CONSTRUCTION PLANNING AND SCHEDULING

COTM4221

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Chapter Two

Time Planning

Contents

1. Introduction

Project planning

- ✓ **The success of a project will depend greatly on careful and continuous planning, and management of the execution of activities according to plan.**

“Failing to Plan is Planning to Fail”

Project Scheduling

Project scheduling is the determination of the timing and sequence of operations in the project and their assembly to give the overall completion time.

- ✓ **At this stage, managers decide how long each activity will take and compute how many people and how much material will be needed at each stage of construction.**

Scheduling involves:

- ✓ **Breakdown of the project into definable, measurable and identifiable tasks/activities(WBS),**
- ✓ **Establishes the logical interdependence among them.**
- ✓ **Estimate activity duration**
- ✓ **Draw graphical presentation(bar/network)**
- ✓ **Analyze the network**

Project Scheduling

Why Schedule projects?

1. To calculate the project completion
2. To calculate the start and end of a specific activity
3. To predict and calculate the cash flow
4. To evaluate the effect of change orders
5. To improve work efficiency
6. To resolve delay claims
7. To serve as an effective project control tool

Project Scheduling

Scheduling involve four main steps:

1. **Performing breakdown of work items involved in the project into activities.**
2. **Activities representation**
3. **Identifying the proper sequence by which the activities should be executed.**
4. **Estimating and assigning the resources, time and cost of individual activities.**

WORK BREAKDOWN STRUCTURE

The WBS is described as a hierarchical structure which is designed to logically sub-divide all the work-elements of the project into a graphical presentation.

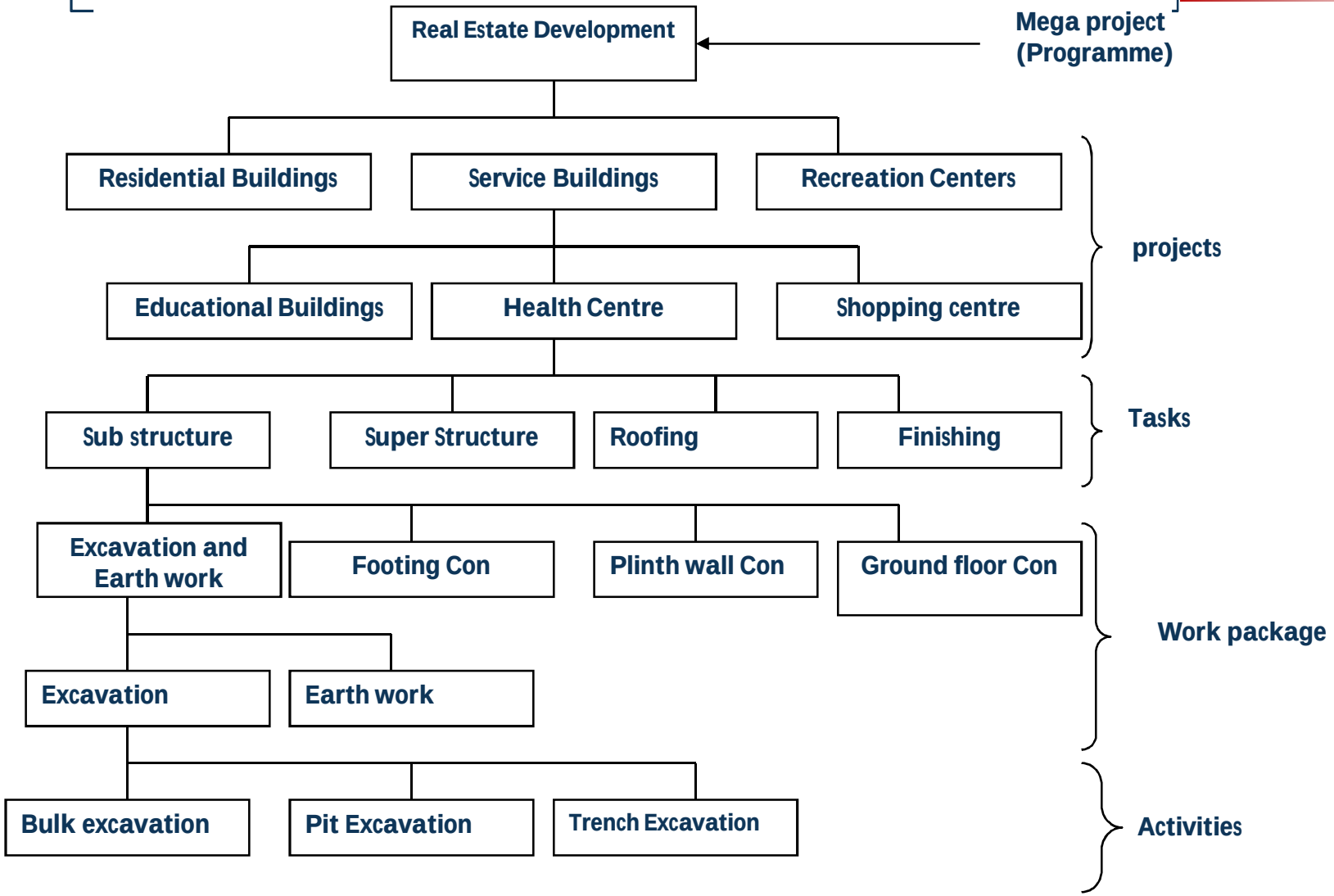
- ✓ **The full scope of work for the project is placed at the top of the diagram, and then sub-divided smaller elements of work at each lower level of the breakdown.**
- ✓ **The work breakdown structure typically decreases in size from top to bottom:**
- ✓ **Effective use of the WBS will outline the Scope of the project and activities.**

WBS: Level of divisions

To the level that estimates and forecasts about the resources required, durations and activity relationships are realistically estimated for each activity;

- ✓ **Program:**
- ✓ **Project level: Projects are derived by dividing a large project, usually termed *a program*, into independent large-volume mini projects.**
- ✓ **Task level: A task is an identifiable and deliverable major work which can be performed without major interference from other tasks.**
- ✓ **Work package level: A work package contains an identifiable, constable and controllable package of work.**
- ✓ **Activity level: An activity is a sub division of a work package and is defined as a work which has a definite start and end and consumes resources and time and which is measurable.**

WBS…..


Real Estate Development
Mega project
(Programme)
Residential Buildings
Service Buildings
Recreation Centers
Educational Buildings
Health Centre
Shopping centre
projects
Sub structure
Super Structure
Roofing
Finishing
Tasks
Excavation and
Earth work
Footing Con
Plinth wall Con
Ground floor Con
Work package
Excavation
Earth work
Bulk excavation
Pit Excavation
Trench Excavation
Activities

Activity relationships

Is determining

- ✓ **Which activities must be finished before the current can start?**
- ✓ **What activity(ies) may be constructed concurrently the current one?**
- ✓ **What activity(ies) must follow the current one?**

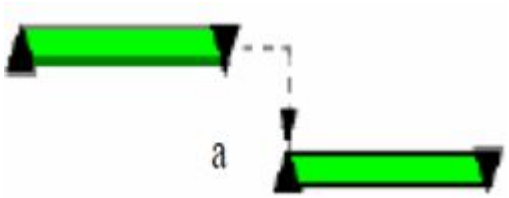
Types of activities relationships

- ✓ Relationships are defined from the predecessor to the successor activity.
- ✓ Four types of relationships exist

A) Finish to start (FS)

The successor activity can begin only when the current activity completes.

Example: the Formwork installation must be finished before the concrete casting can start.



Types of activities relationships

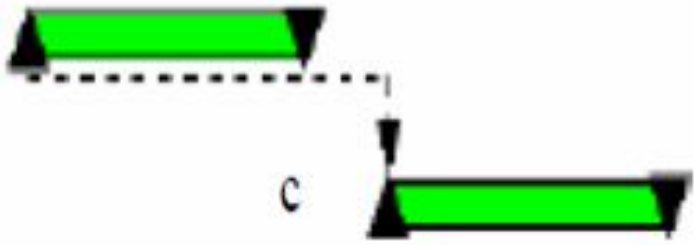
B) Finish to finish (FF)

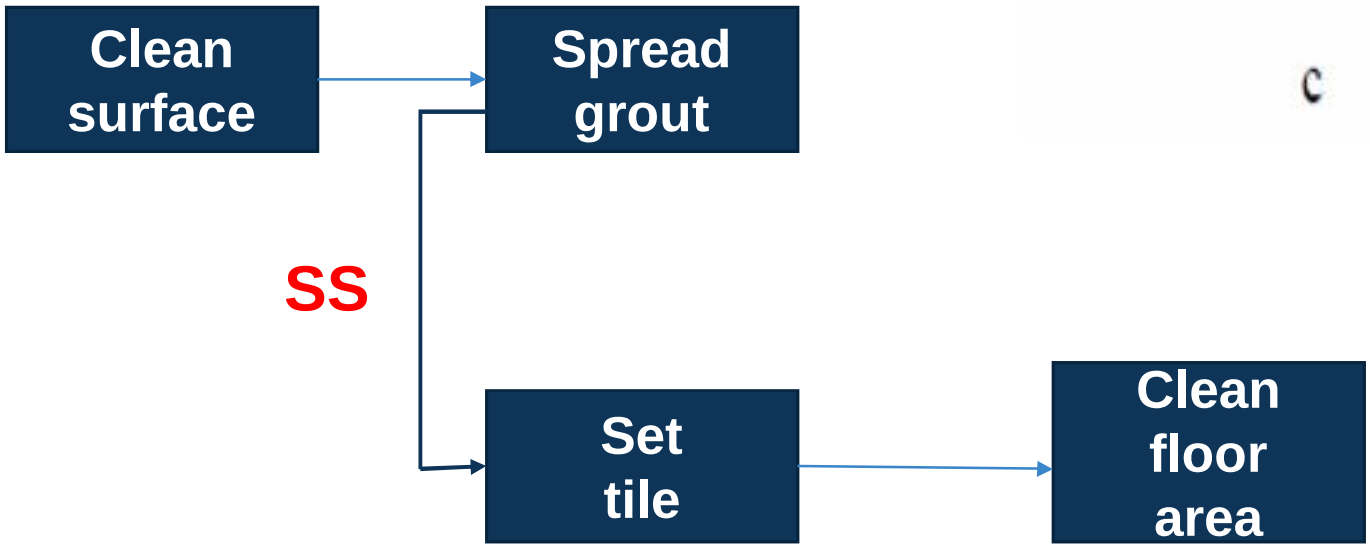
- The **finish** of the **successor** activity depends on the **finish** of the **current** activity.
- Can be used where activities can overlap to a certain limit.
- There might be lag between the two activities

Types of activities relationships

C) Start to Start (SS)

- The **start** of the **successor** activity depends on the **start** of the **current** activity.
- There might be a lag between the two activities

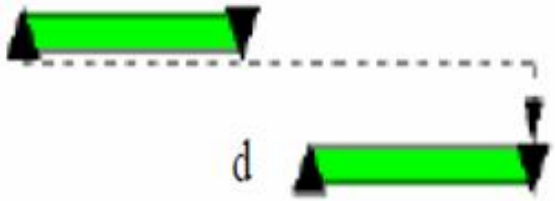


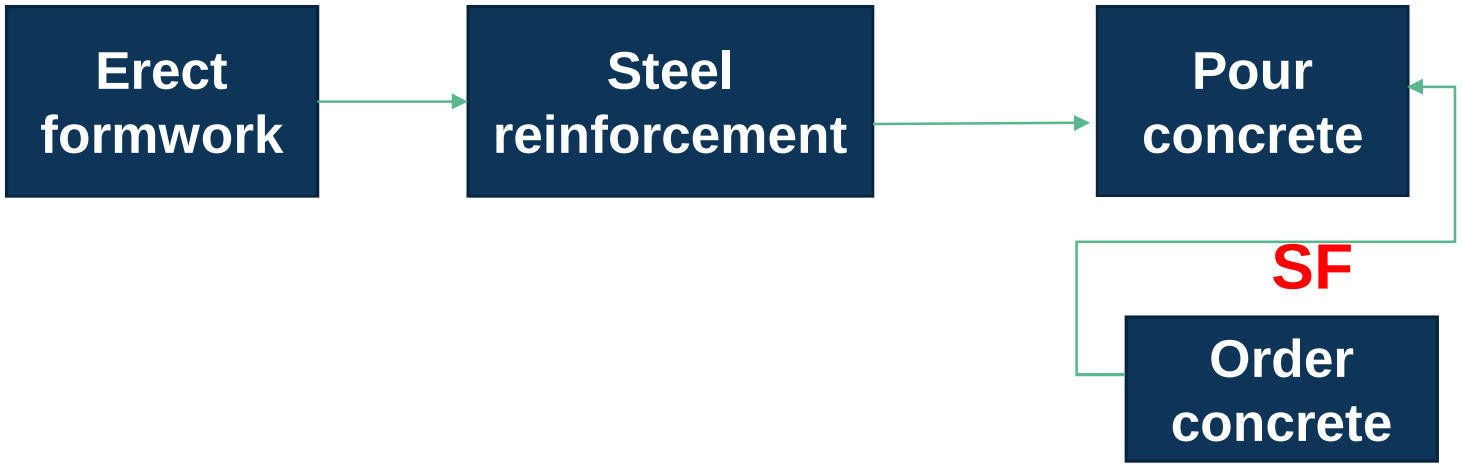


Types of activities relationships

D) Start to Finish (SF)

- The successor activity cannot finish until the current activity starts .
- Not Common
- Typically used with delay time or lag.





Logical relationship considering resource constraints

- ✓ For efficient use of **resources** or in case of **constraint resources**, it might be beneficial to consider the resources when determining the logical relations among the activities that use the same resources.

Example: consider construction a simple project consists of three units and each unit has three sequential activities

Considering resource constraints....

Activity	Description	Predecessors (unconstrained resource)	Predecessors (constrained resource)
A1	Excavation unit 1	-	-
B1	Concreting unit 1	A1	A1
C1	Brickwork unit 1	B1	B1
A2	Excavation unit 2	-	A1
B2	Concreting unit 2	A2	B1,A2
C2	Brickwork unit 2	B2	C1,B2
A3	Excavation unit 3	-	A2
B3	Concreting unit 3	A3	B2,A3
C3	Brickwork unit 3	B3	C2,B3

Project Scheduling...

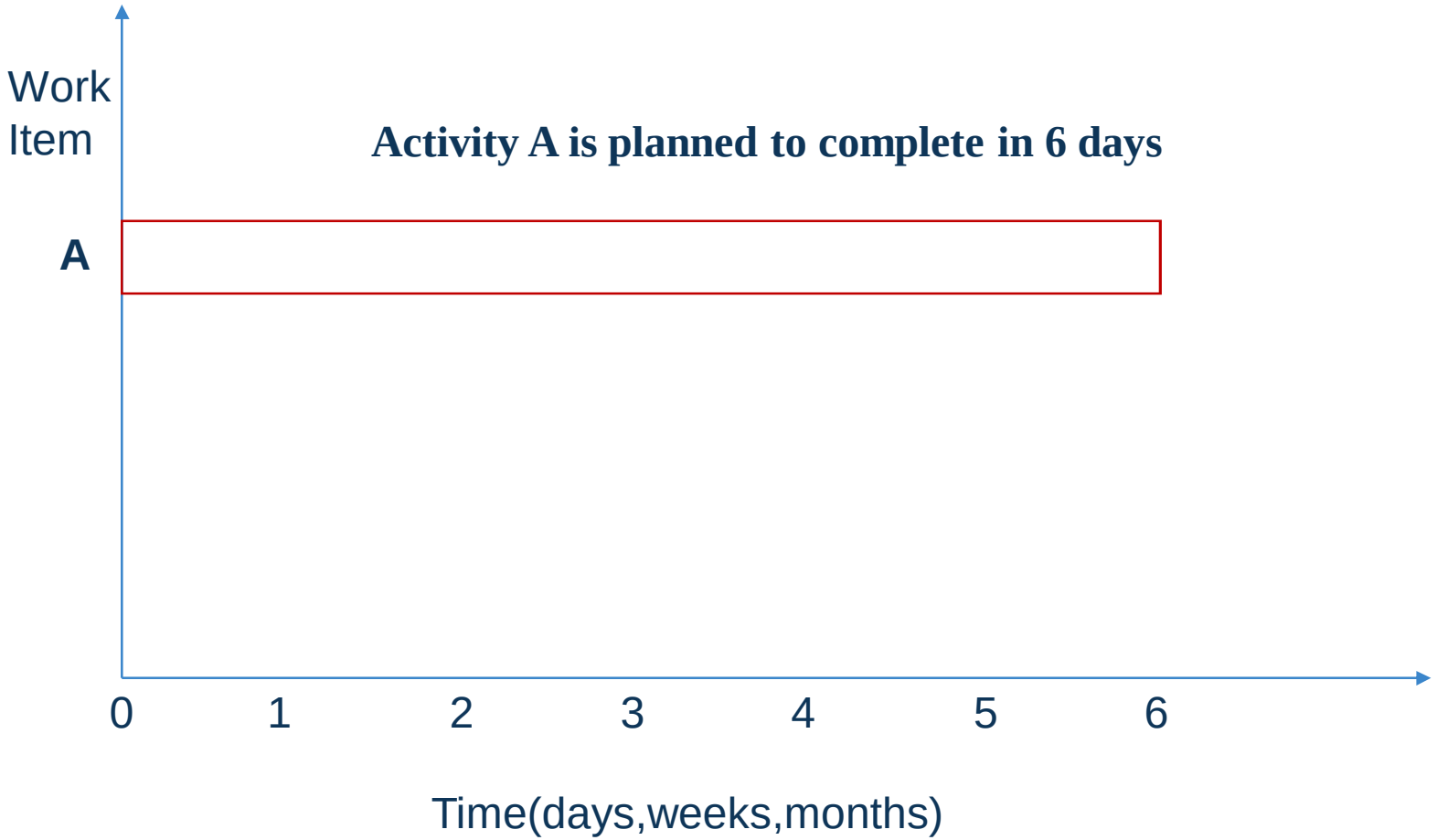
The scheduling techniques widely used in construction management are:

- ✓ **Charts**
- ✓ **Network analysis (CPM/PERT)**
- ✓ **Line of balance and resource levelling**
- ✓ **Others (Q-scheduling, etc..)**

A. Gantt (Bar) Chart

- ✓ Originally developed by **Hennery L. Gantt** in 1917
  - ✓ Used for production in WW-1
  - ✓ Planning of Hoover dam & Interstate highways
- ✓ **Gantt or bar chart** is a popular tool for planning and scheduling simple projects.
- ✓ In a bar chart the activities are shown as **horizontal bars** on a **horizontal time scale**, where the start and end locations of the bars coincide with the start and finish dates of the activities.

