Production and Operations Management

2024/2025

Lisbon School of Economics & Management

U LISBOA | UNIVERSIDADE DE LISBOA

Project Management

Chapter 3

Agenda

- Project characteristics
- Management of projects
- Project Management Techniques
- PERT/CPM
- Project crashing
- Advantages and limitations of PERT/CPM

- **Project definition**

Set of interrelated activities that are carried out to achieve a specific purpose (objective translated by goals and precise specifications).

A temporary effort undertaken to create an exclusive product, service or result. Its temporary nature indicates a **beginning** and an **end well defined**

PMBOK Guide- 6th Edition

Project Characteristics

- Single unit
- Many related activities
- Difficult production planning and inventory control
- General purpose equipment
- High labor skills

Project Examples

Construction project

Investigation project

Management of Projects

1. **Planning** - goal setting, defining the project, team organization
2. **Scheduling** - relates people, money, and supplies to specific activities and activities to each other
3. **Controlling** - monitors resources, costs, quality, and budgets; revises plans and shifts resources to meet time and cost demands

Project Management Activities

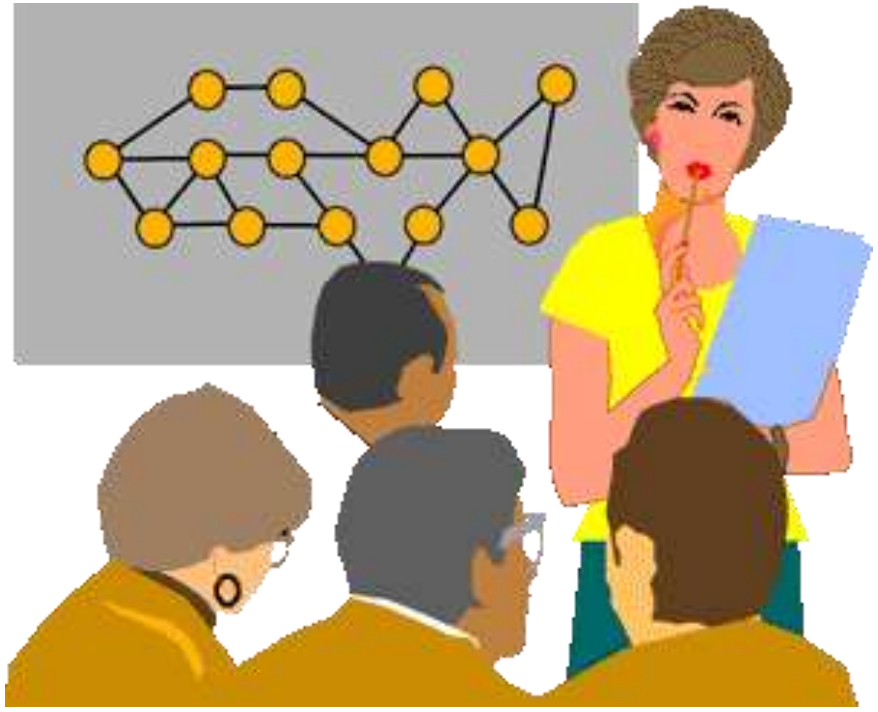
- **Planning**
  - Objectives
  - Resources
  - Work break-down structure
  - Organization

- **Scheduling**
  - Project activities
  - Start & end times
  - Network

- **Controlling**
  - Monitor, compare, revise, action

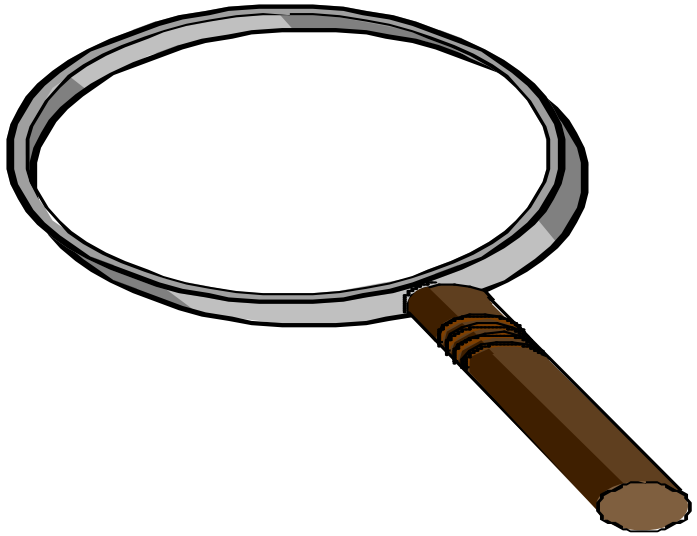
Project Planning

- Establishing objectives
- Defining project
- Creating work breakdown structure
- Determining resources
- Forming organization



Project Planning

- Often temporary structure
- Uses specialists from entire company
- Headed by project manager
  - Coordinates activities
  - Monitors schedule and costs
- Permanent structure called ‘matrix organization’

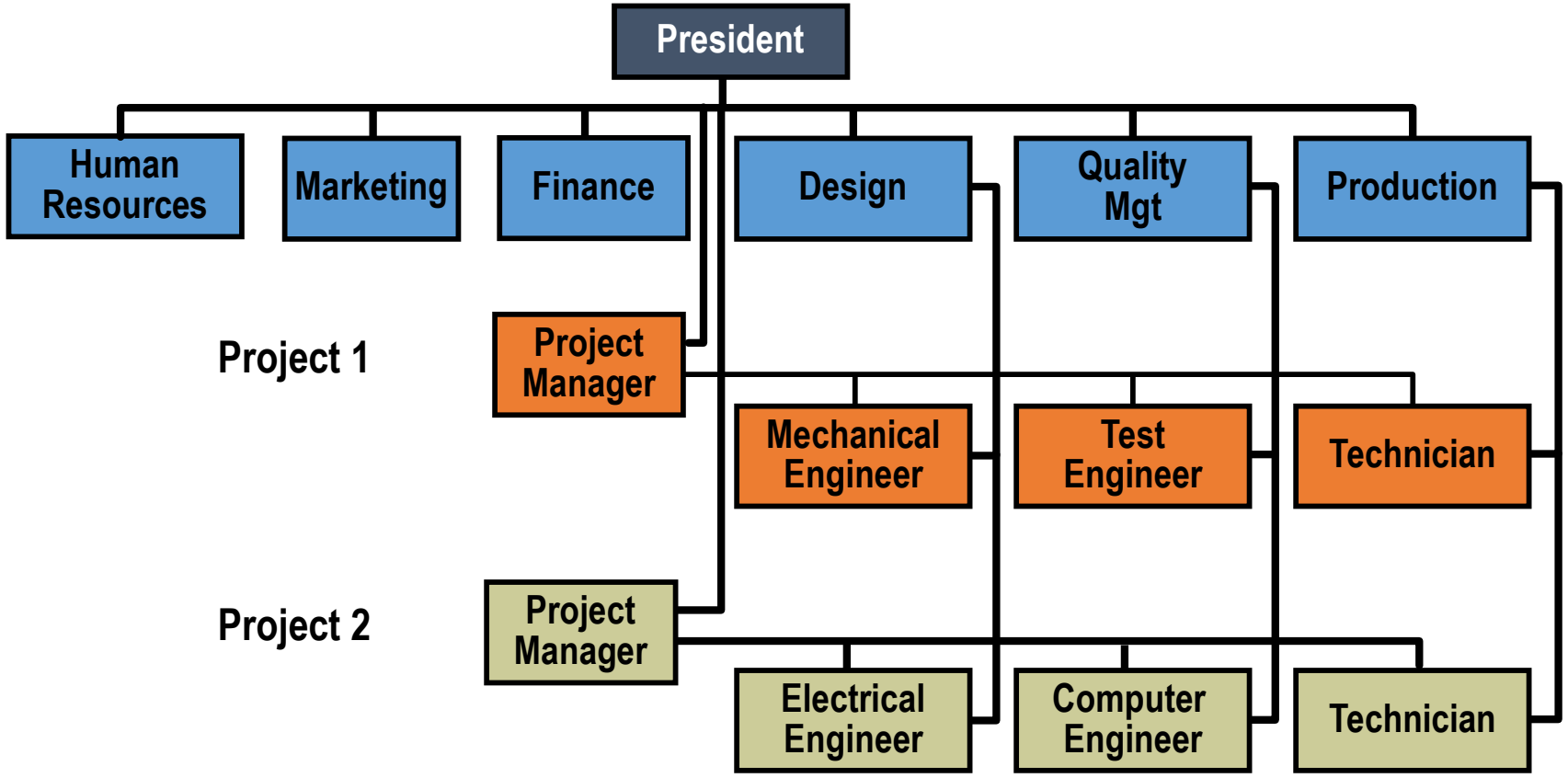


Project Planning

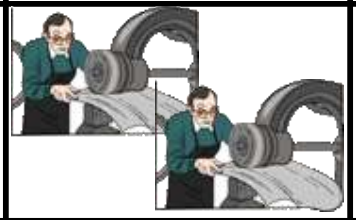
Project Organization works best when….

1. Work can be defined with a specific goal and deadline
2. The job is unique or somewhat unfamiliar to the existing organization
3. The work contains complex interrelated tasks requiring specialized skills
4. The project is temporary but critical to the organization
5. The project cuts across organizational lines

A Sample Project Organization



Project Organization Matrix

	Marketing	Operations	Engineering	Finance
Project 1				
Project 2				
Project 3				
Project 4				

Project managers receive high visibility in a firm and **are responsible for making sure that:**

1) all necessary activities are finished in proper sequence and on time;
2) the project comes in within budget;
3) the project meets its quality goals;
4) the people assigned to the project receive the motivation, direction, and information needed to do their jobs.

The role of project manager

Project managers receive high visibility in a firm and **are responsible for making sure that:**

1) all necessary activities a… d on time;
2) the project comes in wit…
3) the project meets its qua…
4) the people assigned to t… direction, and informatio…

This means that project managers should be:

- good coaches;
- good communicators;
- be able to organize activities from a variety of disciplines.

Ethical Issues

- Project managers also face ethical decisions on a daily basis. How they act establishes the code of conduct for the project.

Project managers often deal with:

1) offers of gifts from contractors;
2) pressure to alter status reports to mask the reality of delays;
3) false reports for charges of time and expenses;
4) pressures to compromise quality to meet bonuses or avoid penalties related to schedules.

Work Breakdown Structure (WBS)

Divides the project into its various subcomponents and defines hierarchical levels of detail

