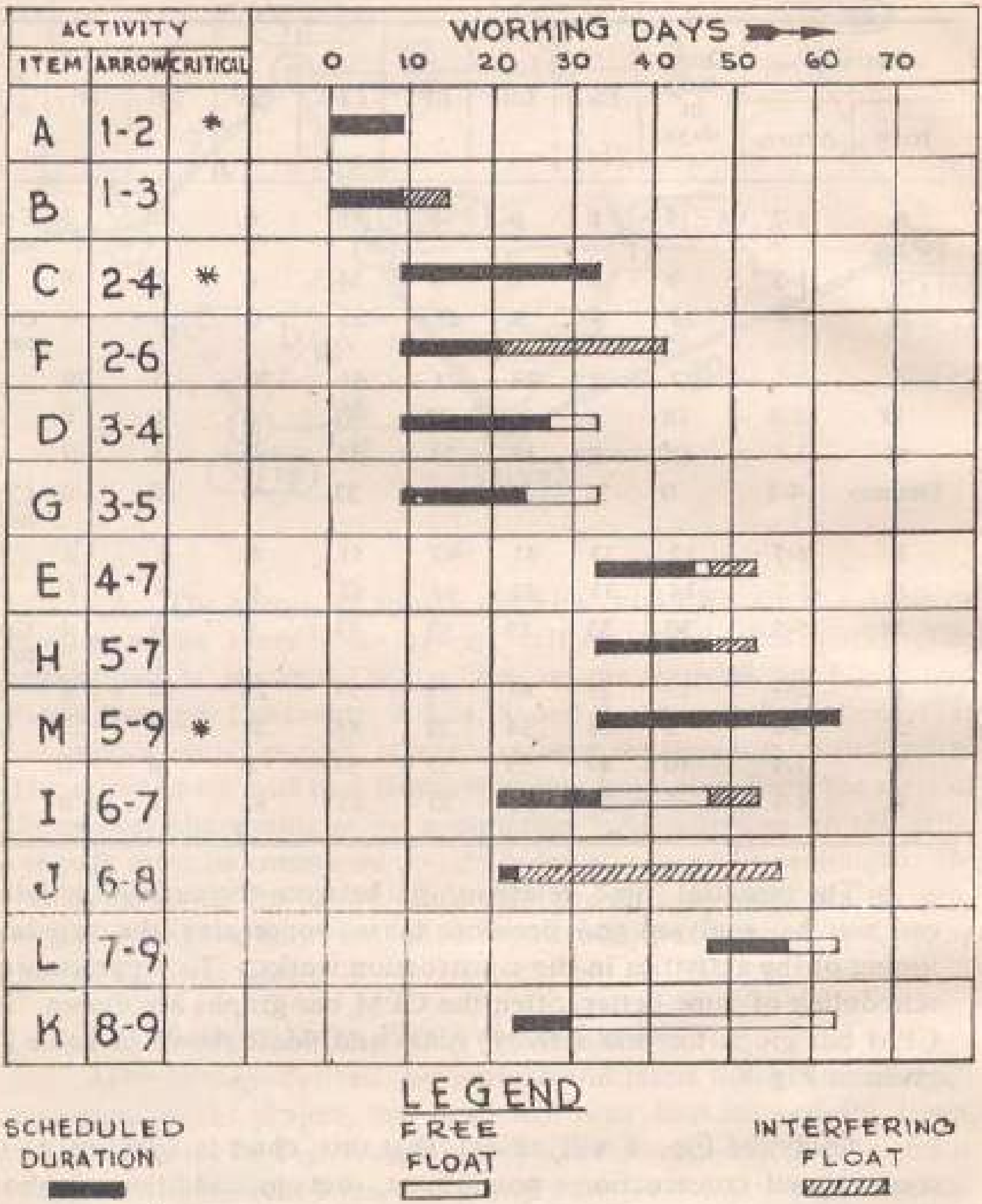


Fig. 8. Bar Graph

6

Cost-Time Balancing

CHAPTER 6

6. COST—TIME BALANCING

6.1. It was mentioned in Chapter 4 that the initial network utilises time estimates which are "normal" or "average" times, assuming that all resources can be applied for the completion of each activity. Obviously such a scheduling is not the best one financially, and many alternatives will have to be considered before a final one can be selected. The selection of an appropriate alternative is rendered simple by the CPM technique.

6.2. The effect of altering the duration of a particular activity may be very marked on the project as a whole. This is illustrated by considering the network of Fig 7. If the activity 5-9 can be carried out in say, 21 days instead of 30 days, the network gets altered. The modified network would be as shown in Fig 9.

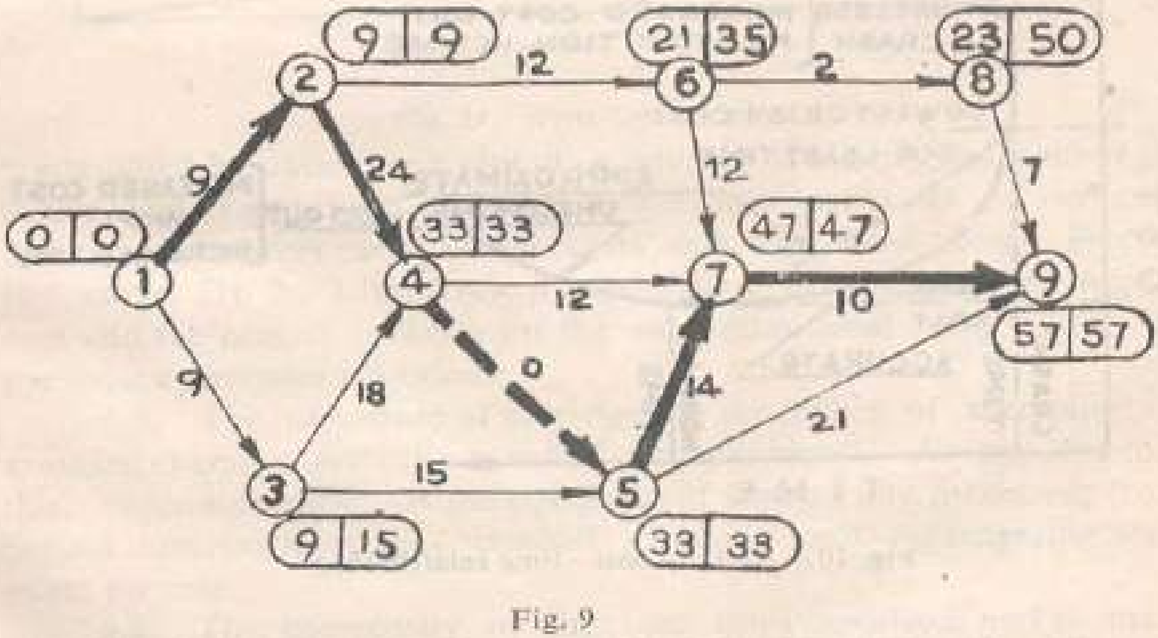


Fig. 9

It will be seen that the critical path which was earlier along 1, 2, 4, 5 and 9 has changed to 1, 2, 4, 5, 7 and 9 and the project duration time has shortened to 57 days from the earlier period of 63 days.

6.3. In order to evaluate the monetary affect of reducing or increasing the duration of each activity, it is necessary to have activity time/cost relations. Such relations can be established only on the basis of past records of project cost and time. It would be necessary for the organisation to develop a bank of such data so that effective use can be made of them in future scheduling of projects and working out the optimum solution. A typical time/cost curve for an activity is illustrated in Fig. 10. The lowest cost (least cost) is also called the normal cost and the time when this is obtained is called the normal time. From the curve it is seen that as the time is reduced, the cost tends to go up curvilineary, till a point of least time reached. Further reduction in time is not possible and the cost increases with no time reduction. The least time is often called "crash time" and the operation of speeding up an activity is called "crashing". The minimum cost of the project at the crash time is called the "crash cost for least time". For approximation, the curvilinear relation can be treated as a linear relation shown in dotted line in Figure 10. The slope of the straight line gives an indication of the sensitivity of the activity as far as its time-cost relation is concerned.

