Project Planning, Scheduling & Controlling – CPM, PERT

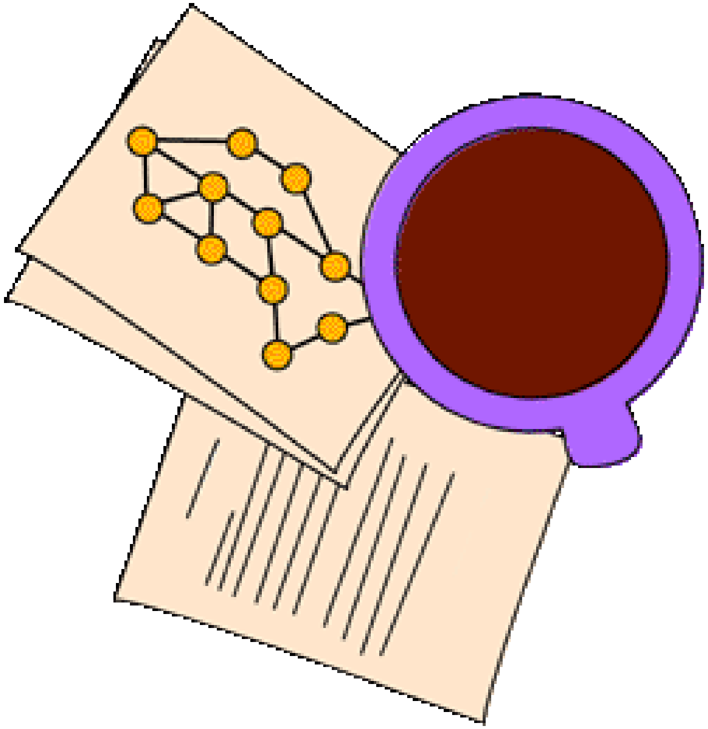
Heerkens – Chapter 9

PM notes

Outline

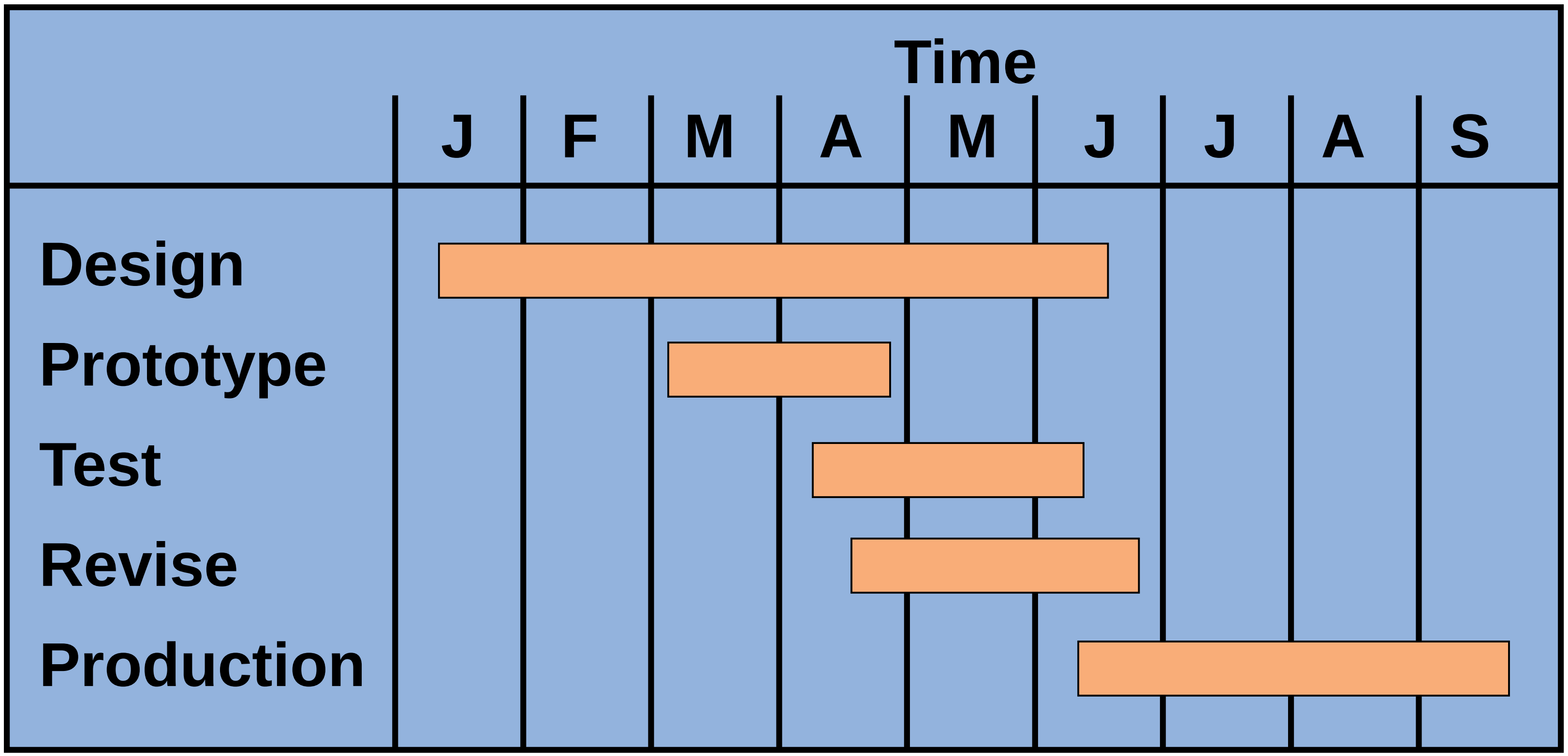
- Project Management Techniques: PERT and CPM
  - The Framework of PERT and CPM
  - Network Diagrams and Approaches
  - Activity-on-Node Example
  - ~~Activity-on-Arrow Example~~
- Determining the Project Schedule
  - Forward Pass
  - Backward Pass
  - Calculating Slack Time and Identifying the Critical Path(s)
- Variability in Activity Times
  - Three Time Estimates in PERT
  - Probability of Project Completion
- Cost-Time Trade-Offs and Project Crashing
- A Critique of PERT and CPM
- Using Microsoft Project to Manage Projects

Project Management Techniques



- Gantt chart
- Critical Path Method (CPM)
- Program Evaluation and Review Technique (PERT)

A Simple Gantt Chart



Gantt Example: Service For a Delta Jet

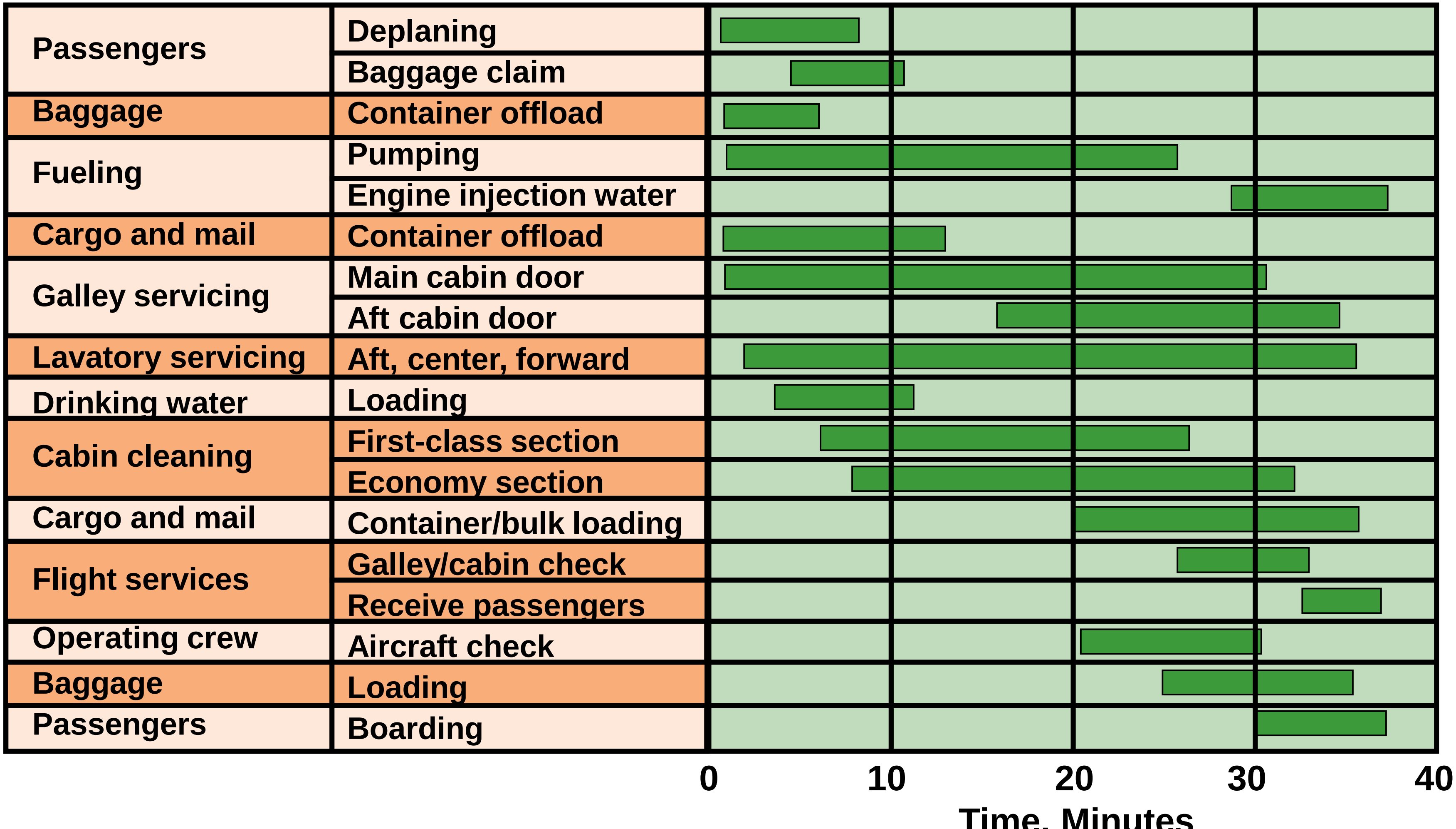


Figure 3.4

Project Control Reports

- Detailed cost breakdowns for each task
- Total program labor curves
- Cost distribution tables
- Functional cost and hour summaries
- Raw materials and expenditure forecasts
- Variance reports
- Time analysis reports
- Work status reports

PERT and CPM

- **Network techniques**
- **Consider *precedence relationships and interdependencies***
- **Each uses a different estimate of activity times**

Six Steps PERT & 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

Questions PERT & CPM Can Answer

1. **When will the entire project be completed?**
2. **What are the critical activities or tasks in the project?**
3. **Which are the noncritical activities?**
4. **What is the probability the project will be completed by a specific date?**
5. **Is the project on schedule, behind schedule, or ahead of schedule?**
6. **Is the money spent equal to, less than, or greater than the budget?**
7. **Are there enough resources available to finish the project on time?**
8. **If the project must be finished in a shorter time, what is the way to accomplish this at least cost?**

A Comparison of AON and AOA Network Conventions

Used in this course

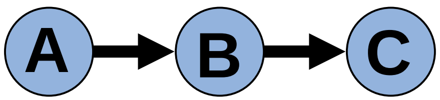
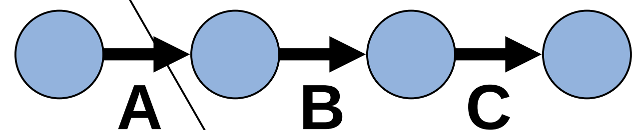
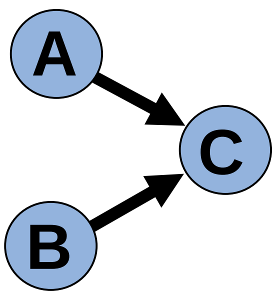
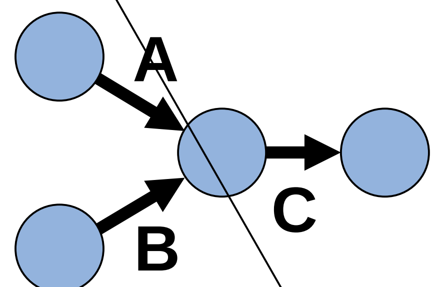
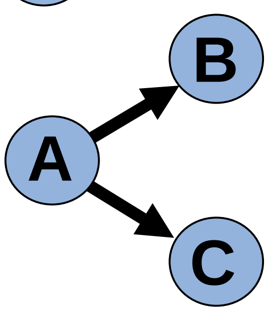
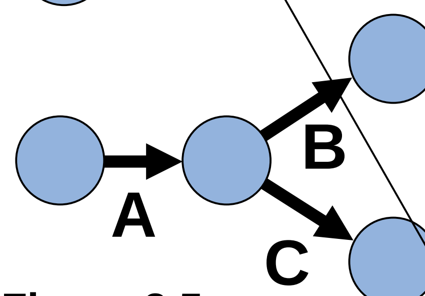
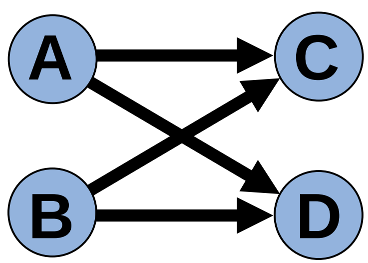
Activity on Node (AON)	Activity Meaning	Activity on Arrow (AOA)
(a) 	A comes before B, which comes before C.	
(b) 	A and B (in parallel) must both be completed before C can start.	
(c) 	B and C cannot begin until A is completed.	