Level

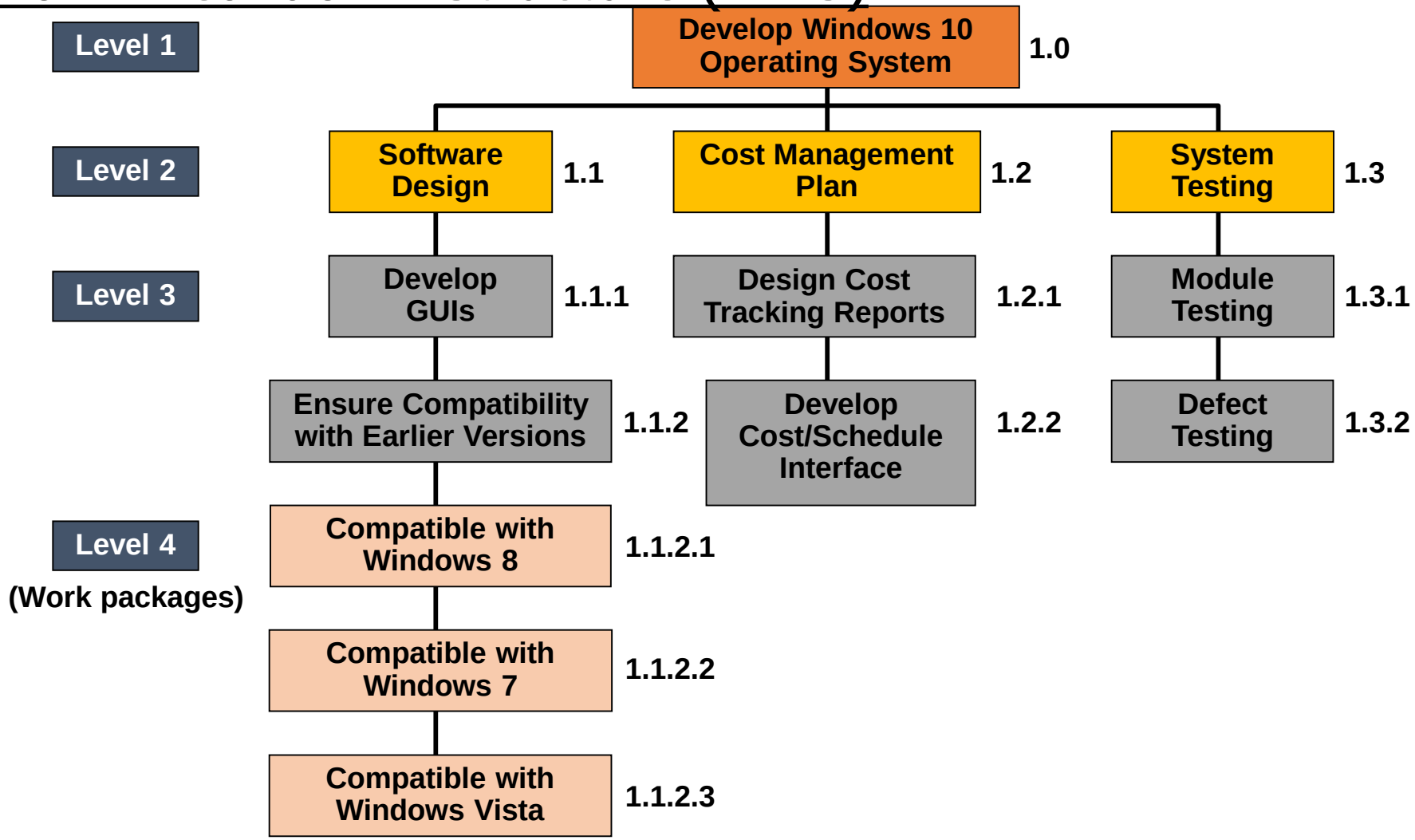
1 Project

2 Major tasks in project

3 Subtasks in major tasks

4 Activities to be completed

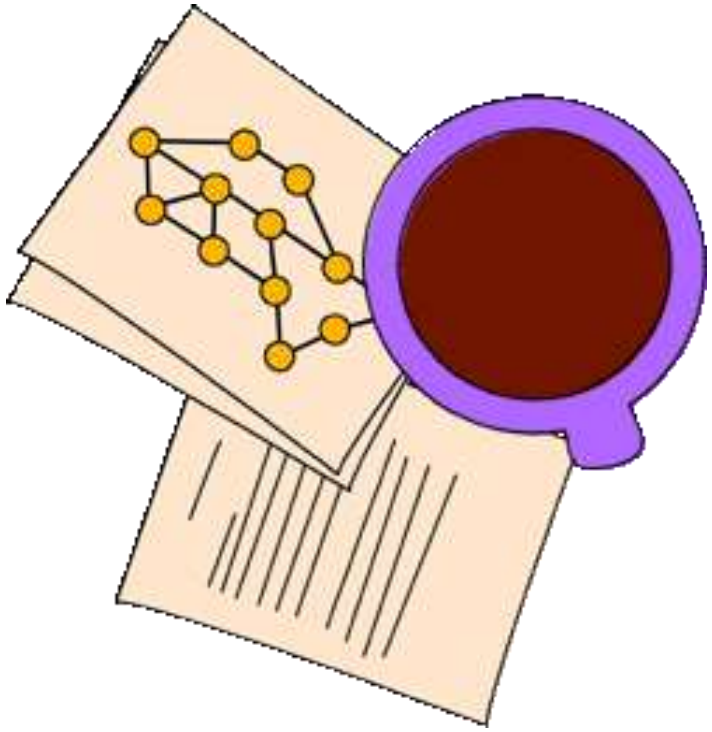
Work Breakdown Structure (WBS)



Project scheduling serves several purposes:

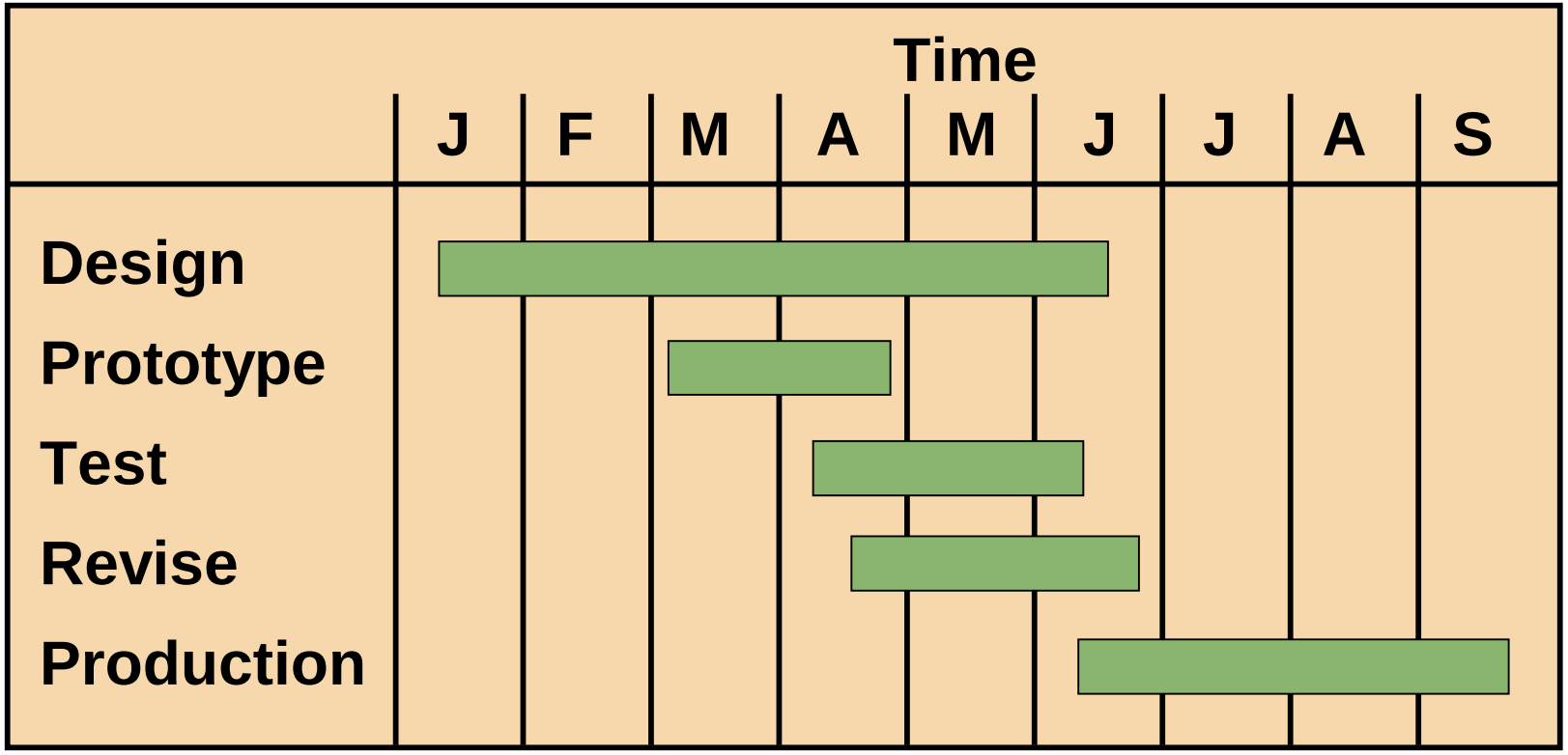
1. It shows the relationship of each activity to others and to the whole project;
2. It identifies the precedence relationships among activities;
3. It encourages the setting of realistic time and cost estimates for each activity;
4. It helps make better use of people, money, and material resources by identifying critical bottlenecks in the project.

Project Management Techniques

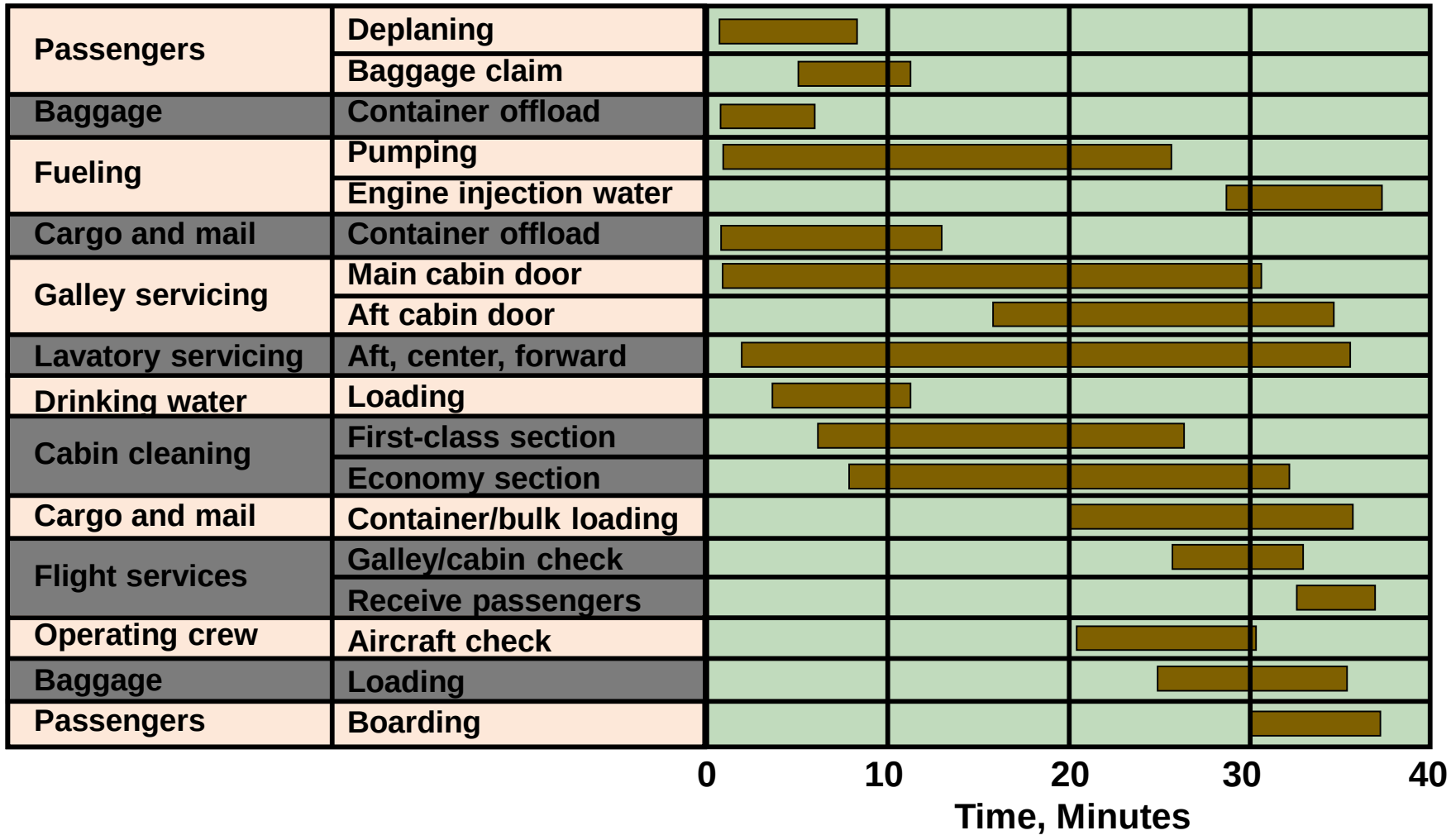


- ✓CPM (*Critical Path Method*)
- ✓PERT (*Program Evaluation & Review Technique*)
- ✓Gantt Chart

Gantt Chart



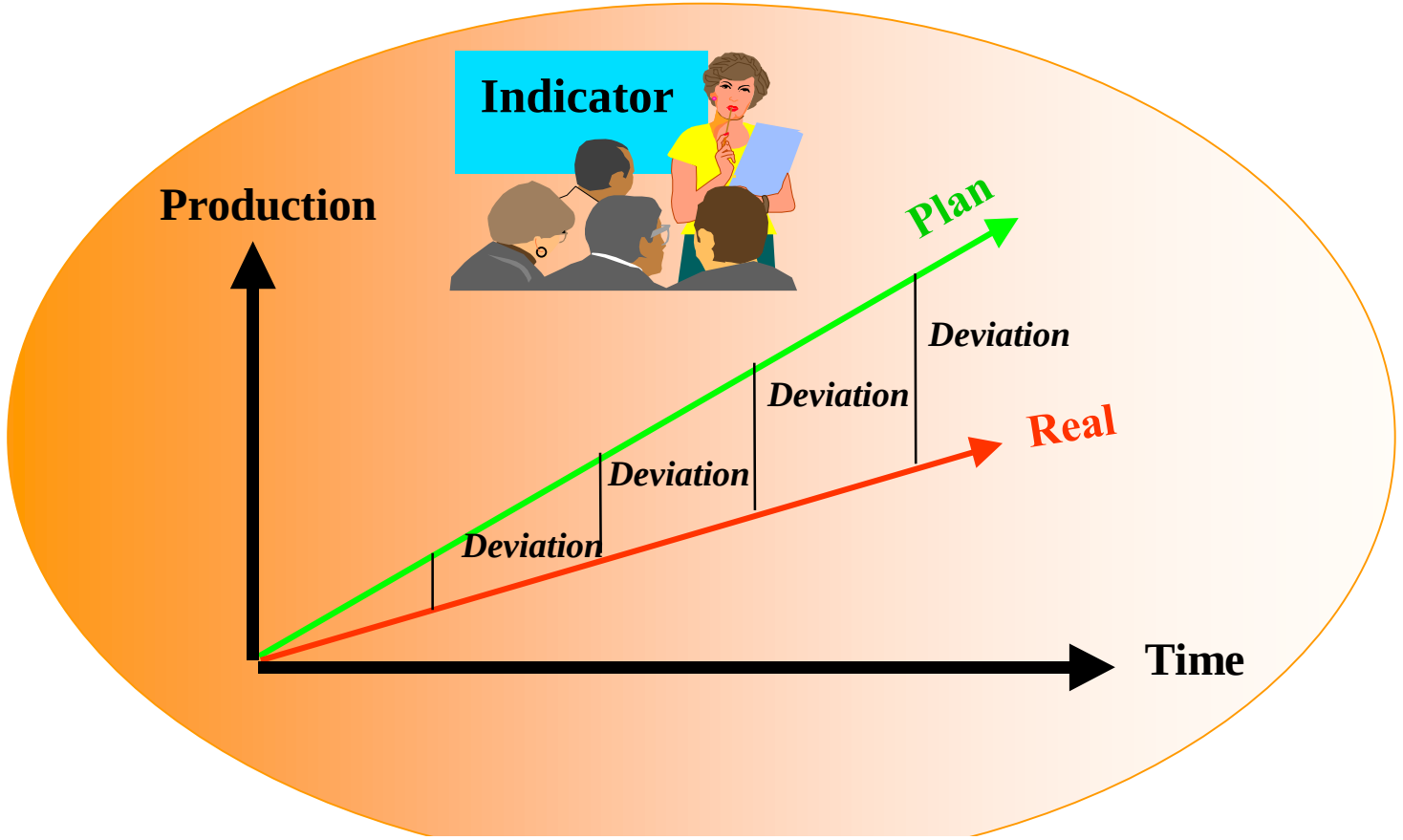
Example: Service for Delta Jet



Project Controlling

- Involves close monitoring of resources, costs, quality, and budgets.
- Control also means using a feedback loop to revise the project plan and having the ability to shift resources to where they are needed most.
- Computerized PERT/CPM reports and charts are widely available today from scores of competing software firms (Oracle Primavera (by Oracle), MindView (by Match Ware), HP Project (by Hewlett-Packard), Fast Track (by AEC Software), and Microsoft Project (by Microsoft Corp.)).

