Course Title

Project Engineering

Chapter 3

PROJECT PLANNING AND SCHEDULING

Lecture 6 (Week 6)

Network Analysis: Introduction to Critical Path Method (CPM)

Lecturer: Associate Prof Ishwar Adhikari

Learning Objective

The main objective of this lecture is to understand about:

- Network analysis process of scheduling.
- Introduction to Critical Path Method.
- Critical Path
- Terminologies of CPM
- Calculation Procedure of CPM
- Advantages and disadvantages of CPM.

Prepared By: Associate Prof. Ishwar Adhikari/Department of Civil Engineering/Kathmandu Engineering College (Affiliated to Tribhuvan University), Kathmandu, Nepal.

3.5.2 NETWORK ANALYSIS

For a project involving large number of activities, the project scheduling becomes very complex and the use of conventional method of scheduling like bar charts will not be effective. The main aim of a project planning is to complete the project within stipulated time and doing the work in planned way. [1] One of the most popular technique of planning and scheduling the complex project is network analysis. Complex projects, if not correctly scheduled, will most probably result in either under estimation or over estimation of the project implementation period, both of which will have serious consequences. [2]

For proper planning, scheduling and control of the activities of a project, given their inter-relationships and constraints on the availability of resources, network analysis have been found quiet useful. [3]A network is the combination of different activities of the project. These activities are so connected that it defines the whole project. [4] Most commonly used network analysis techniques are: *Critical Path Method (CPM)* and *Program Evaluation and Review Technique (PERT).*

Steps for Network analysis;

- Whole Project is divided or broken down into a series of activities or work packages.
- Activities are linked together according to their technological sequence of operation or logical relationship (preceding, succeeding and concurrent)
- The time of completion or duration of each activity is estimated
- The network diagram is drawn and from diagram the completion time of whole project is determined.

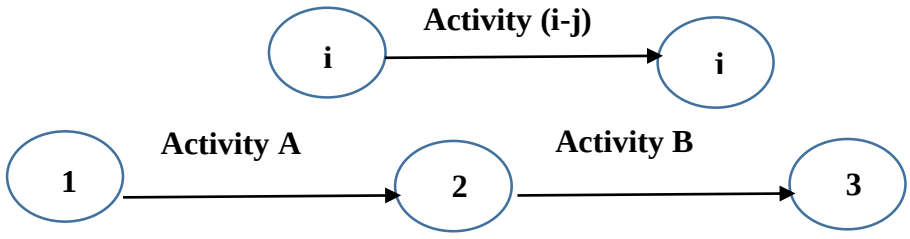
CRITICAL PATH METHOD (CPM)

The technique of network based scheduling by critical path method (CPM) is used for planning and scheduling projects involving sequential operation. [5]It is a deterministic approach and an activity oriented network diagram showing the interdependencies and relationship between the various activities. CPM developed in the year 1957 by Morgan R. Walker of DU Pont and James E. Kelly of Remington Rand for preparing shutdown schedule of a chemical plant.

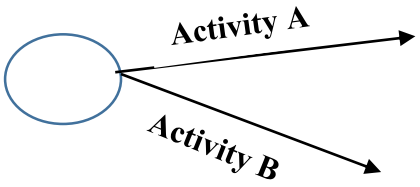
TERMINOLOGIES

1. **Activity(s):**

An activity is a task or closely related group of tasks whose performance contributes to the completion of the overall project. [6]Arrow in a network diagram represents activity and consume resources like manpower, material, money, time etc. Examples: Excavation of foundation, construction of wall, electrical wiring etc.



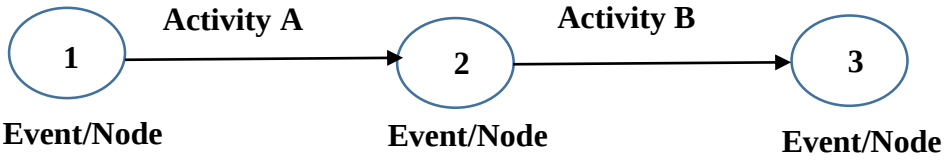
Activity A is predecessor of Activity B Activity B is Successor of Activity A



Activity A and Activity B are Concurrent/Parallel Activity

2. **Event/Node:**

It is the point in time denoting completion of an activity and start of an activity. It does not consume resources.