A. Gantt (Bar) Chart



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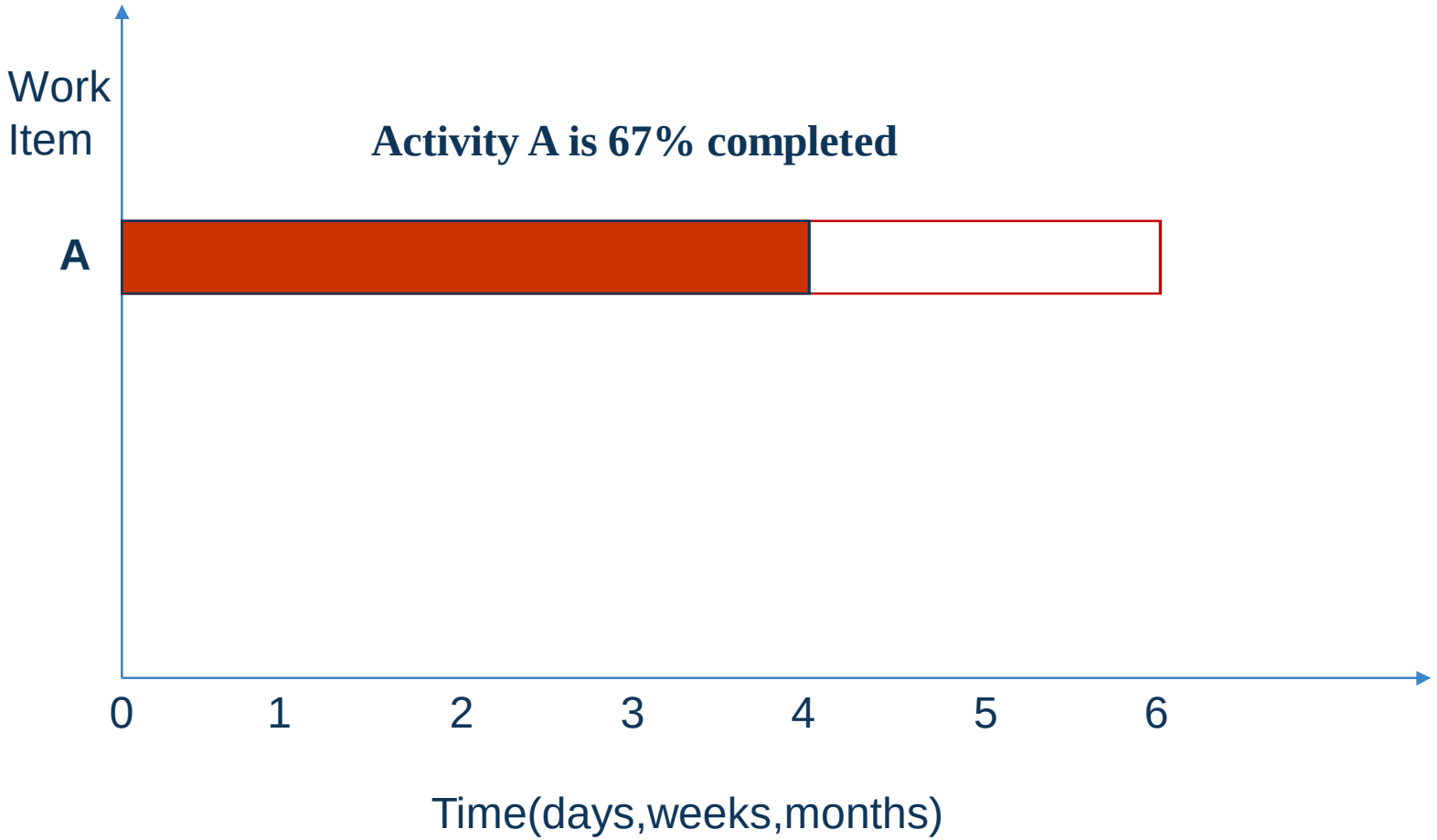
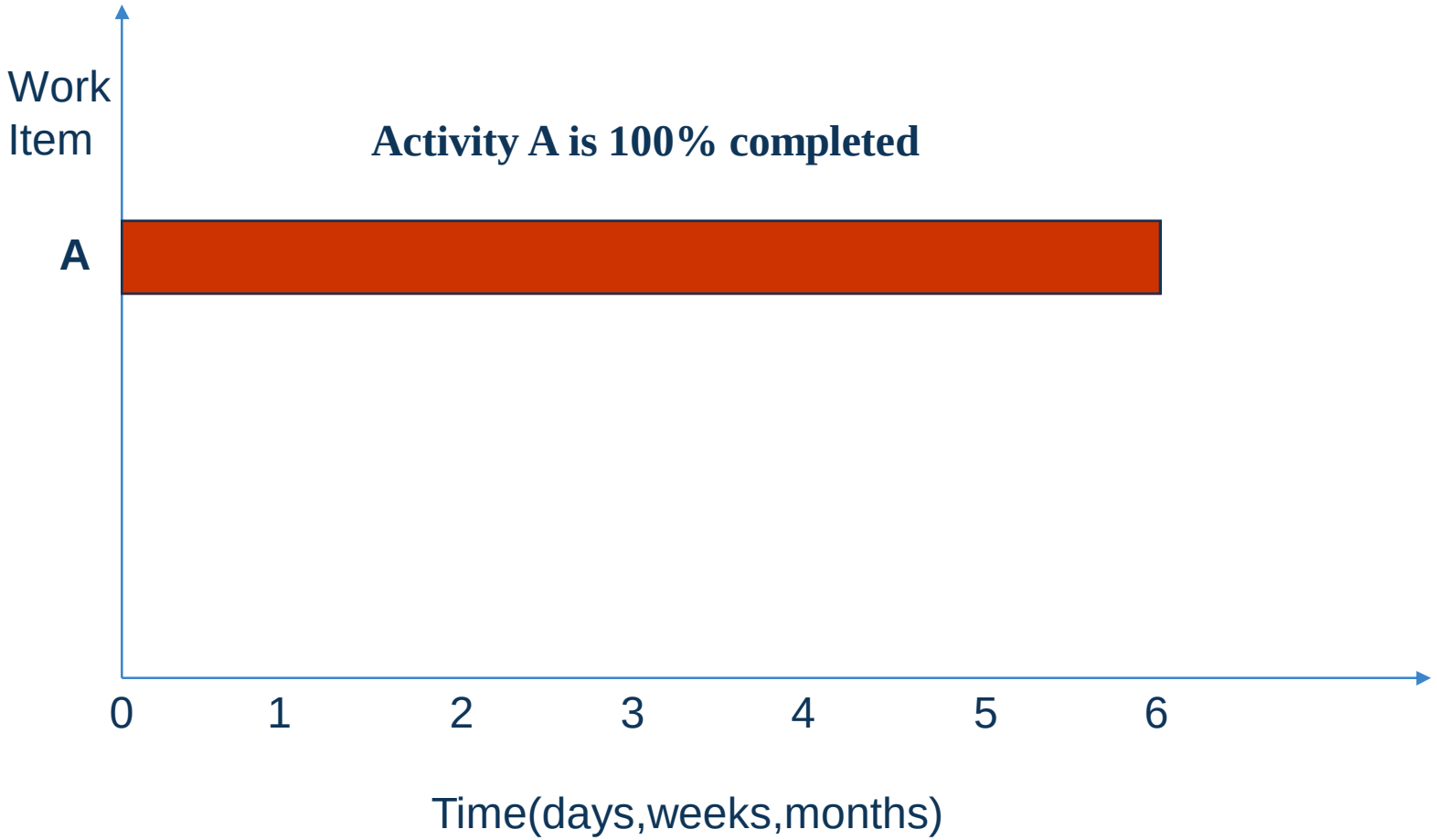
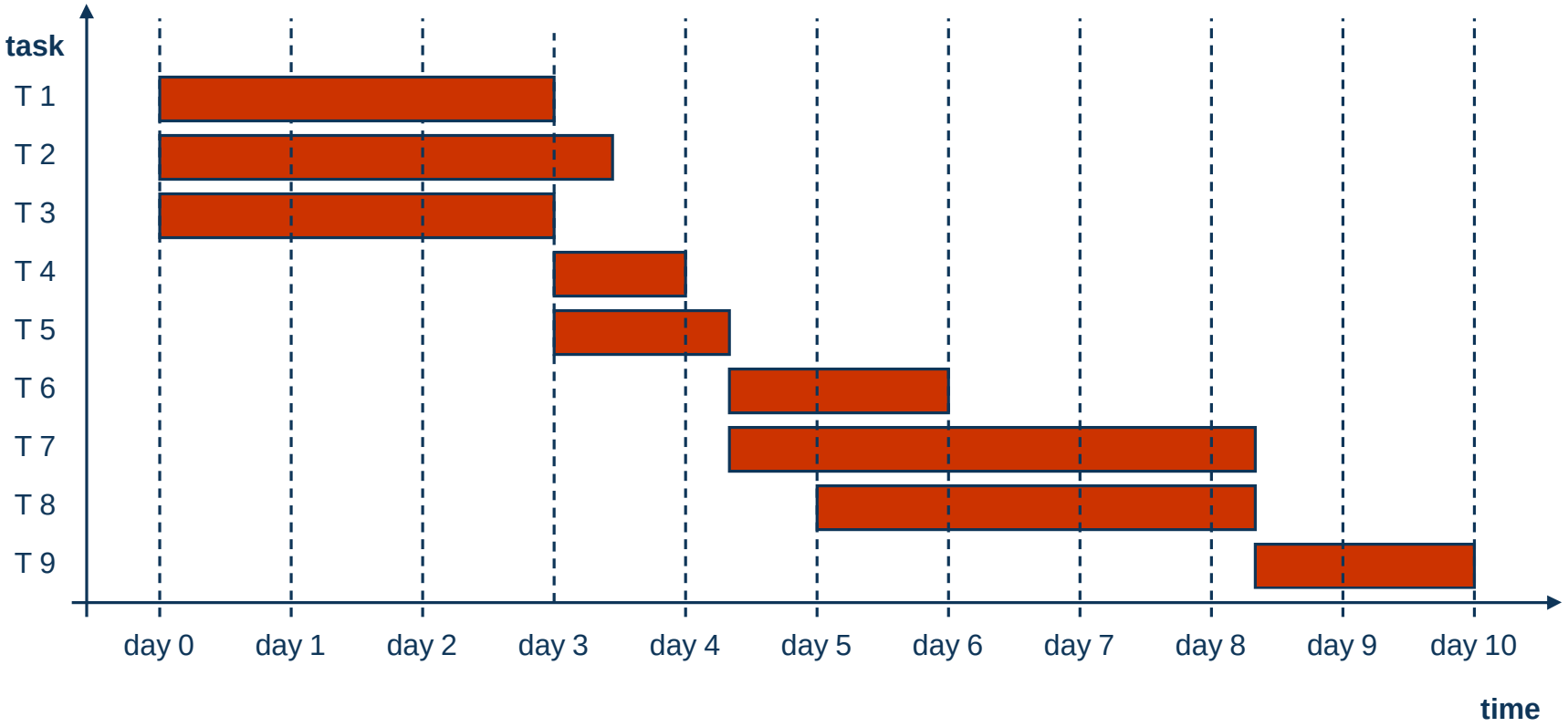


A. Gantt (Bar) Chart



Gantt (Bar) Chart

Gantt (Bar) Chart structure:



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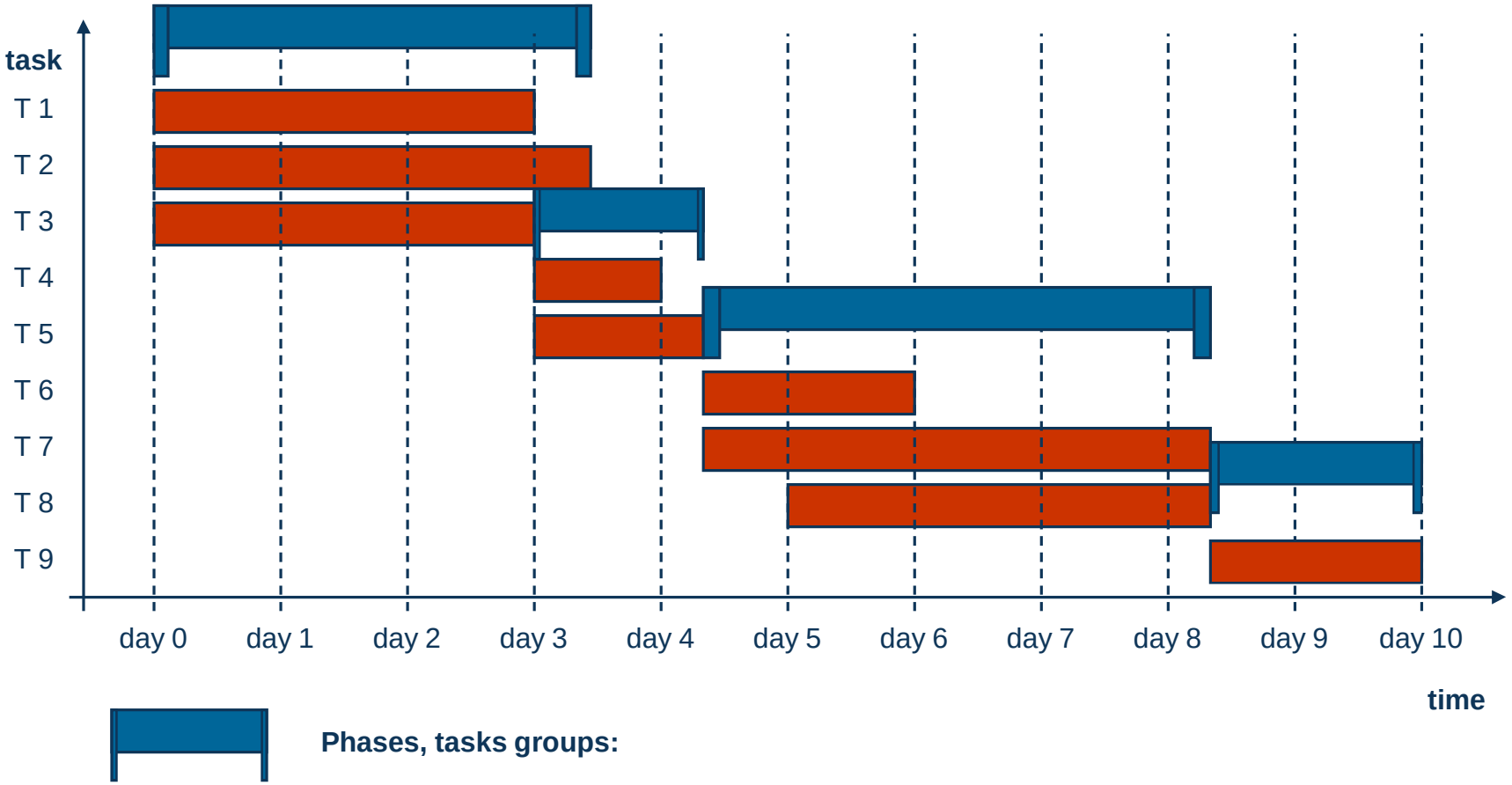
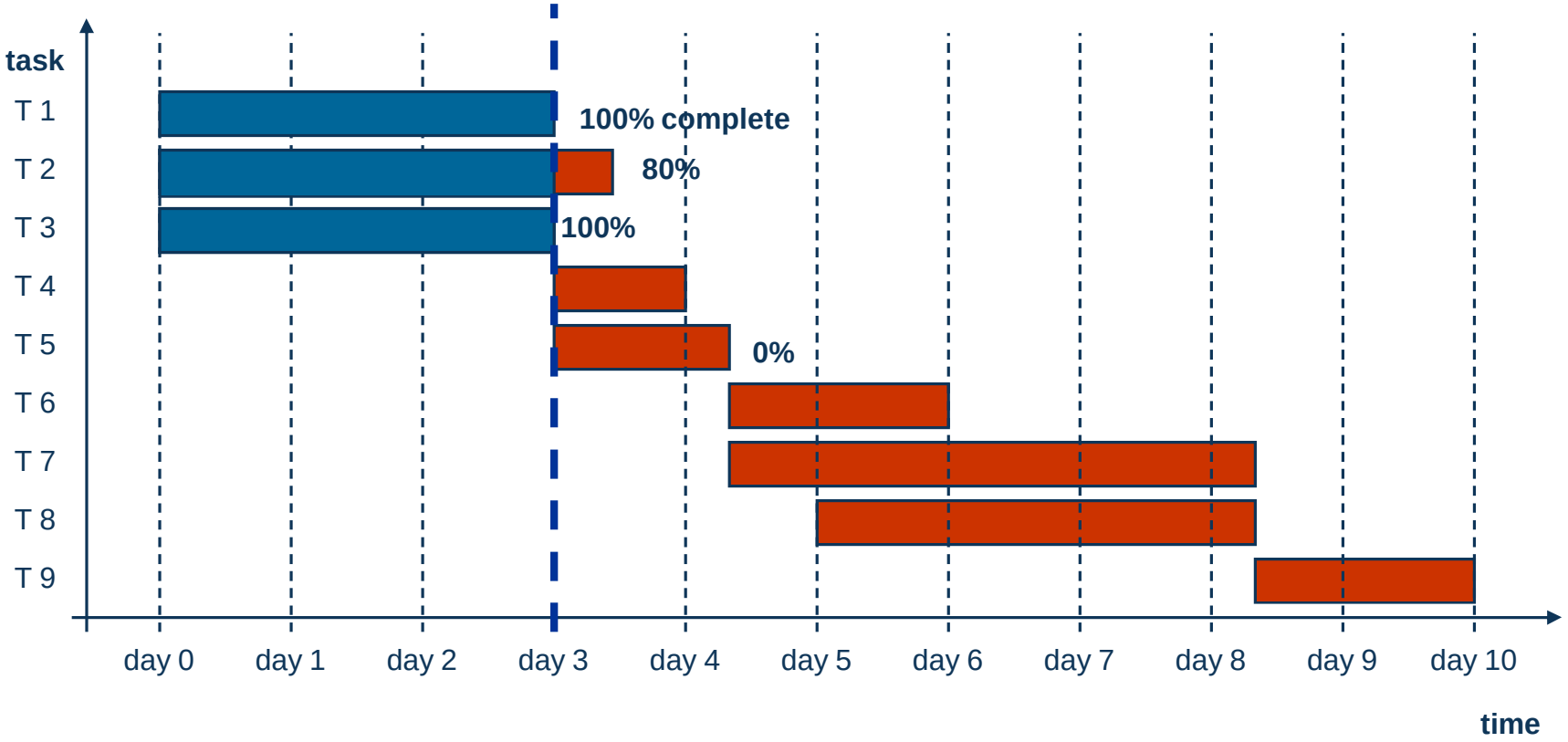