Control – the importance of Revise and Action



… the later the Revision, the greater the Action required

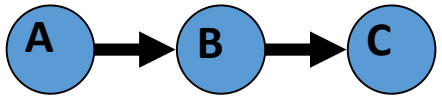
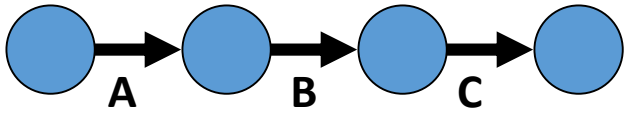
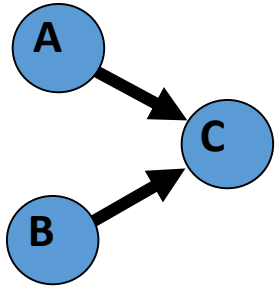
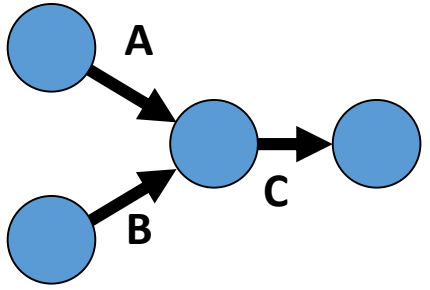
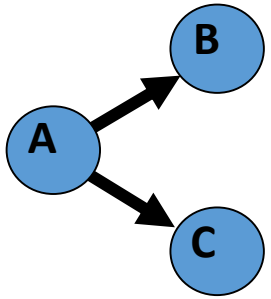
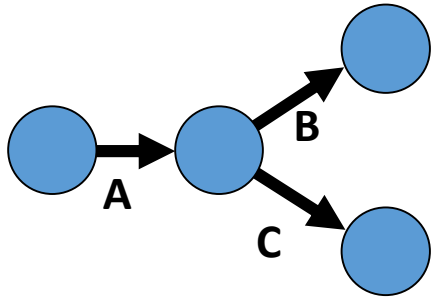
Program Evaluation and Review Technique (PERT) and the Critical Path Method (CPM), both developed in the 1950s

- **CPM** by DuPont for the chemical industry (1957).
- **PERT** by Booz, Allen and Hamilton with the U.S. Navy, for the Polaris missile (1958).
- They consider precedence relationships and interdependencies.
- The major difference is that **PERT** employs three time estimates for each activity. These time estimates are used to compute expected values and standard deviations for the activity.
- **CPM** makes the assumption that activity times are known with certainty and hence requires only one time factor for each activity.

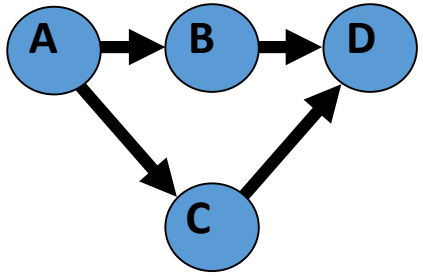
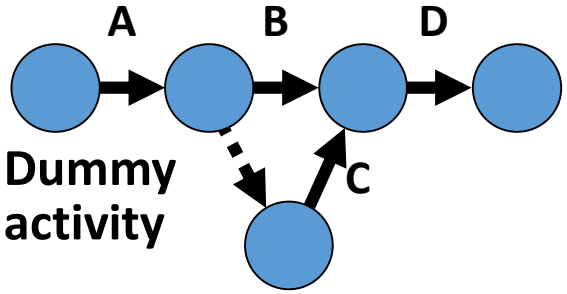
Six Steps of PERT and CPM

1. Define the project and prepare the work breakdown structure
2. Develop relationships among the activities - decide which activities must precede and which must follow others
3. Draw the network connecting all of the activities
4. Assign time and/or cost estimates to each activity
5. **Compute the longest time path through the network – this is called the Critical Path**
6. Use the network to help plan, schedule, monitor, and control the project

A Comparison of AON and AOA Network Conventions

Activity on Node (AON)	Activity Meaning	Activity on Arrow (AOA)
(a) 	A comes before B, which comes before C.	
(b) 	A and B must both be completed before C can start.	
(c) 	B and C cannot begin until A is completed.	

A Comparison of AON and AOA Network Conventions

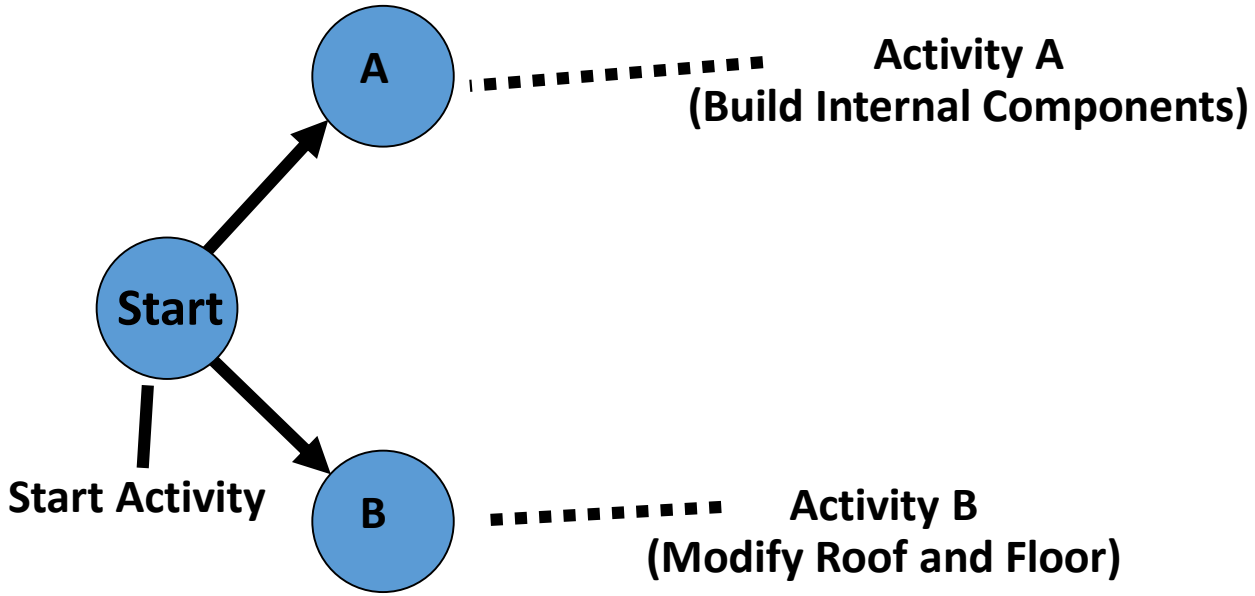
Activity on Node (AON)	Activity Meaning	Activity on Arrow (AOA)
(f) 	B and C cannot begin until A is completed. D cannot begin until both B and C are completed. A dummy activity is again introduced in AOA.	

Example 1 – Milwaukee Paper Manufacturing's

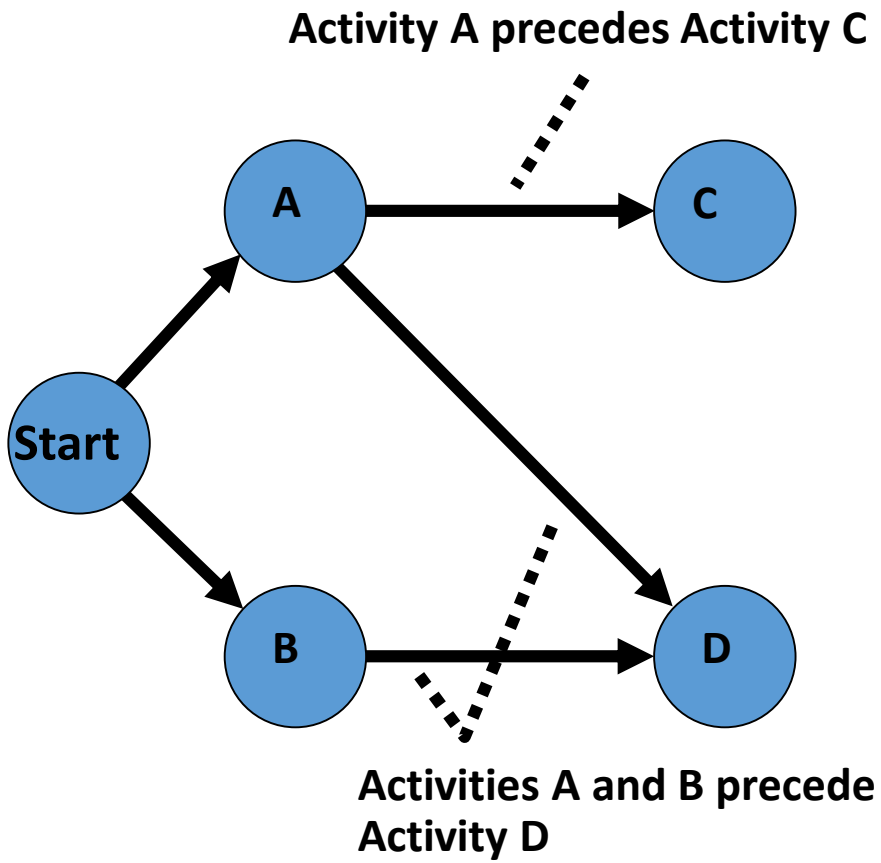
Activities and Predecessors

Activity	Description	Immediate Predecessors
A	Build internal components	—
B	Modify roof and floor	—
C	Construct collection stack	A
D	Pour concrete and install frame	A, B
E	Build high-temperature burner	C
F	Install pollution control system	C
G	Install air pollution device	D, E
H	Inspect and test	F, G