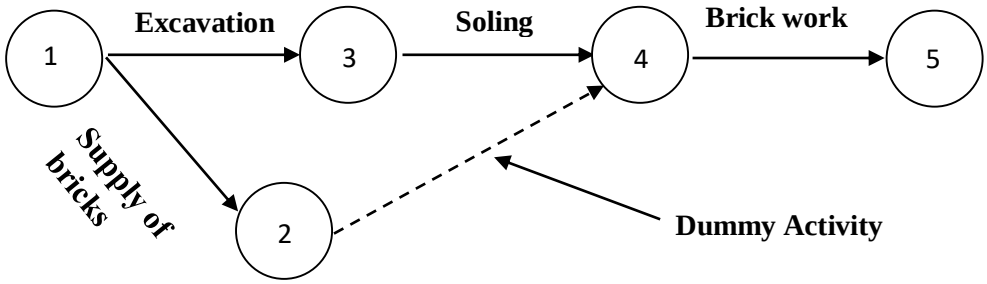
3. **Duration (t)**

Estimated time to perform a definite activity/task. It is mentioned alongside with activity name. The time unit for the project can be minutes, hours, work days, calendar days, weeks or months.

Activity Duration = Work Quantity/ Production rate

4. **Dummy Activity**

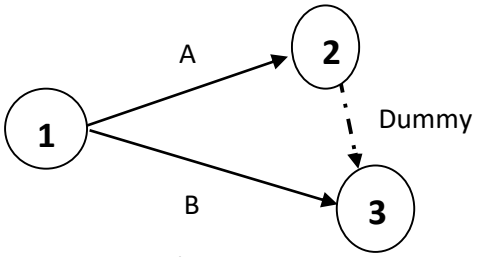
A dummy activity is an imaginary (hypothetical) activity included in a network. Since it is not a real activity, it does not consume time, manpower, material and other resources. It is included in a network to maintain the relationship between activities appropriately. It is represented by dotted arrow.



Uses of dummies: Dummies serve two purposes in a network: Grammatical purpose and b) Logical purpose

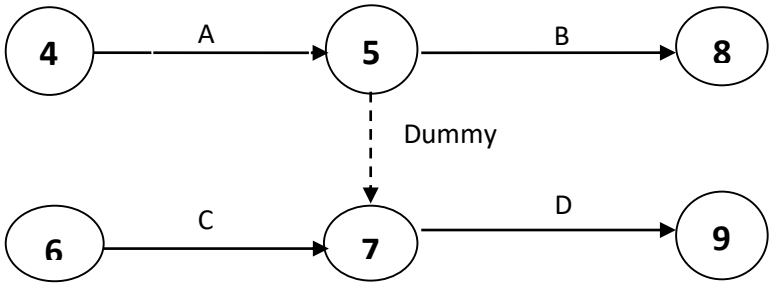
a) Grammatical purpose

It is used to prevent two arrows having common beginning and end nodes for two or more activities. For example, consider the arrows of activities A and B; both starts from node 1 and end at node 2. Due to this an inconvenience results when the network is used for computation, i.e., uniqueness in the identification is lost. This inconvenience frequently leads to mistake. [7]



b) Logical purpose

Dummies are also used to give logical clear representation in a network having an activity common to two sets of operations running parallel to each other.

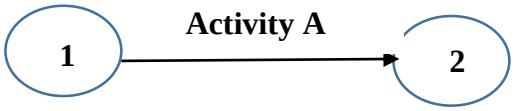


Here, Activity D cannot be started until Activity A is completed. The inter dependency or logical relation between two activities are clearly known.

Graphical Representation of activities and events

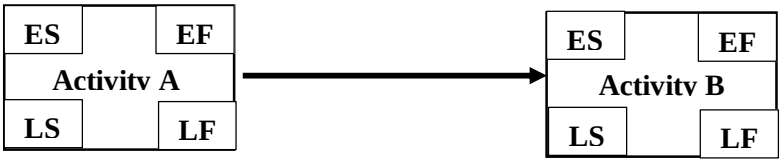
1. **Activity on Arrow (AOA) system**

In this system, an activity is represented by an arrow with circles at both ends drawn from left hand side to the right hand side. The tail end of the arrow represents the start of an activity and head of arrow represents completion of activity.