Fig. 10. Activity cost—time relationship

6.4. In a net-work, if the project is to be completed with a smaller period, it is necessary to "crash" a number of activities. It is uneconomical to crash all activities (all crash solution) as it will result in useless expenditure of resources. Only those activities which are critical need be crashed so that the project duration is reduced. The solution obtained by crashing the activities along the Critical Path is called the "Least Time Solution". While crashing some of the activities along a critical path, it may so happen that some more activities might become critical. In such cases, it is necessary to crash both the previously critical and the newly critical activities in order to further expedite the project. To arrive at the most economical solution, it is necessary to examine a number of optimal solutions that lie between the all normal solution on the one hand and crashed least time solution on the other hand. The procedure

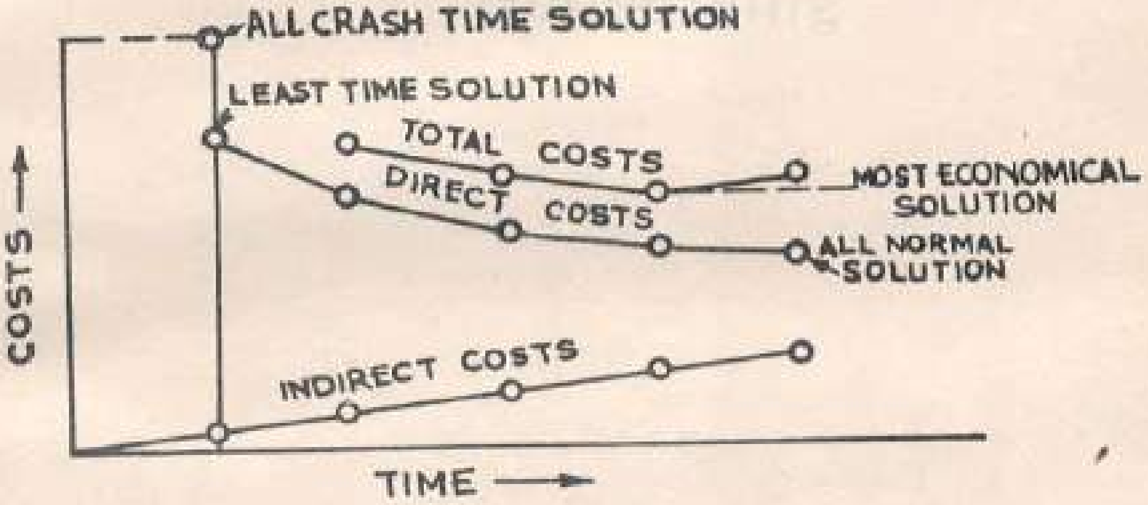


Fig. 11. Cost-time curve

is simplified by obtaining a plot of a number of alternatives involving different costs and duration. Fig. 11 indicates such a set of curves, derived for Indirect costs, Direct costs and the Total costs. From the curve for the Total costs, it is possible to obtain minimum total cost and the project duration for the minimum total cost. This is the most economical solution.

6.5. The procedure of investigating the effect of successively crashing various activities is called "compression". As opposed to this, "decompression" is the operation of successively increasing the project duration from the "crashed solution" and investigating its effect on cost.

6.6. The complexity of the operations involved makes the calculations laborious. If the operations are too large, use of computors become inevitable. Activities upto 200-400 can reasonably be handled manually, but a larger number needs computors.

7

Resources (Manpower, Equipment) Scheduling

CHAPTER 7

7. RESOURCES (MANPOWER, EQUIPMENT) SCHEDULING

7.1. It has been mentioned earlier in Chapter 4 that when the initial CPM network is drawn up, the duration of each activity is fixed on the assumption that all resources are available and can be applied for the completion of each activity. In actual practice, this ideal condition is hardly met with as there will always be a limit to the availability of resources such as labour, plant and equipment. At a particular time, there may be many activities in a project that demand allocation of these resources. It, therefore, often becomes necessary to schedule the requirements of the resources on a time base. The concept will be illustrated by the following example.

7.2. Fig. 12 shows a network of a project which involves the use of a concrete mixer. The period of each activity in days is indicated above the activity line and the number of mixers required on each day of the activity duration is given in brackets.

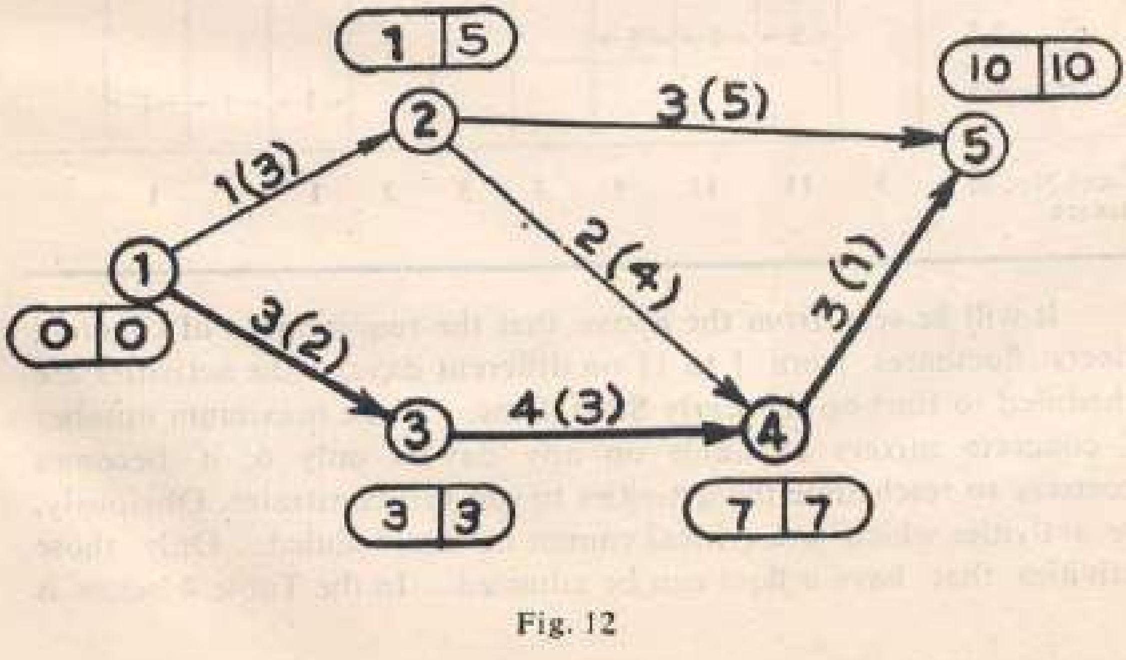


Fig. 12

Table 2 below depicts the schedule of the project.

TABLE 2

Activities	Duration	EFT	LFT	EST	LST	Total Float	Remarks
1-2	1	1	5	0	4	4	
1-3	3	3	3	0	0	0	Critical
3-4	4	7	7	3	3	0	Critical
2-4	2	3	7	1	5	4	
2-5	3	4	10	1	7	6	
4-5	3	10	10	7	7	0	Critical

Table 3 represents the requirements of the concrete mixers for each day of the project duration of 10 days, assuming that the activities start at EST.

TABLE 3 SHOWING NUMBERS OF MIXERS ON EACH DAY

Activities / Days→0	1	2	3	4	5	6	7	8	9	10
1-2	←3→									
1-3	←2→	←2→	←2→							
3-4				←3→	←3→	←3→	←3→			
2-4		←4→	←4→							
2-5		←5→	←5→	←5→						
4-5								←1→	←1→	←1→
Total No. of mixers	5	11	11	8	3	3	3	1	1	1

It will be seen from the above that the requirement of concrete mixers fluctuates from 1 to 11 on different days, if the activities are scheduled to start on the Early Start Time. If the maximum number of concrete mixers available on any day is only 6, it becomes necessary to reschedule the activities to suit this constraint. Obviously, the activities which are critical cannot be rescheduled. Only those activities that have a float can be adjusted. In the Table 4 below is shown a rescheduling of the non-critical activities within the leeway provided by their float, so as to limit the maximum number of mixers per day to 6.

TABLE 4 SHOWING NUMBER OF MIXERS ON EACH DAY AFTER RESCHEDULING THE PROJECT

Activities / Days→	0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10
1-2	3									
1-3	2	2	2							
3-4				3	3	3	3			
2-4		4	4							
2-5				1	2	2	2	3	3	2
4-5								1	1	1
Total No. of mixers	5	6	6	4	5	5	5	4	4	3

From the above example, it is seen how the CPM enables one to reschedule the project, without prolonging it, within the constraints of resources availability.

8

Budgeting and Actual Cost

CHAPTER 8

8. BUDGETING AND ACTUAL COSTS

Generally in most projects, the planner is time as well as cost bound. The planner has to coordinate his resources so as to meet the actual requirements and at the same time keep to the time schedule. For projects, it is possible to draw a graph of resources vs time. Normally manpower constitutes the most common resource, and a graph of number of man-hours vs time can be drawn to indicate to the planner the actual manpower requirements during a particular period and thus gives him sufficient warning to arrange the same timely.