Figure 3.5

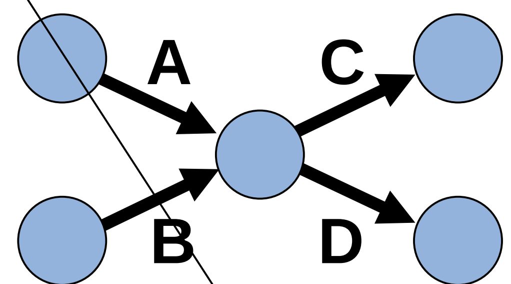
A Comparison of AON and AOA Network Conventions

Activity on Node (AON)	Activity Meaning	Activity on Arrow (AOA)

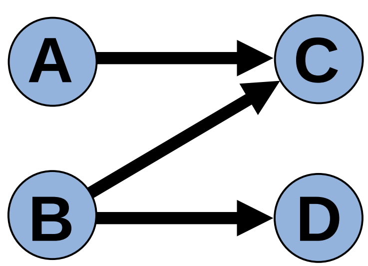
(d)



C and D cannot begin until both A and B are completed.



(e)



C cannot begin until both A and B are completed; D cannot begin until B is completed. A dummy activity is introduced in AOA.

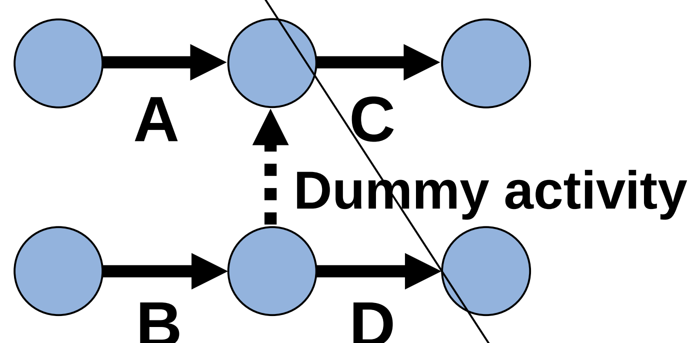


Figure 3.5

A Comparison of AON and AOA Network Conventions

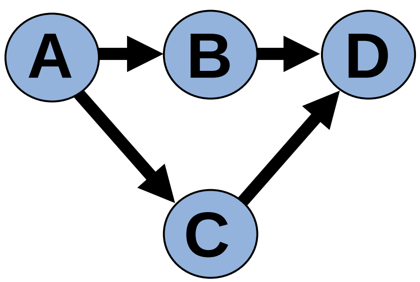
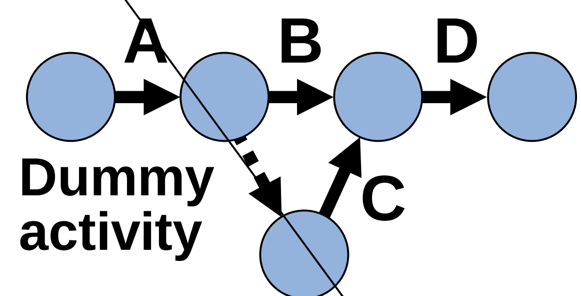
Activity on Node (AON)	Activity Meaning	Activity on Arrow (AOA)
(f) 	B and C cannot begin until A is completed. D cannot begin until both B and C are completed. A dummy activity is again introduced in AOA.	

Figure 3.5

AON Example

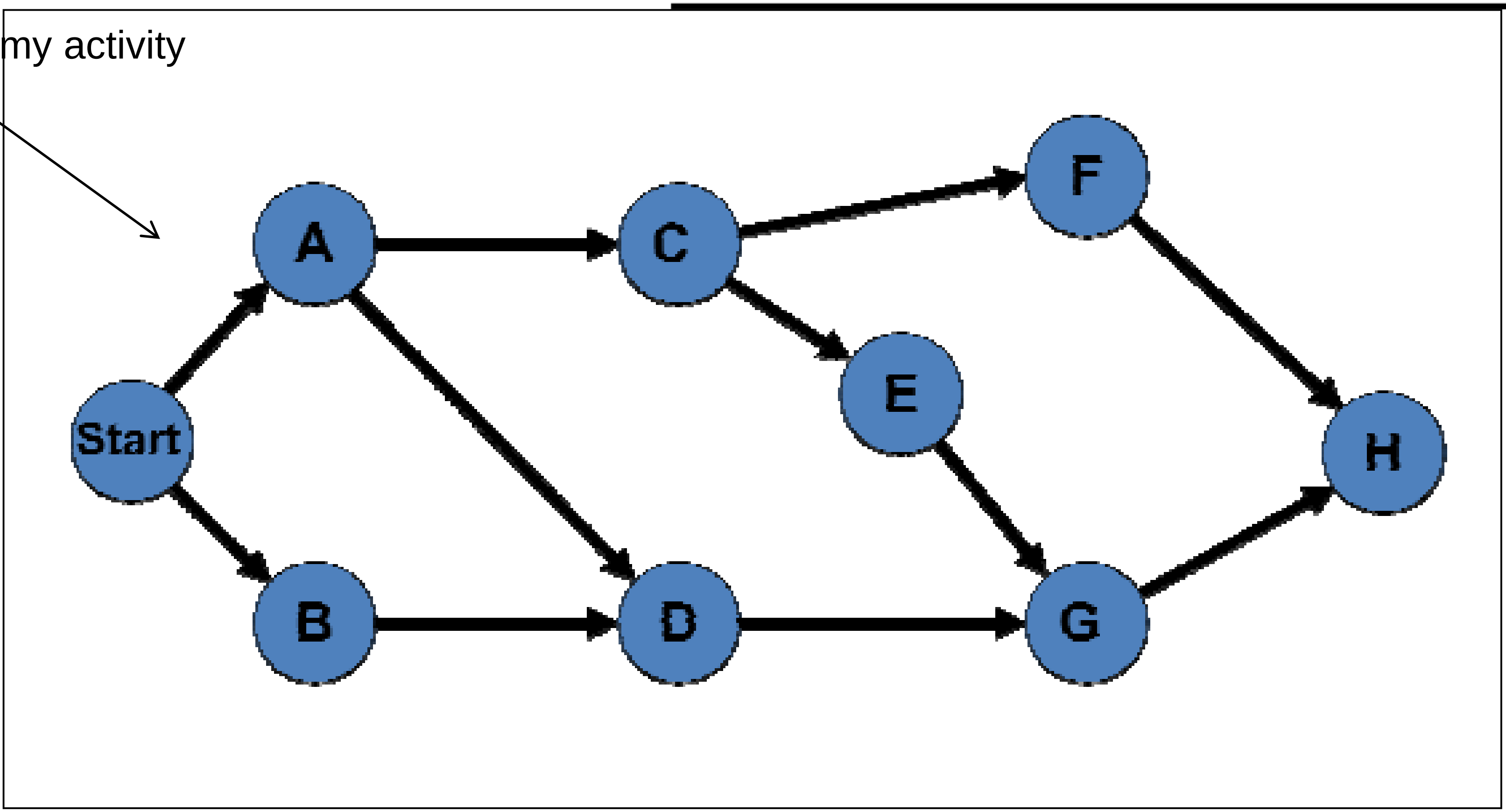
Paper Manufacturing's Activities and Predecessors

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

Be able to draw this up from a worded Description

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

Dummy activity



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

Determining the Project Schedule

Duration of activity
"expected time"

Perform a Critical Path Analysis

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

Determining the Project Schedule

Perform a Critical Path Analysis

Earliest start (ES) = earliest time at which an activity can start, assuming all predecessors have been completed

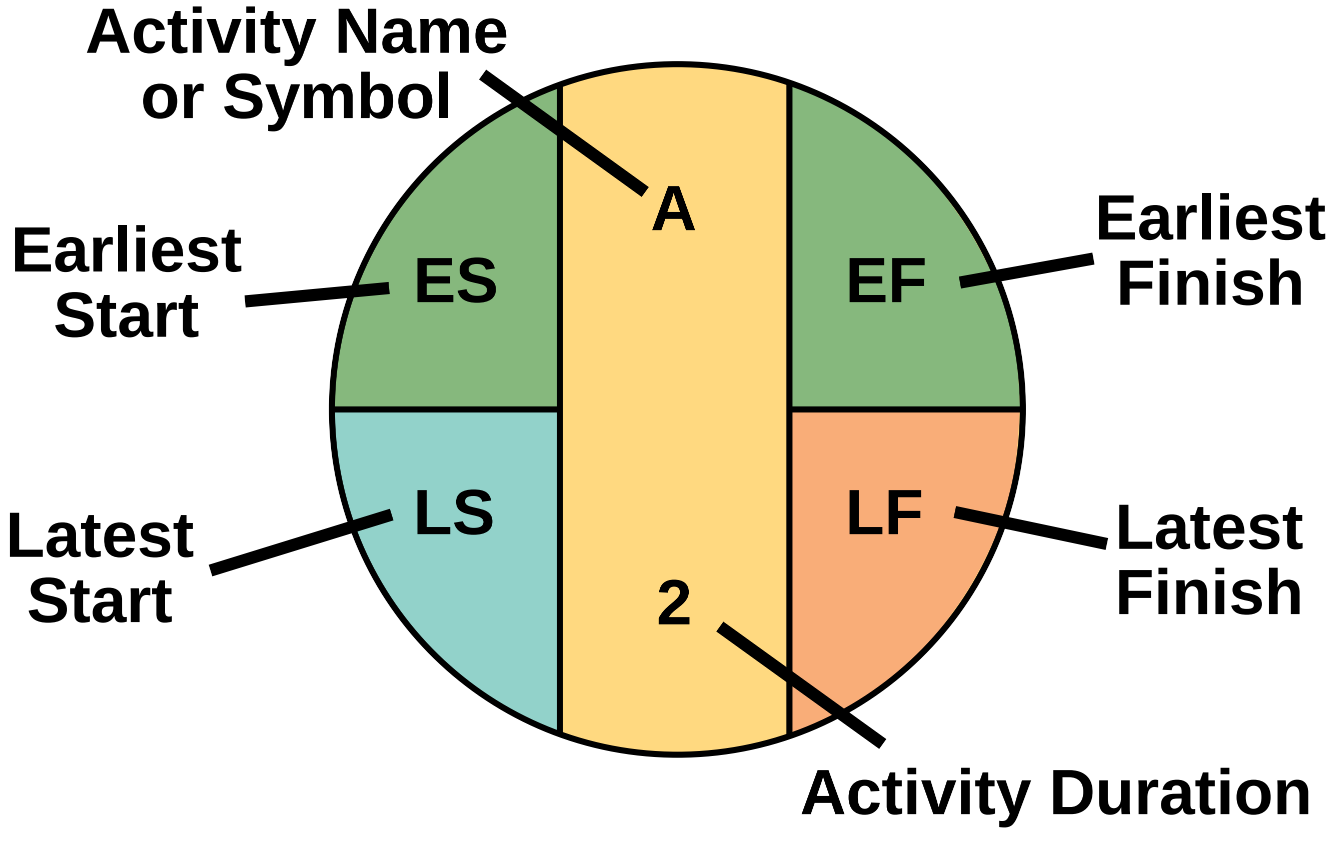
Earliest finish (EF) = earliest time at which an activity can be finished

Latest start (LS) = latest time at which an activity can start so as not to delay the completion time of the entire project

Latest finish (LF) = latest time by which an activity has to be finished so as not to delay the completion time of the entire project