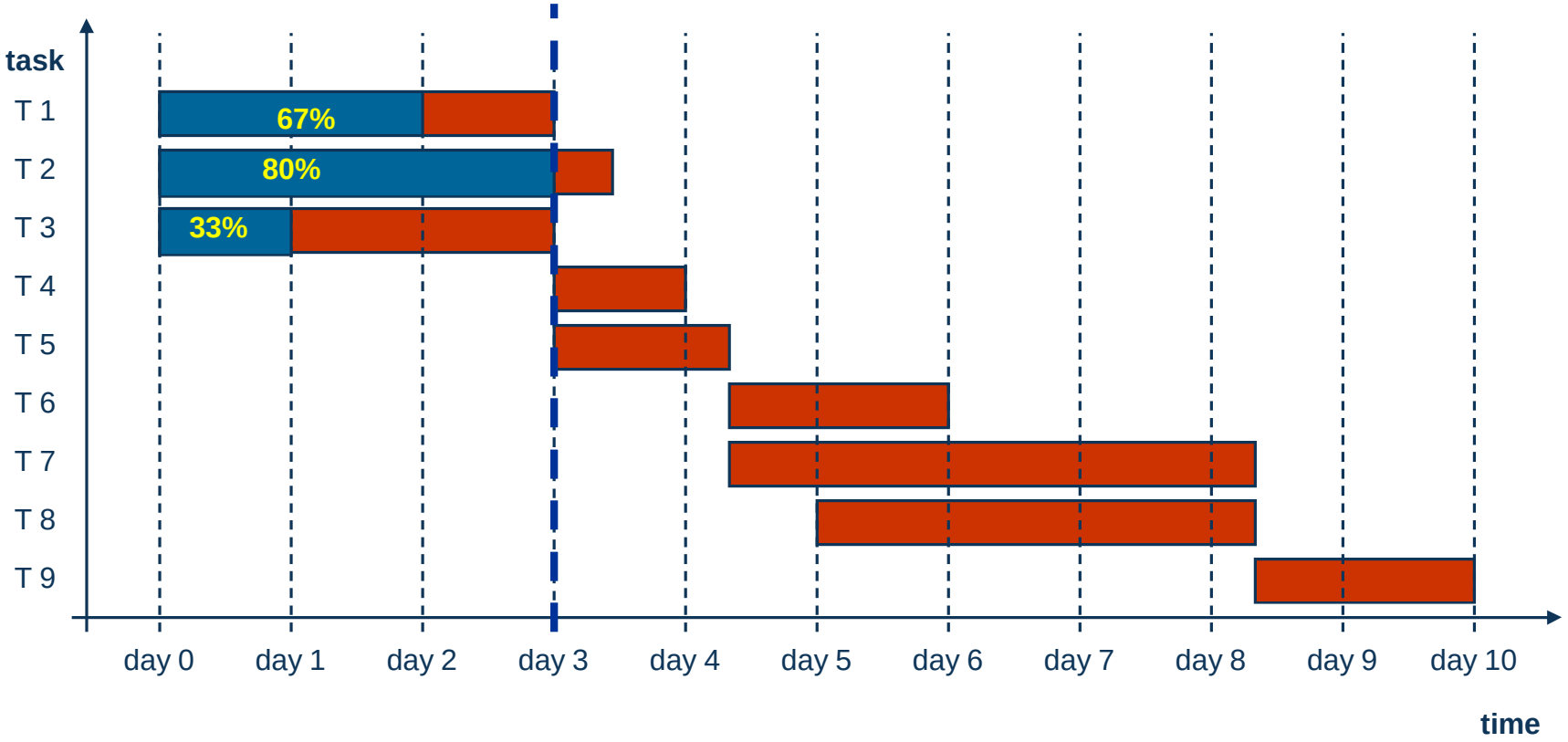
Gantt (Bar) Chart

Scope planned to complete in 3 days



Gantt (Bar) Chart

Scope actually completed in 3 days



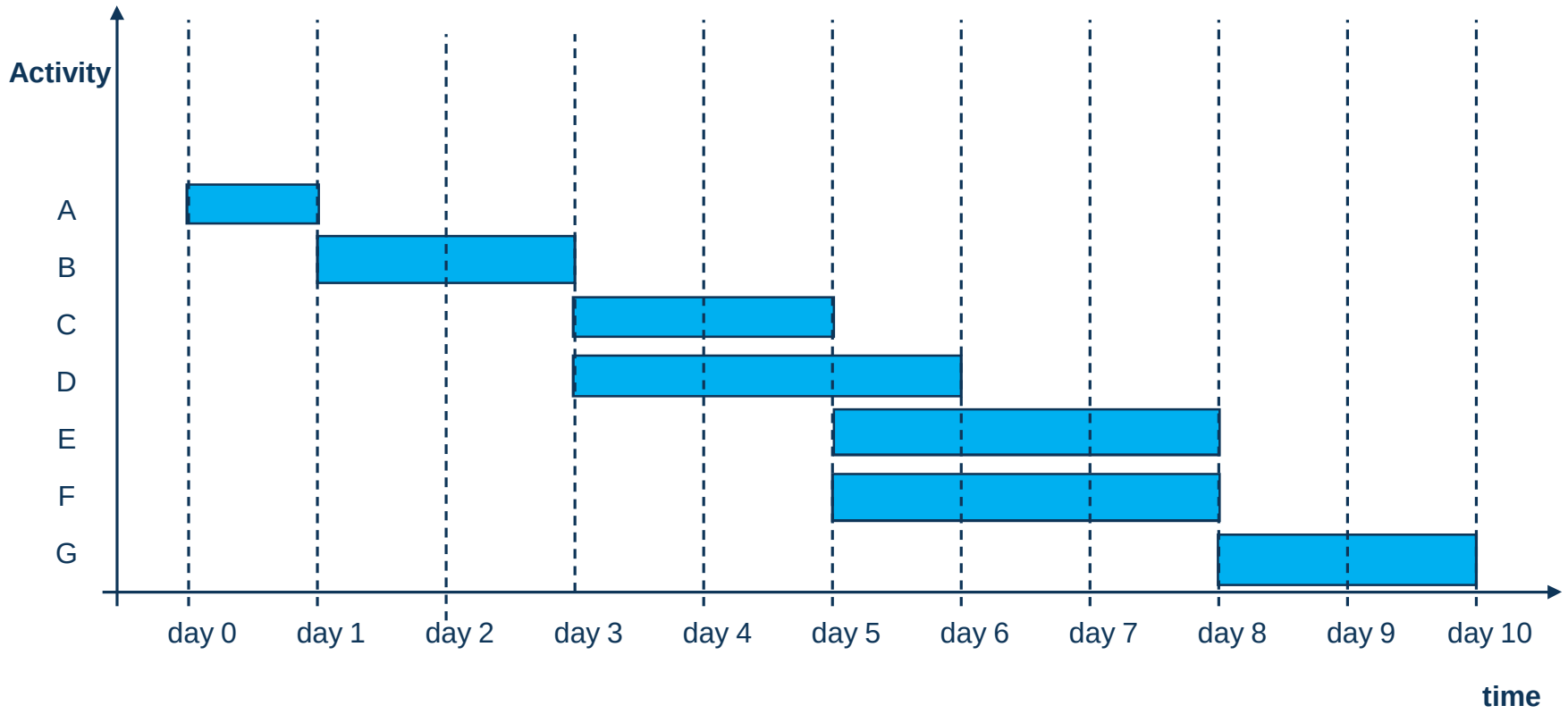
Example

Draw the Gantt (bar) chart and estimate the total duration for the following activities:

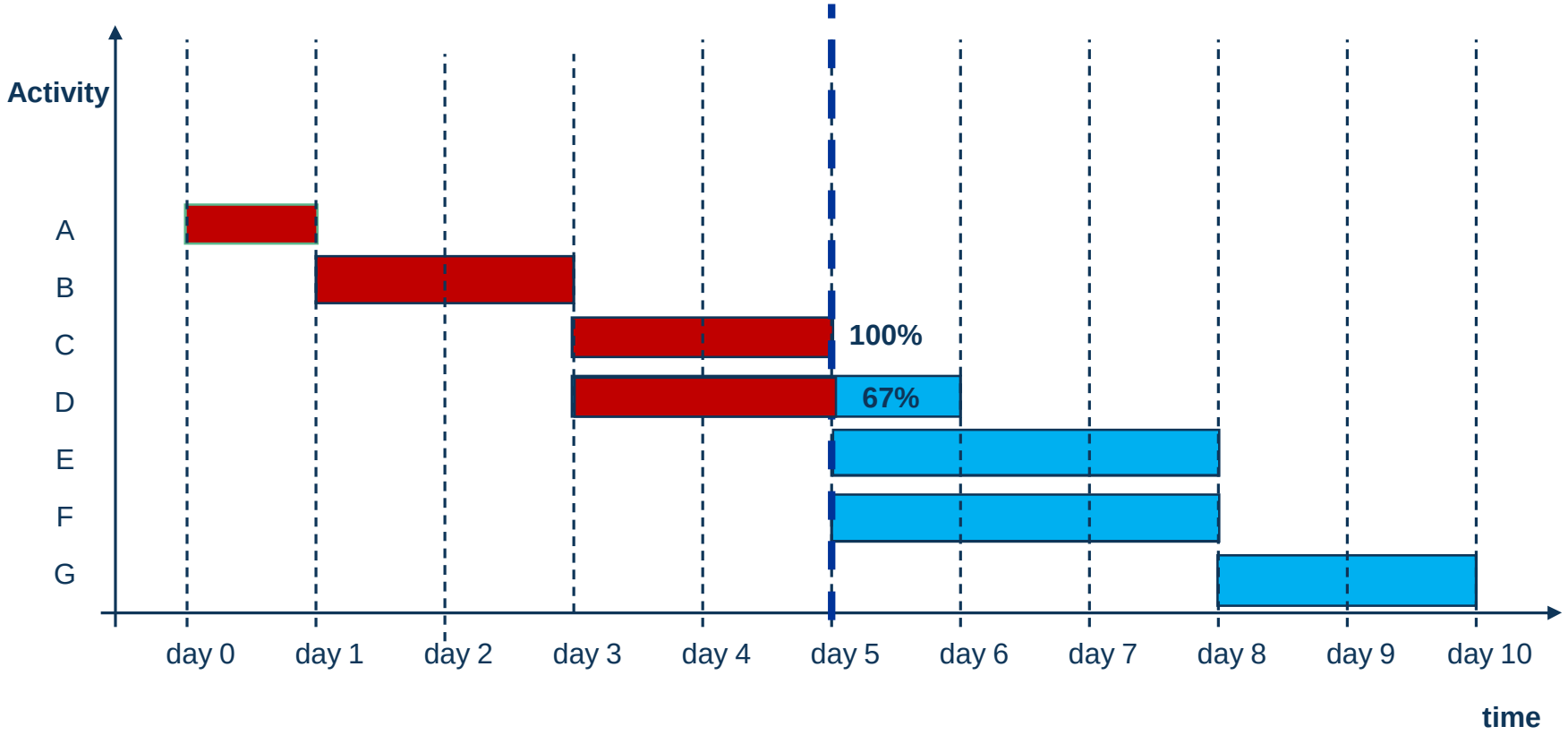
Activity	description	Duration	predecessors
A	Site clearing	1	-
B	General excavation	2	A
C	Excavation for utility trenches	2	B
D	Placing formwork and reinforcement bars	3	B
E	Installing sewer lines	3	C
F	Installing other utilities	3	C
G	Pouring concrete	2	D,E

- ✓ **Today is the end of day 5 and the site engineer reported that Activity C is 80% completed and Act. D is 33% completed; comment on the progress of the project and which and by how much activities are delayed.**

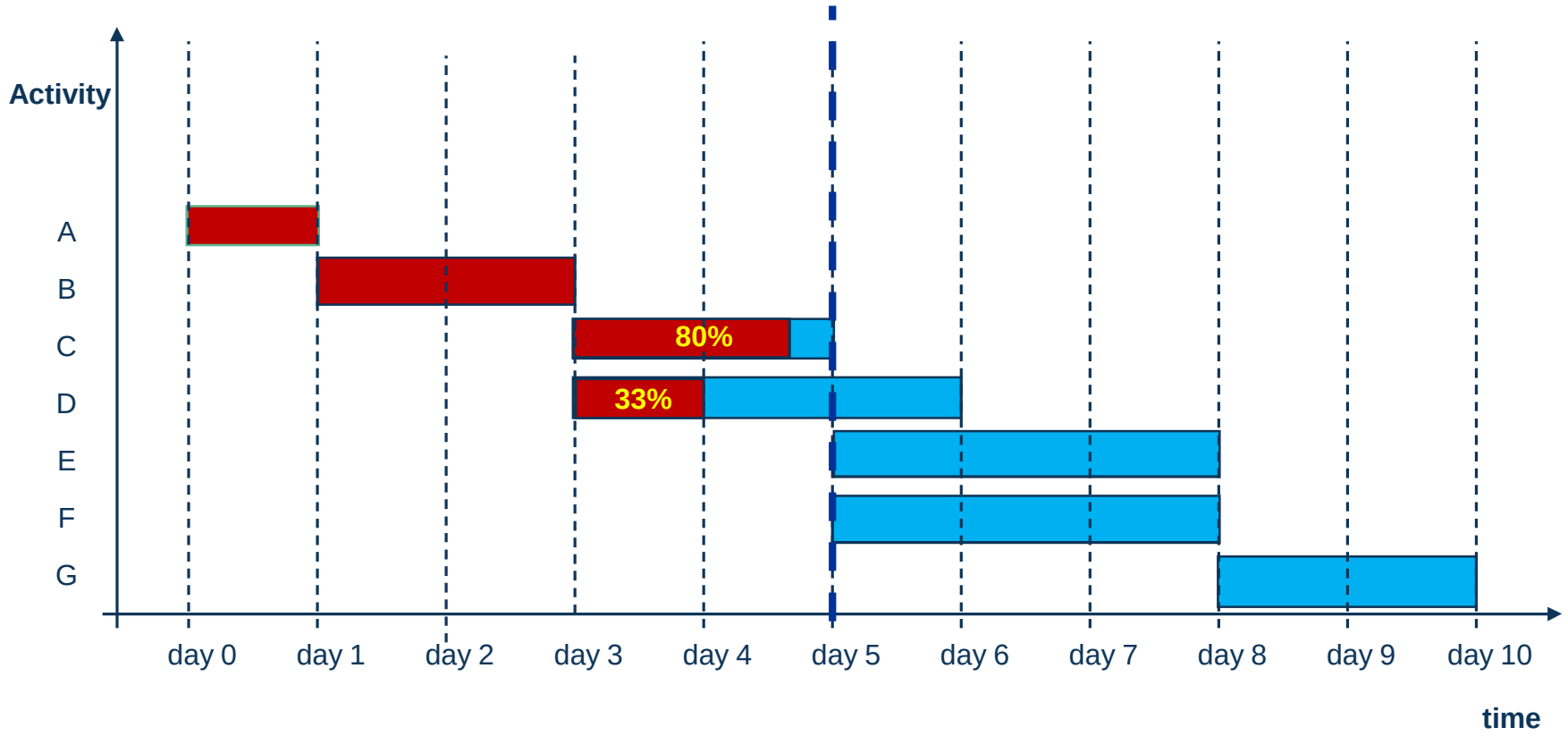
Gantt (Bar) Chart



Gantt (Bar) Chart



Gantt (Bar) Chart



Gantt (Bar) Chart

Advantages of Bar chart :

- **Useful to report information to people who are concerned about a project but may not be involved in day-today management.**
- **A simple format and readily understood at all levels of management,**
- **It can provide a quick, visual overview of a project in convenient way to monitor job progresses, schedule equipment and crews and record project advancement.**

Gantt (Bar) Chart

Disadvantages:

- **Interdependencies among activities are difficult to show. The bar chart itself doesn’t provide a basis for ascertaining which activities are critical and which are floaters.**
- **It is not an adequate planning and scheduling tool because it doesn’t show a detailed, integrated and complete plan of operations.**
- **Can't tell what will be the effect of a delay today will have on the timing of future activities.**

B. Network Techniques

The critical path method (CPM) and program evaluation and review technique (PERT) are two of the most widely used network techniques.