Similarly with the data available from CPM network it is also possible after having drawn the bar graph to draw the graph of total expenditure against time. In this very graph, the expenditure actually incurred can also be shown so as to indicate to the planner, whether the actual expenditure is likely to exeed the budgetary provision and if so what precautionary steps have to be taken.

9

Application of CPM to other related Highway Matters

CHAPTER 9

9. APPLICATION OF CPM TO OTHER RELATED HIGHWAY MATTERS

9.1. Apart from highway construction, the CPM technique has found useful application in a variety of areas being dealt with by the Highway Department. Some of these are :

(i) Highway Planning
(ii) Transportation Planning
(iii) Highway Location Studies
(iv) Investigation studies for Bridge Projects
(v) Design of Highways
(vi) Design of Bridges
(vii) Acquisition of Right-of-way
(viii) Preparation of Plans and Estimates and Contract Award
(ix) Highway Maintenance

9.2. Highway Planning

Highway Planning for a State or a Country or urban street planning for cities involve a number of time-bound activities such as preparation of highway inventory, conducting traffic census, forecasting demand, establish sufficiency ratings, determine highway needs, establish design geometric standards, fix priorities, determine financing procedure, etc. A network can be prepared interconnecting all such activities to keep a close watch on the actual progress.

9.3. Transportation Planning

Transportation Planning is a complex task and involves a large number of detailed activities, such as examination of adequacy of existing facilities, study of accident data, compilation of traffic data, preparation of traffic flow maps, study of travel time, collection of data on existing street inventory, study of land-use, review of parking needs and existing facilities, development of origin and destination survey data, formulation of future transportation facilities, etc. CPM network analysis will help to monitor such a large planning exercise.

9.4. Highway Location Studies

The activities that generally constitute highway location studies could be a review of existing facilities and their shortcomings including sub-standard geometrics and capacity, establishment of design controls and standards, selection of alternative routes on existing maps, preliminary engineering studies, alternate rough cost estimates, cost-benefit analysis, final recommendation of location, etc.

9.5. Investigation Studies for Bridge Projects

The investigation studies for Bridge Projects embrace activities such as site selection, foundation exploration, compilation and analysis of hydraulic data, water-way fixation, selection of alignment of approaches, etc. If a good degree of control is desired over these inter-related activities, a network analysis should be prepared.

9.6. Design of Highways

The activities involved for designing highways are many and varied. They pertain to soil studies, pavement design, embankment design, geometric design of highways, drainage studies, preparation of plans, centre line survey, etc.

9.7. Design of Bridges

Design of Bridges can be broken down to smaller activities such as fixation of water-ways, arrangement of spans, selection of type of substructure and superstructure, detailed design of foundations substructure and superstructure, preparation of detailed drawings, etc. If a good amount of control is desired over the time for preparation of the designs and if the schedule is to be kept up, considerable gain can be had from applying the CPM techniques.

9.8. Acquisition of Right-of-way

Acquisition of Right-of-way in this country involves a number of distinct stages, and some of them are governed by the legal provisions of the Land Acquisition Act. Matters can be sorted out properly if the individual steps are identified and the critical activities given special attention.

9.9. Preparation of Plans and Estimates and Contract Award

The preparation of detailed drawings that form the basis for award of contracts and the preparation of estimates are involved in a large way in the working of any Highway Department. The steps involved in this work can be broken down and a linear programme evolved for effective control over the time. The work of award of contract also involves certain time-related sub-activities, such as preparation of bill of quantities, preparation of specifications, preparation of general conditions of contract, issuing press notice for inviting tenders, receipt of tenders, scruitiny of tenders, negotiation with tenders, approval of tender and award of work. This work also lends itself to advantageous application of the CPM technique.

9.10. Highway Maintenance

Highway maintenance is an operation that involves judicious use of scarce equipment and resources. In addition, the work is highly time-related since certain operations can be carried out only during certain seasons. An annual procedure for maintenance operations, considering the maintenance needs and other circumstances, can be evolved with the C.P.M. technique.

10

Advantages of the Application of CPM to Highway Projects

CHAPTER 10

10. ADVANTAGES OF THE APPLICATION OF CPM TO HIGHWAY PROJECTS

10.1. The use of CPM is becoming increasingly popular in highway projects. The general feeling that such projects do not offer precise mathematical solutions as produced by CPM should not lessen the usefulness of the technique in any way. In our country, there are certain peculiar constraints such as non-availability of essential materials, and it is often argued that the initial schedule can hardly be kept up for many projects. It should, however, be realised that such constraints are no deterrents to the application of CPM. In fact CPM owing to its flexibility not only facilitates amendments to a large extent but also clearly indicates the effect of delays and as such provides satisfactory ways of dealing with these problems.

10.2. Experience has shown that the application of CPM to highway projects results in several advantages over the conventional reporting system. These are:

(a) The pre-requisite of CPM analysis requires a thorough and detailed examination of the project.

(b) It enables the planner to chalk out a logical programme with inter-dependence of the various activities and restraints.

(c) It provides a useful method of scheduling the resources to the best of advantage.

(d) It indicates and emphasizes the likely activities which may be the cause of the trouble and delay in the project.

(e) It provides a basis for reporting progress.

(f) It indicates, in case some activities are delayed, where extra effort has to be applied to restore the progress and effect timely completion.

(g) It facilitates any change in programme when the situation warrants.

(h) It provides for an easy and clear method of communicating the engineer's plan to the others.

(i) It can be applied to various fields such as planning, design, construction and maintenance, which a Highway Department is called upon to deal with.

(j) Considerable saving in time and money is possible with the application of CPM.

10.3. While CPM is no substitute for proper planning, good estimating and effective control, it does enable those concerned to make the best use of their skiil and available data.

11

Limitations of CPM

CHAPTER 11

11. LIMITATIONS OF CPM

It would thus appear that CPM has a very wide range of application. However, it has its own limitations and problems. Perfection cannot be achieved without experience and anyone using CPM for the first time may not find the desired results. It is imperative that expert advice be had on factors like duration of activity, restraints, cycle of activities, etc.

Any basic error in feeding the data to the network cannot be checked and this would result in completely erroneous results.

CPM costs more to implement than other planning methods since it necessitates a very detailed study of the project, which may not be called for in case of small projects where the engineer himself is competent to do correct planning and sound control.

It is, however, felt that CPM is by far the best tool available to the engineer to keep close watch and control on projects whether big or small and at the same time a very convenient means of expressing himself to the common man.

No doubt all the possible uses and advantages of CPM on the variety of problems encountered in highway projects have not yet been fully explored. Further study, research and application by the users themselves are essential to obtain the maximum benefit from CPM.

12

Example of a Bridge Project

CHAPTER 12

12. EXAMPLE OF A BRIDGE PROJECT

12.1. The principles explained in the earlier pragraphs will be illustrated by an example of a bridge project. The bridge being considered comprises three clear spans of 25 metres each with well foundations, Fig. 13. The entire bridge project has been broken up into a number of activities as listed in *Appendix-1*, the activities therein appear in sequential order. The normal duration of the activities and their cost are also indicated in the same Table.

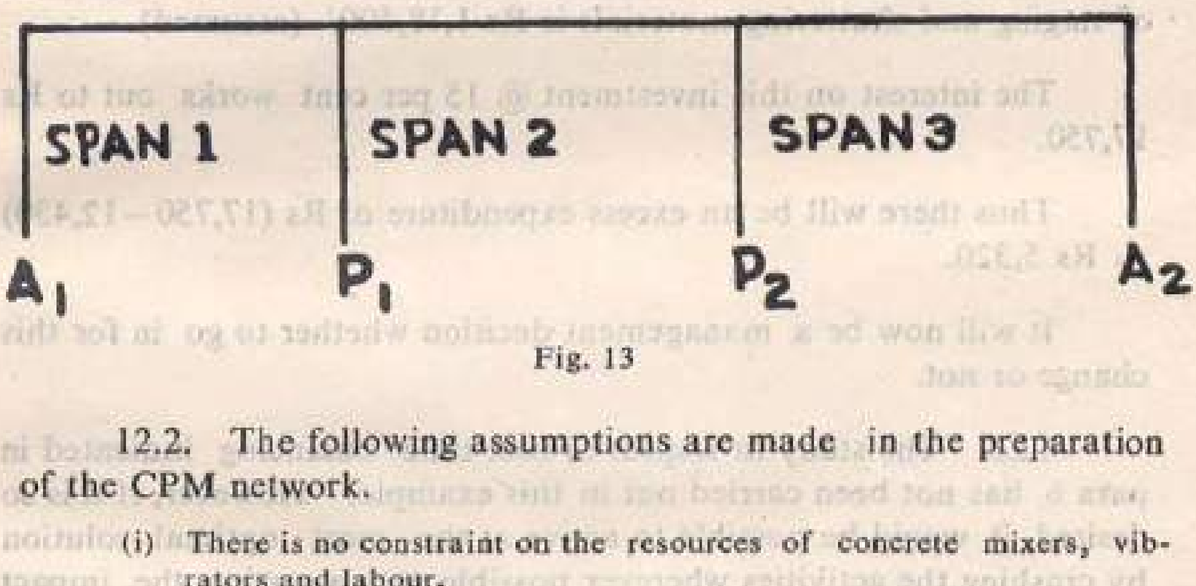


Fig. 13

12.2. The following assumptions are made in the preparation of the CPM network.

(i) There is no constraint on the resources of concrete mixers, vibrators and labour.