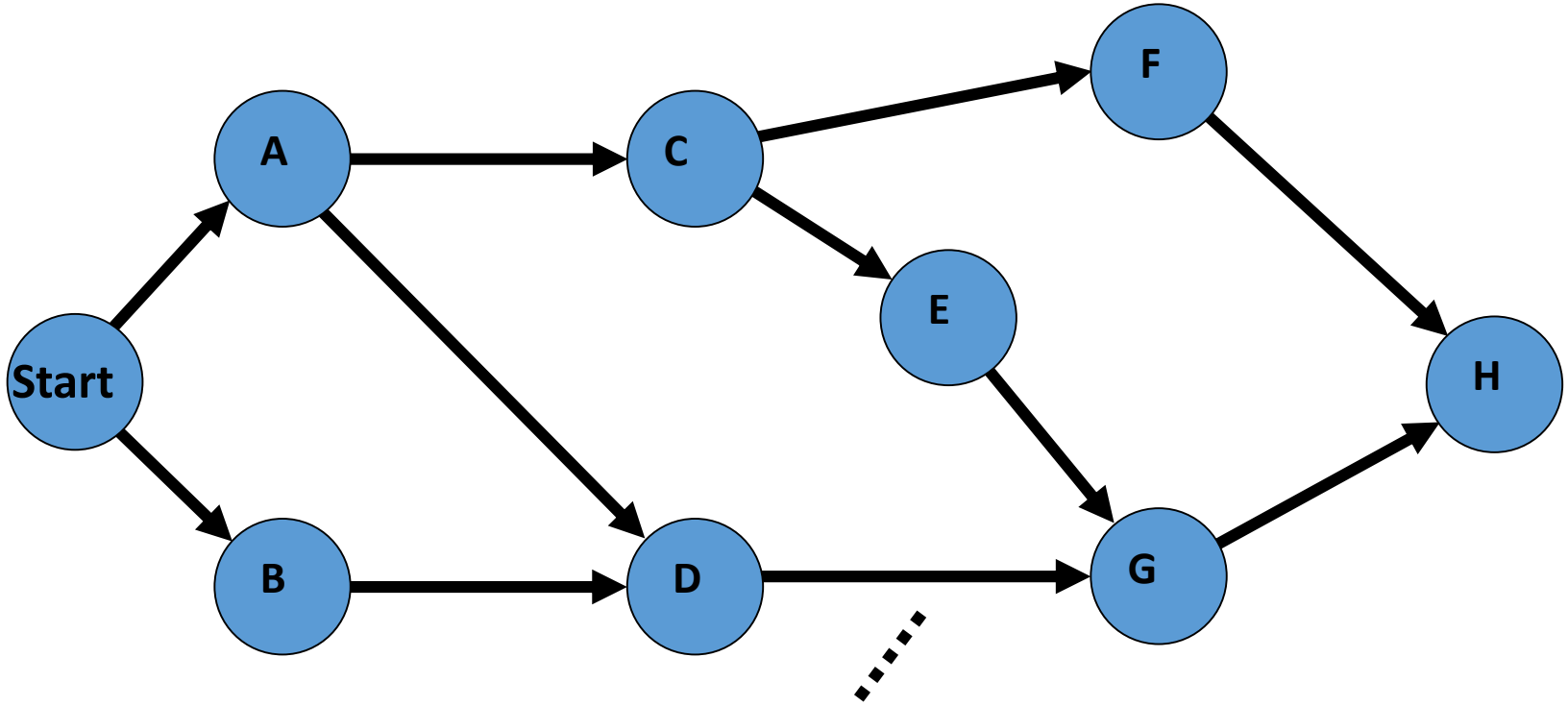
AON Network for Milwaukee Paper



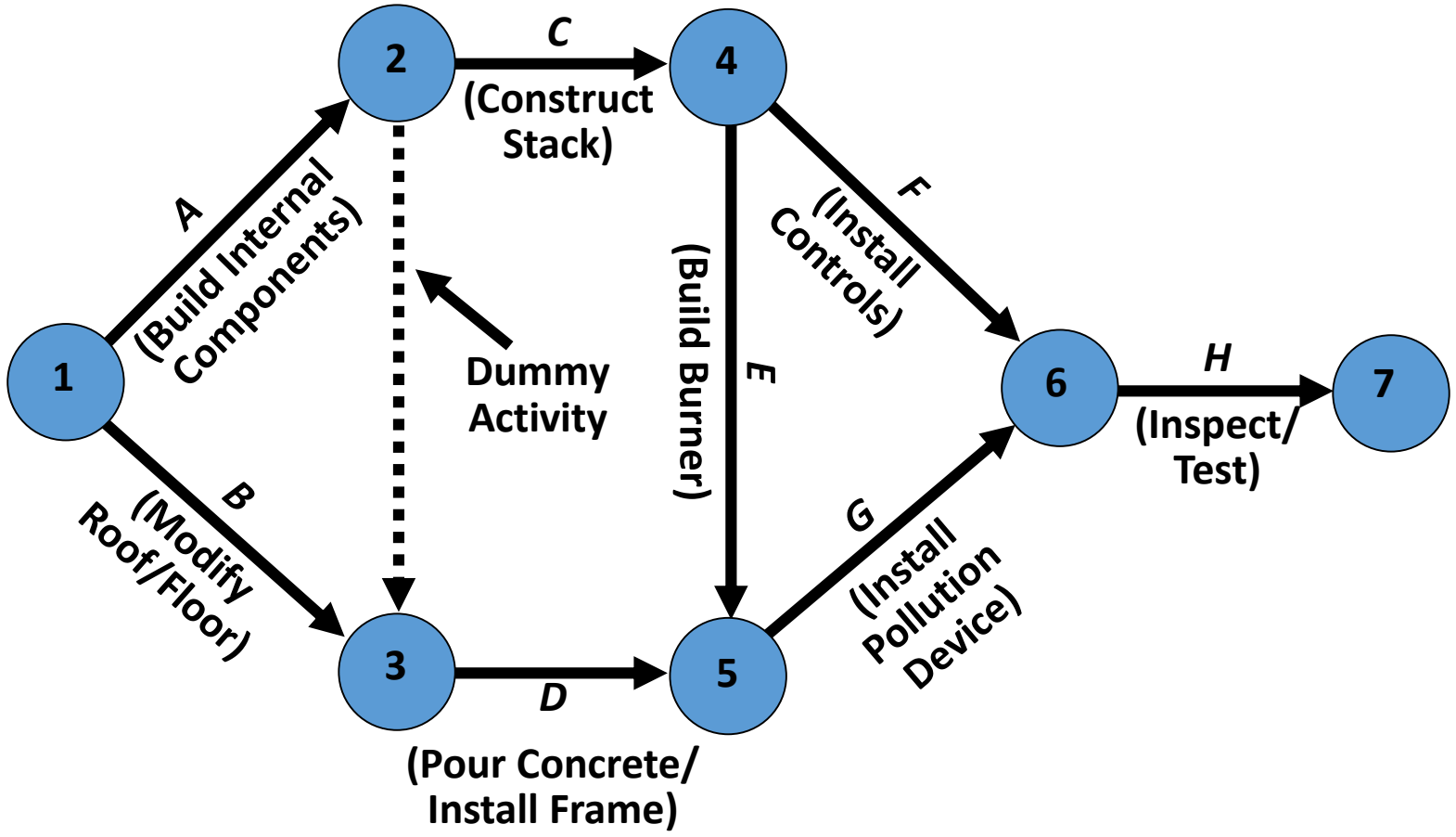
AON Network for Milwaukee Paper



AON Network for Milwaukee Paper



AOA Network for Milwaukee Paper



Determining the Project Schedule

Perform a Critical Path Analysis

- The critical path is the **longest path** through the network
- The critical path is the **shortest time** in which the project can be completed
- Any delay in critical path activities delays the project
- Critical path activities have no slack time

Critical Path Analysis

Begin at starting event and work forward

Earliest Start Time Rule:

- If an activity has only a single immediate predecessor, its ES equals the EF of the predecessor
- If an activity has multiple immediate predecessors, its ES is the maximum of all the EF values of its predecessors

ES = Max {EF of all immediate predecessors}

Critical Path Analysis

Begin at starting event and work forward

Earliest Finish Time Rule:

- The earliest finish time (EF) of an activity is the sum of its earliest start time (ES) and its activity time

EF = ES + Activity time

Critical Path Analysis

Begin with the last event and work backwards

Latest Finish Time Rule:

- If an activity is an immediate predecessor for just a single activity, its LF equals the LS of the activity that immediately follows it
- If an activity is an immediate predecessor to more than one activity, its LF is the minimum of all LS values of all activities that immediately follow it

LF = Min {LS of all immediate following activities}

Critical Path Analysis

Begin with the last event and work backwards

Latest Start Time Rule:

- The latest start time (LS) of an activity is the difference of its latest finish time (LF) and its activity time

LS = LF - Activity time

Critical Path Analysis

- **Slack** is the length of time an activity can be delayed without delaying the project

Slack = LS – ES or LF – EF

- **Activities with 0 slack are Critical Activities**
- The **Critical Path** is a continuous path through the network from start to finish that include only critical activities

Perform a Critical Path Analysis

Example 1:

Activity	Description	Time (weeks)
A	Build internal components	2
B	Modify roof and floor	3
C	Construct collection stack	2
D	Pour concrete and install frame	4
E	Build high-temperature burner	4
F	Install pollution control system	3
G	Install air pollution device	5
H	Inspect and test	2
	Total Time (weeks)	25

Critical Path Analysis

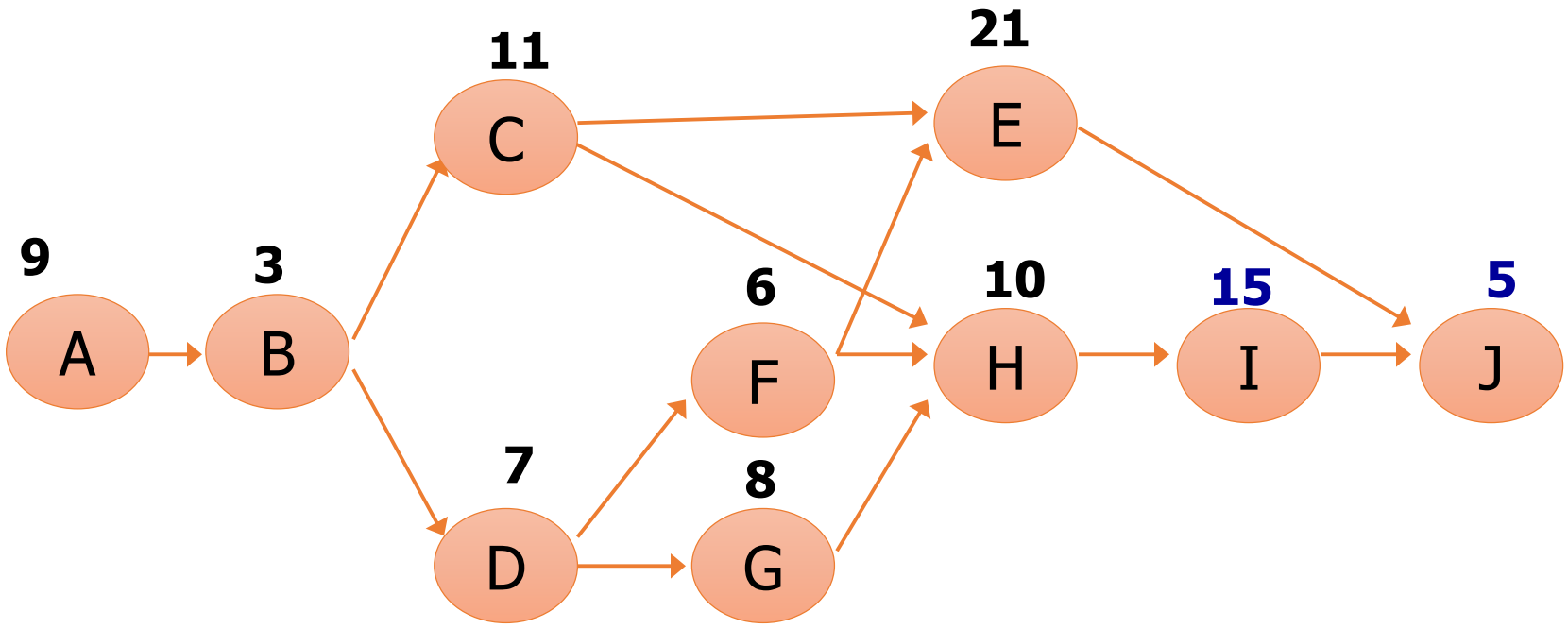
Activity		t	ES →	EF	LS ←	LF	Slack	On the critical path?
A	—	2	0	2	0	2	0	Yes
B	—	3	0	3	1	4	1	No
C	A	2	2	4	2	4	0	Yes
D	A, B	4	3	7	4	8	1	No
E	C	4	4	8	4	8	0	Yes
F	C	3	4	7	10	13	6	No
G	D, E	5	8	13	8	13	0	Yes
H	F, G	2	13	15	13	15	0	Yes

Perform a Critical Path Analysis

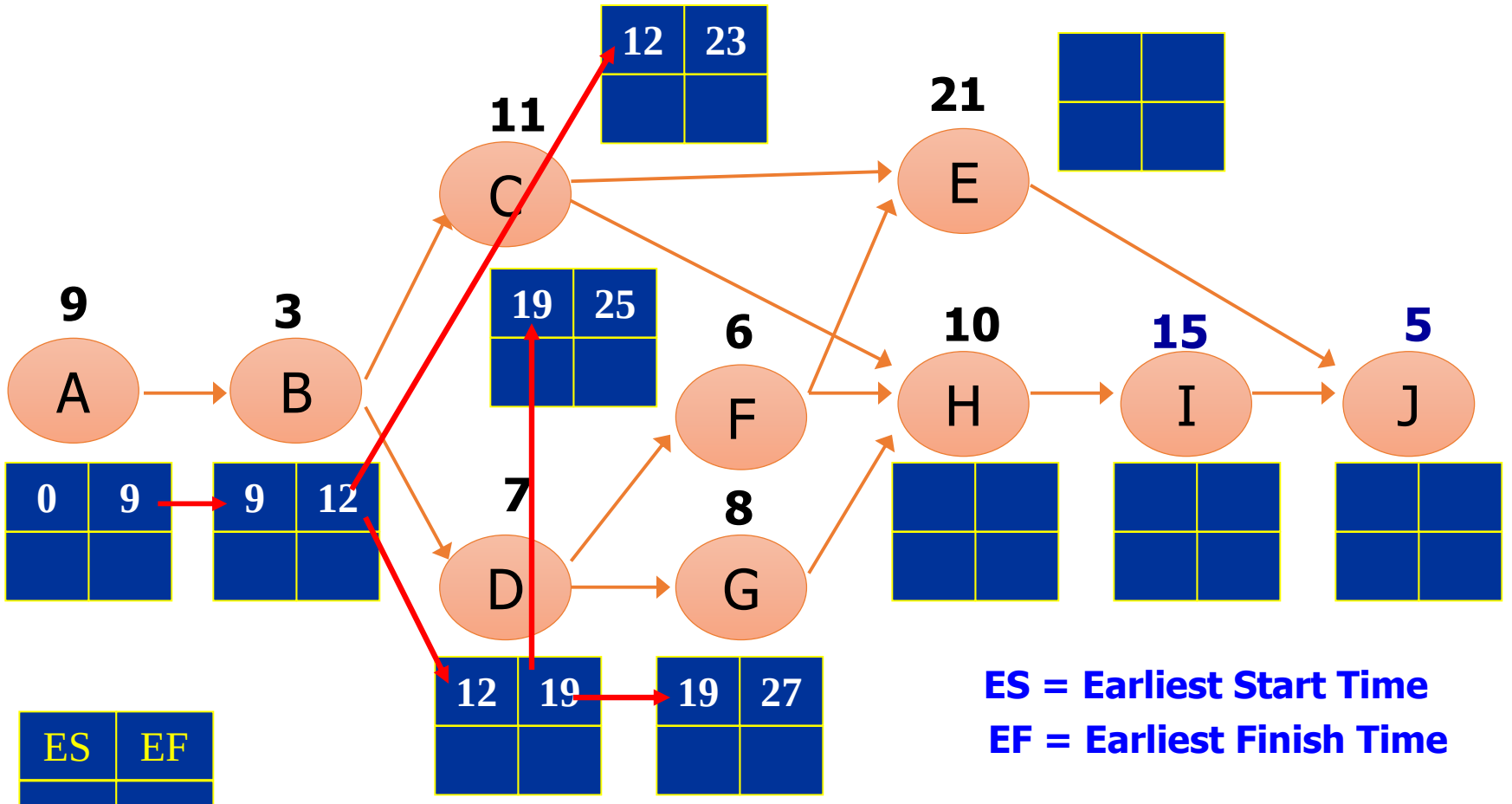
Example 2:

Activity	Duration (days)	Immediate Predecessors
A	9	----
B	3	A
C	11	B
D	7	B
E	21	F,C
F	6	D
G	8	D
H	10	C,F,G
I	15	H
J	5	E,I