2. **Activity on Node (AON) system**

In this system, activities are represented by nodes or circles. Arrow only shows the dependence of activities on each other. No dummy activity is required to represent the inter dependency between succeeding and preceding activity. It is also called precedence diagramming method (PDM)

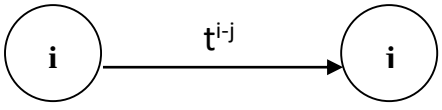


5. **Earliest start time (EST)**

It is the earliest possible time that the activity can start.

6. **Earliest finish time (EFT)**

It is the earliest possible time for completion of an activity or operation without delaying the project completion time. It can be computed by adding activity duration by EST.



EST (i-j)

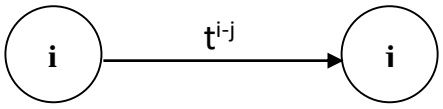
EFT (i-j) = EST (i-j) +t_{i-j}

7. **Latest finish time (LFT)**

It is the latest possible time that an activity can be finished based on the logic and duration identified on the network without extending the project duration. [8]

8. **Latest start time (LST)**

It is the latest possible time; an activity can be started without delaying the project.



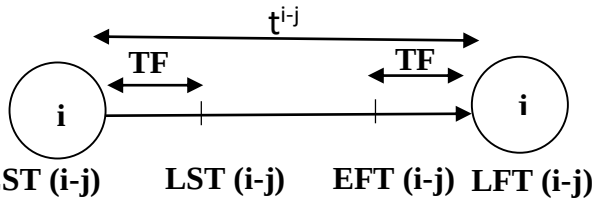
$$\mathbf{LST\ (i\text{-}j) = LFT\ (i\text{-}j) - t_{i\text{-}j}}$$

9. **Float / Slack**

The free time available to the activity is called float or slack.

(a) Total float (TF)

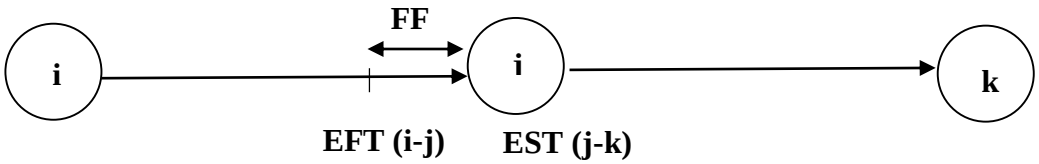
It is the extra time available when the start or finish of an activity can be delayed, without delaying the completion of the project. [5]



$$\mathbf{EFT_{(i\text{-}j)} = EST_{(i\text{-}j)} + t_{(i\text{-}j)}}$$
$$\mathbf{LFT_{(i\text{-}j)} = LST_{(i\text{-}j)} + t_{(i\text{-}j)}}$$
$$\mathbf{LFT_{(i\text{-}j)} - EFT_{(i\text{-}j)} = LST_{(i\text{-}j)} - EST_{(i\text{-}j)}}$$
$$\mathbf{TF_{(i\text{-}j)} = LFT_{(i\text{-}j)} - EFT_{(i\text{-}j)}\ OR\quad LST_{(i\text{-}j)} - EST_{(i\text{-}j)}}$$

(b) **Free float (FF)**

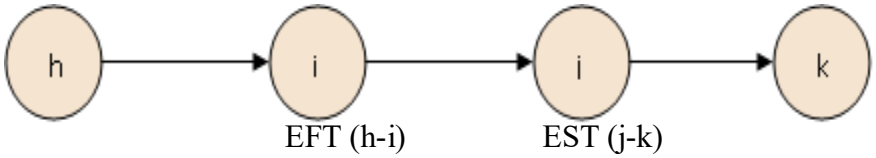
It is the delay that can be permitted in an activity so that succeeding activities in the path are not affected. [2]In other words, it is the extra time available when the activity is delayed without delaying the early start time of succeeding activity.



$$\mathbf{FF_{(i\text{-}j)} = EST_{(j\text{-}k)} - EFT_{(i\text{-}j)}}$$

(c) **Independent float (IF_1)**

It is the spare time available for the activity, if preceding activity is started as late as possible and succeeding activities are finished as early as possible.