(ii) Only two sets of well steining shutterings are available.

(iii) For staging and shuttering of the bridge superstructure, two sets of centering and formwork material are available.

12.3. The CPM network for the bridge project has been drawn on the above basis and is given in Plate 1. The duration, E.S.T. L.S.T., E.F.T., L.F.T., T.F., F.F. and I.F. of the activities are indicated in *Appendix-2*. It will be seen that the duration of the project will be 247 days. The critical path is indicated in thick line. The bar graph for this project is given in Plate II.

12.4. The effect of inducting one additional set of centering and shuttering materials for superstructure, will now be examined.

With this additional resource being available, it is possible to cast all the three superstructure spans simultaneously. The modified activities and CPM network are shown in *Appendix-3*, and Plate III respectively. It will be seen that the critical path has now altered and the project duration has got reduced to 225 days. The financial implication of this modification is as under.

Assuming that the indirect costs are 10 per cent of the project and this varies linearly with time, the indirect cost/day

$$= \frac{10\% \text{ of Rs } 13,98,068}{247} = \text{Rs } 565$$

The saving in the indirect cost due to reduction of 22 days in the project duration is : 22 × 565 = Rs 12,430. As against this, the extra expenditure to be incurred in procuring the additional set of staging and shuttering materials is Rs 1,18,500/- (assumed).

The interest on this investment @ 15 per cent works out to Rs 17,750.

Thus there will be an excess expenditure of Rs (17,750 – 12,430) = Rs 5,320.

It will now be a management decision whether to go in for this change or not.

12.5. The study in respect of cost-time balancing indicated in para 6, has not been carried out in this example. However, if it is so desired, it wouid be possible to arrive at the most optimal solution by crashing the activities wherever possible and assessing the impact on the project cost.

13

Example of a Road Project

CHAPTER 13

13. EXAMPLE OF A ROAD PROJECT

13.1. The case of a Road Project will now be considered. The project consists of widening the existing single lane pavement to two lanes and simultaneous strengthening the pavement to meet the demands of traffic. The existing road will have to be realigned at a number of locations in order to improve the geometrics and avoid congested town and villages. The entire project has been broken down into a number of activities listed in *Appendix-4*, and the activities have been generally listed in the sequential order. The normal duration and the cost are also indicated in *Appendix-4*.

13.2. The following assumptions are made in the preparation of the network :

(i) There is no constraint on the resources of plant and equipment and labour.

(ii) The work can commence in the month of April. There is a period of about 1½ months (July and August) when due to monsoons the only activity that can be proceeded with is the water bound macadam.

(iii) The work should be completed before the onset of the second monsoon season.

(iv) Land has already been acquired and the alignment has already been staked out.

(v) The work can be split up into 4 smaller convenient sub-sections.

13.3. The network is given in Plate IV. It will be seen that the duration is 292 days. The critical path is indicated in thick line. The bar chart for the project is shown in Plate V. The particulars of the activities such as duration, E.S.T., L.S.T., E.F.T., L.F.T., T.F., F.F. and I.F. are given in *Appendix-5*.

14

Appendices

Appendix-1

R.C.C. BRIDGE OF 3 SPANS 25 METRES EACH WITH WELL FOUNDATIONS

Activity No.	Description	Quantity	Normal Duration (days)	Cost in Rs.	Remarks
0–1	Moving in and Site Clearance	Job	10	1,000	
1–2	Construction of labourer's camp, site office and staff quarters	Job	30	10,000	
2–3	Setting out the bridge	Job	5	5,000	
2–4	Fabrication of cutting edges (4 Nos.)	6.376 M.T.	10	9,370	
4–5	Laying of cutting edge	4 nos.	2	1,000	
5–6	Erecting shuttering, laying reinforcements and concreting of abutment well curbs No. A_1 and A_2	49.3 cu. m.	3	19,321	
6–7	—do— —do— for pier wells No. P_1 and P_2	49.3 cu. m.	3	19,321	
2–8	Procurement of Bearings	9 Rocker bearings 9 Rocker-cum-Roller bearings	90	81,000	
7–9	Erecting, shuttering, laying reinforcements and concreting first lift of abutment wells Nos. A_1 and A_2	One lift (one metre)	3		
9–10	Erecting, shuttering, laying reinforcements and concreting remaining lifts and sinking the entire well Nos. A_1 and A_2	remaining 14 lifts	75	4,53,672	
9–11	Erecting, shuttering, laying reinforcements, concreting and sinking the entire well Nos. P_1 and P_2	15 lifts	78		

Appendix-1 (Contd.)

Activity	Description	Quantity	Normal Duration (days)	Cost in Rs	Remarks
10−12	Laying of Bottom Plugs for well Nos. A_1 and A_2	162 cu. m.	4	26,568	
11−13	—do— —do— well Nos. P_1 and P_2	162 cu. m.	4	26,568	
12−14	Sand Filling in well Nos. A_1 and A_2	230.5 cu. m.	16	2,444	
13−15	—do— —do— for well Nos. P_1 and P_2	230.5 cu. m.	16	2,444	
14−16	Laying of intermediate plug for well Nos. A_1 and A_2	43 cu. m.	2	5,719	
15−17	—do— —do— for well Nos. P_1 and P_2	43 cu. m.	2	5,719	
16−18	Erecting shuttering, laying reinforcements and concreting of well caps for well Nos. A_1 and A_2	88.7 cu. m.	8	36,300	
17−19	—do— —do— for well Nos. P_1 and P_2	88.7 cu. m.	8	36,300	
18−20	Erecting, shuttering, laying reinforcements and concreting of abutment columns and abutment caps	39.048 cu. m.	20	25,937	
19−21	—do— —do— for Pier and Pier caps	87.54 cu. m.	30	29,024	
20−22	Fixing of bearing over Abutment caps.	6 Nos.	3	3,000	
21−23	—do— —do— over Pier caps	12 Nos.	3	6,000	
18−24	Erecting staging, shuttering for super structure span 1	1 No.	15	36,038	
19−25	—do— —do— for span 2	1 No.	15	36,038	

Appendix-1 (Contd.)

Activity	Description	Quantity	Normal Duration (days)	Cost in Rs	Remarks
24–26	Laying Reinforcements and concreting of superstructure span 1	148.24 cu. m.	6	86,882	
23–27	—do— —do— for span 2	148.24 cu. m.	6	86,882	
26–28	Erecting Railings for span 1	56.75 m.	5	3,177	
27–29	—do— —do— for span 2	56.75	5	3,177	
26–30	Release of centering and shuttering from span 1 and erecting the same for span 3	1 No.	22	36,038	
30–31	Laying of reinforcements and concreting superstructure span 3	148.24 cu. m.	6	86,882	
31–32	Erecting Railings for span 3	56.75 m	5	3,177	
32–36	Laying of Reinforcements and concreting of wearing coat, fixing drainage spouts and expansion joints for all spans	Job	6	21,160	
20–33	Erection of shuttering, laying reinforcement and concreting of R.C.C. Returns	27.5 m^3	7	20,388	
33–34	Earth filling behind abutments	8670 m^3	30	91,902	
34–36	Laying of Approach Slab, inclusive of linked items like soling etc.	11.08 m^3	2	6,580	
33–35	Protection works	Job	30	74,040	
			Total	13,98,068	