A-O-N



Determine ES and EF



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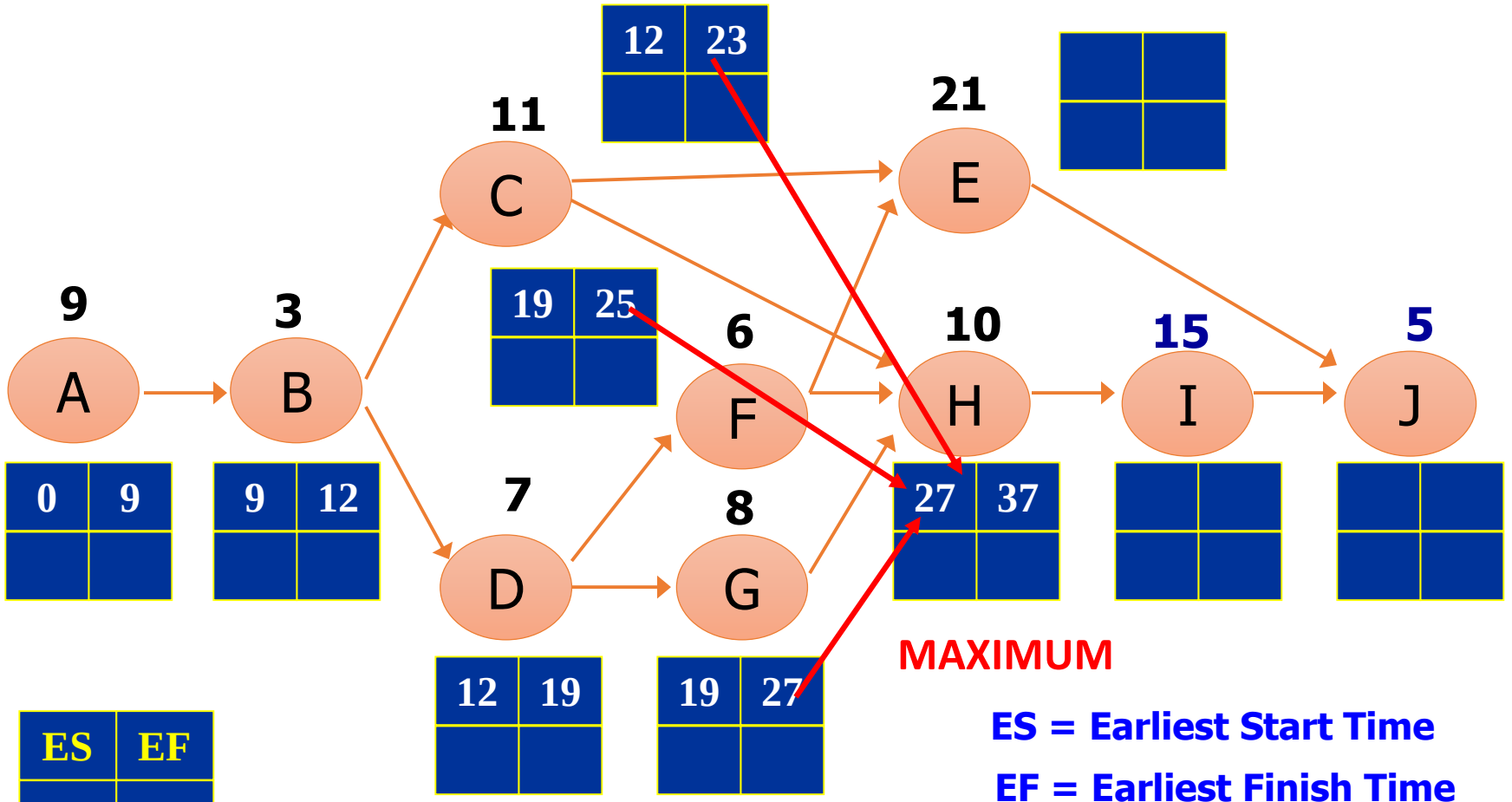

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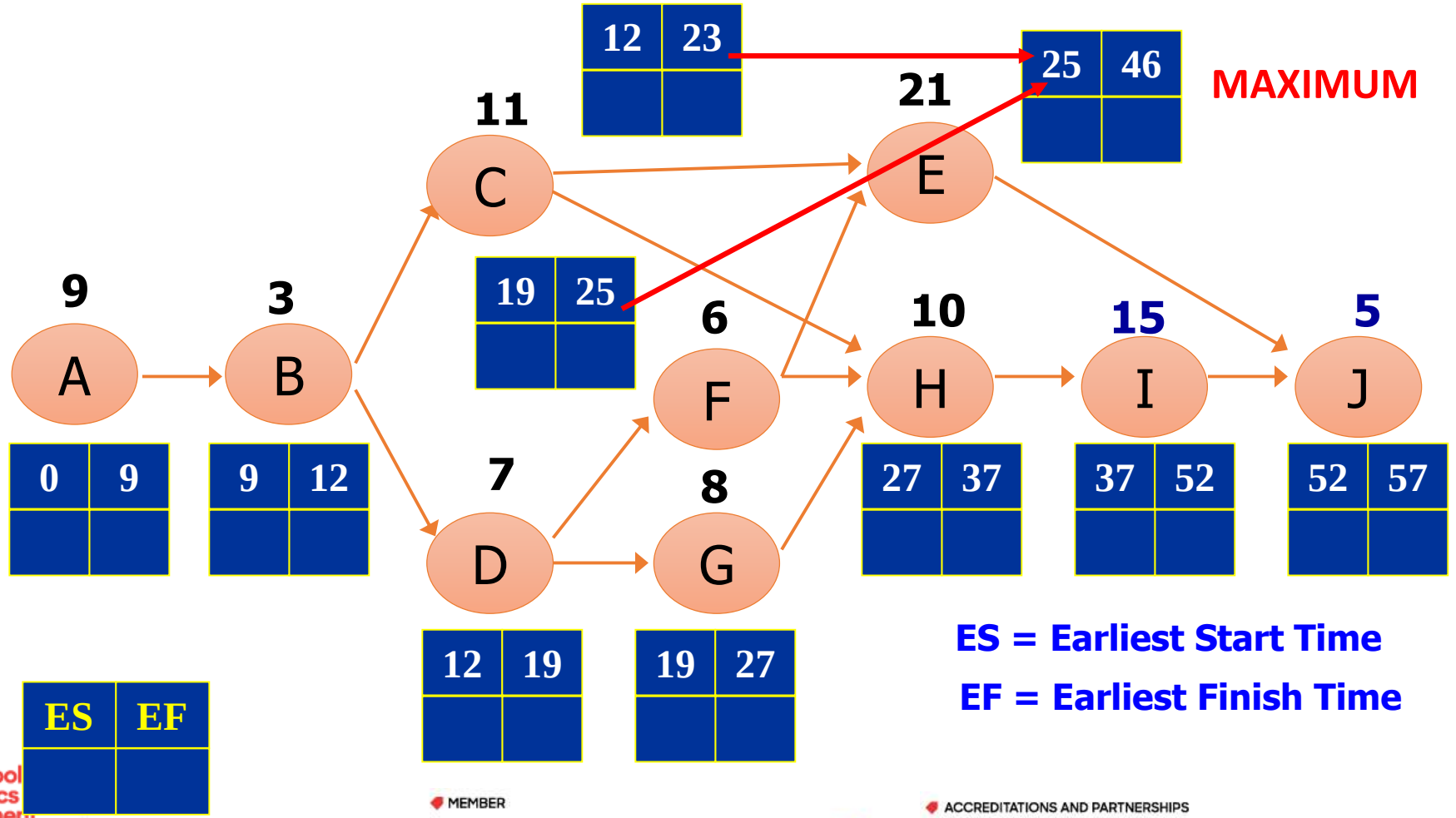
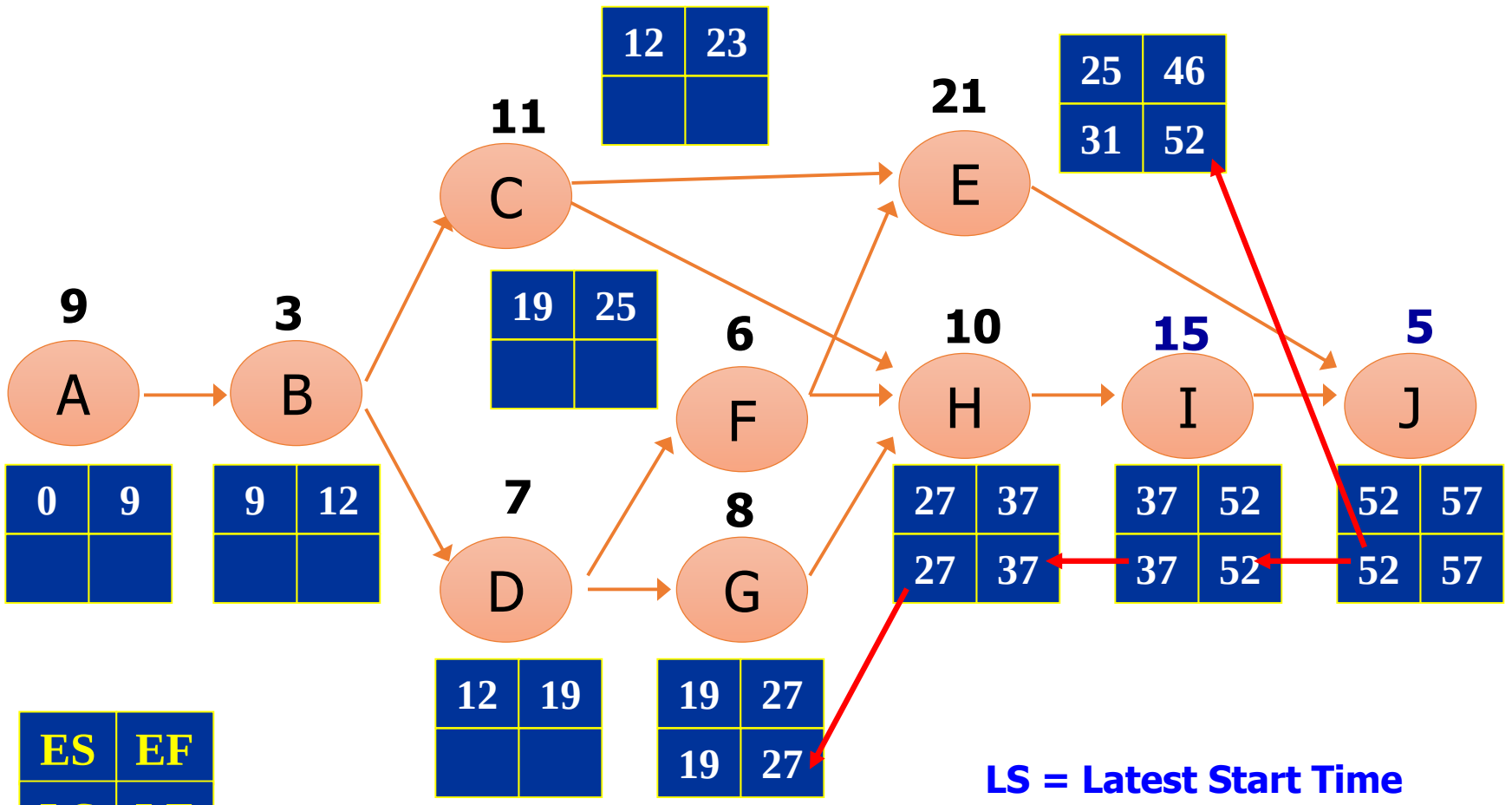