- ✓ **A network is a logical and chronological graphic representation of the activities (and events) composing a project.**
- ✓ **The Network Diagram is essentially a flowchart of the project tasks.**
- ✓ **A project network is asset of arrows and nodes.**

Network Techniques...

- ✓ Network diagrams are the preferred technique for showing activity sequencing.
- ✓ When tasks starting and ending time are uncertain, the Network Diagram is often a better technique to use than the Gantt (bar) chart.
- ✓ There are two ways that are commonly used to draw a network diagram for a project

Two classic representations

- AOA: Activity on Arrow
- AON: Activity on Node

Activity- on- arrow (AOA)

- Also called **arrow diagramming method (ADM)** network diagram or (I- J) method (because activities are defined by the form node, I, and the to node, J)
- Activities are represented by **arrows**.
- **Nodes** or circles are the starting and ending points of activities.
- It can only show **finish- to- start** dependencies

AOA....

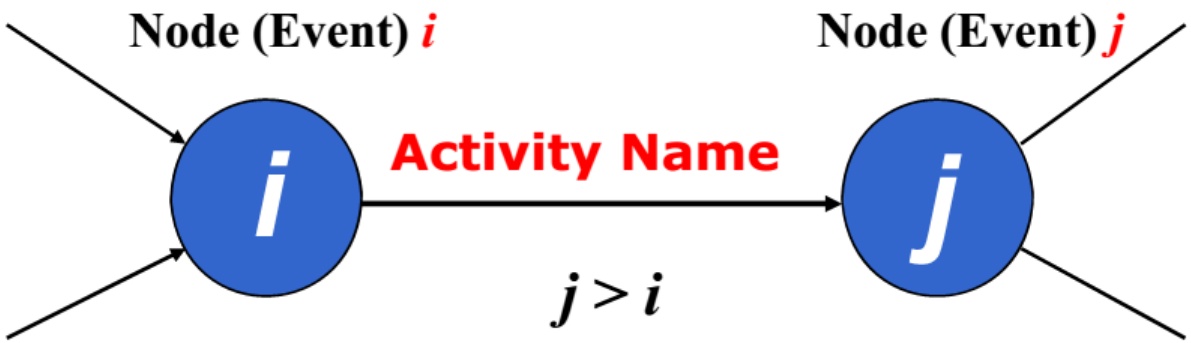
Information required for drawing networks

- ✓ List of individual activities
- ✓ Activity interdependencies
- ✓ Activity time estimates.

Ground rules for developing a network :

- ✓ Each event should have preceding and succeeding event except the starting and ending event
- ✓ Commencement → completion
- ✓ Events should have a distinct number

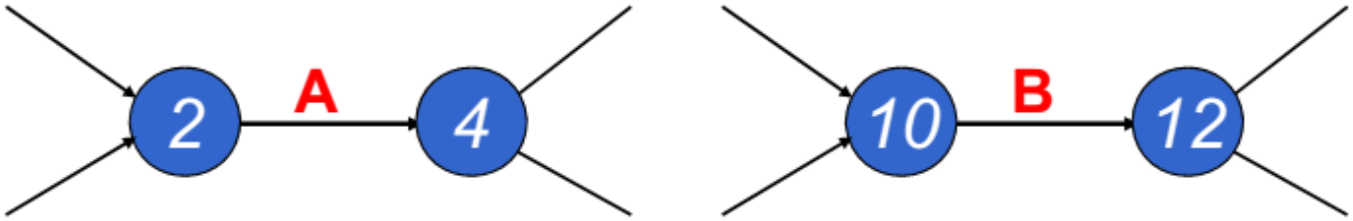
Basic Logic Patterns for Arrow Diagrams



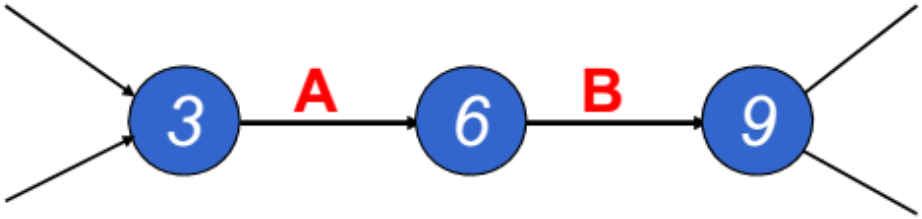
Each activity should have a unique $i-j$ value

(a) Basic Activity

AOA....

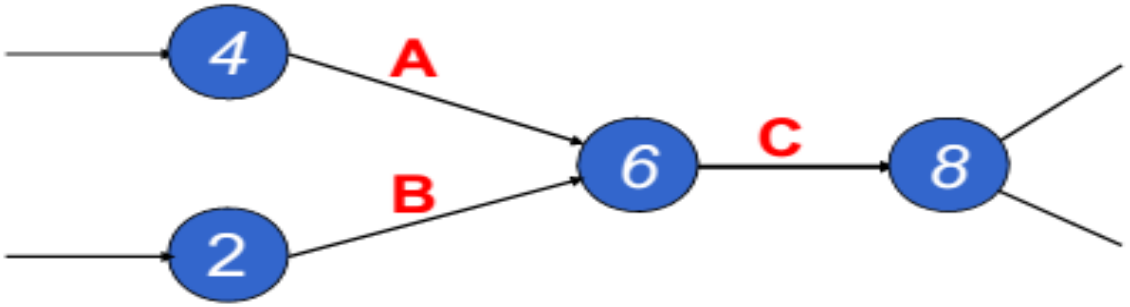


(b) Independent Activities



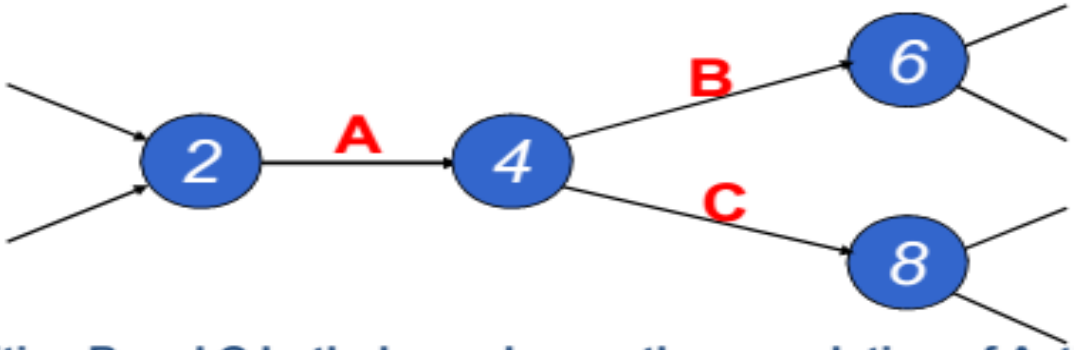
(c) Dependent Activities

AOA....



Activity C depends upon the completion of both Activities A & B

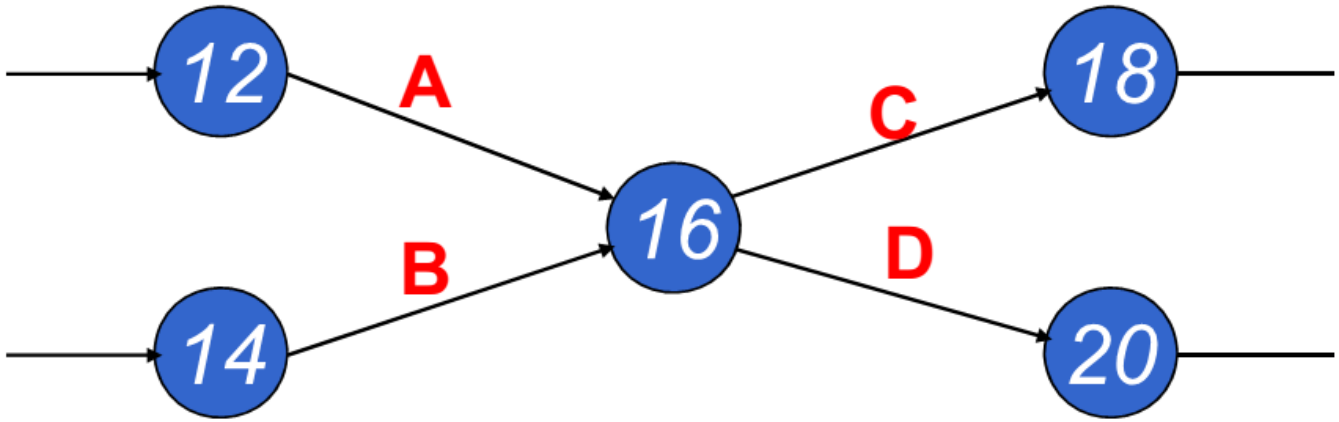
(d) A Merge



Activities B and C both depend upon the completion of Activity A

(e) A Burst

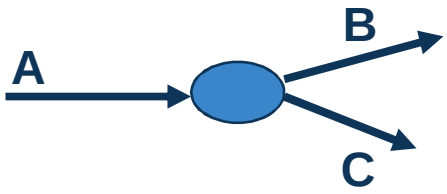
AOA....



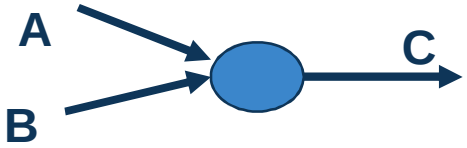
Activities C and D both depend upon the completion of activities A and B

(f) A Cross

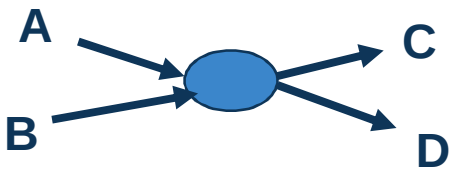
Situations in network diagram



A must finish before either B or C can start



Both A and B must finish before C can start



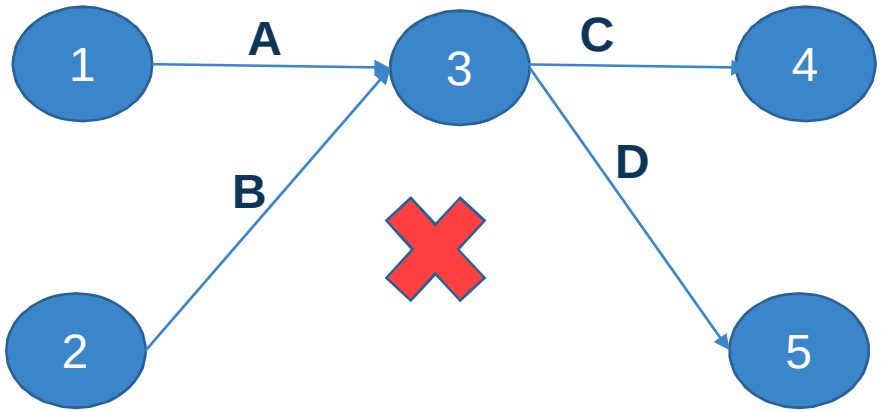
Both A and B must finish before either of C or D can start

Dummy activity (fictitious)

- The dummy activity is an activity with zero duration, consumes no resources, drawn as dashed lines, and used to adjust the network diagram.
- A dummy activity is also used when one activity depends upon two preceding activities and another activity depends only upon one of these two preceding activities.

Dummy activity (fictitious)

- C depends on A and B
- D depends on B only



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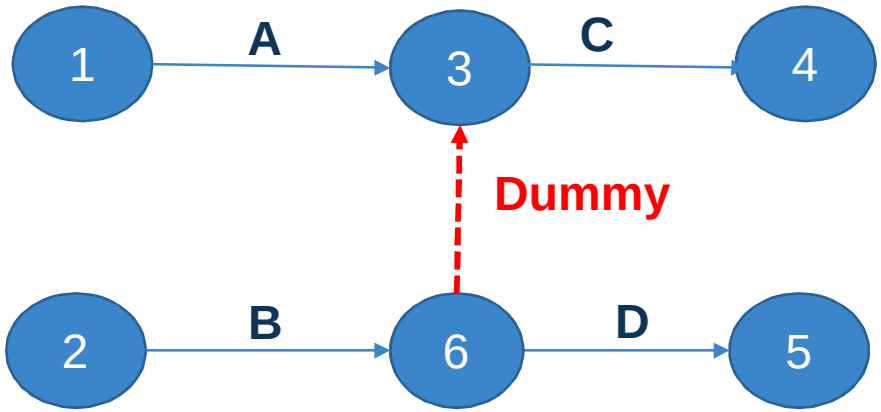
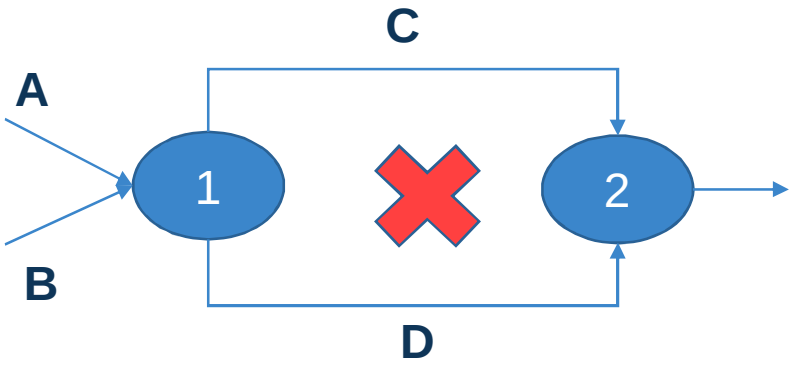
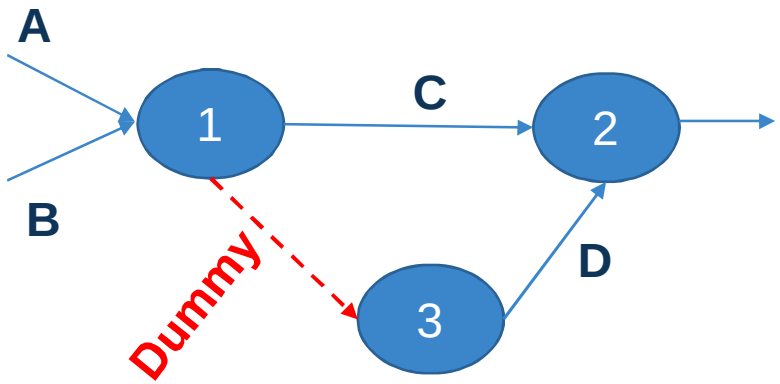


Dummy activity (fictitious)

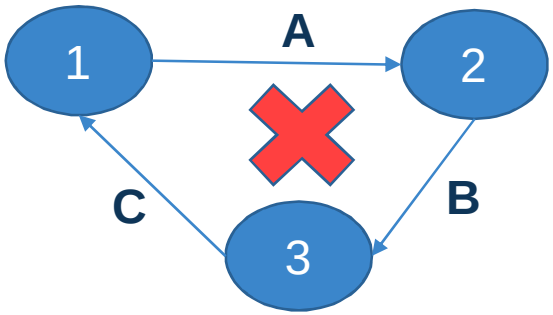
- Used to maintain unique numbering of activities
- Not more than one activity should have the same preceding and succeeding events, i.e. only one activity may connect any two events.