IF_1= EST (j-k) – EFT (h-i)-t_{i-j}, Also, IF_1= FF (i-j)-Tail event slack

(d) **Interfering Float (IF_2)**

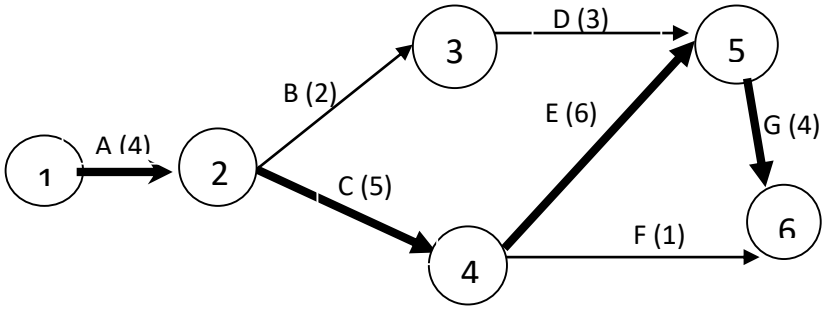
It is the name given to head event slack. It is the difference between total float and free float.

$$IF_2 = TF\ (i\text{-}j) - FF\ (i\text{-}j)$$

10. Critical Path

In a network diagram, the activities are represented by arrows and arrows flow from left to right. In a network, there may be many paths starting from the initial event and leading to the last event. If the duration of all the activities that lie on particular paths is added, it gives the duration of the path. Each path in a network will have a different duration.

The path that has the longest duration is called the critical path and the activities lying on the critical path are critical activities. In a network diagram, the path along which the project takes the maximum time from start to finish is called critical path. It is the longest path of the network and gives the total time taken to complete the project. Any delay along this path delays the project.



Path	Description	Duration	Remarks
1	1 – 2 – 3 – 5 - 6	4+2+3+4 =13 days	
2	**1 – 2 – 4 – 5 - 6**	**4+5+6+4 =19 days**	**Longest/Critical path**
3	1 – 2 – 4 - 6	4+5+1 =10 days	

<u>Characteristics of Critical Path</u> [2]

- Critical path is the longest path (time wise) connecting the initial and final events.
- Critical activity may run through dummy activity/activities also.
- The number of activities lying on critical path may be less than the number of activities in other non-critical activities.

- It is possible that a network may have more than one critical path i.e. if two or more paths have the same time duration which is maximum, then all such paths will be critical paths.

Super critical activity

When the total float of the activity is negative, then this activity is called the super critical activity and demand very special attention and action. [1]

Critical activity

When the total float of the activity is zero, then this activity is called critical activity. Such activity permit no freedom of action and demand normal action.

Sub critical activity

When the total float is positive, then the activity is known as sub critical activity and permit freedom and demand normal attention.

Calculation Procedure of CPM

Forward pass calculation

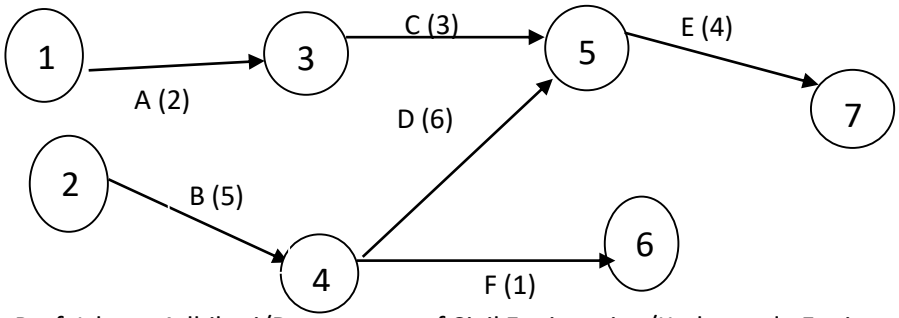
- In the forward pass calculation, all activities in the network are assumed to start as early as possible.
- The calculation begins from the left to the right side of the network.
- When two or more activities merge into a event, the largest value is taken as an earliest occurrence time of that event.
- Forward pass calculation gives the EST and EFT of each activity.

Backward pass calculation

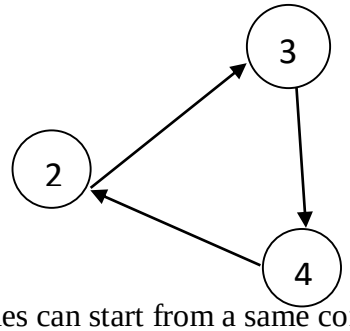
- In the backward pass calculation, all activities in the network are assumed to start as late as possible.
- The calculation begins from the right to the left side of the network.
- When two or more activity merges at a node, the smallest value is taken as a latest occurrence time of that event.
- Backward pass calculation gives the LST and LFT of each activity.