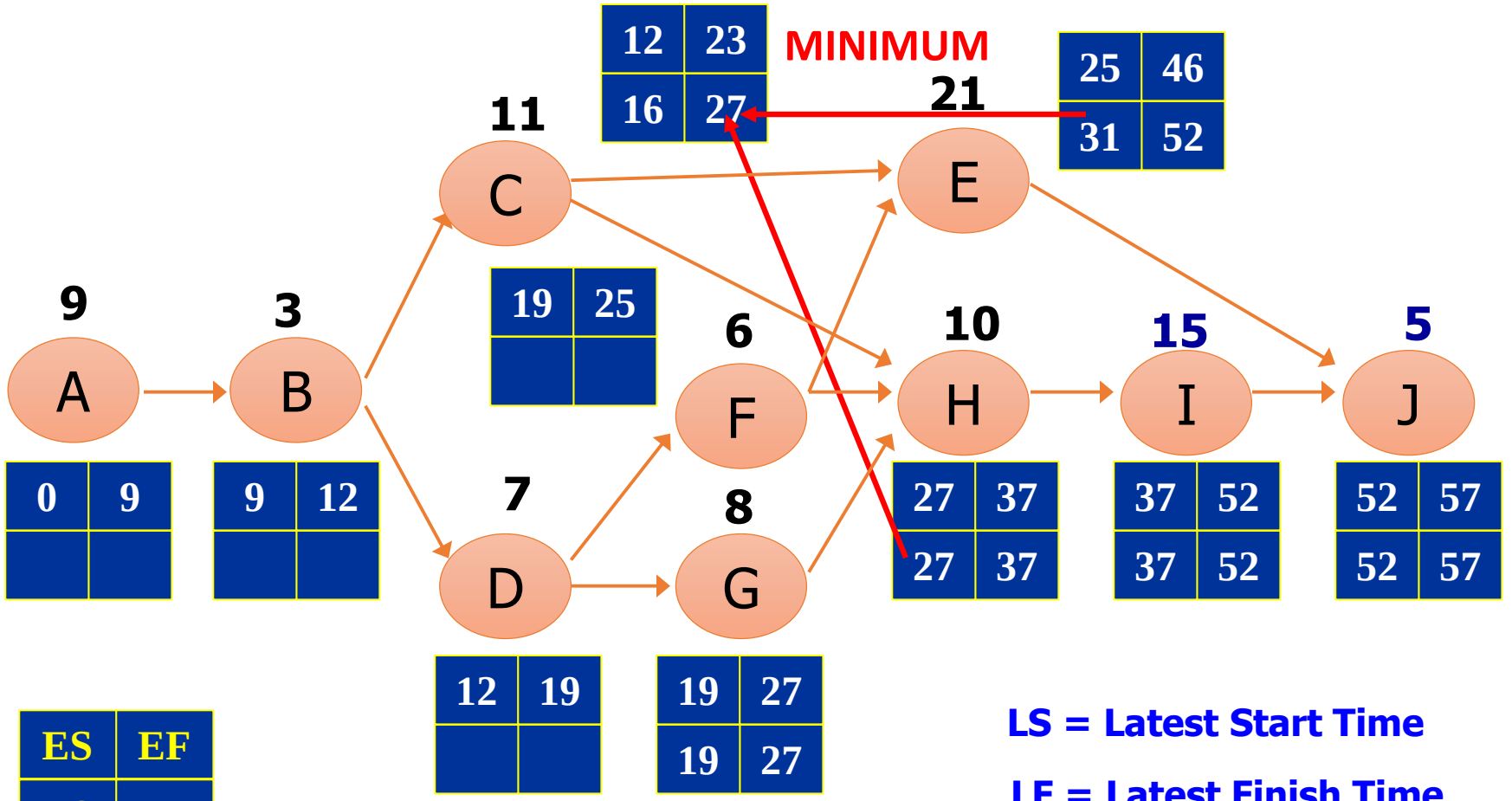
Determine LF and LS



LS = Latest Start Time

LF = Latest Finish Time

Determine LF and LS



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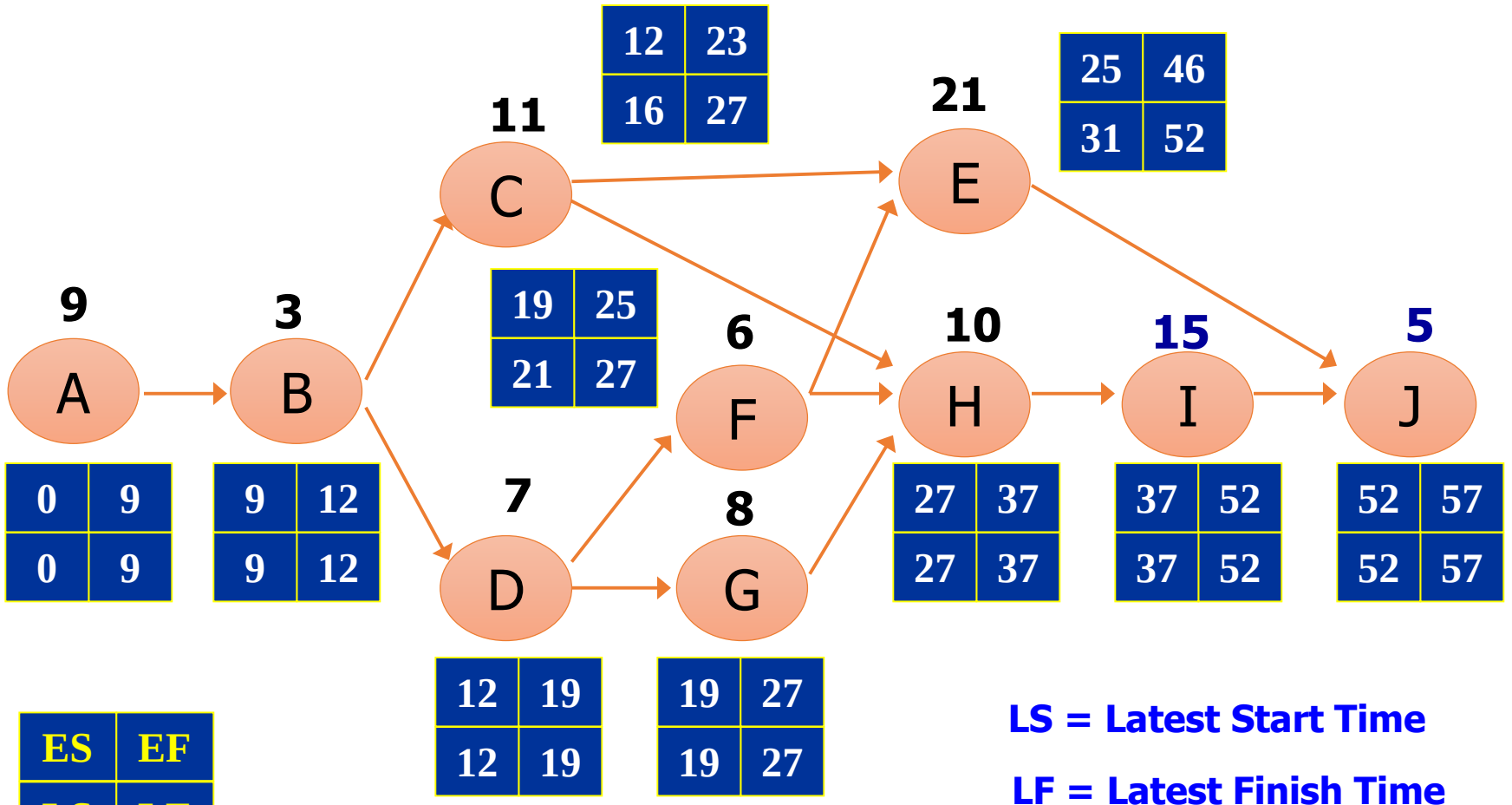
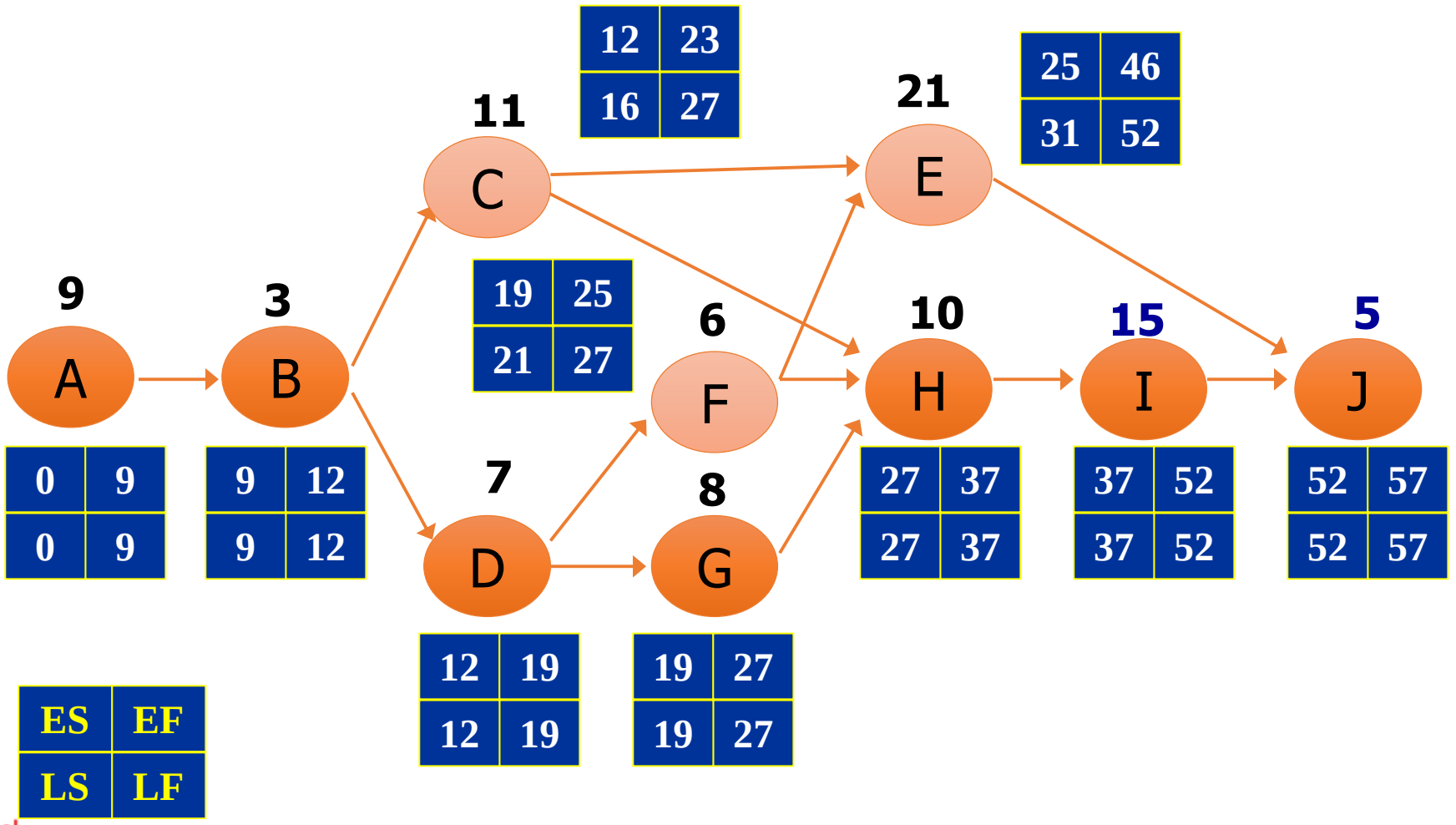
Determine LF and LS