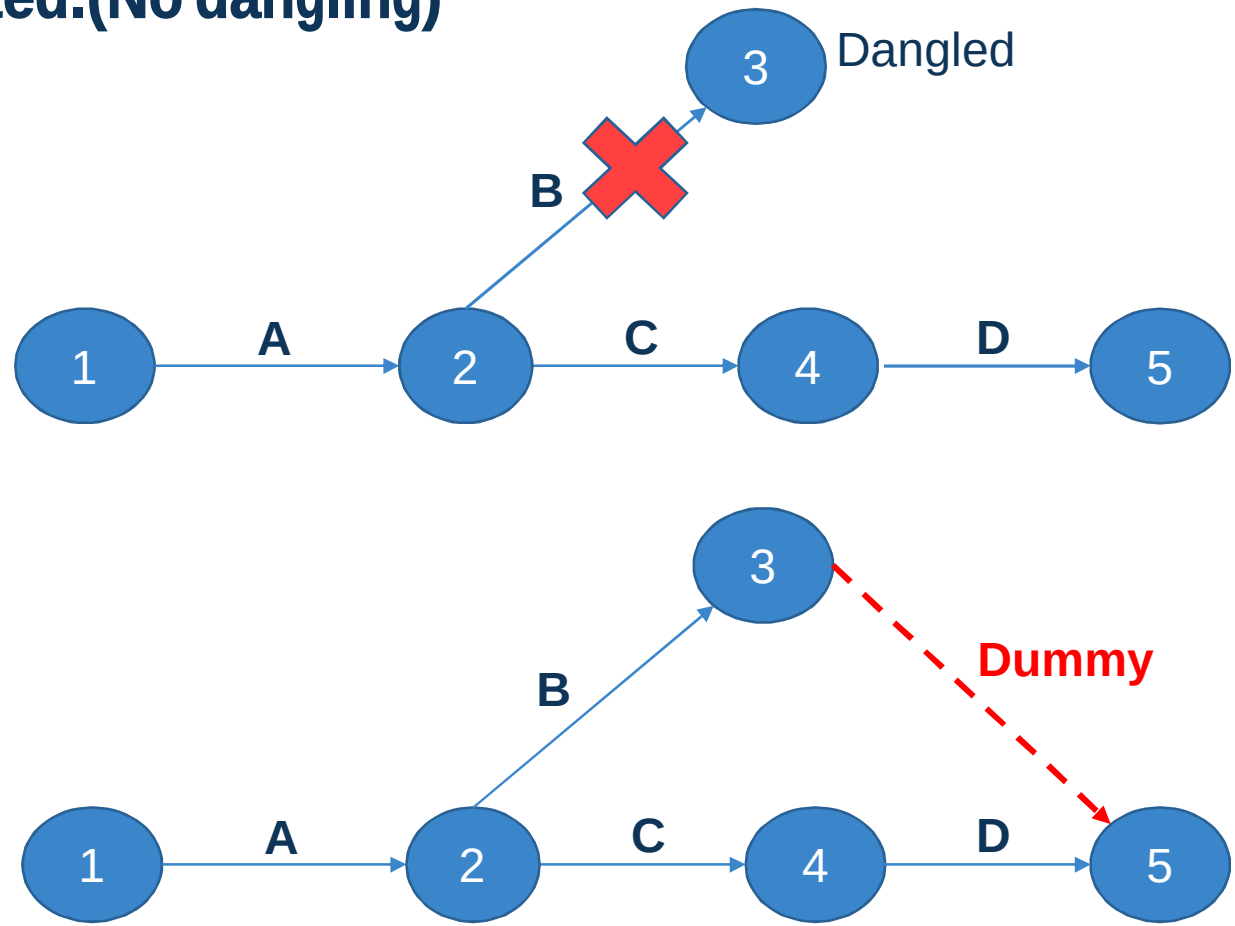
Some additional rules / laws

- ✓ The Network must have **definite** points of beginning and finish.
- ✓ There should not be a **loop** formation in a network, No activity should lead back to previous activity “No looping”



Some additional rules / laws

- ✓ The network must be continuous. No activity should be disconnected.(No dangling)

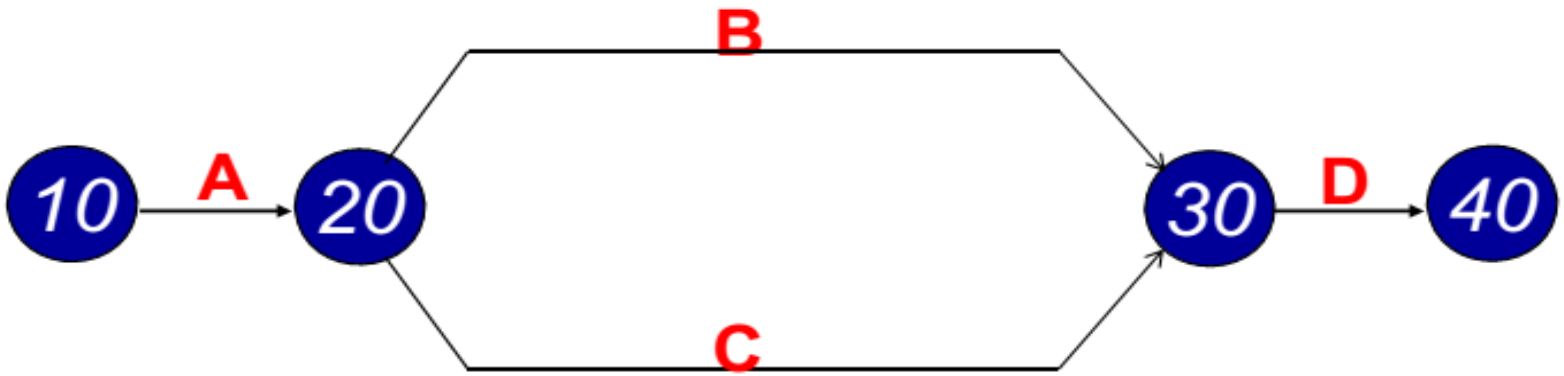


Example

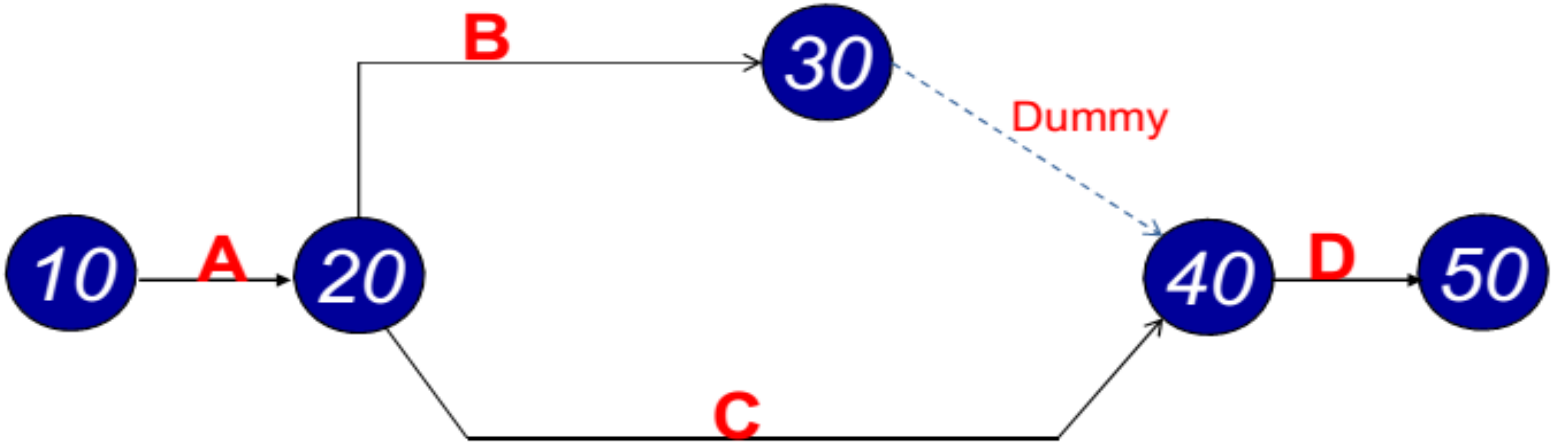
- Draw the arrow network for the project given next.

Activity	IPA
A	-
B	A
C	A
D	B,C

Solution



Improper solution



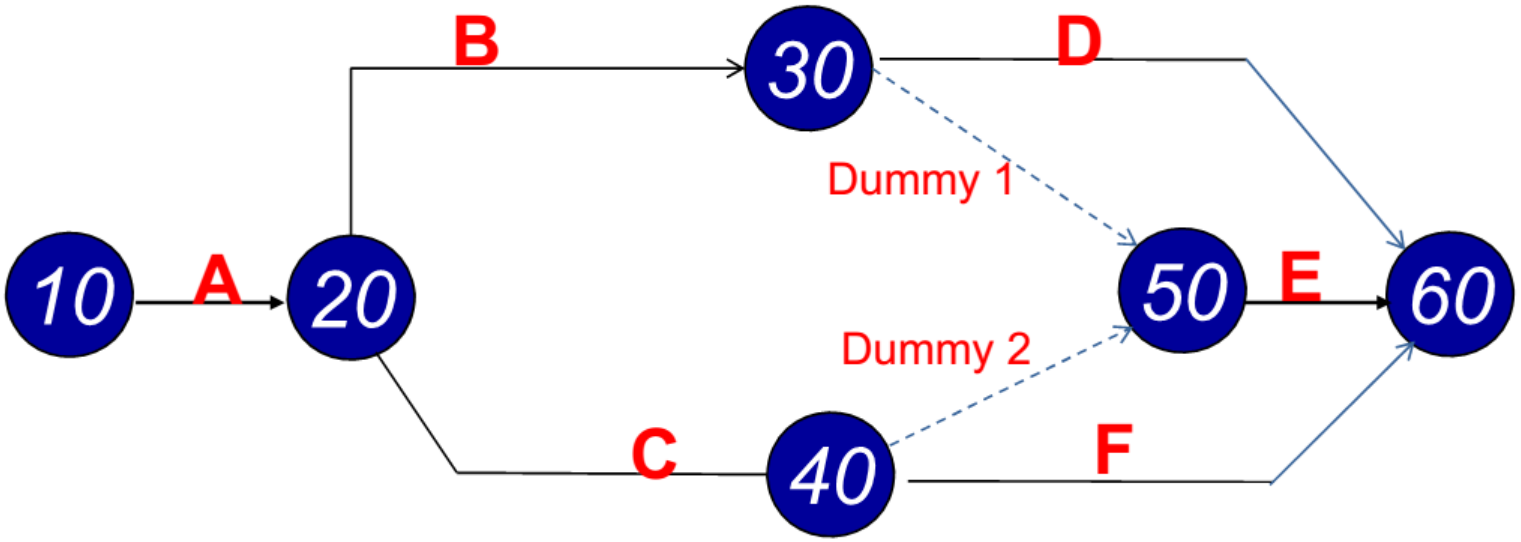
proper solution

Example

- Draw the arrow network for the project given next.

Activity	IPA
A	-
B	A
C	A
D	B
E	B,C
F	C

Solution



Activity on Node(AON)

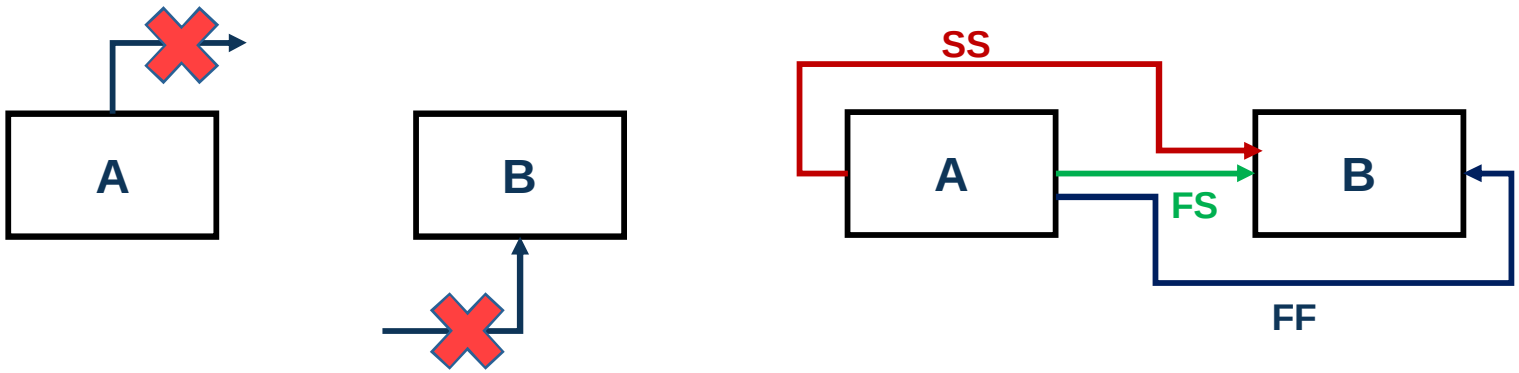
AON: Activity on Node

- ✓ **A matter of preference which one to use**
- ✓ **Each activity labeled with Identifier (usually a letter/code) and duration (in std. Unit like days)**
- ✓ **There is one start & one end event**
- ✓ **Time goes from left to right**

Activity on Node(AON)

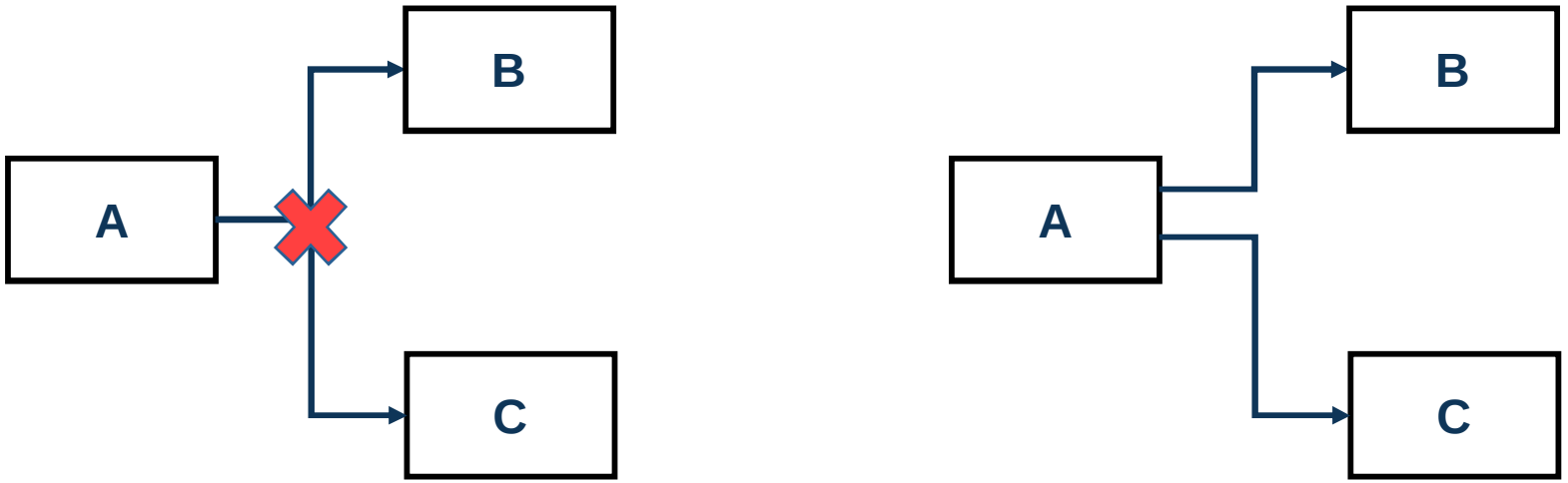
Basic Recommendations on drawing AON diagram:

- ✓ **The activities in the node diagrams are preferable to be drawn as rectangles instead of circles.**
- ✓ **Don’t connect from top or bottom. Sides only.**



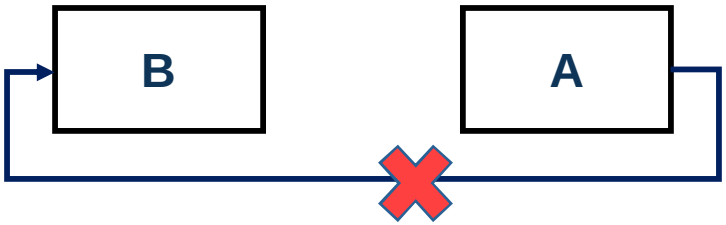
Activity on Node(AON)

- ✓ **Don’t combine relationship lines.**



Activity on Node(AON)

- ✓ **Design from left to right in chronological order**

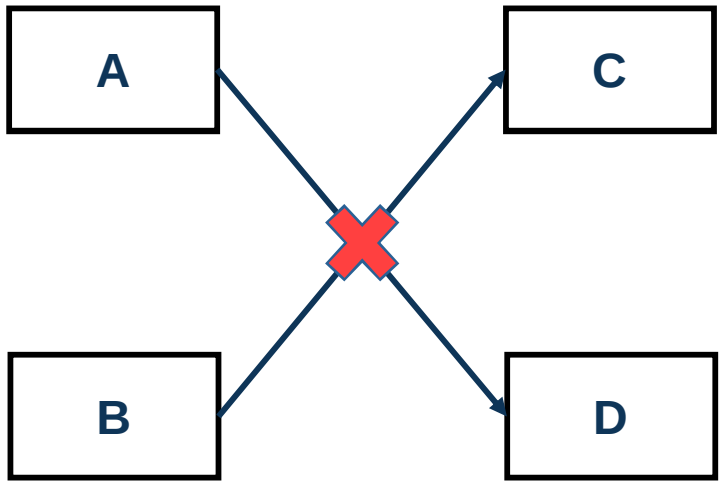


Activity on Node(AON)

- ✓ **Design from left to right in chronological order**

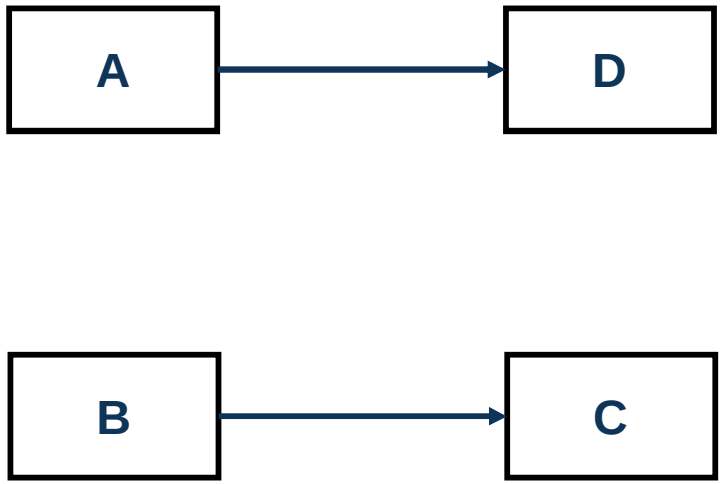
Activity on Node(AON)