DETAILS OF ACTIVITIES OF BRIDGE PROJECT

Activity Arrow	Duration (days)	EST	LST	EFT	LFT	TF	FF	IF	Remarks
0−1	10	0	0	10	10	0	0	0	Critical
1−2	30	10	10	40	40	0	0	0	Critical
2−3	5	40	45	45	50	5	5	0	
2−4	10	40	40	50	50	0	0	0	Critical
2−8	90	40	109	130	199	69	69	0	
3−4	0	45	50	45	50	5	5	0	
4−5	2	50	50	52	52	0	0	0	Critical
5−6	3	52	52	55	55	0	0	0	Critical
6−7	3	55	55	58	58	0	0	0	Critical
7−9	3	58	58	61	61	0	0	0	Critical
9−10	75	61	74	136	149	13	0	13	
10−12	4	136	149	140	153	13	0	13	
12−14	16	140	153	156	169	13	0	13	
14−16	2	156	169	158	171	13	0	13	
16—18	8	158	171	166	179	13	0	13	
18−20	20	166	179	186	199	13	0	13	
18−24	15	166	187	181	202	21	21	0	
9−11	78	61	61	139	139	0	0	0	Critical
11−13	4	139	139	143	143	0	0	0	Critical
13−15	16	143	143	159	159	0	0	0	Critical
15—17	2	159	159	161	161	0	0	0	Critical
17−19	8	161	161	169	169	0	0	0	Critical
19−21	30	169	169	199	199	0	0	0	Critical
19−25	15	169	187	184	202	18	0	18	
21−23	3	199	199	202	202	0	0	0	Critical
25−23	0	184	202	184	202	18	18	0	
20−22	3	186	199	189	202	13	0	13	
20−33	7	186	208	193	215	22	0	22	
22−24	0	189	202	189	202	13	13	0	
23−24	0	202	202	202	202	0	0	0	Critical
24−26	6	202	202	208	208	0	0	0	Critical
26−28	5	208	236	213	241	28	0	28	

Appendix-2 (Contd.)

Activity Arrow	Duration (days)	EST	LST	EFT	LFT	TF	FF	IF	Remarks
26–30	22	208	208	230	230	0	0	0	Critical
8–21	0	130	199	130	199	69	69	0	
8–20	0	130	199	130	199	69	56	13	
30–31	6	230	230	236	236	0	0	0	Critical
31–32	5	236	236	241	241	0	0	0	Critical
28–32	0	213	241	213	241	28	28	0	
23–27	6	202	230	208	236	28	0	28	
27–29	5	208	236	213	241	28	0	28	
29–32	0	213	241	213	241	28	28	0	
33—34	30	193	215	223	245	22	0	22	
33–35	30	193	217	223	247	24	0	24	
34–36	2	223	245	225	247	22	22	0	
35–36	0	223	247	223	247	24	24	0	
32–36	6	241	241	247	247	0	0	0	Critical

Appendix-3

MODIFIED ACTIVITIES FOR R.C.C. BRIDGE OF 3 SPANS 25 METRES EACH WITH WELL FOUNDATIONS

Activity No.	Description	Quantity	Normal Duration (days)	Remarks
0–1	Moving in and Site Clearance	Job	10	
1–2	Construction of labourers' Camp, site office and staff quarters	Job	30	
2–3	Setting out the bridge	Job	5	
2–4	Fabrication of cutting Edges (4 Nos.)	6.376 M.T.	10	
4–5	Laying of cutting edge	4 nos.	2	
5–6	Erecting shuttering, laying reinforcements and concreting of abutment well curb Nos. A_1 and A_2	49.3 cu.m.	3	
6–7	—do— —do— for pier well Nos. P_1 and P_2	49.3 cu.m.	3	
2–8	Procurement of Bearings	9 Rocker bearings 9 Rocker-cum-Roller Bearings	90	
7–9	Erecting shuttering, laying reinforcements and concreting first lift of abutment well Nos. A_1 and A_2	One lift (one metre)	3	
9–10	Erecting shuttering, laying reinforcements and concreting remaining lifts and sinking the entire well Nos. A_1 and A_2	remaining 14 lifts	75	
9–11	Erecting shuttering, laying reinforcements, concreting and sinking the entire well Nos. P_1 and P_2	15 lifts	78	
10–12	Laying of Bottom Plugs for well Nos. A_1 and A_2	162 cu.m.	4	
11–13	—do— —do— well Nos. P_1 and P_2	162 cu.m.	4	

Appendix-3 (Contd.)

Activity No.	Description	Quantity	Normal Duration (days)	Remarks
12–14	Sand Filling in well Nos. A_1 and A_2	230.5 cu m.	16	
13–15	—do— —do— for well Nos. P_1 and P_2	230.5 cu.m.	16	
14–16	Laying of intermediate plug for well Nos. A_1 and A_2	43 cu.m.	2	
15–17	—do— —do— for well Nos. P_1 and P_2	43 cu.m.	2	
16–18	Erecting shuttering, laying reinforcements and concreting of well caps for well Nos. A_1 and A_2	88.7 cu.m.	8	
17–19	—do— —do—for well Nos. P_1 and P_2	88.7 cu.m.	8	
18–20	Erecting shuttering, laying reinforcements and concreting of abutment columns and abutment caps	39.048 cu.m.	20	
19–21	—do— —do— for Pier and Pier caps.	87.54 cu.m.	30	
20–22	Fixing of bearing over Abutment caps.	6 Nos.	3	
21–23	—do— —do— over Pier caps	12 Nos.	3	
18–24	Erecting, staging, shuttering for superstructure span 1	1 No.	15	
19–24	—do— —do— for spans 2 and 3	2 Nos.	15	
24–31	Laying reinforcements and concreting of superstructure spans 1, 2 and 3	444.72 cu.m.	6	
31–32	Erecting railings for spans 1, 2 and 3	170.25 m	5	
32–36	Laying reinforcements and concreting of wearing coat, fixing drainage spouts and expansion joints for all spans	Job	6	
20–33	Erection of shuttering laying reinforcements and concreting of R.C.C. returns	27.5 m^3	7	
33–34	Earth filling behind abutments	8670 m^3	30	
34–36	Laying of approach slab, inclusive of linked items like soling etc.	11.08 m^3	2	
33–35	Protection Works	Job	30	

WIDENING, STRENGTHENING AND REALIGNING EXISTING ROAD

Activities	Description	Quantity	Normal Duration (days)	Cost in Rs	Remarks
0–1	Clearing and grubbing in Section I	Job	4	6,570	
0–2	—do— —do— in Section II	Job	4	6,570	
0–3	—do— —do— in Section III	Job	4	6,570	
0–4	—do— —do— in Section IV	Job	4	6,570	
0–5	Construction of diversion for traffic	Job	30	1,54,940	
5–6	Dismantling existing culverts	Job	15	6,810	
1–7	Dismantling existing Pavement in Section I	Job	4	800	
2–8	—do— —do— in Section II	Job	4	800	
3–9	—do— —do— in Section III	Job	4	800	
4–10	—do— —do— in Section IV	Job	4	800	
1–15	Construction of temporary Service Roads for realignment in Section I	Job	7	33,110	
2–16	—do— —do— in Section II	Job	7	33,110	
3–17	—do— —do— in Section III	Job	7	33,110	
4–18	—do— —do— in Section IV	Job	7	33,110	
7–11	Dismantling houses in Section I	Job	4	2,500	
8–12	—do— —do— in Section II	Job	4	2,500	
9–13	—do— —do— in Section III	Job	4	2,500	
10–14	—do— —do— in Section IV	Job	4	2,500	

Appendix-4 (Contd.)