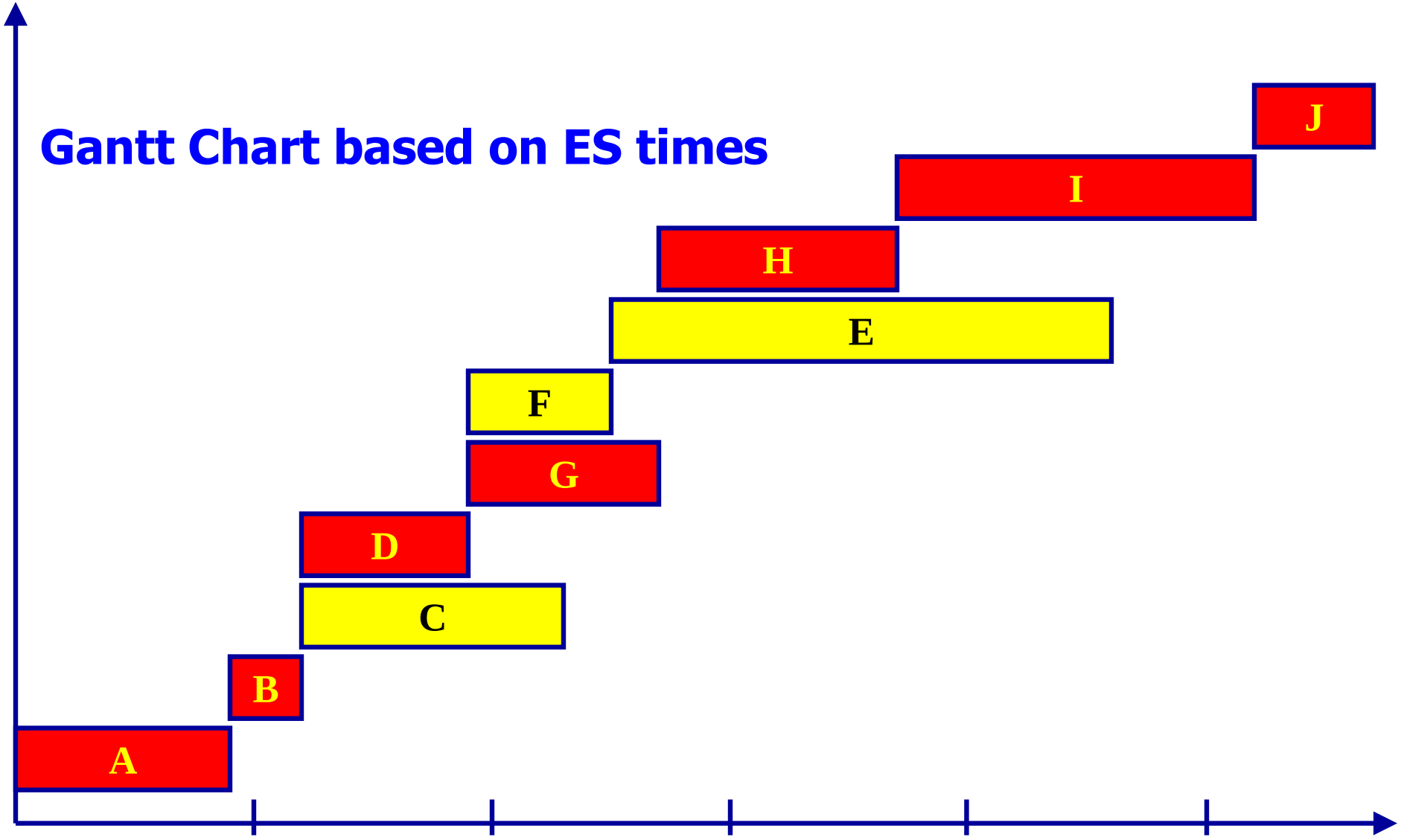
LS = Latest Start Time

LF = Latest Finish Time

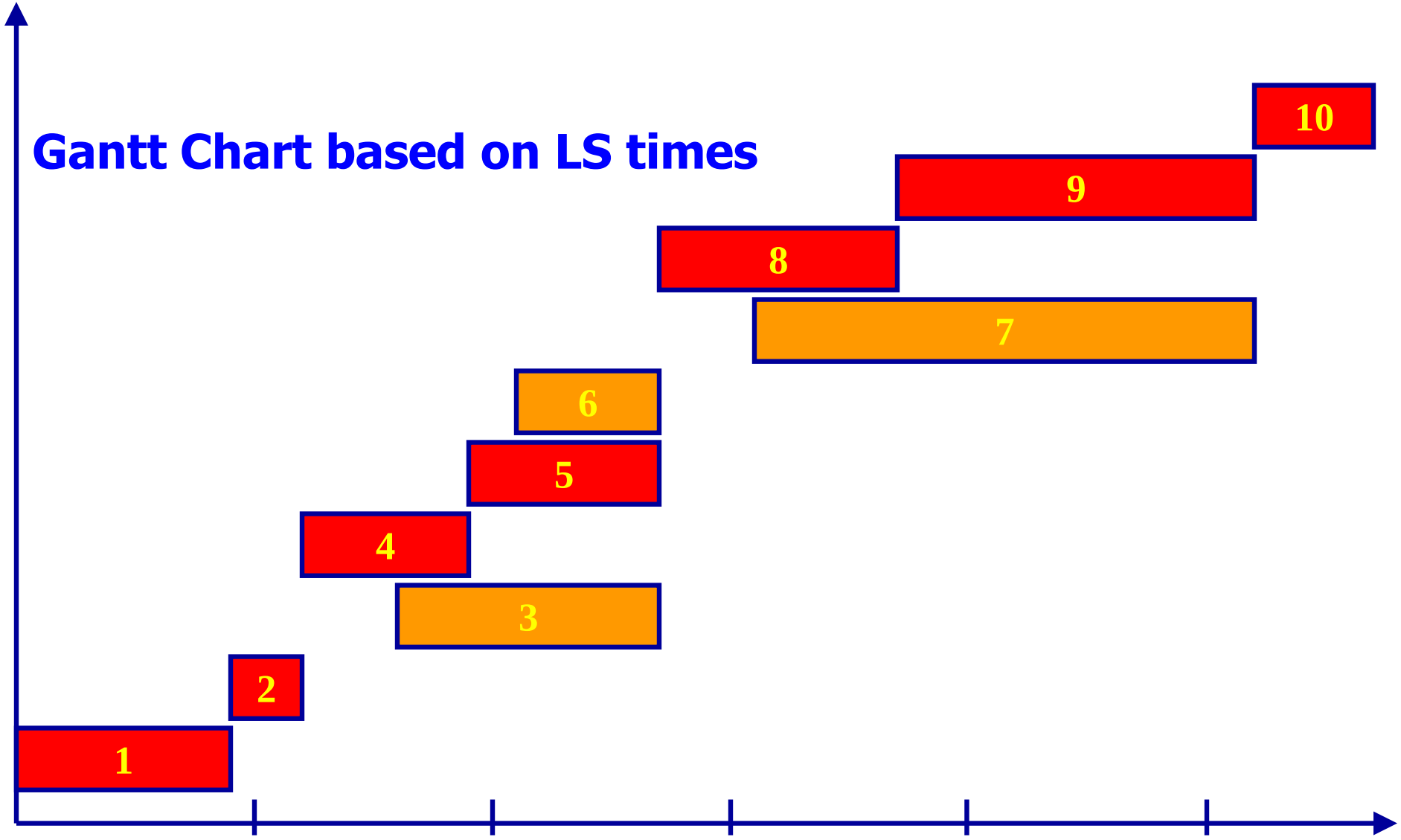
Critical Path



Gant Chart based on ES times



Gant Chart based on LS times



Variability in Activity Times

- CPM assumes we know a **fixed time** for each activity and there is no variability in activity times
- PERT uses a probability distribution for activity times to allow for variability

Variability in Activity Times

- Three time estimates are required
  - **Optimistic time (*a*)** – if everything goes according to plan
  - **Pessimistic time (*b*)** – assuming very unfavorable conditions
  - **Most likely time (*m*)** – most realistic estimate

Variability in Activity Times

Estimate follows beta distribution

Expected time:

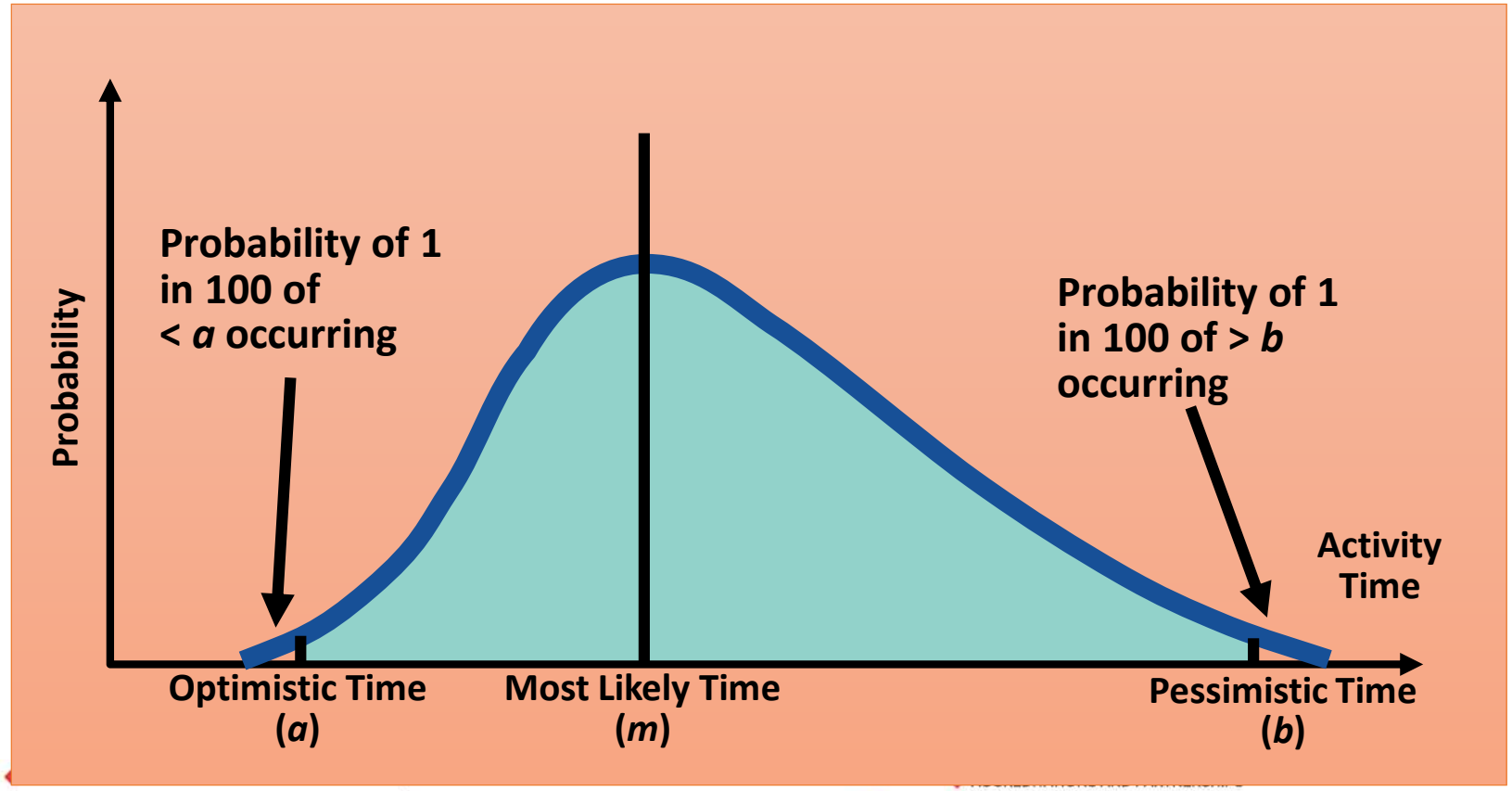
$$t = (a + 4m + b)/6$$

Variance of times:

$$v = [(b - a)/6]^2$$

Variability in Activity Times

Estimate follows beta distribution



Computing Variance

Activity	Optimistic a	Most Likely m	Pessimistic b	Expected Time $t = (a + 4m + b)/6$	Variance $[(b - a)/6]^2$
A	1	2	3	2	0.11
B	2	3	4	3	0.11
C	1	2	3	2	0.11
D	2	4	6	4	0.44
E	1	4	7	4	1.00
F	1	2	9	3	1.78
G	3	4	11	5	1.78
H	1	2	3	2	0.11

Project variance is computed by summing the variances of critical activities

σ_p^2 = Project variance

= $\sum$(variances of activities on critical path)

Project variance

$$\sigma_p^2 = 0.11 + 0.11 + 1.00 + 1.78 + 0.11 = 3.11$$

Project standard deviation

$$\sigma_p = \sqrt{\text{Project variance}}$$

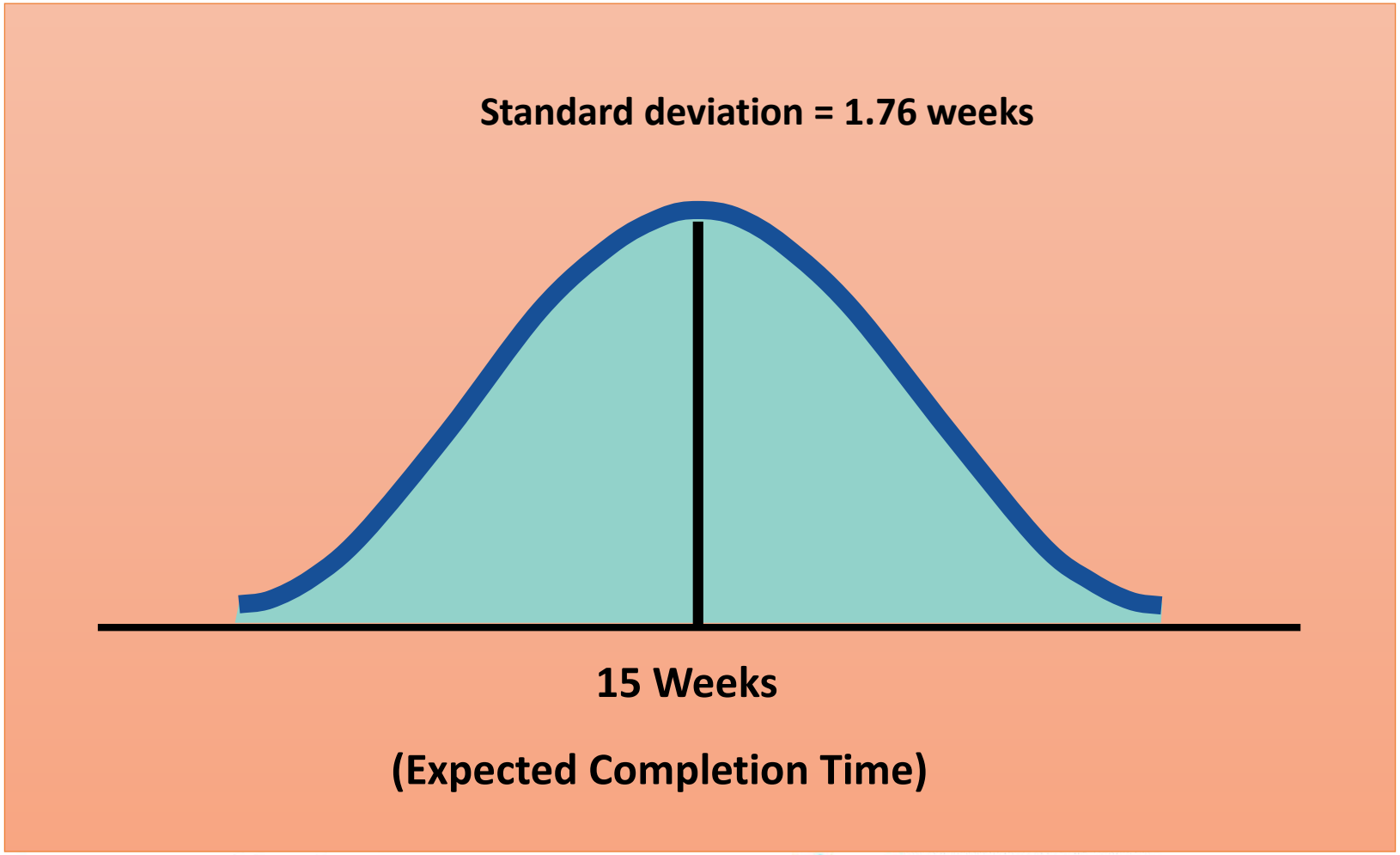
$$= \sqrt{3.11} = 1.76 \text{ weeks}$$

Project Completion Time

PERT makes two more assumptions:

- Total project completion times follow a normal probability distribution
- Activity times are statistically independent

Project Completion Time



Probability of Project Completion

What is the probability this project can be completed on or before the 16 week deadline?

$$Z = \left(\begin{array}{c}\text{Due} \\ \text{date}\end{array} - \begin{array}{c}\text{Expected date} \\ \text{of completion}\end{array} \right) / \sigma_p$$

$$= (16 \text{ wks} - 15 \text{ wks})/1.76 \text{ wks}$$

$$= 0.57$$

Where Z is the number of standard deviations the due date or target date lies from the mean or expected date

Probability of Project Completion

From Appendix I

	.00	.01	≈	.07	.08
.1	.50000	.50399		.52790	.53188
.2	.53983	.54380		.56749	.57142
≈					
.5	.69146	.69497		.71566	.71904
.6	.72575	.72907		.74857	.75175

= 0.57

Where Z is the number of standard deviations that the finish date deviates from the expected duration