Determining the Project Schedule

Node notation



Determine SLACK in the network

1. Forward Pass

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}

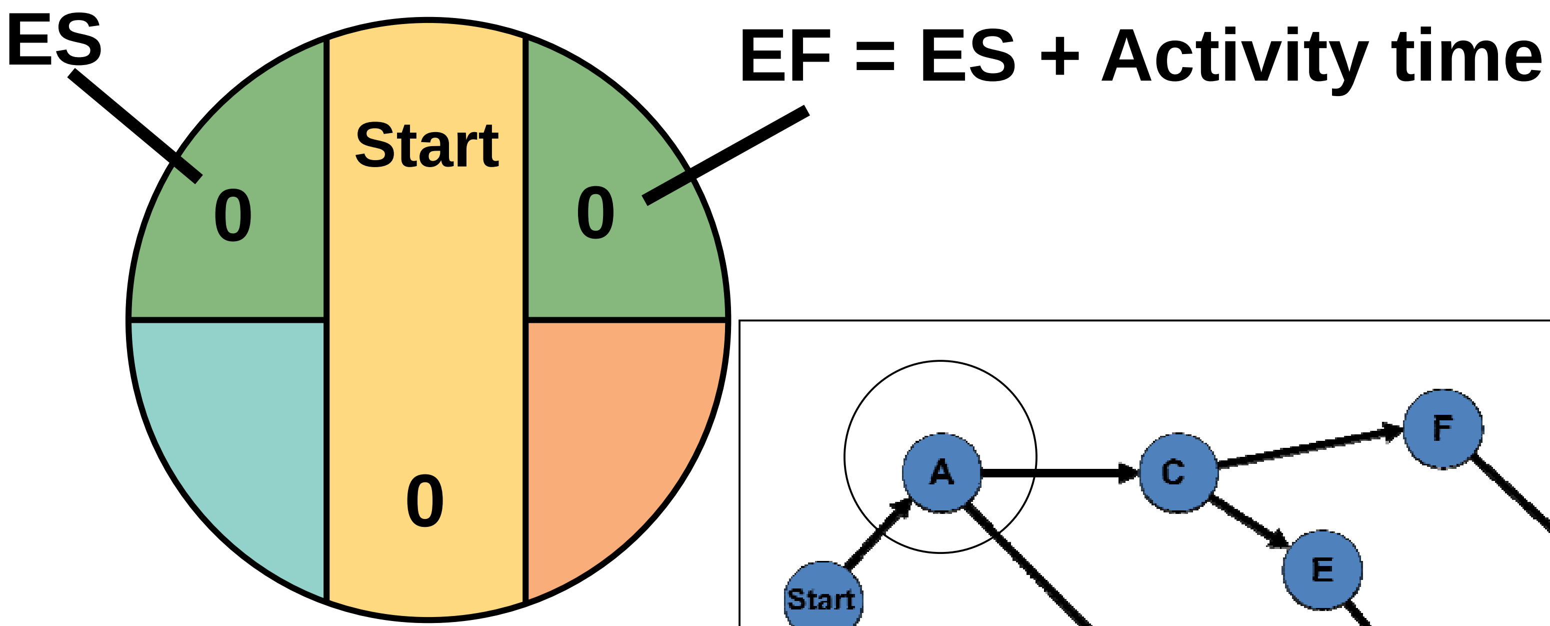
Earliest Finish Time Rule:

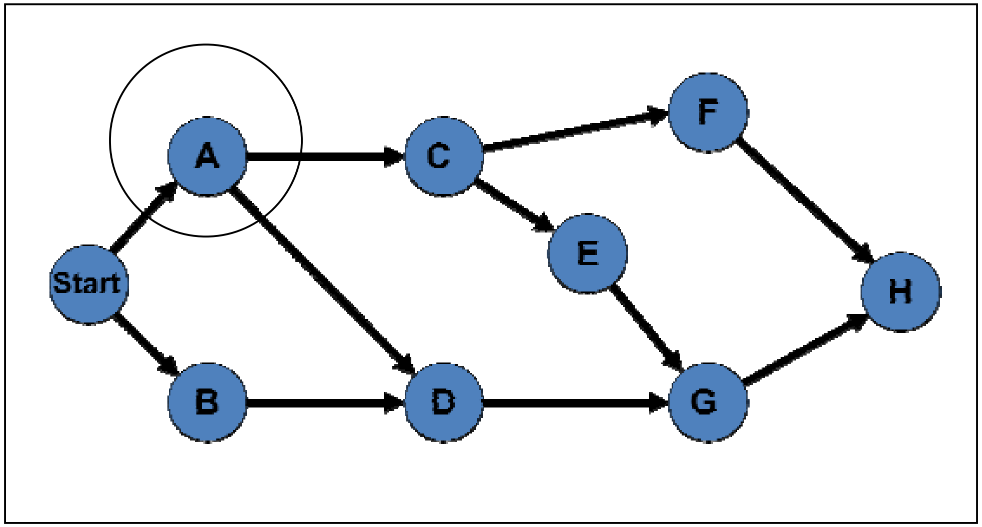
- **The earliest finish time (EF) of an activity is the sum of its earliest start time (ES) and its activity time**

EF = ES + Activity time

ES/EF Network for Paper Manufacture

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





ES/EF Network for Paper Manufacture

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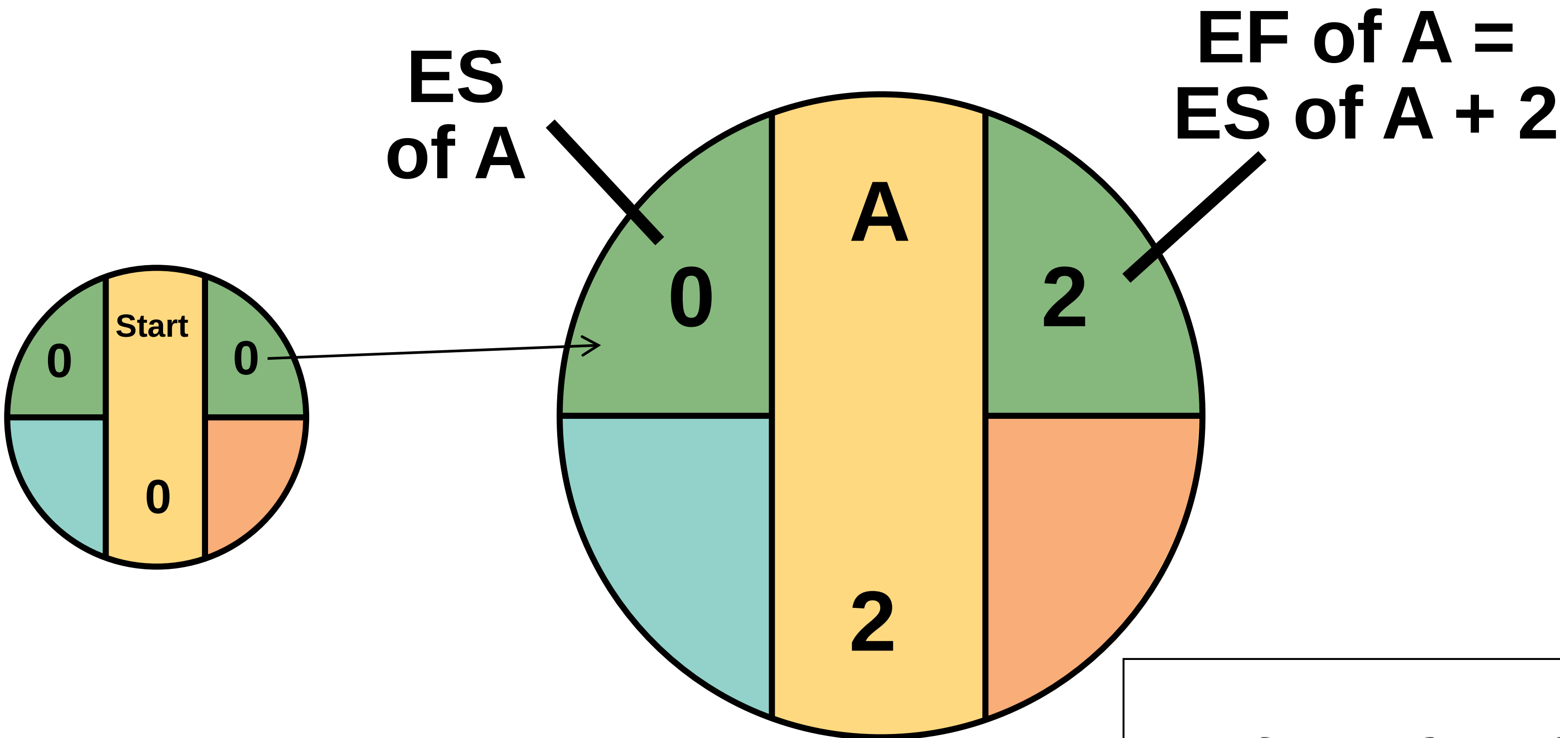

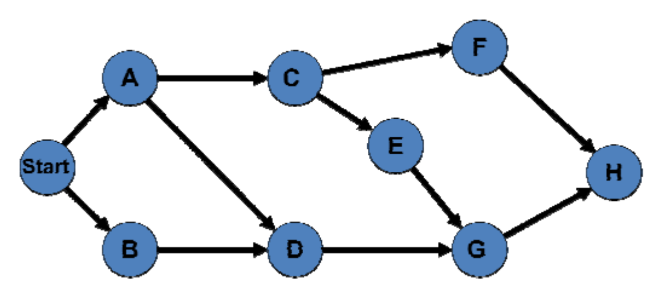

ES/EF Network for Paper Manufacture

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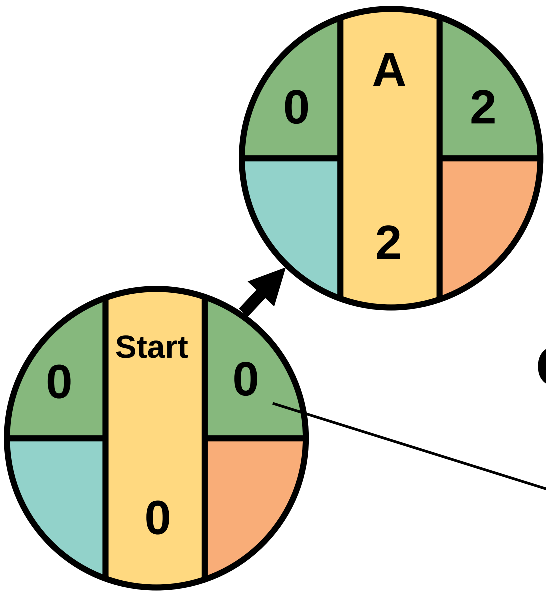