Activities	Description	Quantity	Normal Duration (days)	Cost in Rs	Remarks
11–19	Earthwork inclusive of carriage and compaction in Section I	47,500 cu.m.	45	2,98,100	
12–20	—do— —do— in Section II	79,400 cu.m.	55	4,95,100	
13–21	—do— —do— in Section III	69,600 cu.m.	52	4,35,200	
14–22	—do— —do— in Section IV	57,200 cu.m.	48	3,57,100	
19–23	Gravel Sub-base in Section I	1,500 cu.m.	10	9,270	
20–24	—do— —do— in Section II	1,500 cu.m.	10	9,270	
21–25	—do— —do— in Section III	1,500 cu.m.	10	9,270	
22–26	—do— —do— in Section IV	1,500 cu.m.	10	9,270	
23–27	Water Bound Macadam Base course in Section I	895 cu.m.	20	28,200	
24–28	—do— —do— in Section II	895 cu.m.	20	28,200	
25–29	—do— —do— in Section III	895 cu.m.	20	28,200	
26–30	—do— —do— in Section IV	895 cu.m.	20	28,200	
27–31	Water Bound Macadam Top course in Section I	895 cu.m.	20	30,850	
28–32	—do— —do— in Section II	895 cu.m.	20	30,850	
29–33	—do— —do— in Section III	895 cu.m.	20	30,850	
30–34	—do— —do— in Section IV	895 cu.m.	20	30,850	
31–35	Providing tack coat in Section I	23,020 sq.m.	44	14,770	
32–36	—do— —do— in Section II	23,020 sq.m.	44	14,770	
33–37	—do— —do— in Section III	23,020 sq.m.	44	14,770	
34–38	—do— —do— in Section IV	23,020 sq.m.	44	14,770	

Appendix-4 (Contd)

Activities	Description	Quantity	Normal Duration (days)	Cost in Rs	Remarks
31–39	Providing levelling course of lean bituminous macadam in Section I	765 cu.m.	45	93,120	
32–40	—do— —do— in Section II	765 cu.m.	45	93,120	
33–41	—do— —do— in Section III	765 cu.m.	45	93,120	
34–42	—do— —do— in Section IV	765 cu.m.	45	93,120	
39–43	Providing bituminous macadam in Section I	1,382 cu.m.	80	2,04,470	
40–44	—do— —do— in Section II	1,382 cu.m.	80	2,04,470	
41–45	—do— —do— in Section III	1,382 cu.m.	80	2,04,470	
42–46	—do— —do— in Section IV	1,382 cu.m.	80	2,04,470	
43–47	Semi-Dense Carpet for Section I	644 cu.m.	40	1,37,230	
44–48	—do— —do— in Section II	644 cu.m.	40	1,37,230	
45–49	—do— —do— in Section III	644 cu.m.	40	1,37,230	
46–50	—do— —do— in Section IV	644 cu.m.	40	1,37,230	
6–51	Construction of Culverts	15 nos.	60	4,50,000	
47–52	Fixing Kilometre Stones, Road Signs in Section I	Job	5	5,000	
48–52	—do— —do— in Section II	Job	5	5,000	
49–52	—do— —do— in Section III	Job	5	5,000	
50–52	—do— —do— in Section IV	Job	5	5,000	
52–53	Finishing and opening	Job	5	5,000	
				44,65,810	

Appendix-5

DETAILS OF ACTIVITIES OF A ROAD PROJECT

Activity Arrow	Duration (days)	EST	LST	EFT	LFT	TF	FF	IF	Remarks
0—1	4	0	10	4	14	10	0	10	
0—2	4	0	0	4	4	0	0	0	Critical
0—3	4	0	3	4	7	3	0	3	
0—4	4	0	7	4	11	7	0	7	
0—5	30	0	182	30	212	182	0	182	
1—15	7	4	15	11	22	11	1	10	
1—7	4	4	14	8	18	10	0	10	
2—16	7	4	5	11	12	1	1	0	
2—8	4	4	4	8	8	0	0	0	Critical
3—17	7	4	8	11	15	4	1	3	
3—9	4	4	7	8	11	3	0	3	
4—18	7	4	12	11	19	8	1	7	
4—10	4	4	11	8	15	7	0	7	
15—11	0	11	22	11	22	11	1	10	
7—11	4	8	18	12	22	10	0	10	
16—12	0	11	12	11	12	1	1	0	
8—12	4	8	8	12	12	0	0	0	Critical
17—13	0	11	15	11	15	4	1	3	
9—13	4	8	11	12	15	3	0	3	
18—14	0	11	19	11	19	8	1	7	
10—14	4	8	15	12	19	7	0	7	
5—6	15	30	212	45	227	182	0	182	
6—51	60	45	227	105	287	182	182	0	
11—19	45	12	22	57	67	10	0	10	
12—20	55	12	12	67	67	0	0	0	Critical
13—21	52	12	15	64	67	3	0	3	
14—22	48	12	19	60	67	7	0	7	
19—23	10	57	67	67	77	10	0	10	
28—24	10	67	67	77	77	0	0	0	Critical
21—25	10	64	67	74	77	3	0	3	
22—26	10	60	67	70	77	7	0	7	
23—27	20	67	77	87	97	10	0	10	

Appendix-5 (Contd.)

Activity Arrow	Duration (days)	EST	LST	EFT	LFT	TF	FF	IF	Remarks
24–28	20	77	77	97	97	0	0	0	Critical
25–29	20	74	77	94	97	3	0	3	
26–30	20	70	77	90	97	7	0	7	
27–31	20	87	97	107	117	10	0	10	
28–32	20	97	97	117	117	0	0	0	Critical
29–33	20	94	97	114	117	3	0	3	
30–34	20	90	97	110	117	7	0	7	
31–35	44	107	118	151	162	11	0	11	
31–39	45	107	117	152	162	10	0	10	
32–36	44	117	118	161	162	1	0	1	
32–40	45	117	117	162	162	0	0	0	Critical
33–37	44	114	118	158	162	4	0	4	
33–41	45	114	117	159	162	3	0	3	
34–38	44	110	118	154	162	8	0	8	
34–42	45	110	117	155	162	7	0	7	
35–39	0	151	162	151	162	11	1	10	
36–40	0	161	162	161	162	1	1	0	
37–41	0	158	162	158	162	4	1	3	
39–42	0	154	162	154	162	8	1	7	
39–43	80	152	162	232	242	10	0	10	
40–44	80	162	162	242	242	0	0	0	Critical
41–45	80	159	162	239	242	3	0	3	
42–46	80	155	162	235	242	7	0	7	
43–47	40	232	242	272	282	10	0	10	
44–48	40	242	242	282	282	0	0	0	Critical
45–49	40	239	242	274	282	3	0	3	
46–50	40	235	242	275	282	7	0	7	
47–52	5	272	282	277	287	10	10	0	
48–52	5	282	282	287	287	0	0	0	Critical
49–52	5	279	282	284	287	3	3	0	
50–52	5	275	282	280	287	7	7	0	
51–52	0	105	287	105	287	182	182	0	
52–59	5	287	287	292	292	0	0	0	Critical

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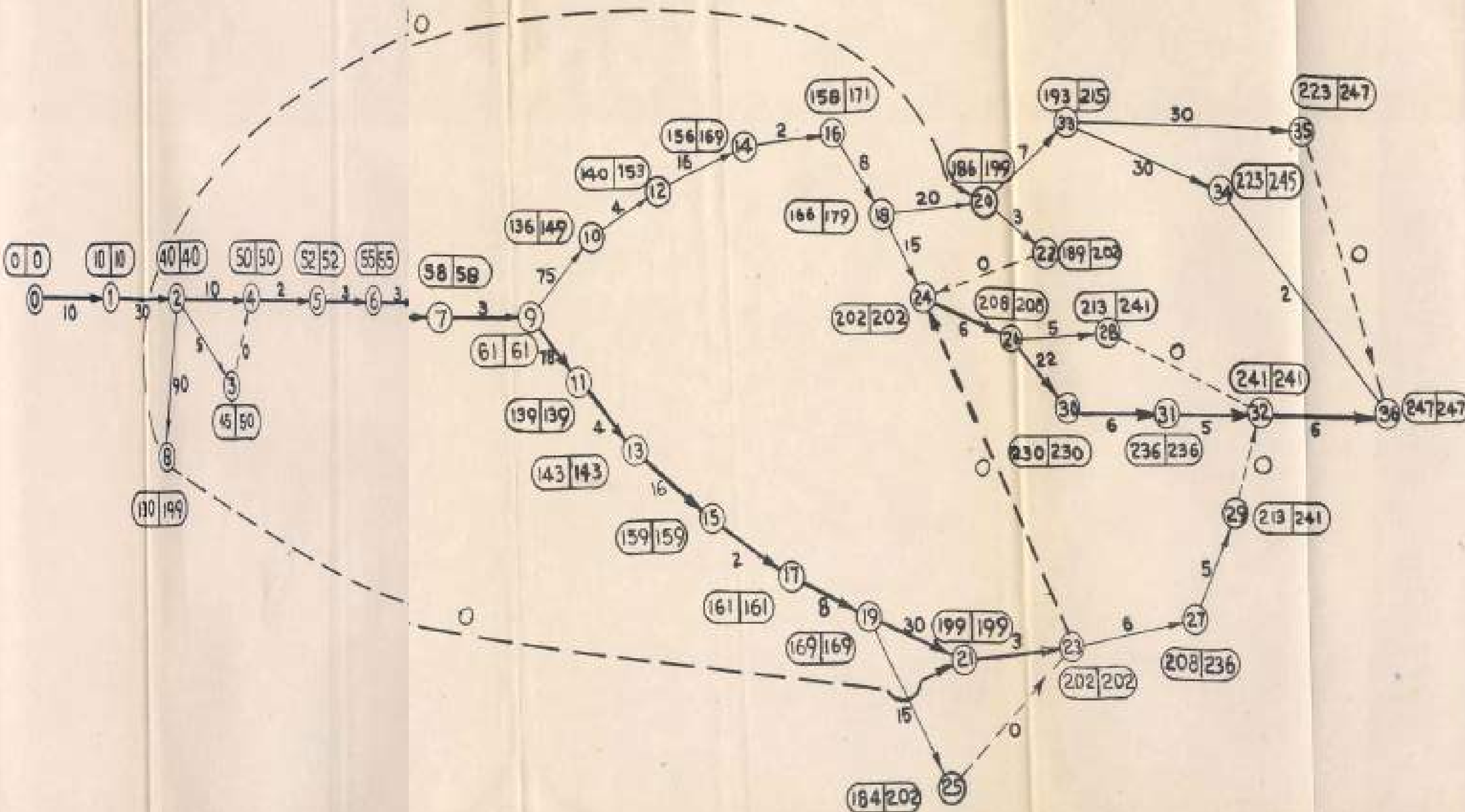
PLATE I