ERRORS IN NETWORK DIAGRAM

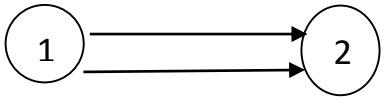
1. Activities should start from a single initial node and end on single final node.



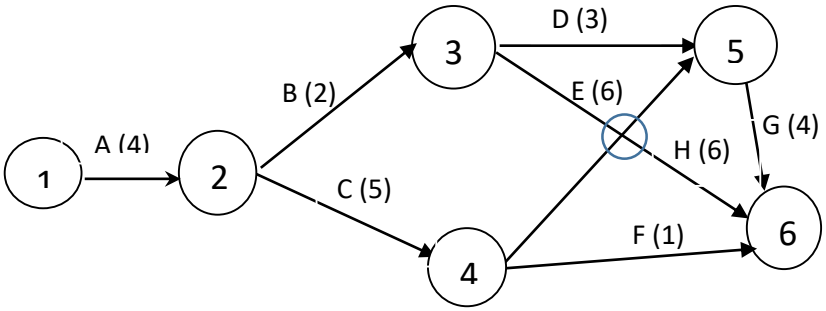
2. There should not be a loop formation in the network.



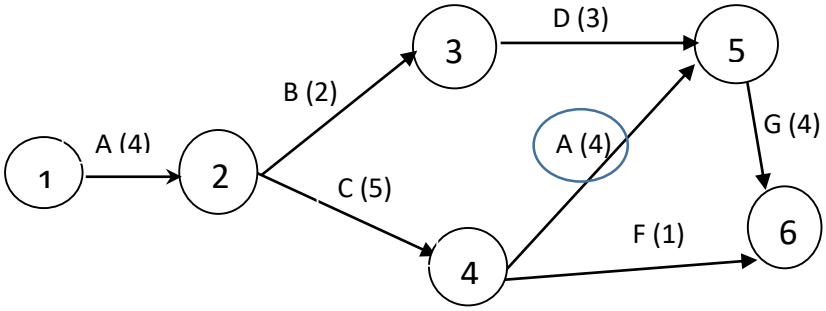
3. Two or more activities can start from a same common node but cannot end on a same common node.



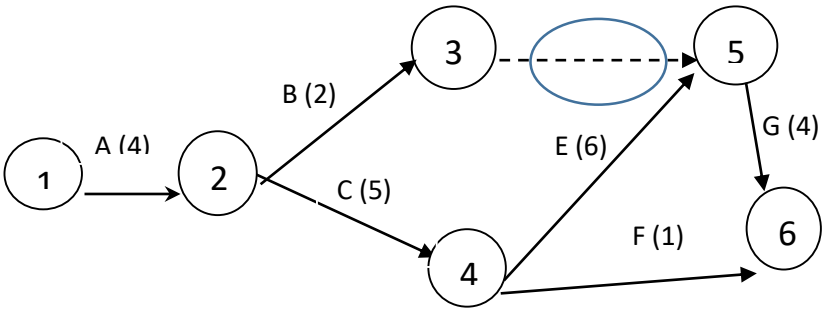
4. There should not be an intersection between the activities.



5. The number of arrows should not be more than the number of activities. The activity should not be repeated.



6. There should not be unnecessary dummy in the network diagram.



ADVANTAGES AND DISADVANTAGES OF CPM

Advantages

1. Makes dependencies visible between the project activities.
2. Organizes large and complex projects, hence allowing a more systematic approach to project planning and scheduling.
3. Enables the calculation of float or slack of each activity.
4. Enables the Project Manager to optimize efficiency
5. Provides opportunities to respond to the negative risk going over schedule.
6. Encourages the Project Manager to reduce the project duration by optimizing the critical path

Disadvantages

1. CPM is not suitable for the project involving some uncertainties like research and development project.
2. Reduced Attention to High-Float Tasks: When using the critical path method, project managers focus on critical path tasks. For large and complex projects, there'll be thousands of activities and dependency relationships. [9]
3. For large projects with thousands of activities, it may be difficult to print the project network diagram.
4. The Critical Path Method does not account for resource and resource allocation**.**

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[9] https://www.smartsheet.com/content/critical-path-advantages-disavantages