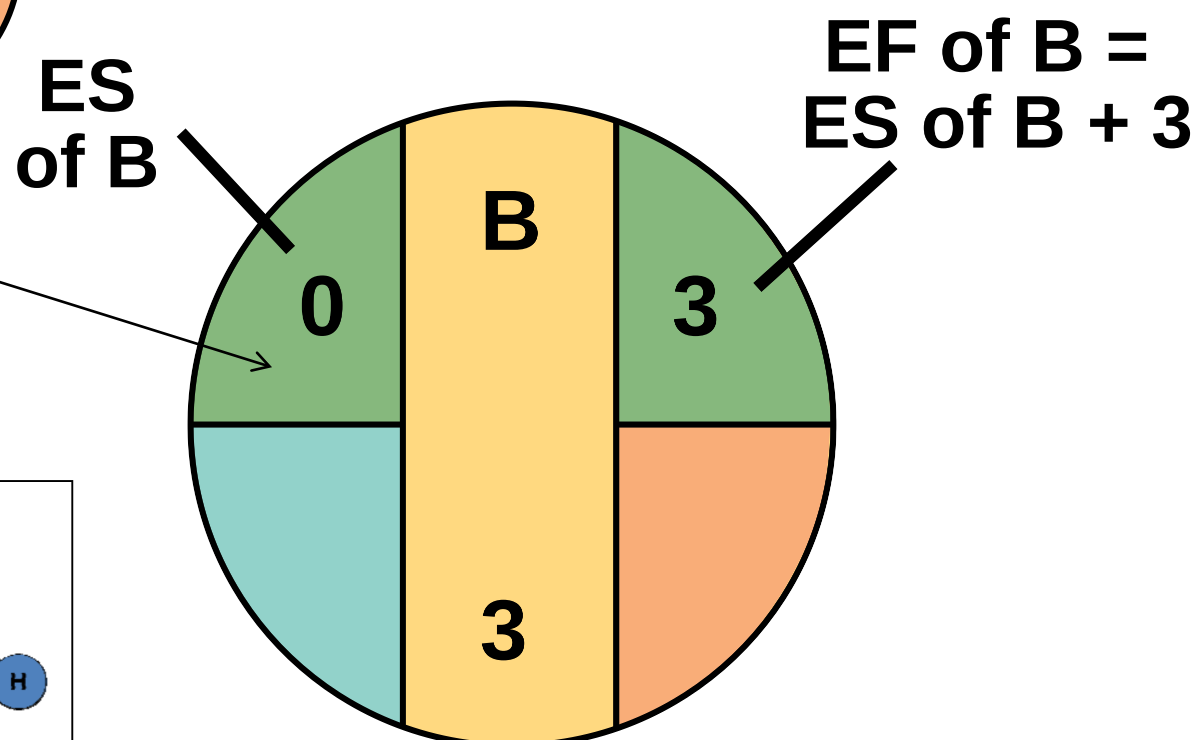

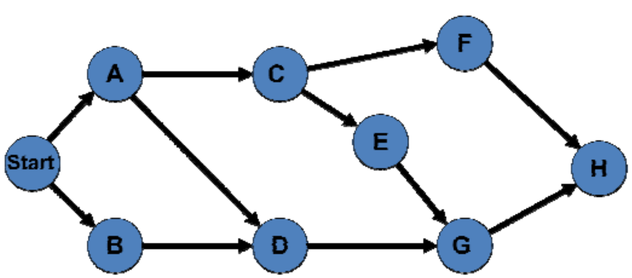

ES/EF Network for Paper Manufacture

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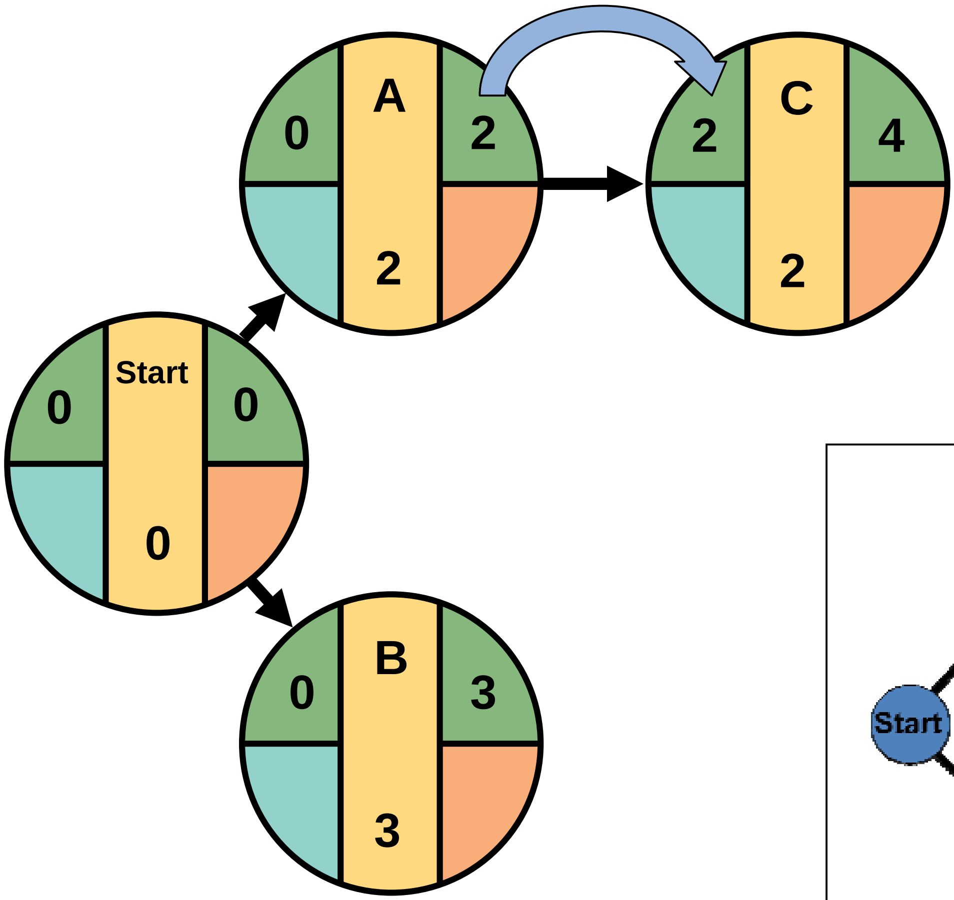

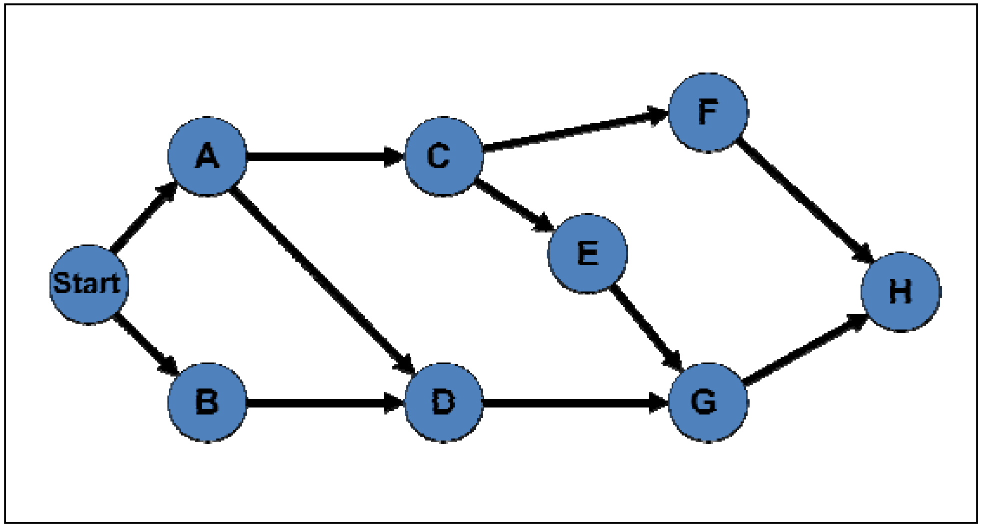

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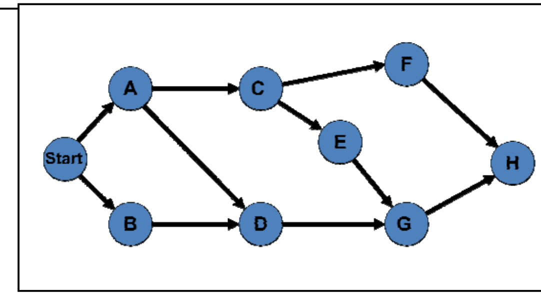
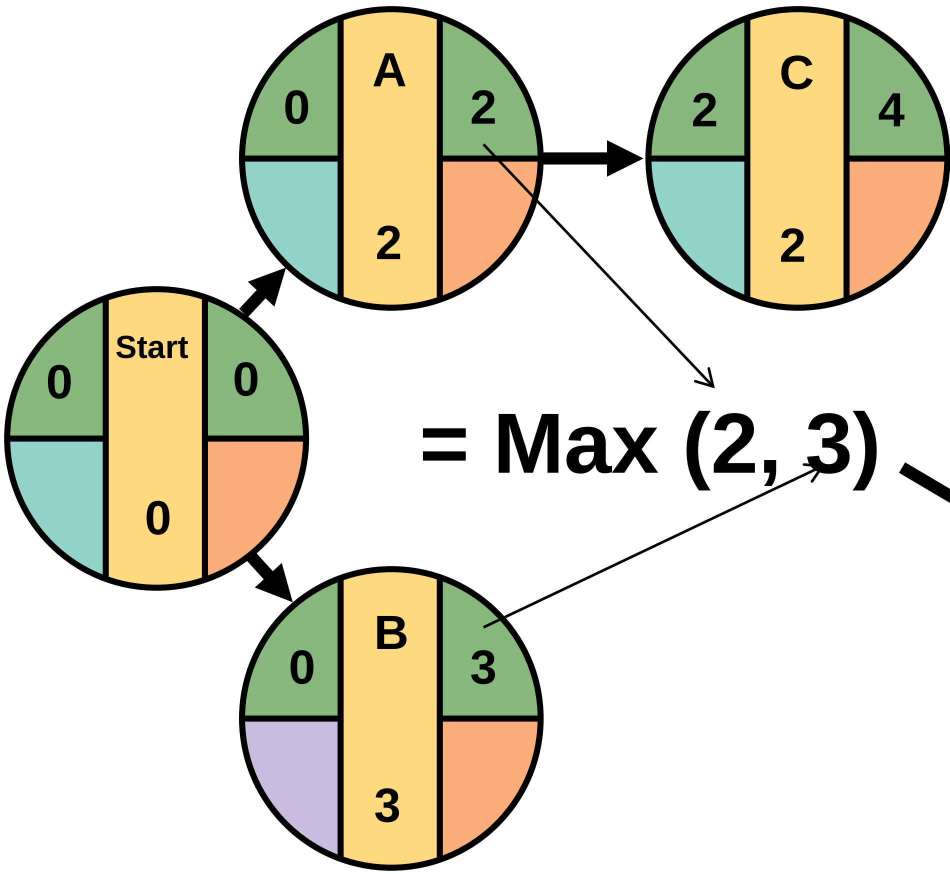
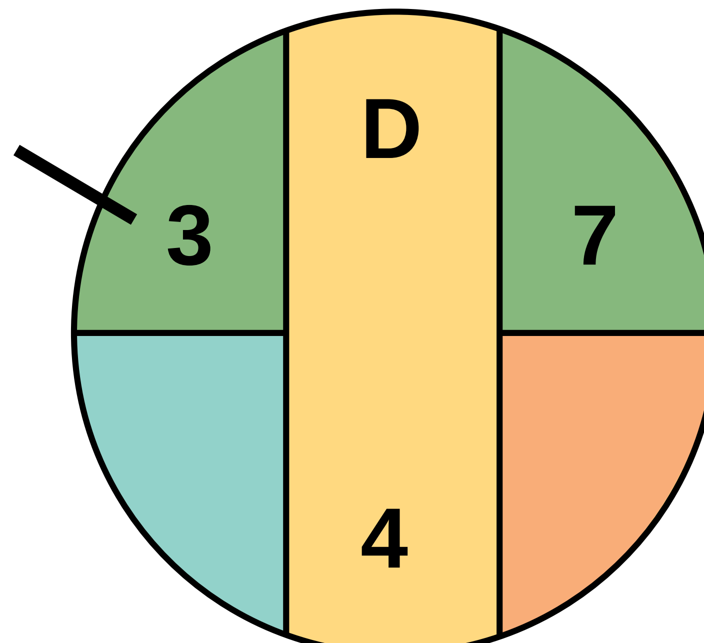
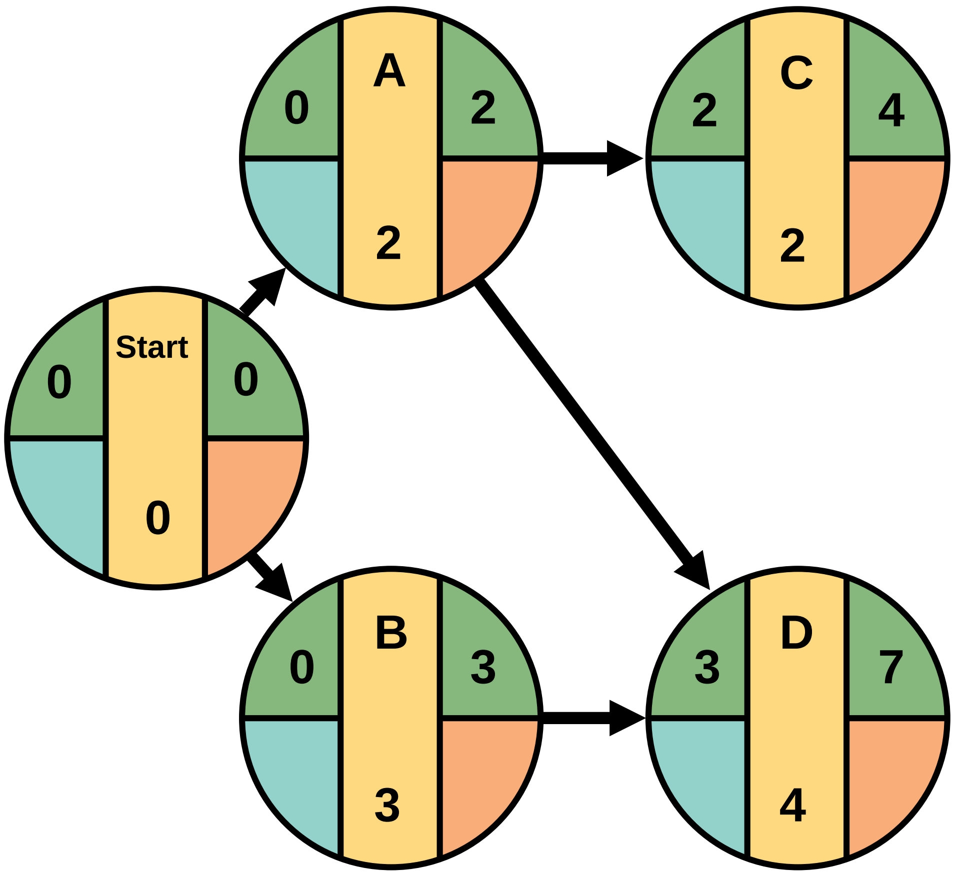