- ✓ Minimize line crossing



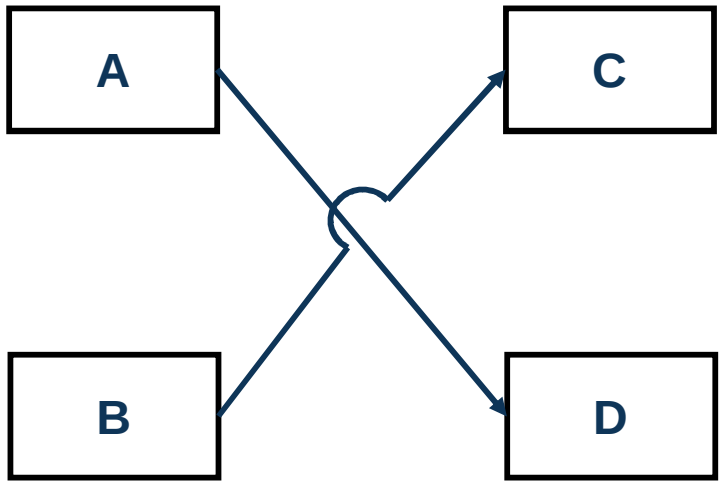
Activity on Node(AON)

- ✓ Minimize line crossing



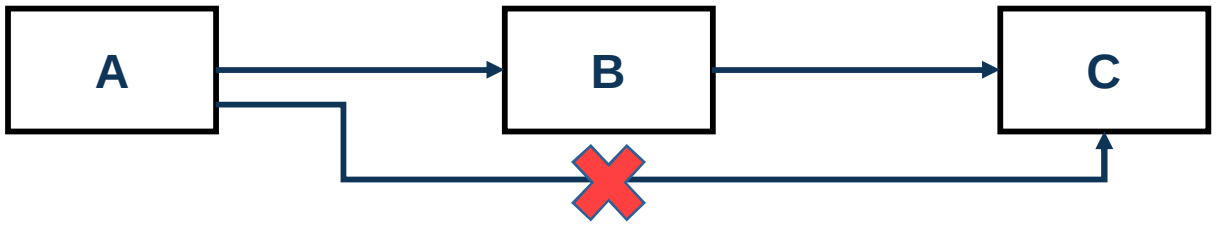
Activity on Node(AON)

- ✓ Minimize line crossing



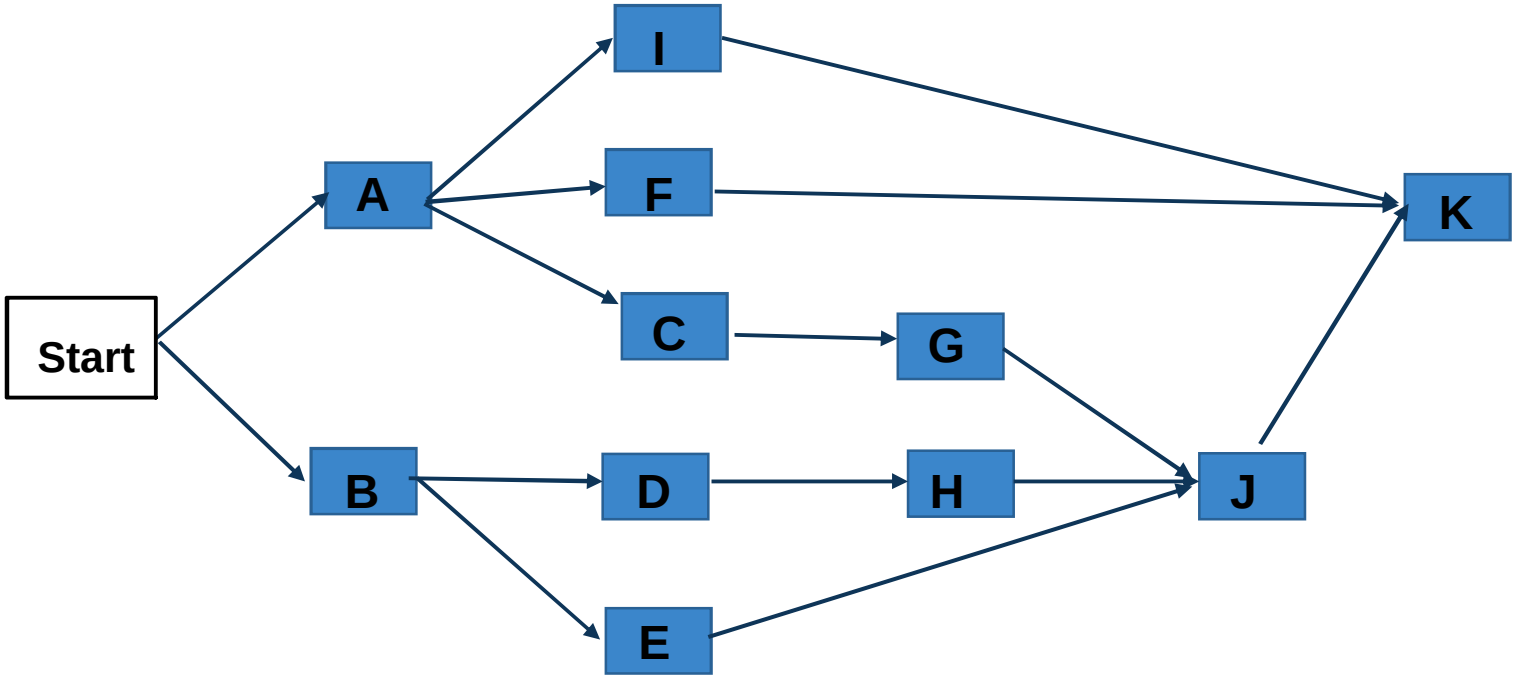
Redundant Relationship

Activity	Depends Upon	Immediately Preceding Activity (IPA)
A	-----	-----
B	A	A
C	~~A~~, B	B



Example

Activity	A	B	C	D	E	F	G	H	I	J	k
Predecessor	-	-	A	B	B	A	C	D	A	G, H, E	J, F, I



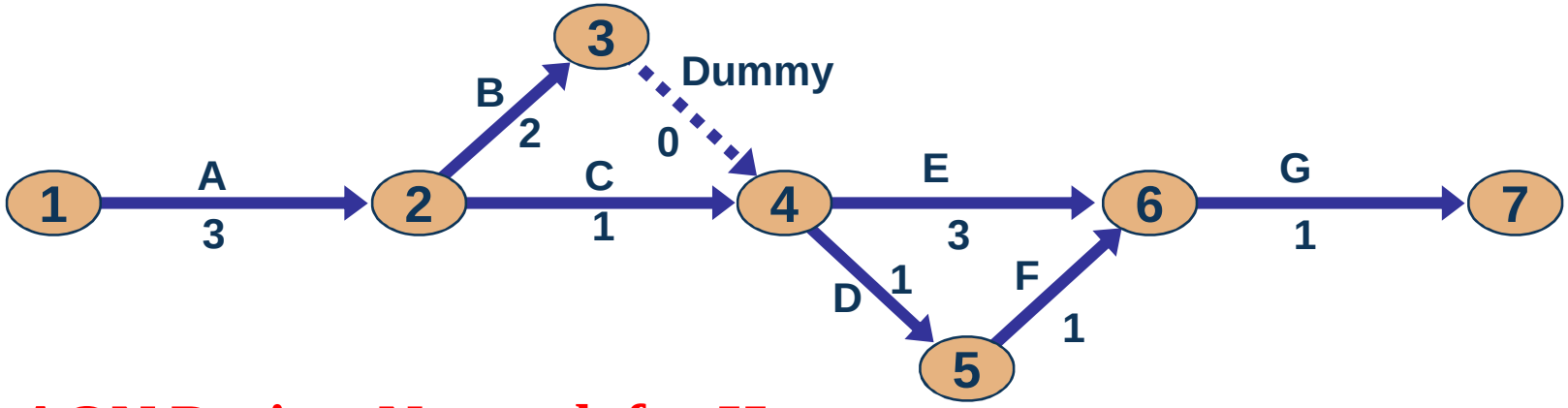
Activity on Node(AON) Network

Example

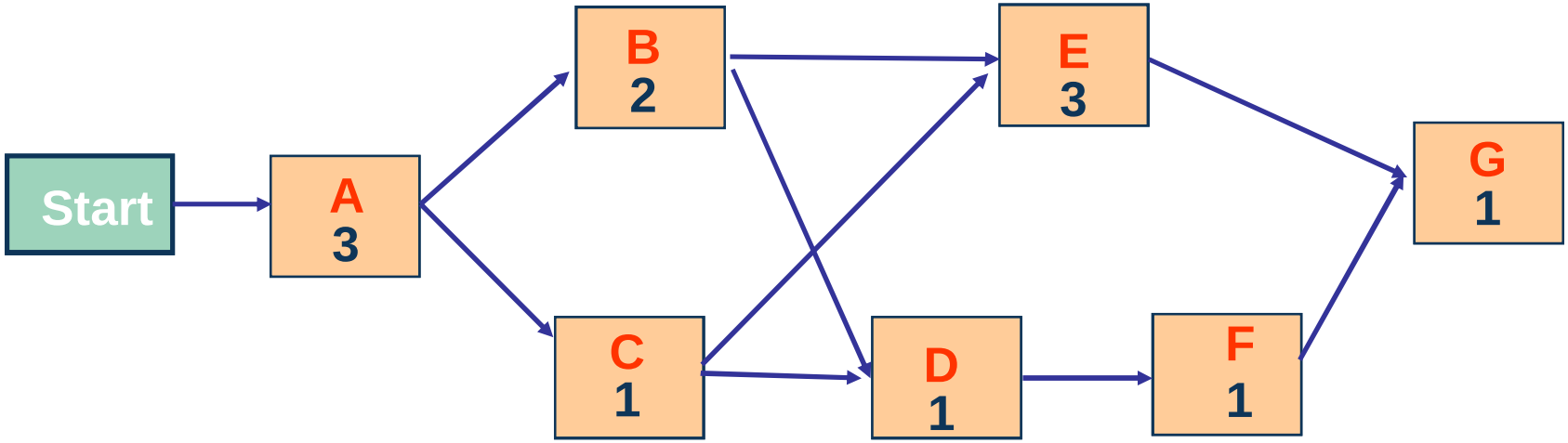
Draw a network by using both AON and AOA.

Activity	description	Duration	predecessors
A	Design house and obtain financing	3	-
B	Lay foundation	2	A
C	Order and receive materials	1	A
D	Select paint	1	B,C
E	Build house	3	B,C
F	Select carpet	1	D
G	Finish work	1	E,F

AOA Project Network for House



AON Project Network for House



Critical Path Method (CPM)

Critical path

Critical activity: any delay on the start or finish of a critical activity will result in a delay in the entire project.

Critical path:

- It represents a series of activities for which each activity is a **Critical activity (zero float time)**.
- **longest time** for the project from start to its completion and decides the time of completion of the project

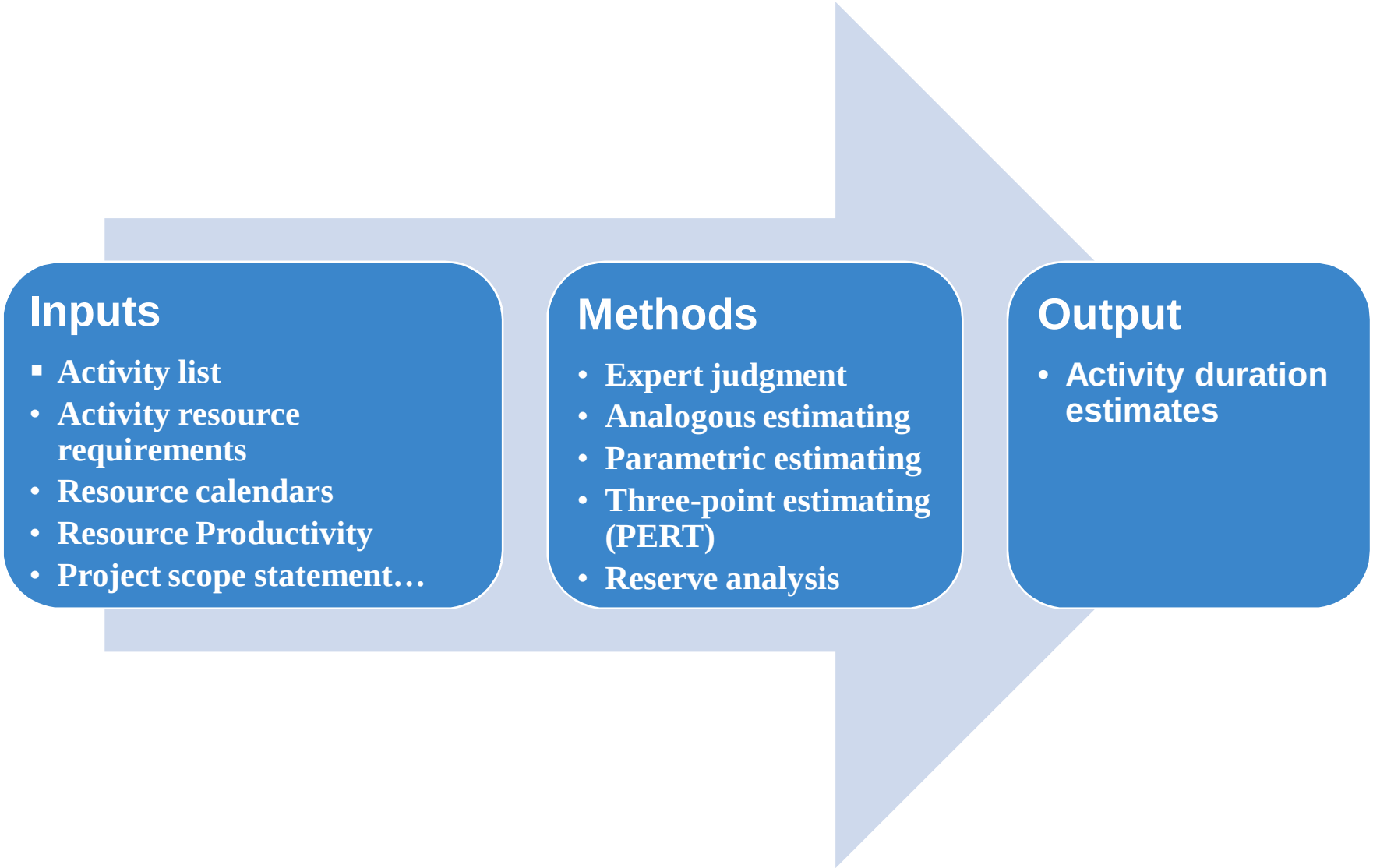
Major steps in CPM

CPM includes four main steps:

1. **Determine the work activities: project breakdown**
   - **Project must be divided into smaller activities or tasks (WBS)**
   - **Prepare a list of all activities.**

Steps in CPM

2. Determine activity duration



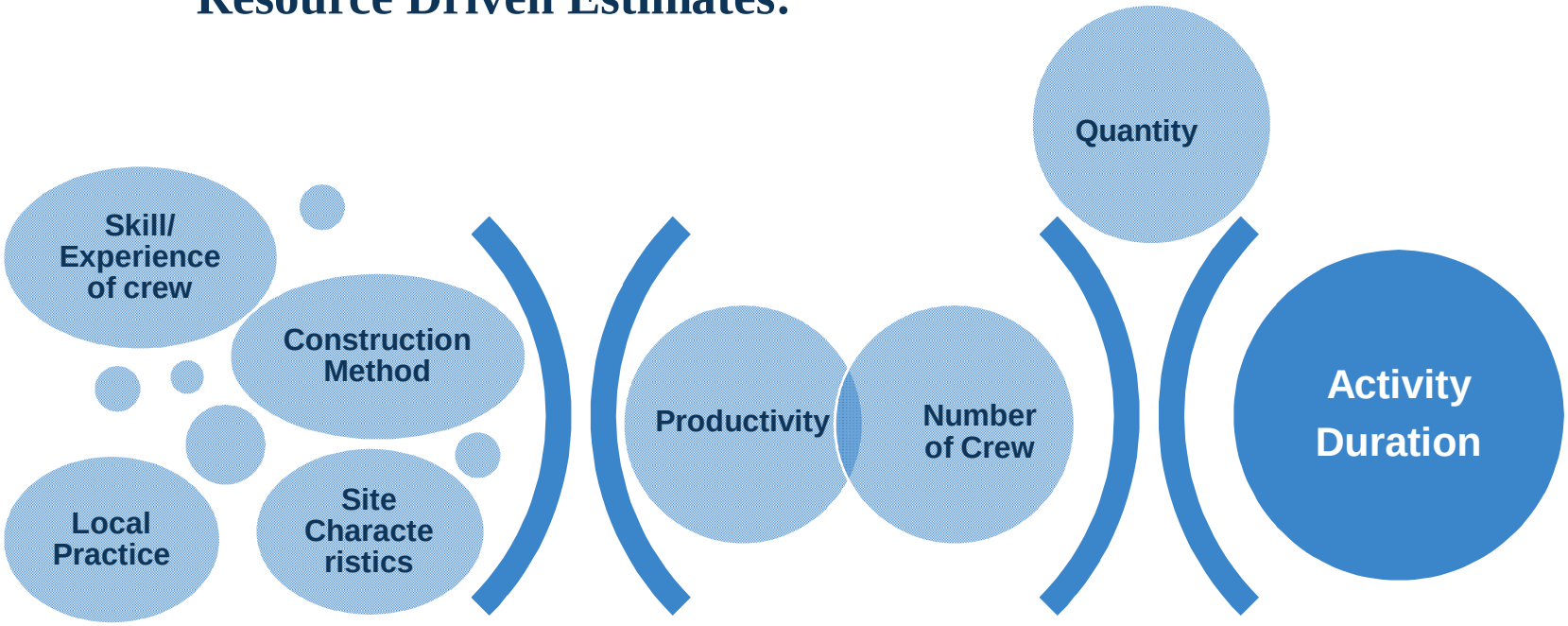
Steps in CPM

Parametric Analysis

- ✓ **Durations are calculated in workdays, ("a 5 or 6-work day /week")**
- ✓ **The time required to complete an activity should depend not only on the quantum of work to be executed (Q) but also the resources allocated (R) and the (unit) productivity of the resources (P).**
- ✓ **Sources of crew productivity data**
  - ***From company's record***
  - ***From standard estimating guide***
  - ***Interviewing field personnel***
- ✓ **Consider days, such as holidays, rain/hot days as non working days .**

Duration cont....