CPM NETWORK FOR A BRIDGE PROJECT

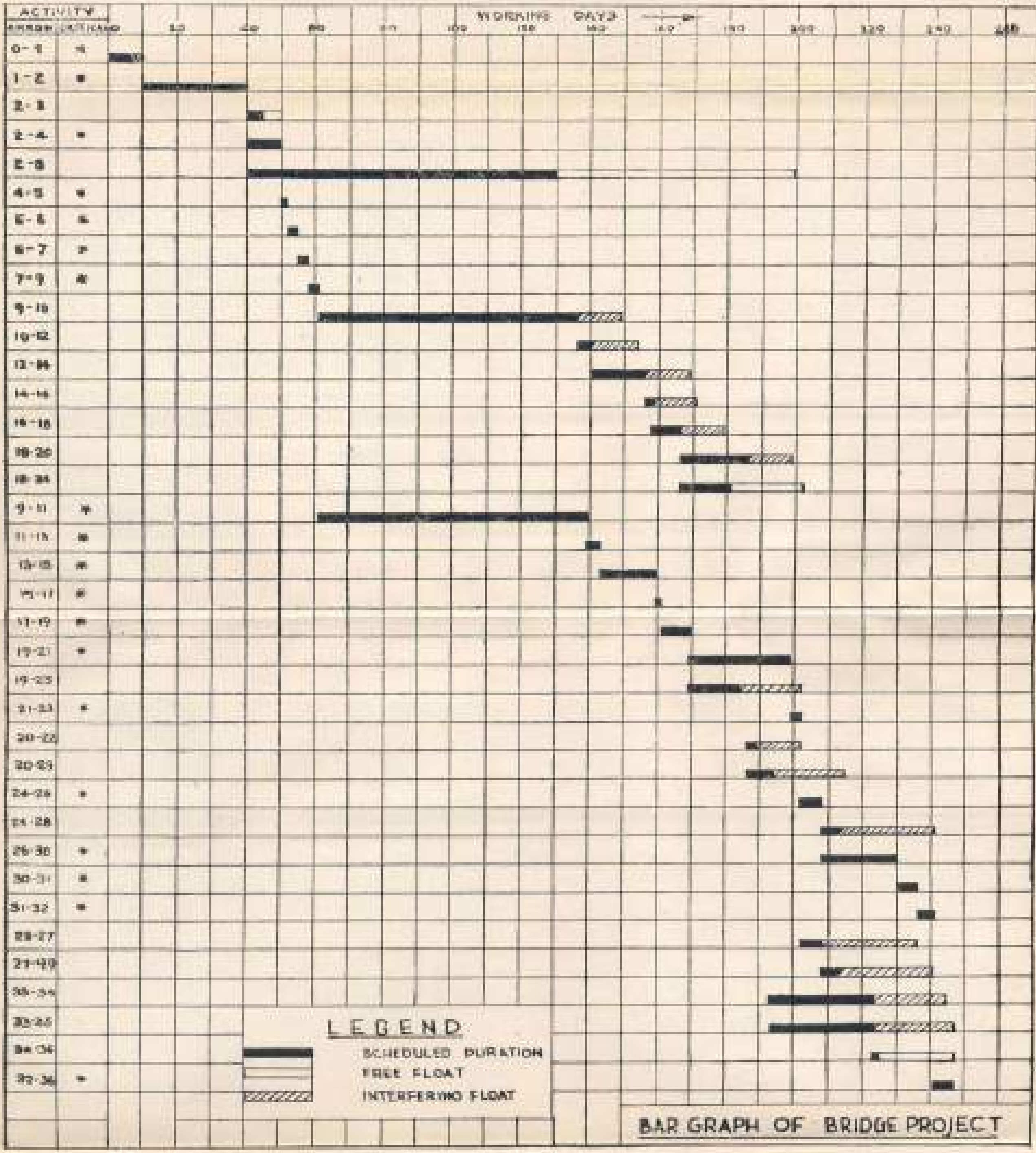
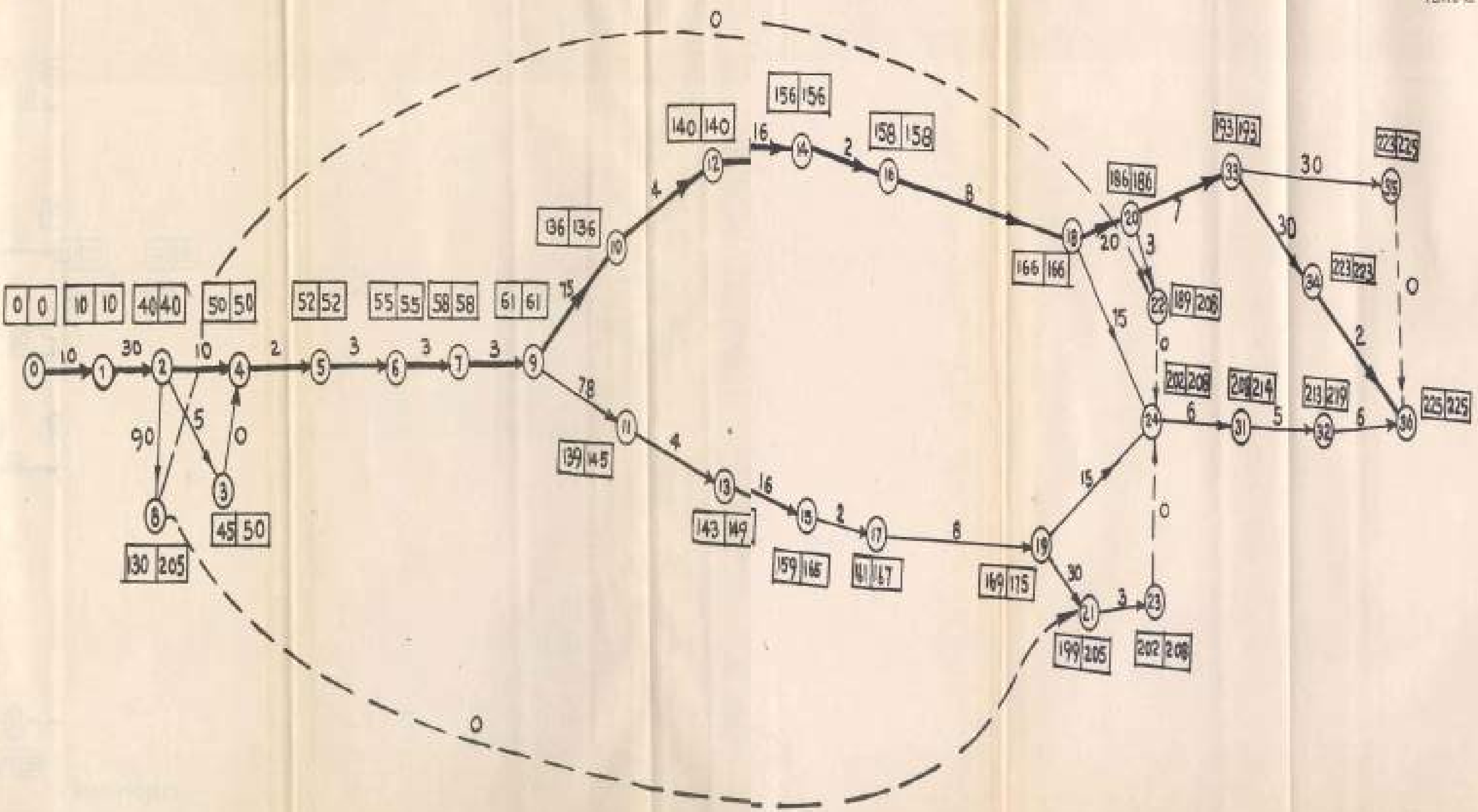
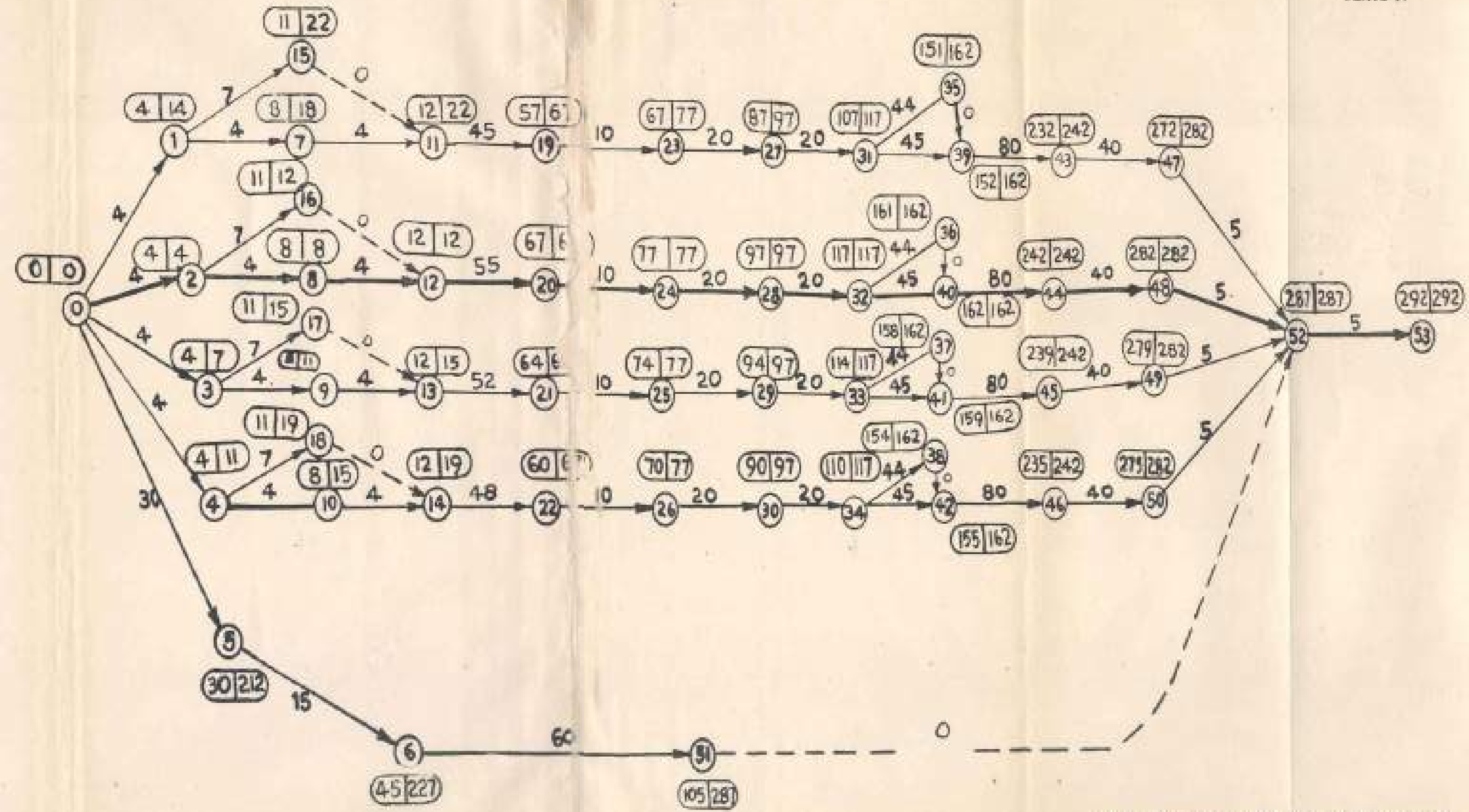