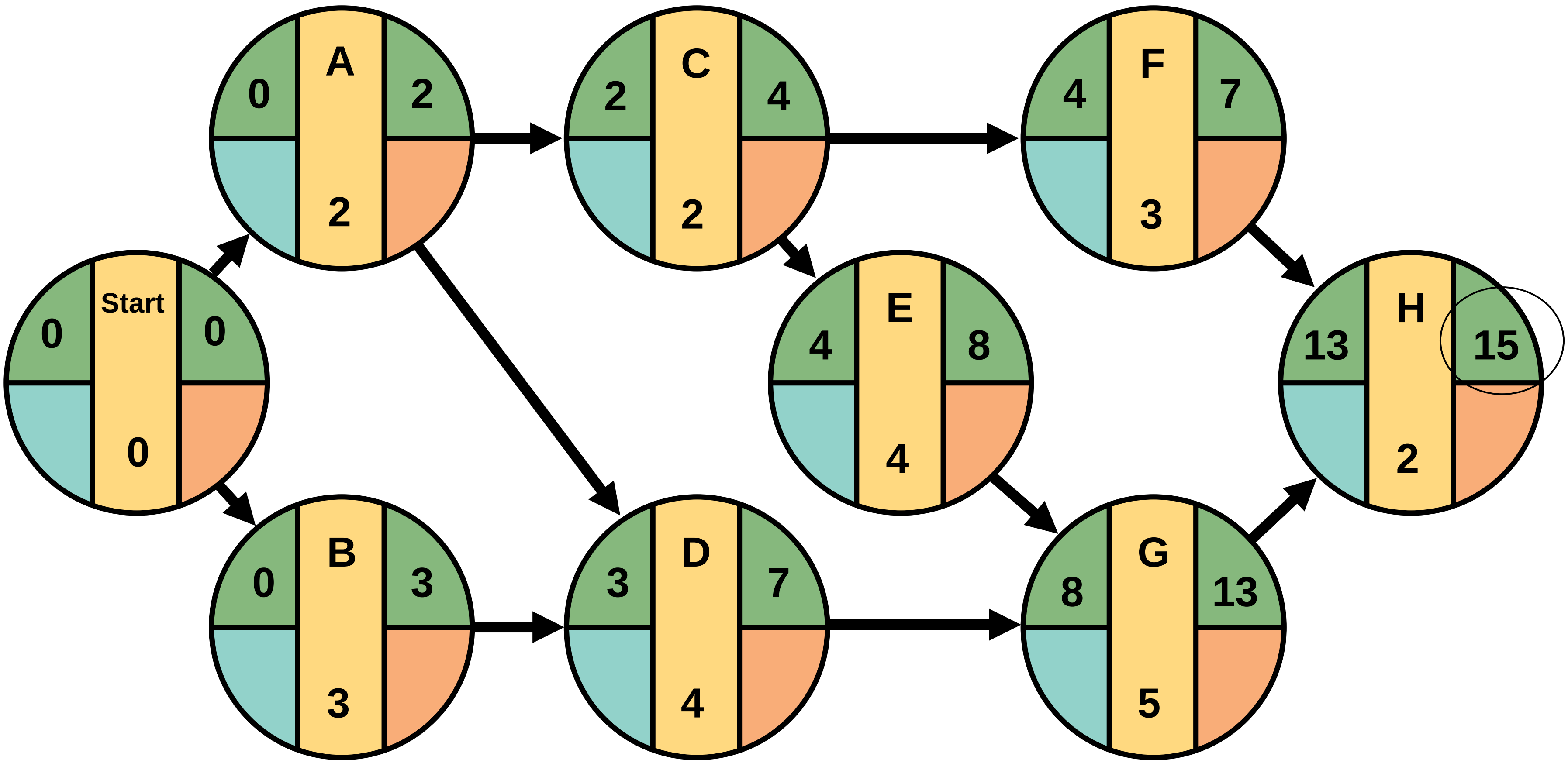


ES = Max {EF of all immediate predecessors}

ES/EF Network for Paper Manufacture



ES/EF Network for Paper Manufacture



End of Forward Pass

2. Backward Pass

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**

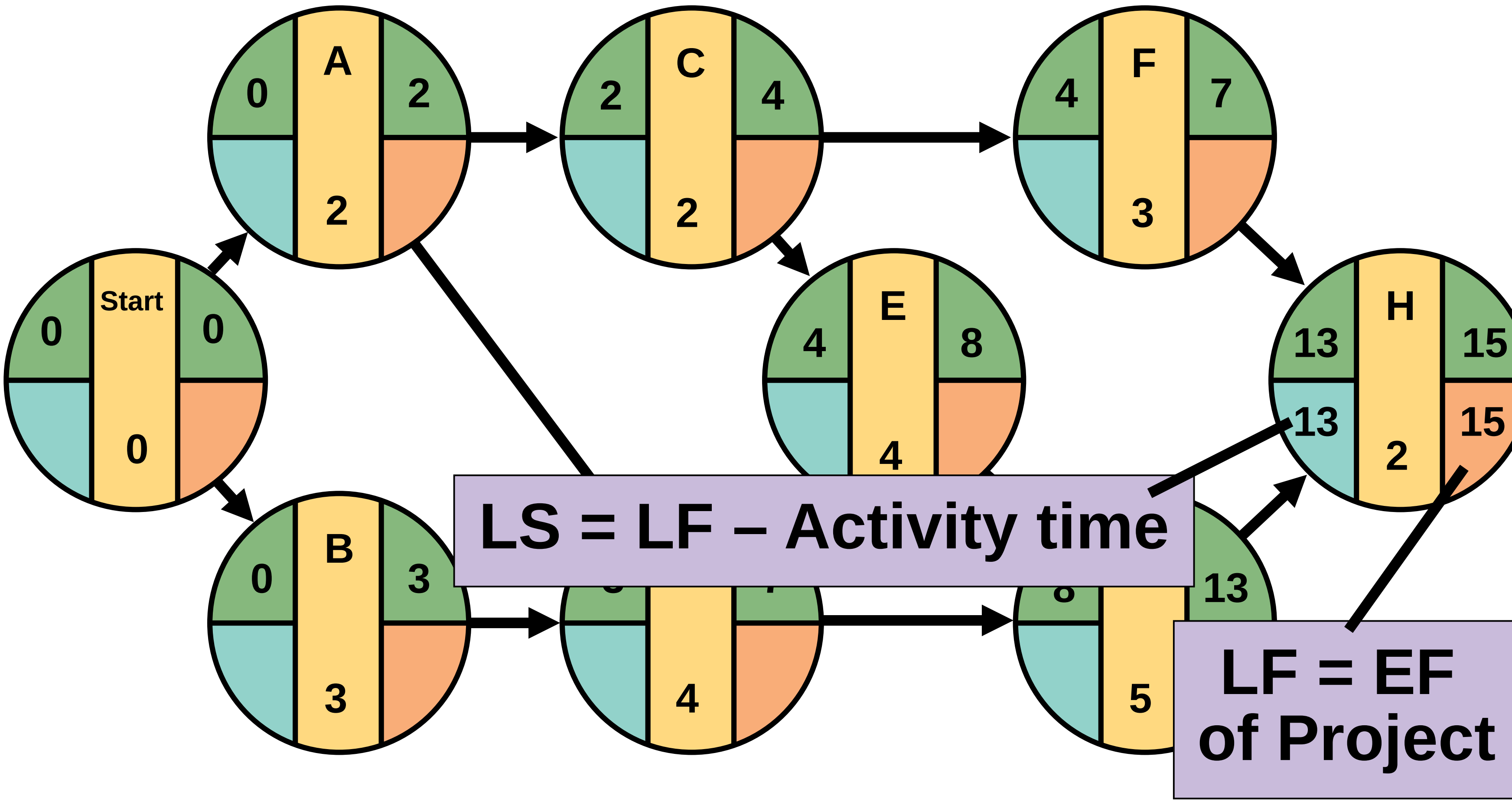
LF = Min {LS of all immediate following activities}

Latest Start Time Rule:

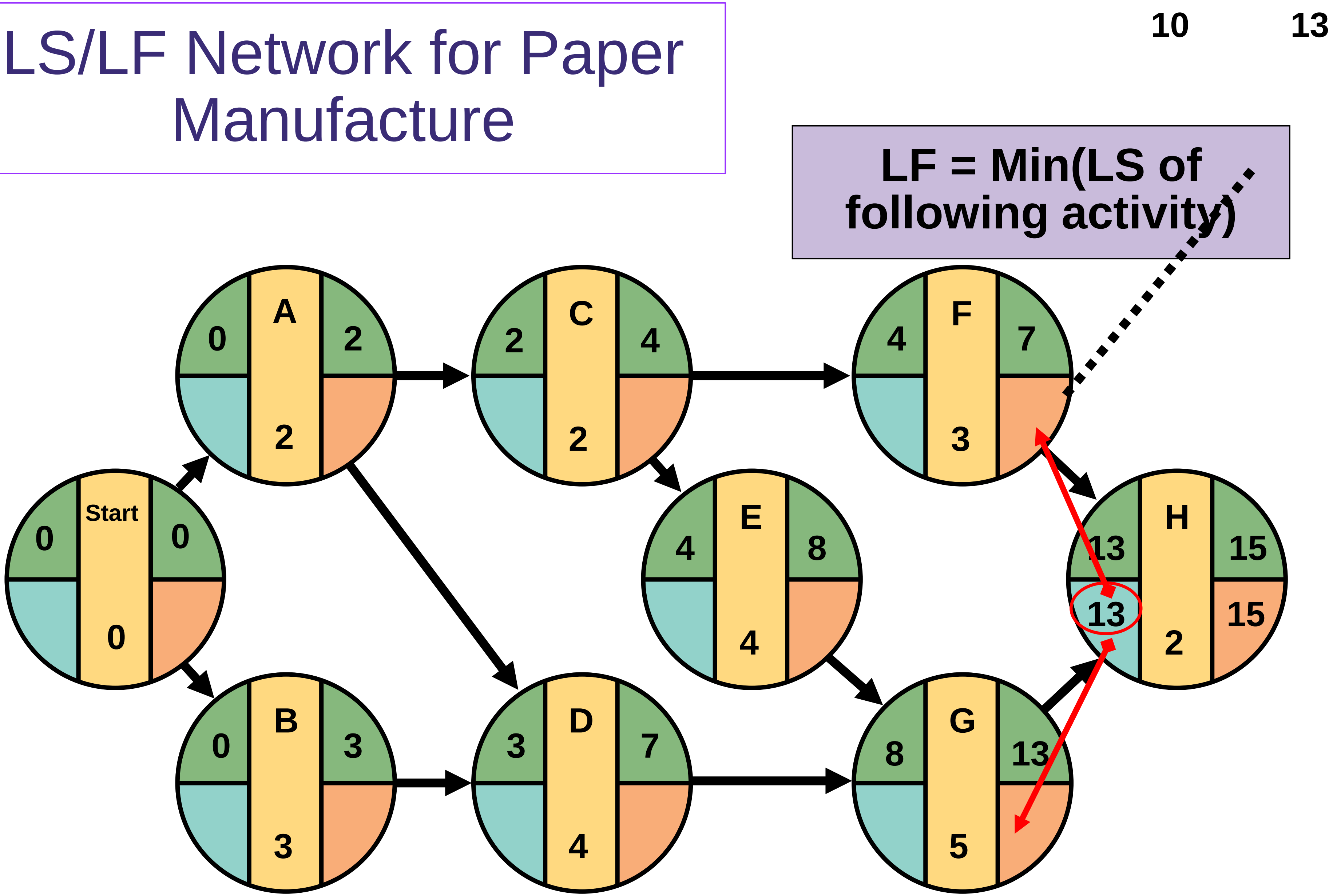
- **The latest start time (LS) of an activity is the difference of its latest finish time (LF) and its activity time**