Resource Driven Estimates:



Factors Affecting Productivity

Total Productivity

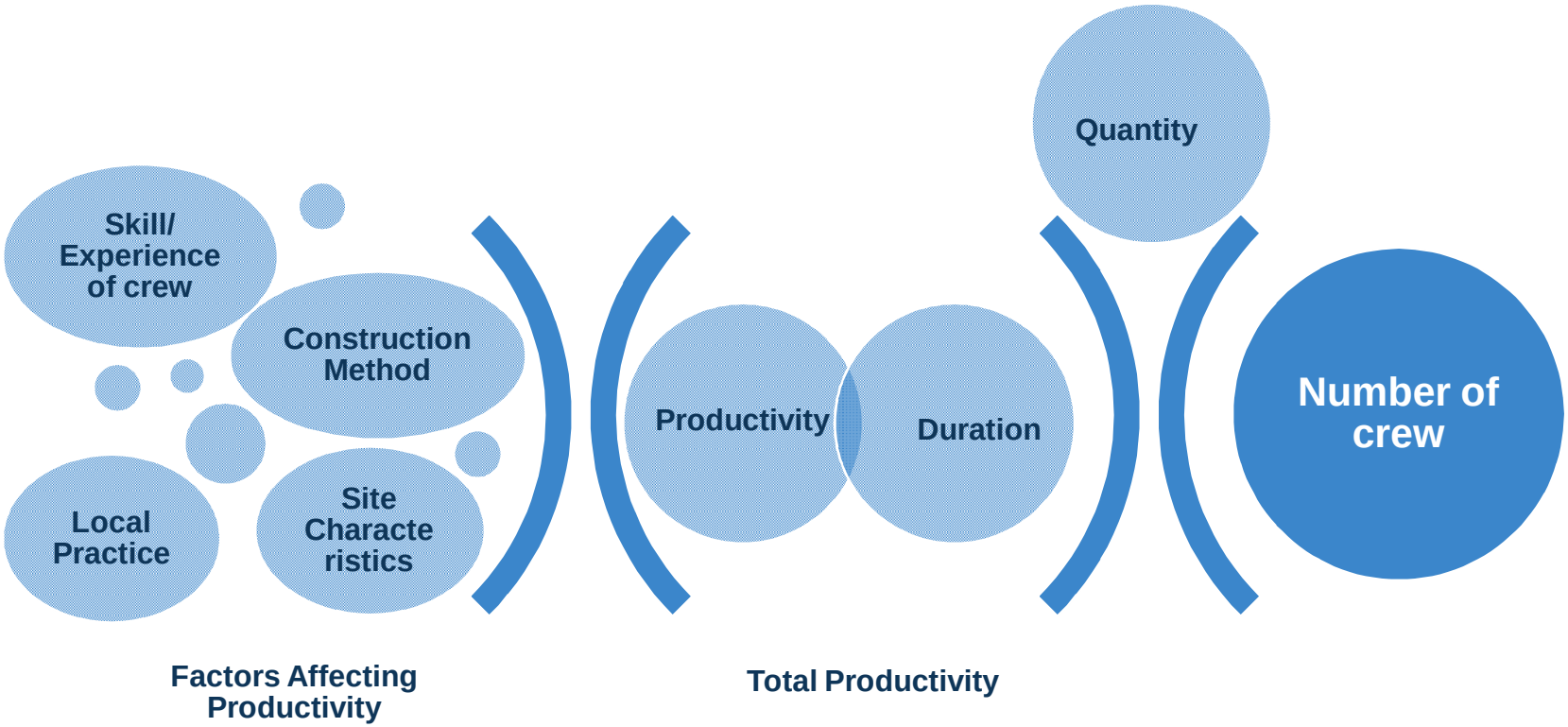
- T = Q / (RxP)

Example: Excavation of soft soil on a site with a given crew amount and construction method. The total quantity of excavation is 1000 cum.

Duration cont....

Duration cont....

Duration Driven Estimation:



Example: Excavation of soft soil on a site has to be completed in 2 days. The total quantity of excavation is 1000 cum.

Duration cont....

Steps in CPM

3. Determine the logical relationships:

- Determine which activity must precede, succeed or maybe done concurrently.
- Consider resource (labor, equipment) limitation.

4. Draw the logic network and perform the CPM calculations:

- Finish date of the project, the critical path, and the available float for non-critical activities.
- CPM network using one of the commercially available computer software programs, such as primavera project manager or Microsoft (MS) project.

Supplemental steps in CPM

5. Resource allocation and levelling
6. Review and analyze the schedule
   a) Review the logic
   b) Make sure the activity has the correct predecessor
   c) Make sure there is no redundant activity
7. Implement the schedule:
   - Take the schedule from the paper to execution
8. Monitor and control the schedule
   - Comparing what is planned to what is actually done
9. Revise the database and record feedback
   - Cost and time estimates for activities are based on past experience

CPM Calculation

Activity On Node:

Early Start	ID	Early Finish
Description		
Late Start	Duration	Late Finish

ES EF

Name
Duration

LS LF

Activity On Arrow:

CPM Calculation

Forward Pass

- **Earliest Start Time (ES)**
  - Earliest time an activity can start without delaying the project
  - ES = maximum EF of immediate predecessors
    - $ES_j = Max(Ef_i)$
- **Earliest finish time (EF)**

  -Earliest time an activity can finish without delaying the project

  -Earliest start time plus activity time
    - $EF_i = ES_i + D_i$

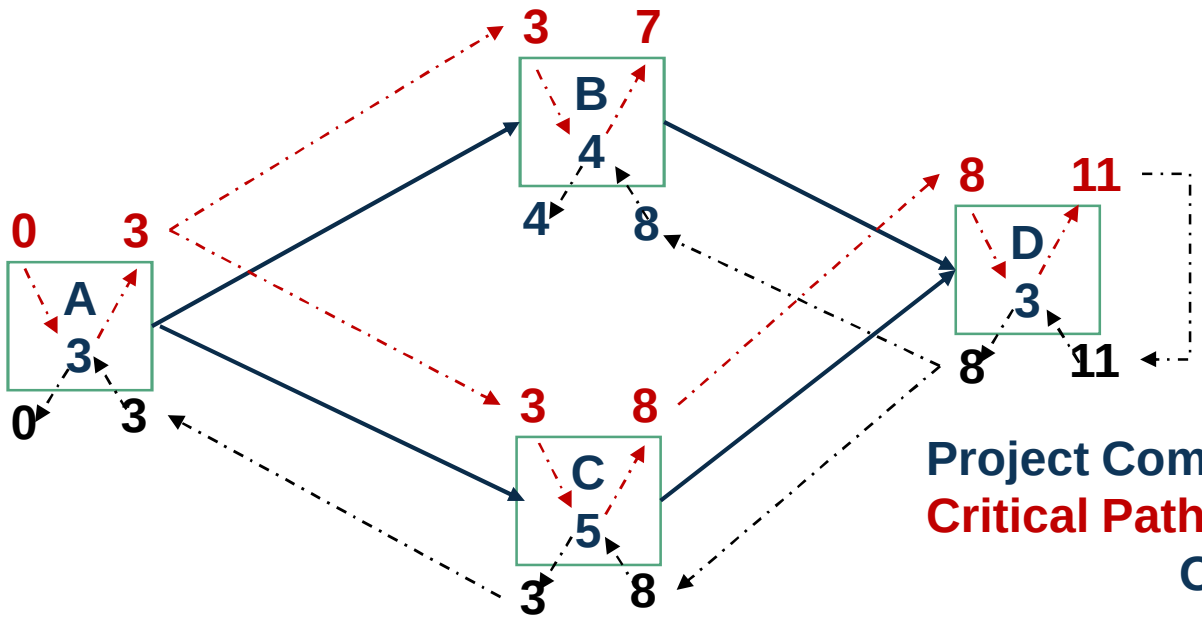
CPM Calculation

Backward Pass

- **Latest finish time (LF)**
  - ✓ Latest time an activity can be completed without delaying the project
  - ✓ Late Finish= Minimum of Late start of immediate successor.
    - **$LF_i = Min(LS_j)$**
- **Latest Start Time (LS)**
  - ✓ Latest time an activity can start without delaying the project
  - ✓ Latest Finish minus activity time
    - **$LS_i = LF_i - D_i$**

Example One

Activity	Predecessor	Duration
A	-	3
B	A	4
C	A	5
D	B,C	3



Project Completion: 11 Days

Critical Path(Longest): A-C-D=3+5+3=11

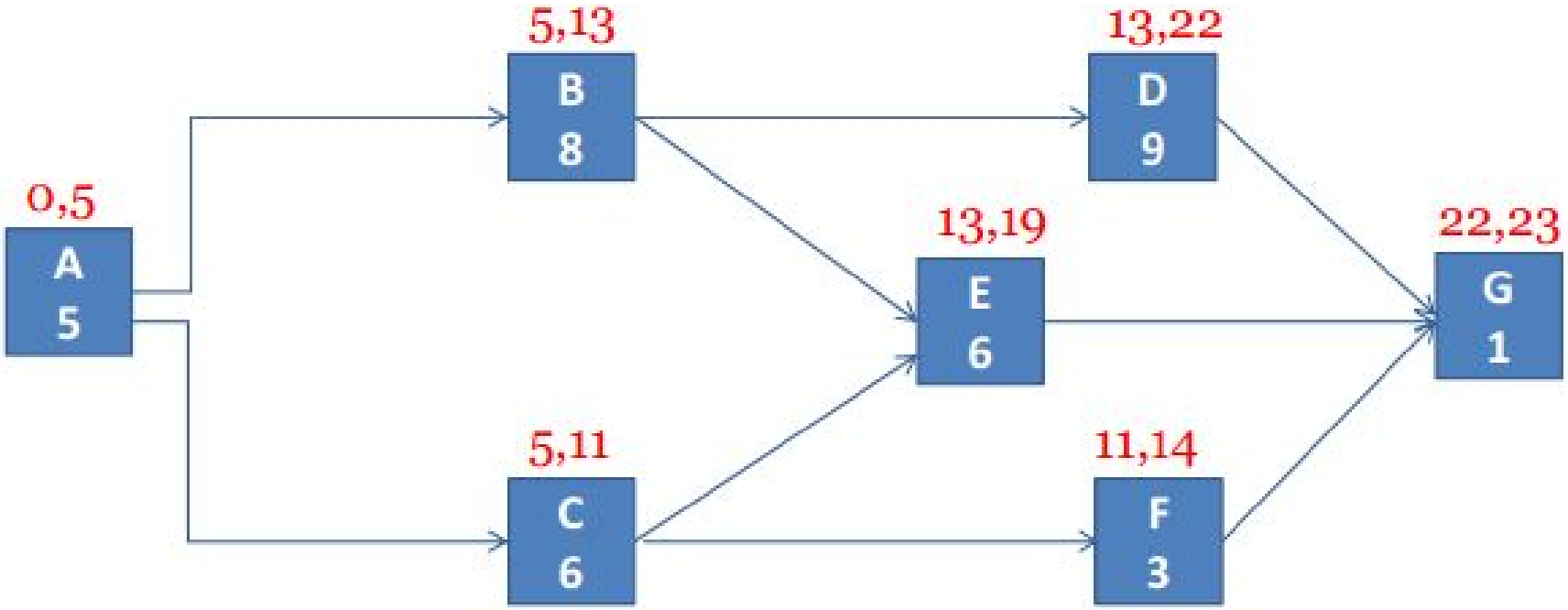
Other Path: A-B-D=3+4+3=10

Example Two

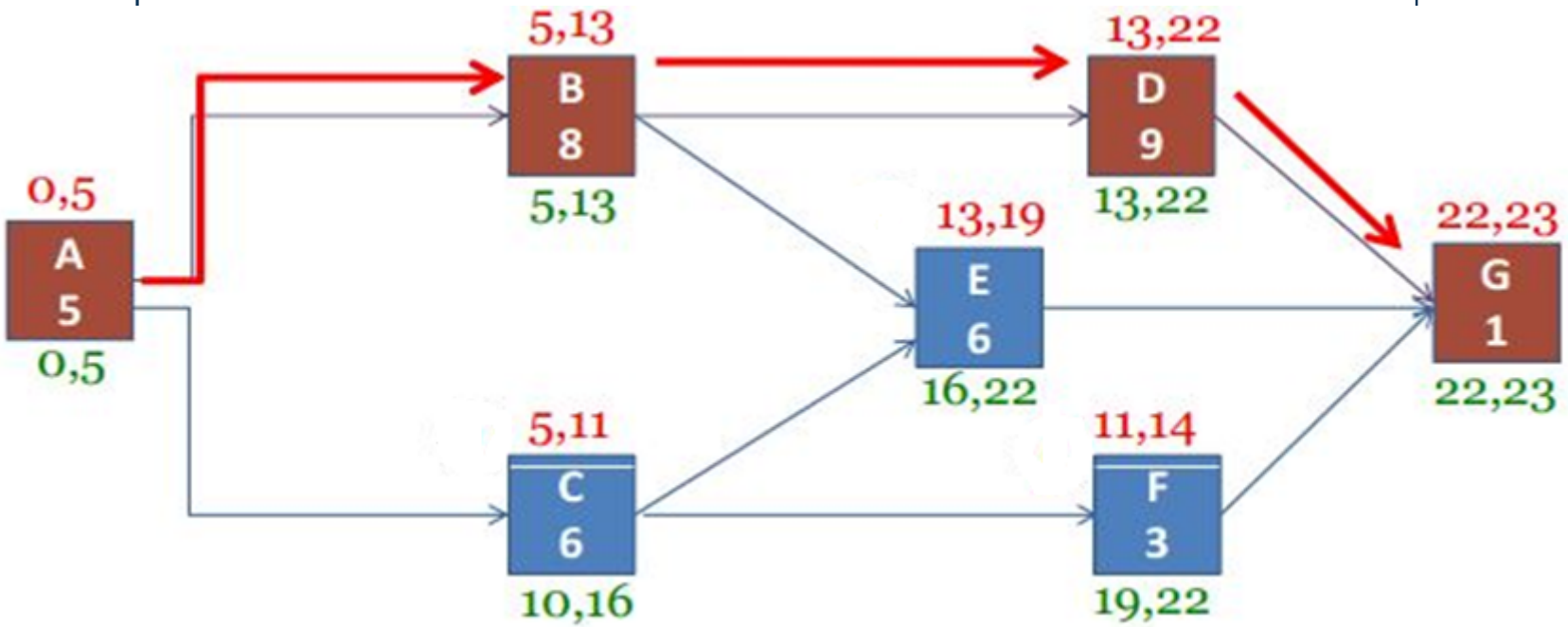
Draw the logic network(AON) and perform the CPM calculation:

Activity	IPA	Duration
A	-	5
B	A	8
C	A	6
D	B	9
E	B,C	6
F	C	3
G	D,E,F	1

Solution



Graphical Solution



Project completion time = 23 days

Critical Path(longest): A-B-D-G=(5+8+9+1)=23

Other Paths: A-B-E-G=(5+8+6+1)=20

A-C-E-G=(5+6+6+1)=18

A-C-F-G=(5+6+3+1)=15

Float

Slack(Float) of an Activity

Slack is the length of time an activity can be delayed without affecting the completion date for the entire project.

Total float (TF): the maximum amount of time an activity can be delayed from its earliest start time without delaying the entire project.

$$TF_i = LS_i - ES_i$$

OR

$$TF_i = LF_i - EF_i \text{ OR}$$

$$TF_i = LF_i - D_i - ES_i$$

Free float (FF): The maximum amount of time an activity can be delayed without delaying the early start of the succeeding activities.

$$FF_i = \min(ES_{i+1}) - EF_i$$

Float calculations

Interfering Float (Int.F): the maximum amount of time an activity can be delayed from its earliest start time without delaying the entire project but delay the early start of the succeeding activities .

$$Int.F_i = TF_i - Ff_i$$

Independent Float (Ind.F): The maximum amount of time an activity can be delayed without delaying the early start of the succeeding activities and without being affected by the allowable delay of the preceding activities.