ACTIVITY
ARROW
CRITICAL
WORKING DAYS
LEGEND
SCHEDULED DURATION
FREE FLOAT
INTERFERING FLOAT
BAR GRAPH OF BRIDGE PROJECT

PLATE II

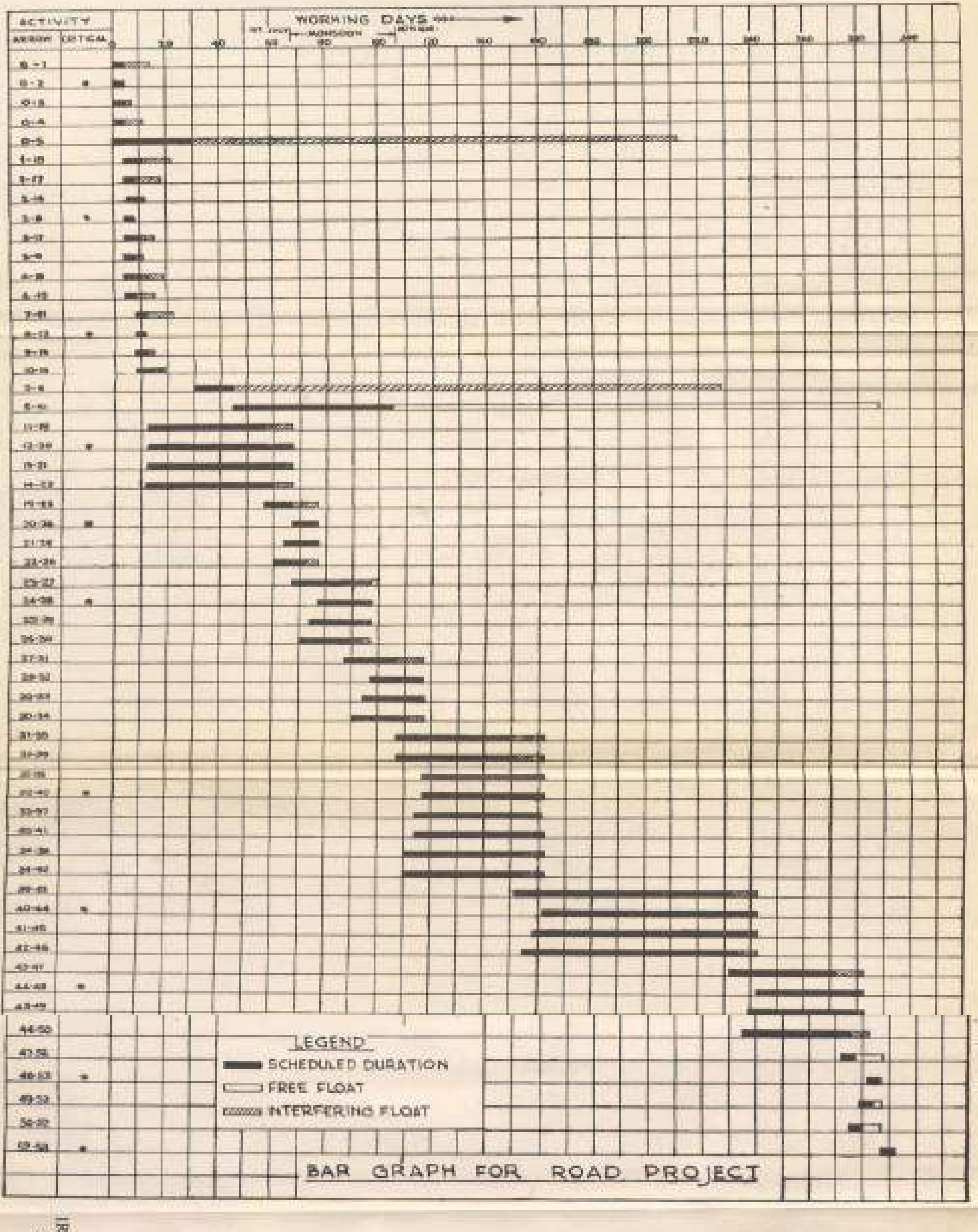


MODIFIED CPM NETWORK FOR A BRIDGE PROJECT

PLATE IV



CPM NETWORK FOR A ROAD PROJECT



IRC MANUAL FOR THE APPLICATION OF THE CRITICAL PATH METHOD TO HIGHWAY PROJECTS IN INDIA

PLATE V