LS = LF – Activity time

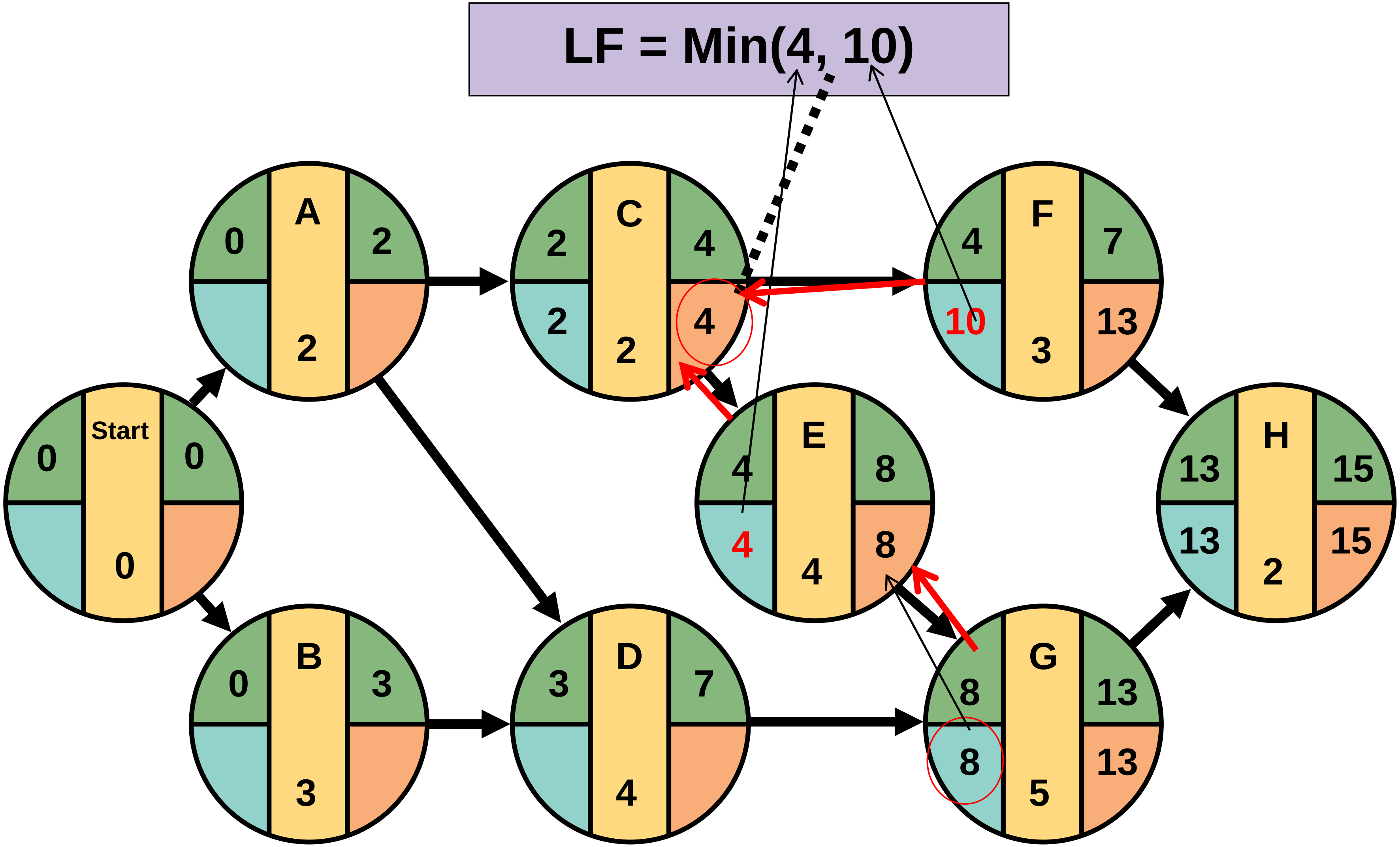
LS/LF Network for Paper Manufacture



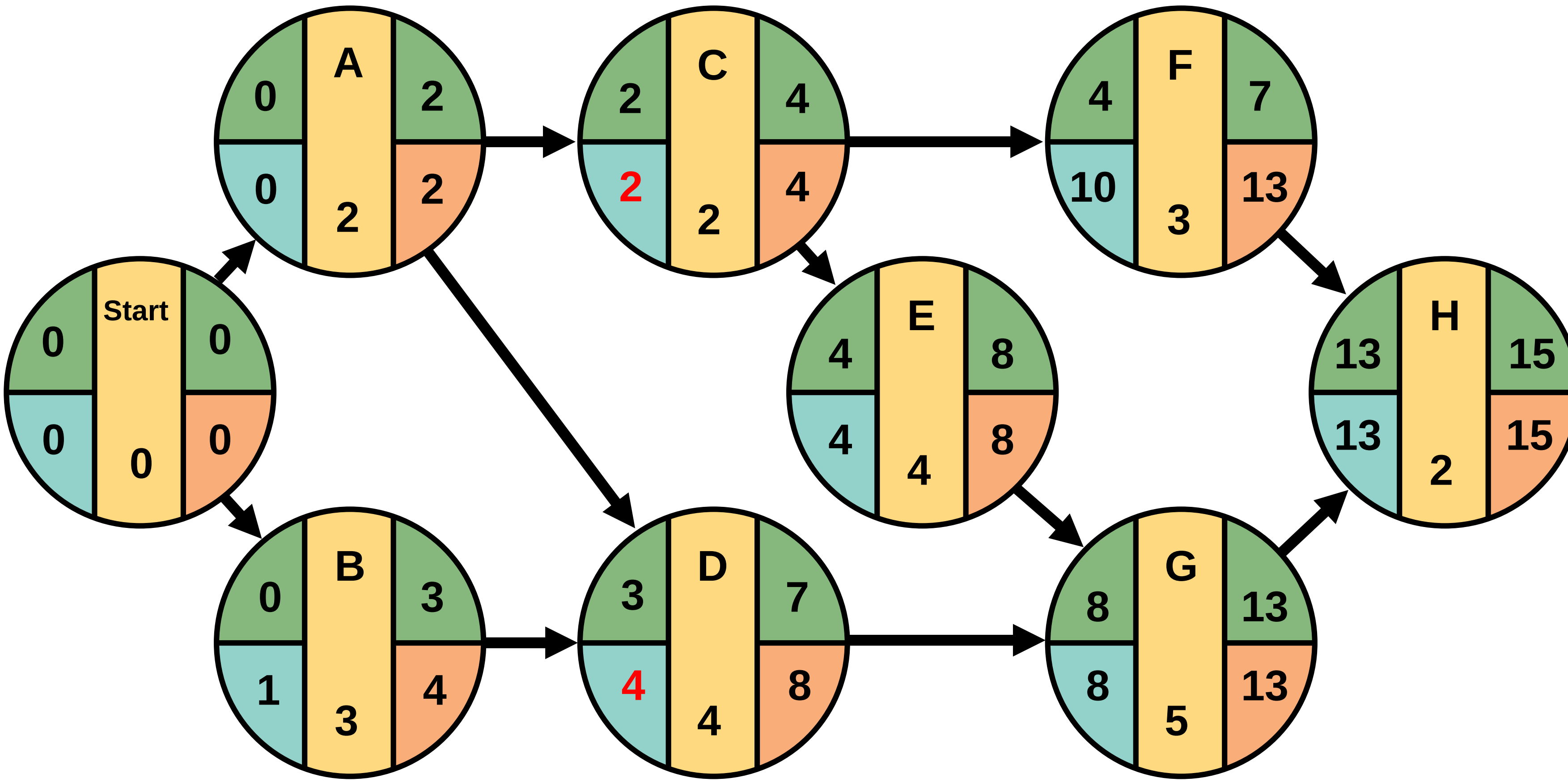
LS/LF Network for Paper Manufacture



LS/LF Network for Paper Manufacture



LS/LF Network for Paper Manufacture



3. Computing Slack Time

After computing the ES, EF, LS, and LF times for all activities, compute the slack or free time for each activity

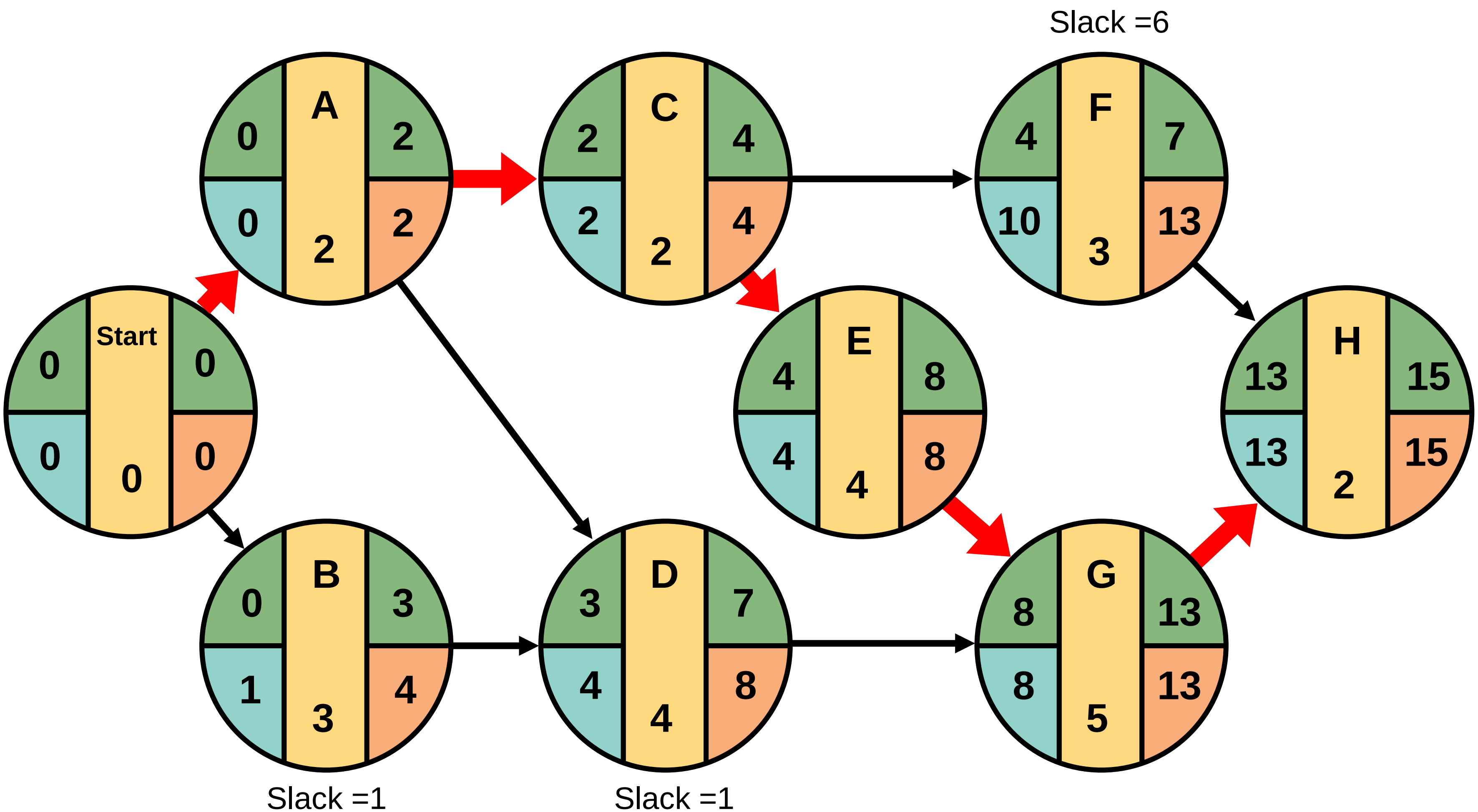
Slack is the length of time an activity can be delayed without delaying the entire project