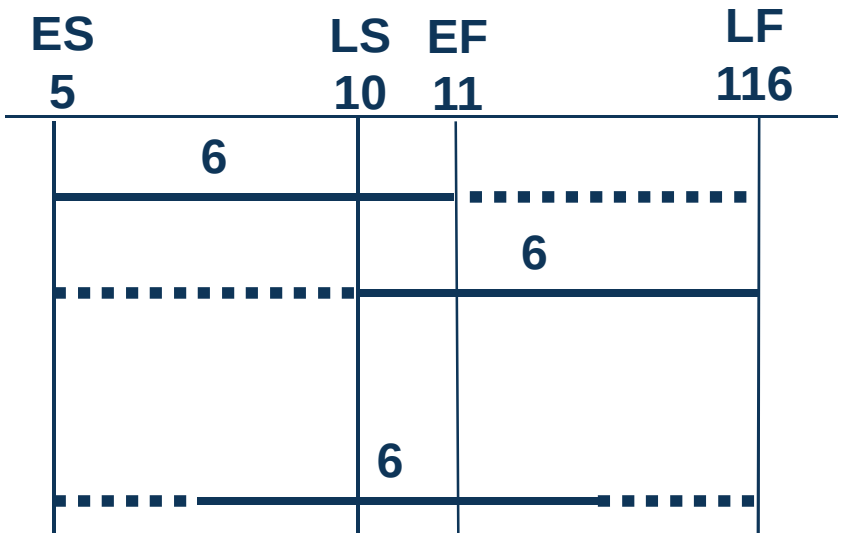
$$Ind.F_i = \min(ES_{i+1}) - Max(Lf_{i-1}) - D_i$$

If “–ve” use “0”

CPM Calculation

Critical activity has a slack of zero.

- **In Example Two, Total Float for C = 5 weeks, i.e. Activity C can be delayed up to 5 weeks (start anywhere between weeks 5 and 10).**



$TF_c = LS_c - ES_c = 10 - 5 = 5$

$FF_c = \text{Min}(ES_E, ES_F) - EF_c$

$= \text{Min}(11,12) - 11 = 11 - 11 = 0$

$\text{Int.}F_c = TF_c - FF_c = 5 - 0 = 5$

$\text{Ind.}F_c = \text{Min}(ES_E, ES_F) - LF_A - D_c$

$= \text{Min}(11,12) - 5 - 6 = 11 - 5 - 6 = 0$

Tabular solution for Example Two

Activity	Duration	ES	EF	LS	LF	TF	FF
A	5	0	5	0	5	0	0
B	8	5	13	5	13	0	0
C	6	5	11	10	16	5	0
D	9	13	22	13	22	0	0
E	6	13	19	16	22	3	3
F	3	11	14	19	22	8	8
G	1	22	23	22	23	0	0

Note: We must always realize that Ind.F ≤ FF ≤ TF

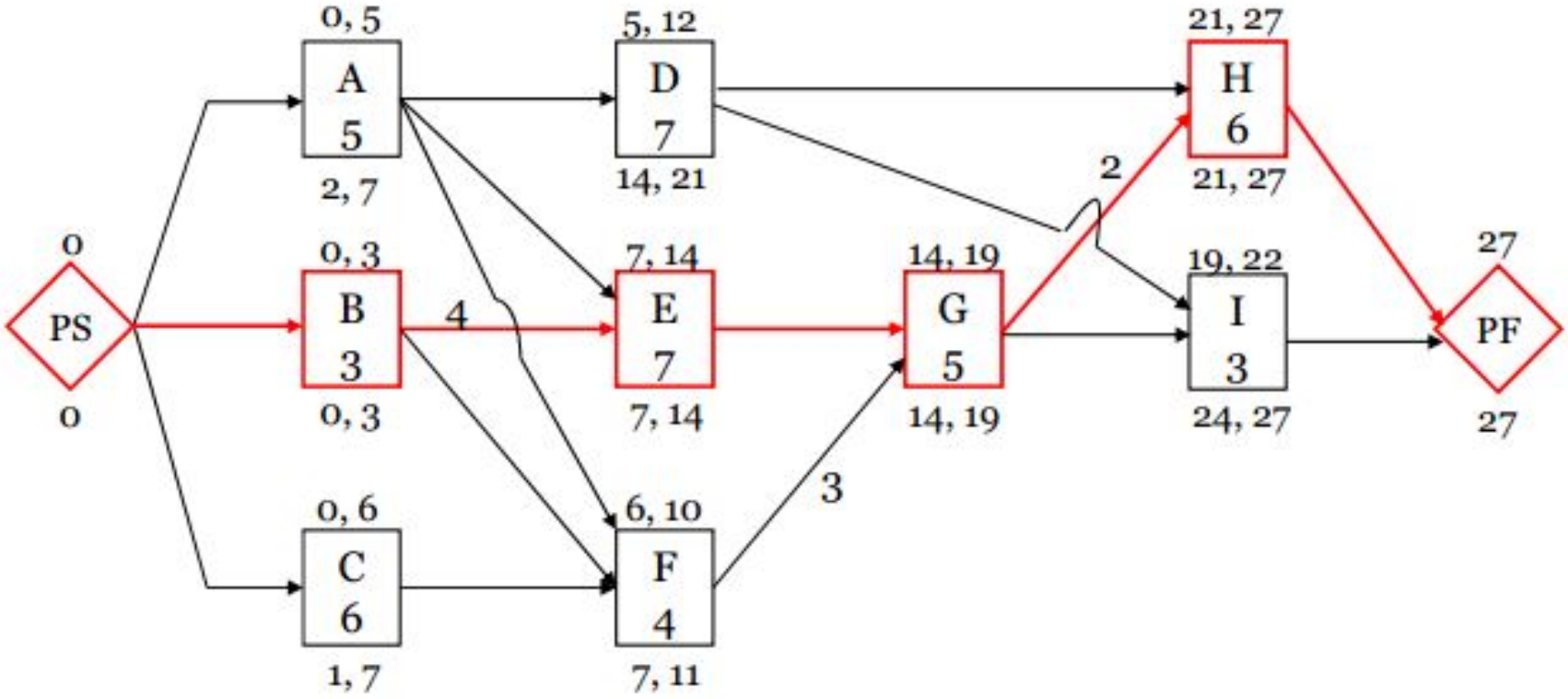
Lags in Node networks

- A lag is a minimum compulsory waiting period between the start/finish of an activity and the start/finish of the successor
  - ✓ Actual waiting period maybe greater, but never less than the lag
  - ✓ Lags are very common with SS & FF relationships
  - ✓ A lead is a negative lag
- The Lag is added in the CPM's forward pass calculations and subtracted in the backward pass.

Example Three

Activity	Duration	Predecessor	Lag
A	5	-	
B	3	-	
C	6	-	
D	7	A	
E	7	A	
		B	4
F	4	A,B,C	
G	5	E	
		F	3
H	6	D	
		G	2
I	3	D,G	

Graphic solution for example 3



Tabular solution for Example 3

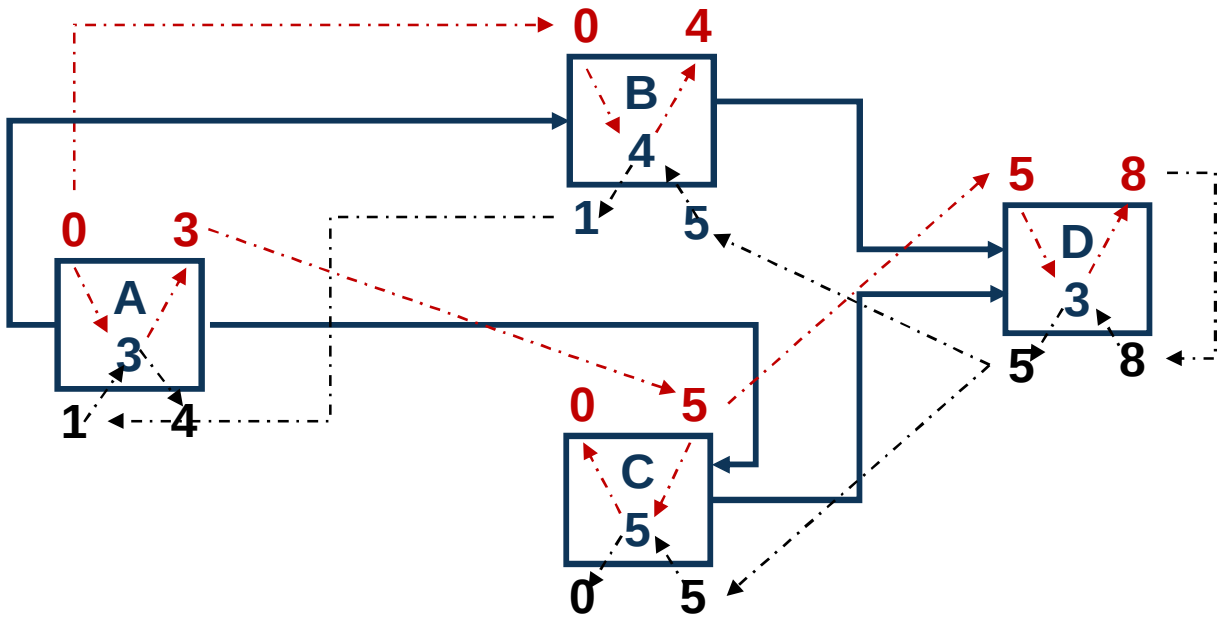
Activity	ES	EF	LS	LF	TF	FF
A	0	5	2	7	2	0
B	0	3	0	3	0	0
C	0	6	1	7	1	0
D	5	12	14	21	9	7
E	7	14	7	14	0	0
F	6	10	7	11	1	1
G	14	19	14	19	0	0
H	21	27	21	27	0	0
I	19	22	24	27	5	5

CPM with SS and FF relationships

Example Four

Activity	Predecessor	Duration
A	-	3
B	A(SS)	4
C	A(FF)	5
D	B,C	3

Project Completion: 8 Days
Critical Path(Longest): C-D



Example Five

Activity	Duration	Predecessor	Lag
A	3	-	
B	2	A	2
C	2	A(SS)	
D	4	B(SS)	1
E	1	C(SF)	1
F	2	C(FF)	3
G	4	D(SS)	1
		E	
H	3	F(SF)	2
		G	

CPM with AOA networks

- ✓ The preceding logic is similar to that of the forward and backward passes:
- ✓ The early event time, T_E, is the largest (latest) date obtained to reach an event (going from start to finish).
- ✓ The late event time, T_L, is the smallest (earliest) date obtained to reach an event (going from finish to start).

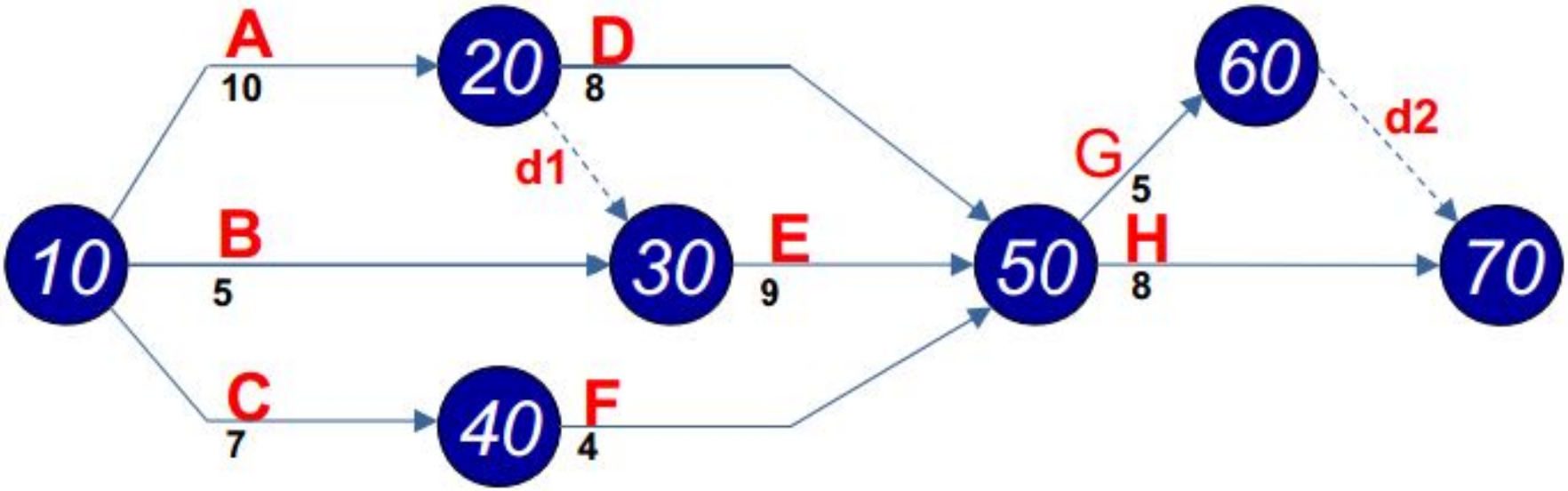
Example Six (AOA network)

Perform the CPM calculations, using the arrow network diagram:

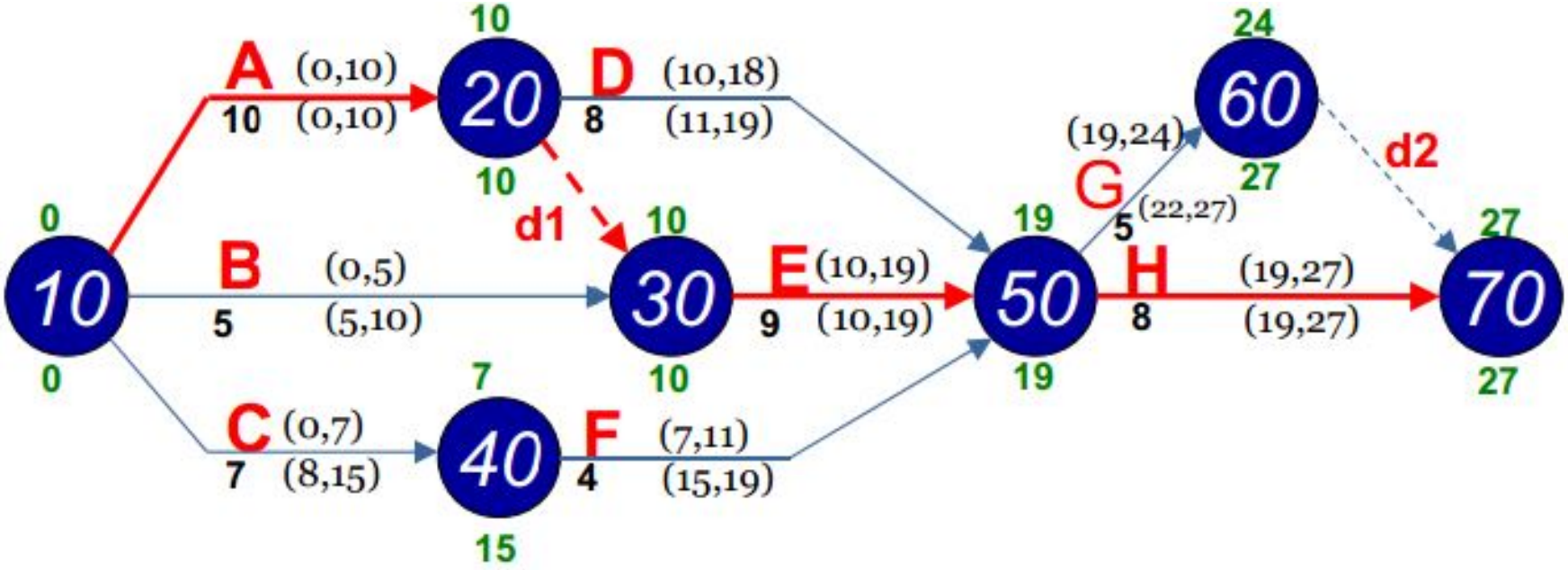
Activity	IPA	Duration(Days)
A	-	10
B	-	5
C	-	7
D	A	8
E	A,B	9
F	C	4
G	D,E,F	5
H	D,E,F	8

Solution

The arrow network shown below:



Solution


10
20
30
40
50
60
70
A
(0,10)
10
(0,10)
B
(0,5)
5
(5,10)
C
(0,7)
7
(8,15)
D
(10,18)
8
(11,19)
d1
E
(10,19)
9
(10,19)
F
(7,11)
4
(15,19)
G
(19,24)
5
(22,27)
H
(19,27)
8
(19,27)
d2
0
0
10
10
10
10
7
15
19
19
24
27
27
27

Working Days Vs Calendar Days

Example Seven:

Describe the result of CPM calculation of example six both in working and calendar days if project starts on January 01/2019.

Activities	Working Days				Calendar Days			
	ES	EF	LS	LF	ES	EF	LS	LF
A	0	10	0	10	Tue 1/1/19	Mon 1/14/19	Tue 1/1/19	Mon 1/14/19
B	0	5	5	10	Tue 1/1/19	Mon 1/7/19	Tue 1/8/19	Mon 1/14/19
C	0	7	8	15	Tue 1/1/19	Wed 1/9/19	Thu 1/17/19	Fri 1/25/19
D	10	18	11	19	Tue 1/15/19	Thu 1/24/19	Wed 1/16/19	Fri 1/25/19
E	10	19	10	19	Tue 1/15/19	Fri 1/25/19	Tue 1/15/19	Fri 1/25/19
F	7	11	15	19	Thu 1/10/19	Tue 1/15/19	Fri 2/1/19	Wed 2/6/19
G	19	24	22	27	Mon 1/28/19	Fri 2/1/19	Thu 1/31/19	Wed 2/6/19
H	19	27	19	27	Mon 1/28/19	Wed 2/6/19	Mon 1/28/19	Wed 2/6/19

Thank You !