Probability of Project Completion

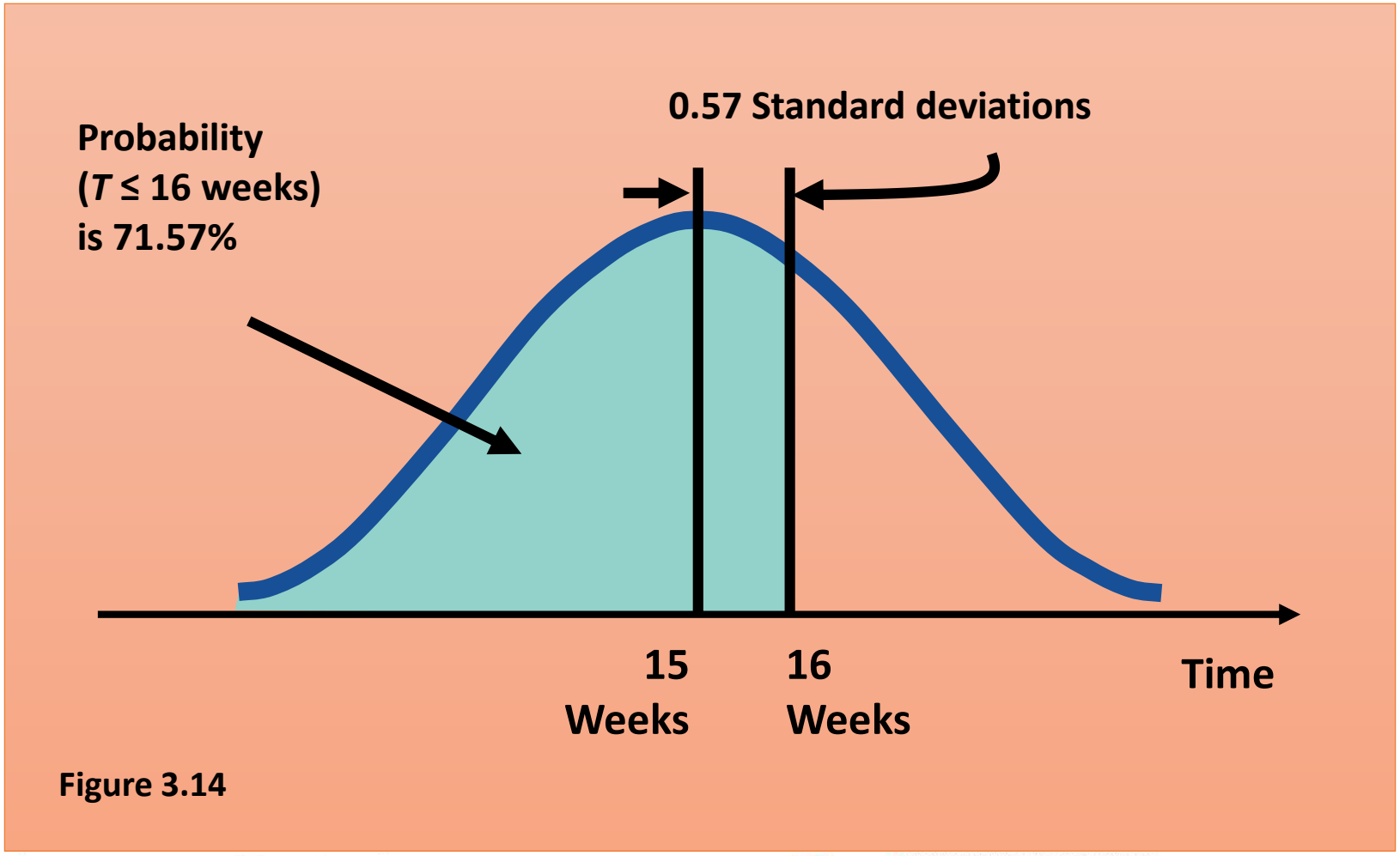


Figure 3.14

99% Probability of Project Completion

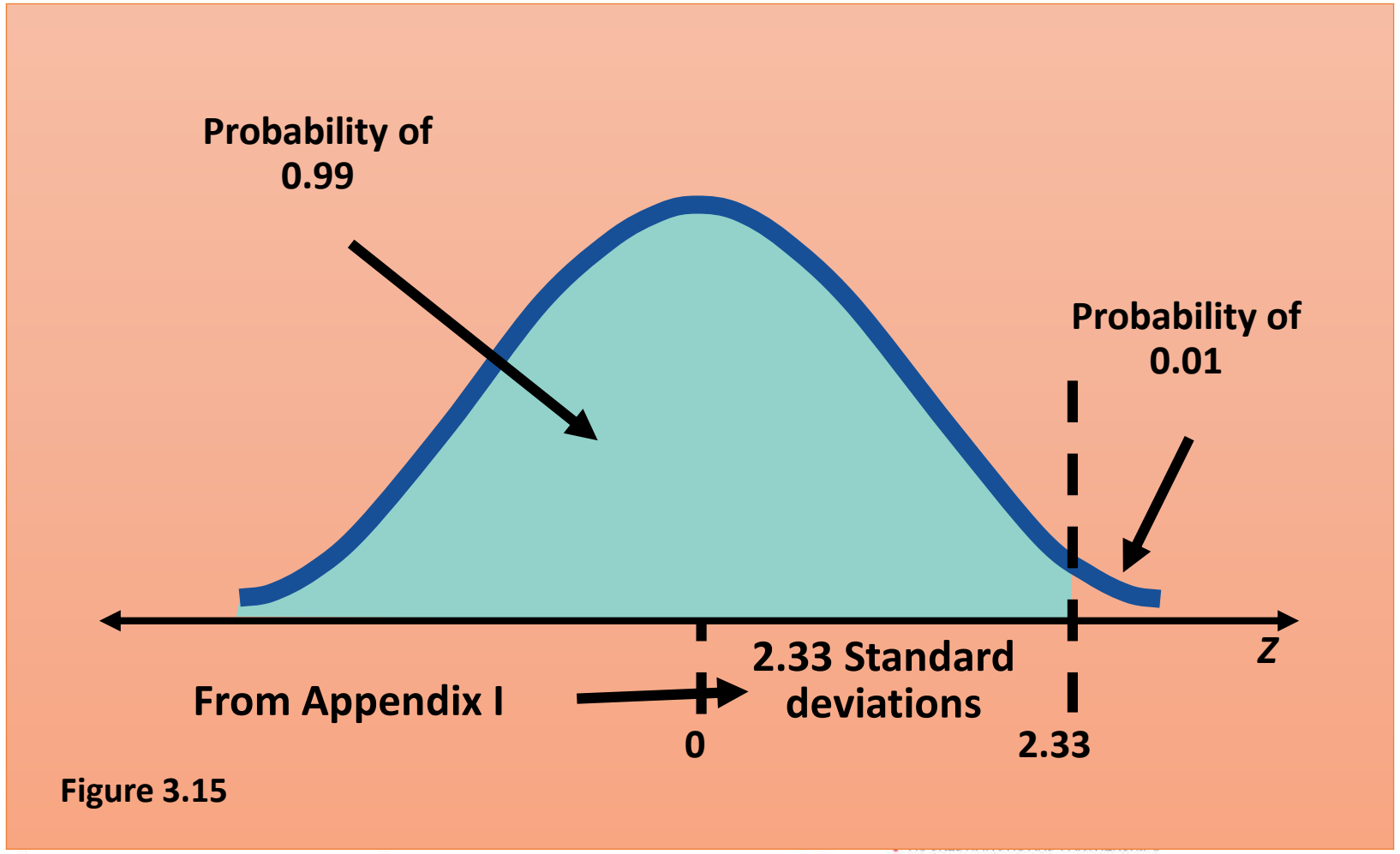


Figure 3.15

Based on 2.33 Standard deviations above the mean project completion time, what is the due date with a 99% probability of *on-time* completion?

Standard normal equation

$$Z = \left(\begin{array}{c} \text{due} \\ \text{date} \end{array} - \begin{array}{c} \text{expected date} \\ \text{of completion} \end{array} \right) / \sigma_p$$

$$= (16 \text{ wks} - 15 \text{ wks})/1.76 \text{ wks} = 0.57$$

Now reverse the equation ……

$$\textit{Due date} = \begin{array}{c} \text{expected date} \\ \text{of completion} \end{array} + \left(Z \times \sigma_p \right)$$

$$= 15 \text{ wks} + (2.33 \times 1.76 \text{ wks}) = 19.1 \text{ wks}$$

Variability of Completion Time for Noncritical Paths

- Variability of times for activities on noncritical paths must be considered when finding the probability of finishing in a specified time
- **Variation in noncritical activity may cause change in critical path**

Trade-Offs and Project Crashing

It is not uncommon to face the following situations:

- The project is behind schedule
- The completion time has been moved forward

Shortening the duration of the project is called Project Crashing

Factors to Consider when Crashing a Project

- The amount by which an activity is crashed is, in fact, permissible.
- Taken together, the shortened activity durations will enable us to finish the project by the due date.
- The total cost of crashing is as small as possible.

Steps in Project Crashing

1. Compute the crash cost per time period. If crash costs are linear over time:

$$\text{Crash cost per time period} = \frac{(\text{Crash cost} - \text{Normal cost})}{(\text{Normal time} - \text{Crash time})}$$

2. Using current activity times, find the critical path and identify the critical activities

Steps in Project Crashing

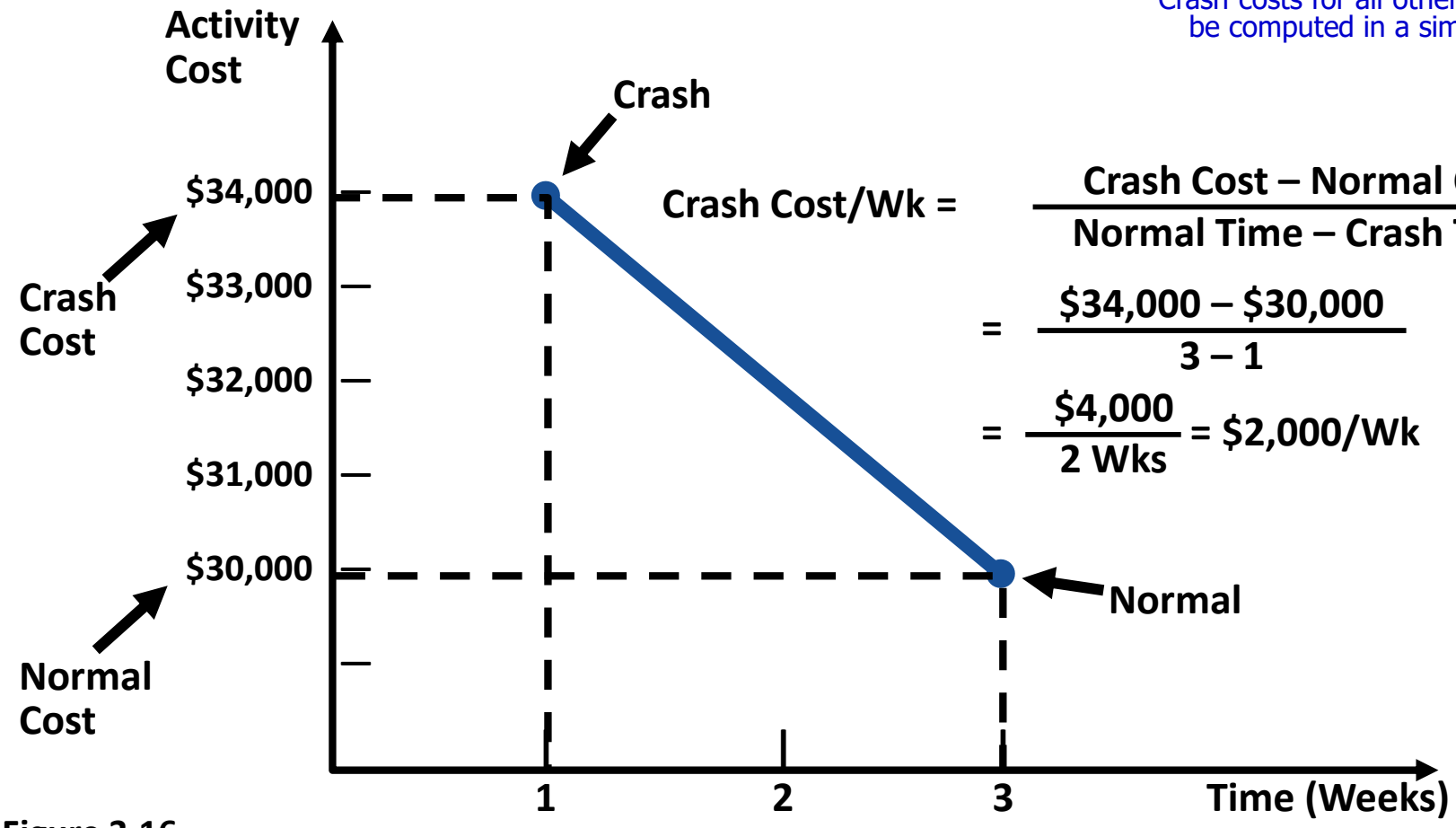
3. If there is only one critical path, then select the activity on this critical path that **(a)** can still be crashed, and **(b)** has the smallest crash cost per period. If there is more than one critical path, then select one activity from each critical path such that **(a)** each selected activity can still be crashed, and **(b)** the total crash cost of all selected activities is the smallest. Note that the same activity may be common to more than one critical path.
4. Update all activity times. If the desired due date has been reached, stop. If not, return to Step 2.

Crashing the Project

	Time (Wks)		Cost ($)			
Activity	Normal	Crash	Normal	Crash	Crash Cost Per Wk ($)	Critical Path?
A	2	1	22,000	22,750	750	Yes
B	3	1	30,000	34,000	2,000	No
C	2	1	26,000	27,000	1,000	Yes
D	4	3	48,000	49,000	1,000	No
E	4	2	56,000	58,000	1,000	Yes
F	3	2	30,000	30,500	500	No
G	5	2	80,000	84,500	1,500	Yes
H	2	1	16,000	19,000	3,000	Yes

Crash and Normal Times and Costs for **Activity B**

Crash costs for all other activities can be computed in a similar fashion



$$\text{Crash Cost/Wk} = \frac{\text{Crash Cost} - \text{Normal Cost}}{\text{Normal Time} - \text{Crash Time}}$$

$$= \frac{\$34,000 - \$30,000}{3 - 1}$$

$$= \frac{\$4,000}{2 \text{ Wks}} = \$2,000/\text{Wk}$$

Figure 3.16

Advantages of PERT/CPM

1. Especially useful when scheduling and controlling large projects;
2. Straightforward concept and not mathematically complex;
3. Graphical networks help highlight relationships among project activities;
4. Critical path and slack time analyses help pinpoint activities that need to be closely watched;
5. Project documentation and graphics point out who is responsible for various activities;
6. Applicable to a wide variety of projects;
7. Useful in monitoring not only schedules but costs as well.

Limitations of PERT/CPM

1. Project activities have to be clearly defined, independent, and stable in their relationships;
2. Precedence relationships must be specified and networked together;
3. Time estimates tend to be subjective and are subject to fudging by managers who fear the dangers of being overly optimistic or not pessimistic enough;
4. There is an inherent danger of **too much emphasis** being placed on the **longest, or critical, path.**

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