Slack = LS – ES   or   Slack = LF – EF

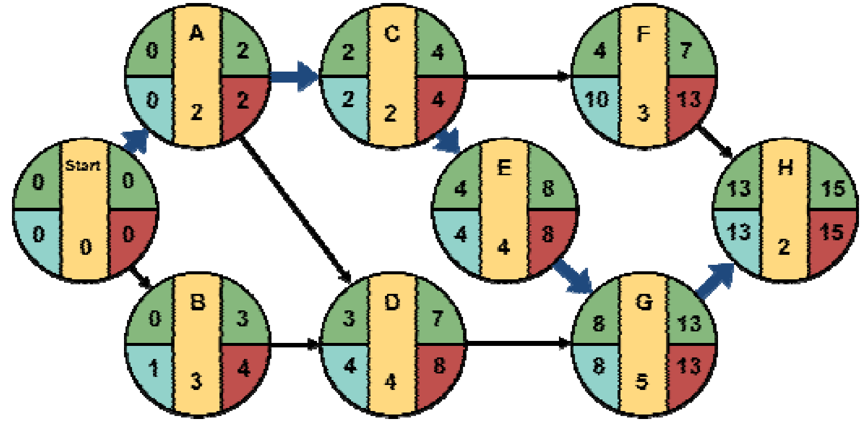
Computing Slack Time

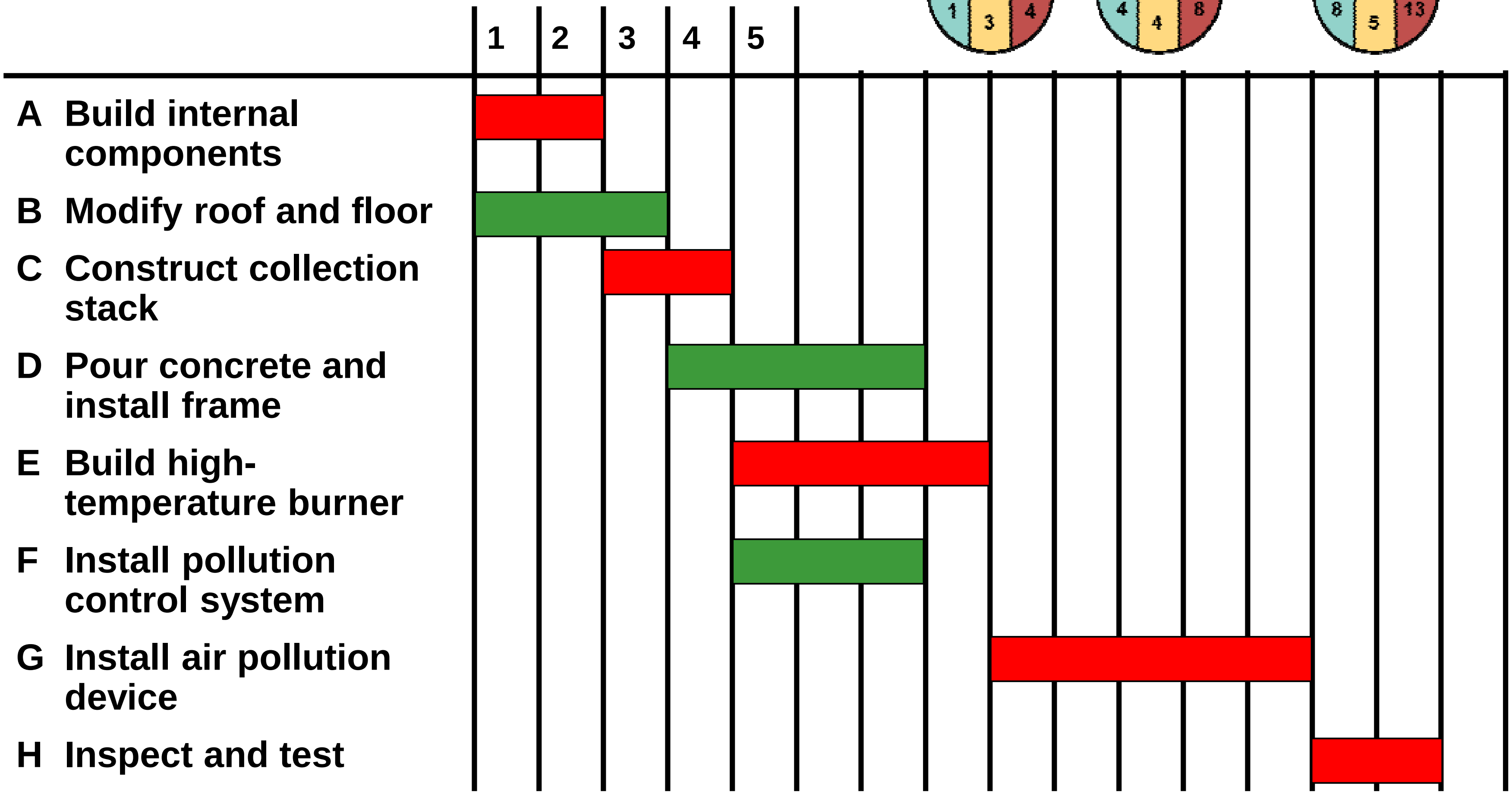
Activity	Earliest Start ES	Earliest Finish EF	Latest Start LS	Latest Finish LF	Slack LS – ES	On Critical Path
A	0	2	0	2	0	Yes
B	0	3	1	4	1	No
C	2	4	2	4	0	Yes
D	3	7	4	8	1	No
E	4	8	4	8	0	Yes
F	4	7	10	13	6	No
G	8	13	8	13	0	Yes
H	13	15	13	15	0	Yes

Critical Path for Paper Manufacture

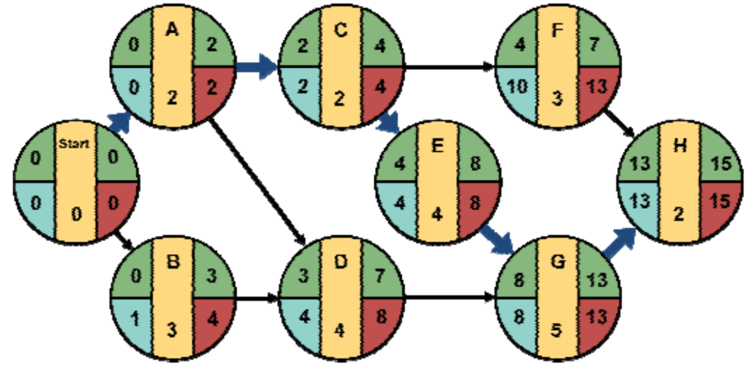


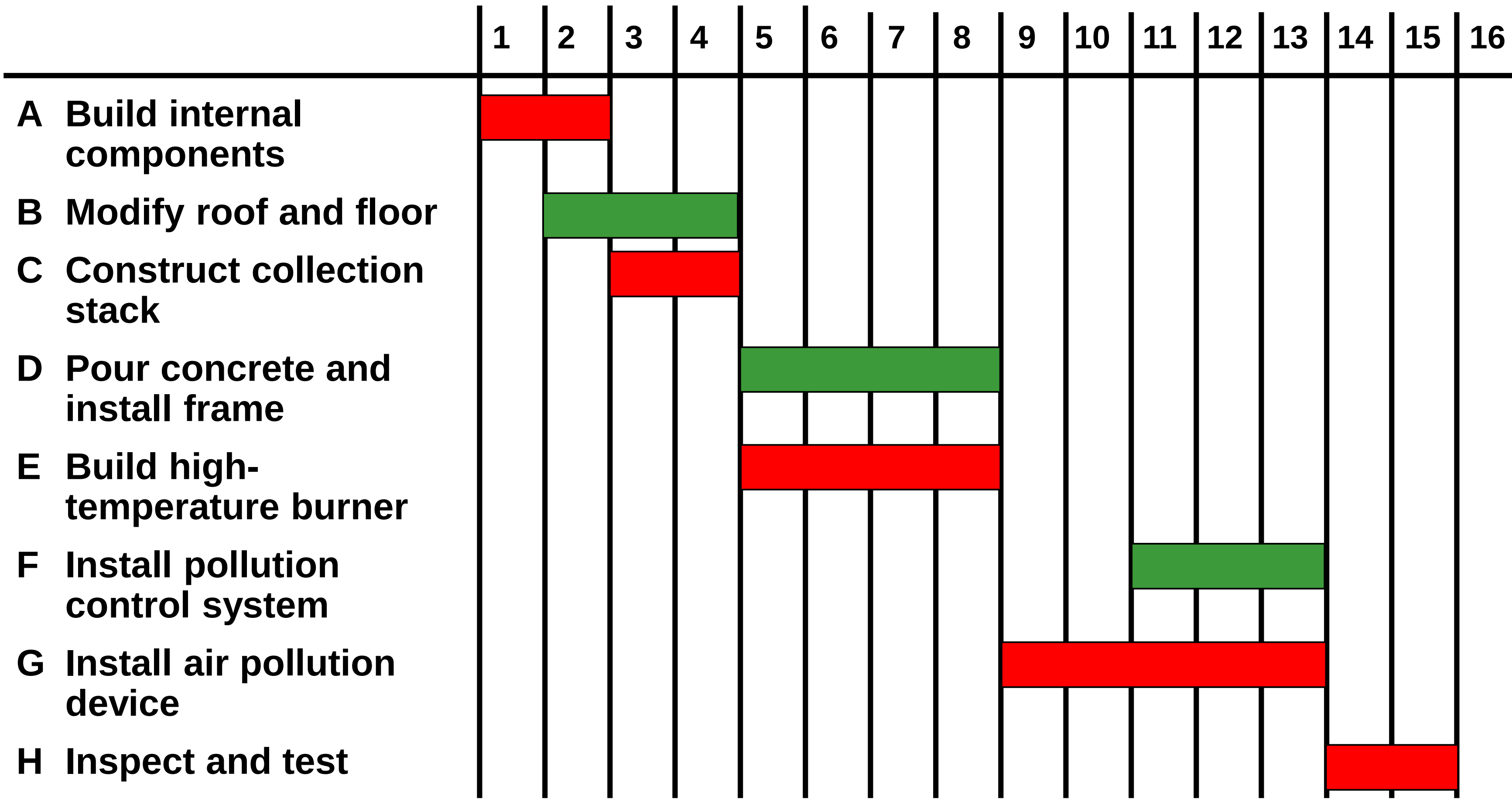
ES – EF Gantt Chart for Paper Manufacture





ES – EF Gantt Chart for Paper Manufacture





PERT next

Program Evaluation and Review Technique - PERT

Variability in Activity Times

- CPM assumes we know a fixed time estimate 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**

Estimate follows beta distribution

Expected (mean) time:

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

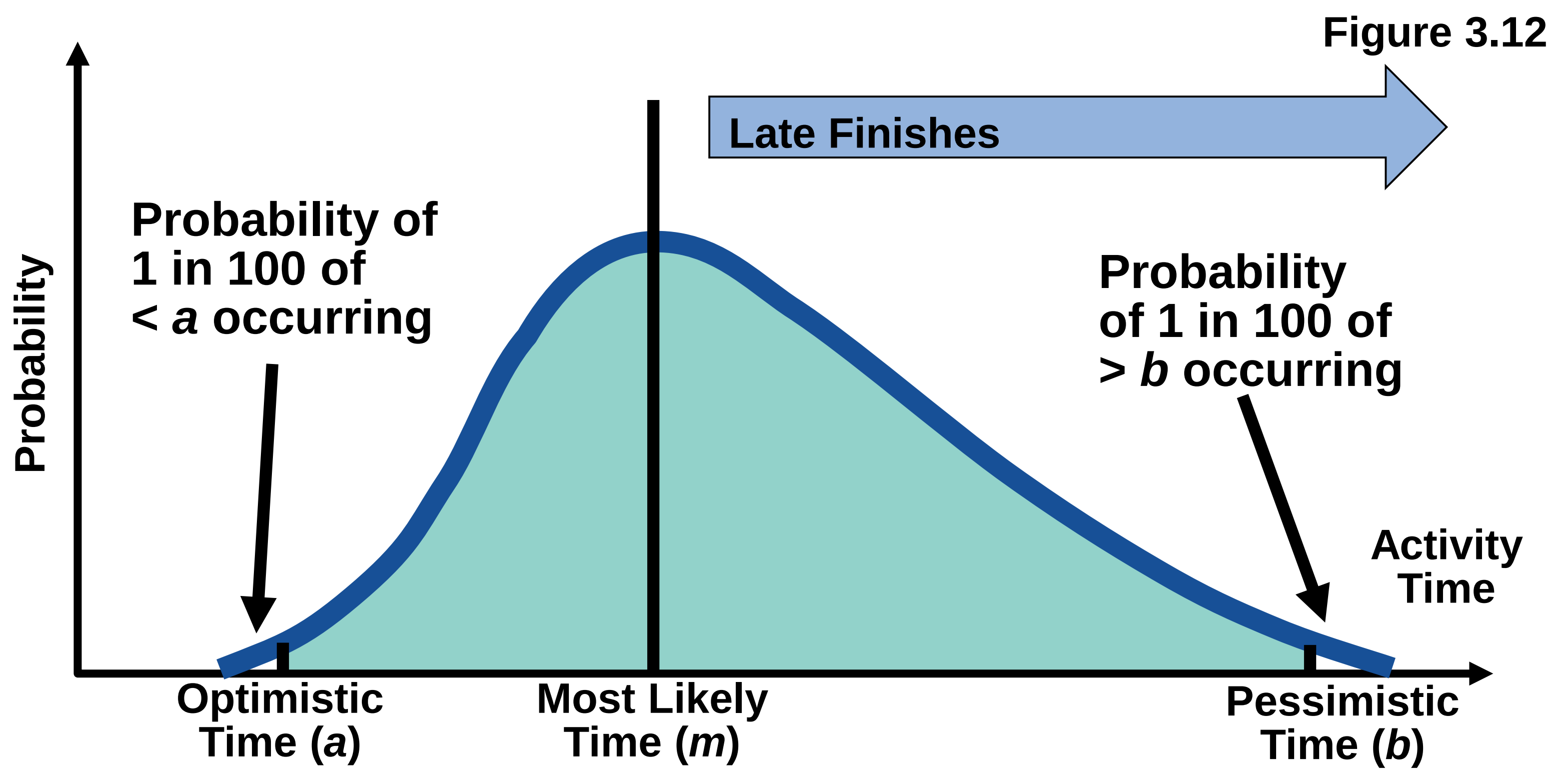
Variance of times:

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

Given to you in the exam

Variability in Activity Times

Estimate follows beta distribution



Computing Variance

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

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	.11
B	2	3	4	3	.11
C	1	2	3	2	.11
D	2	4	6	4	.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	.11

Probability of Project Completion

Project variance is computed by summing the ***variances of critical activities***

σ_p^2 = Project variance

= Σ(variances of activities on critical path)

Project variance

$$\sigma_p^2 = .11 + .11 + 1.00 + 1.78 + .11 = 3.11$$

Project standard deviation

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

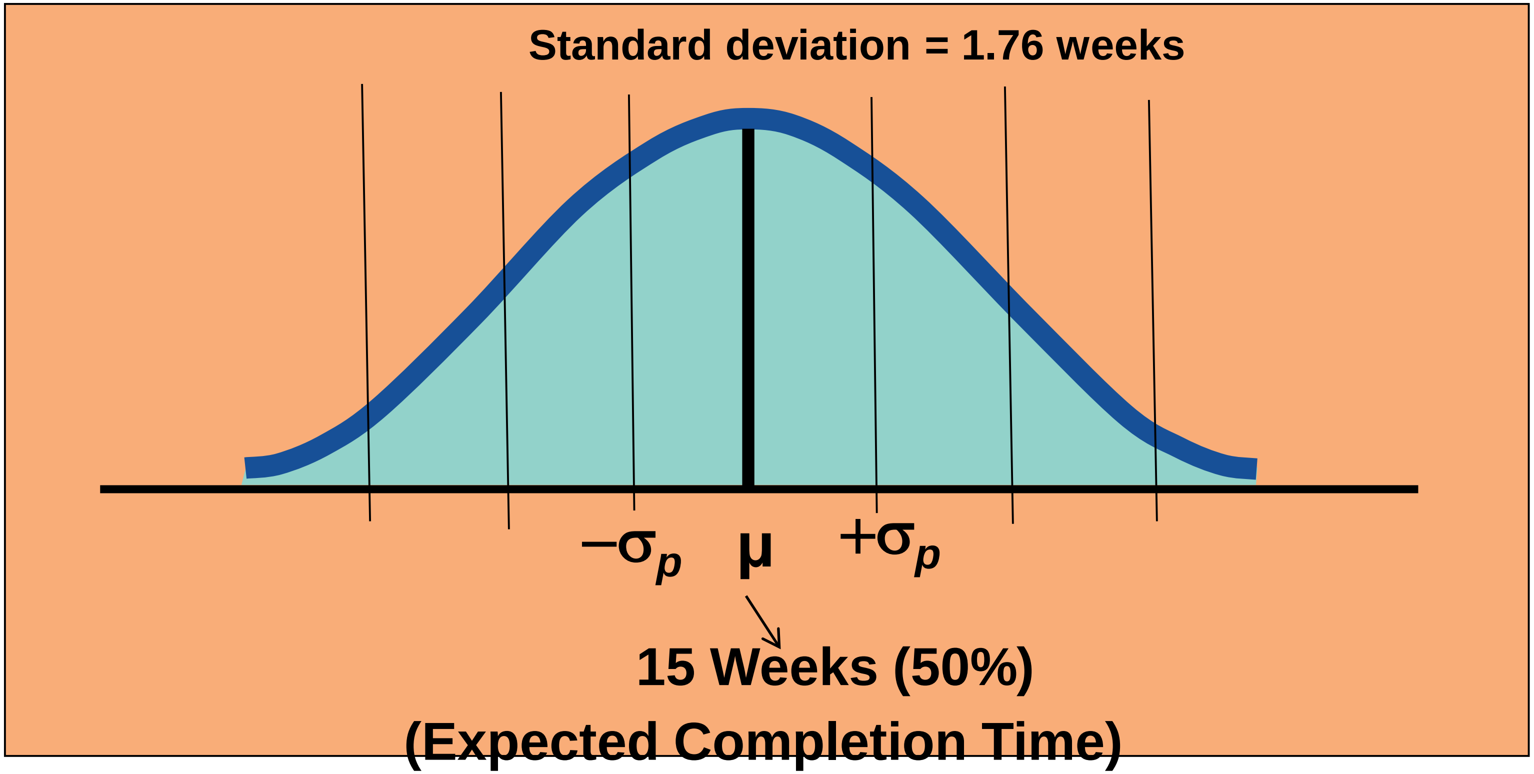
$$= \sqrt{3.11} = 1.76 \text{ weeks}$$

Using z-tables next

Probability of Project Completion

PERT makes two more assumptions:

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



Probability of Project Completion

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

P($T \leq$ 16 weeks)

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

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

$$= 0.57$$

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

Look up in z-Tables

P= 0.71566 or 71,6%

Probability of Project Completion

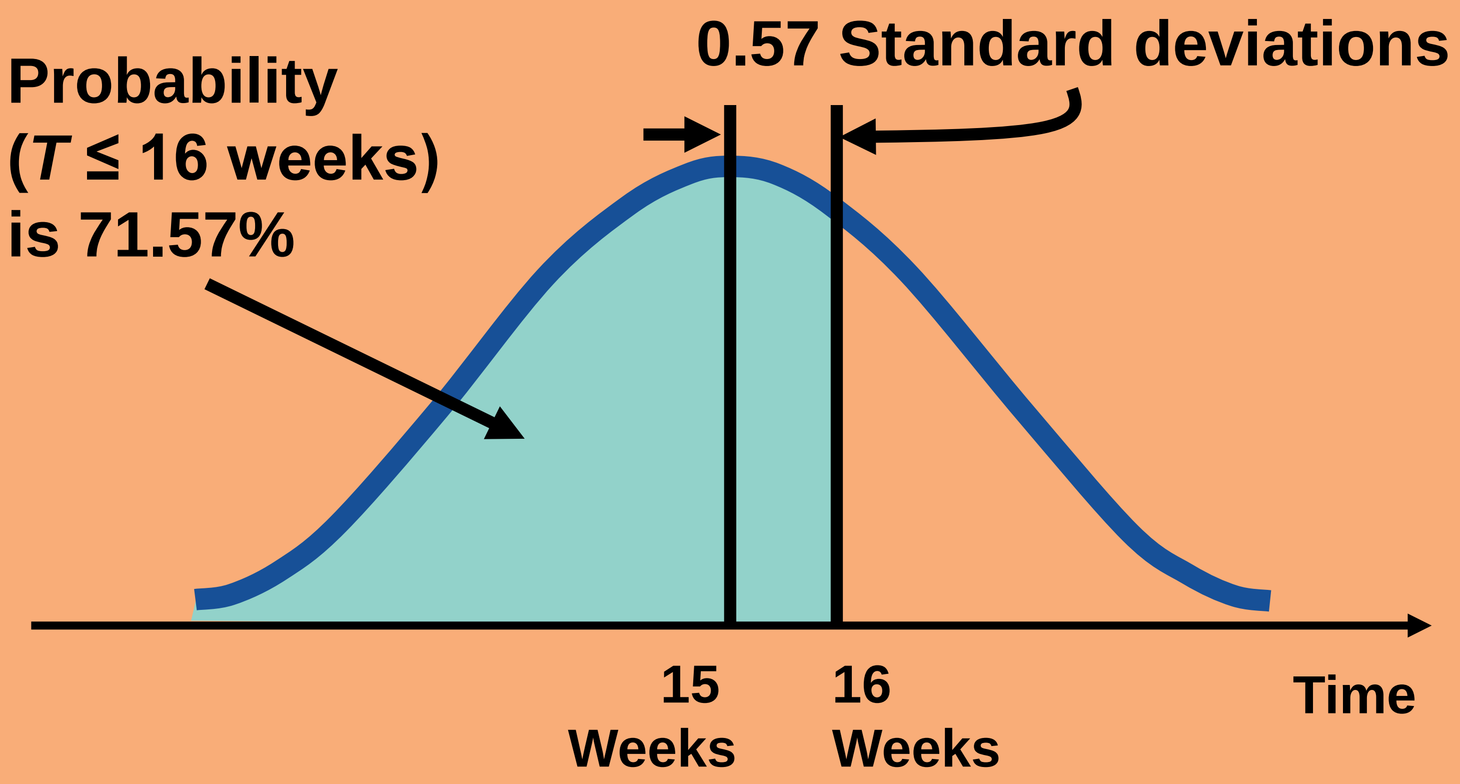


Figure 3.14

Determining Project Completion Time

99% confident of completion in this time

2.33 = (T-15)/ 1.76
T = 19.1weeks

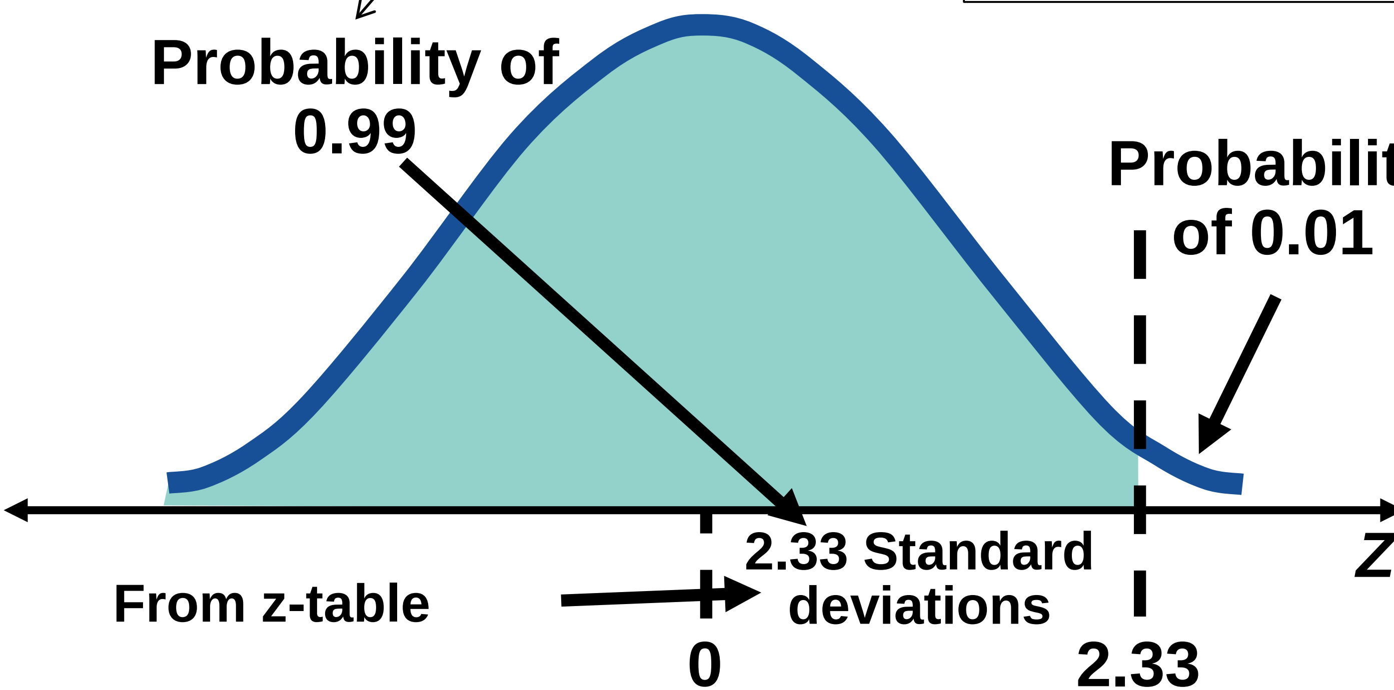


Figure 3.15

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

What Project Management Has Provided So Far

1. The project's expected completion time is 15 weeks
2. There is a 71.57% chance the equipment will be in place by the 16 week deadline
3. Five activities (A, C, E, G, and H) are on the critical path
4. Three activities (B, D, F) are not on the critical path and have slack time
5. A detailed schedule is available

PERT weightings in MSProject

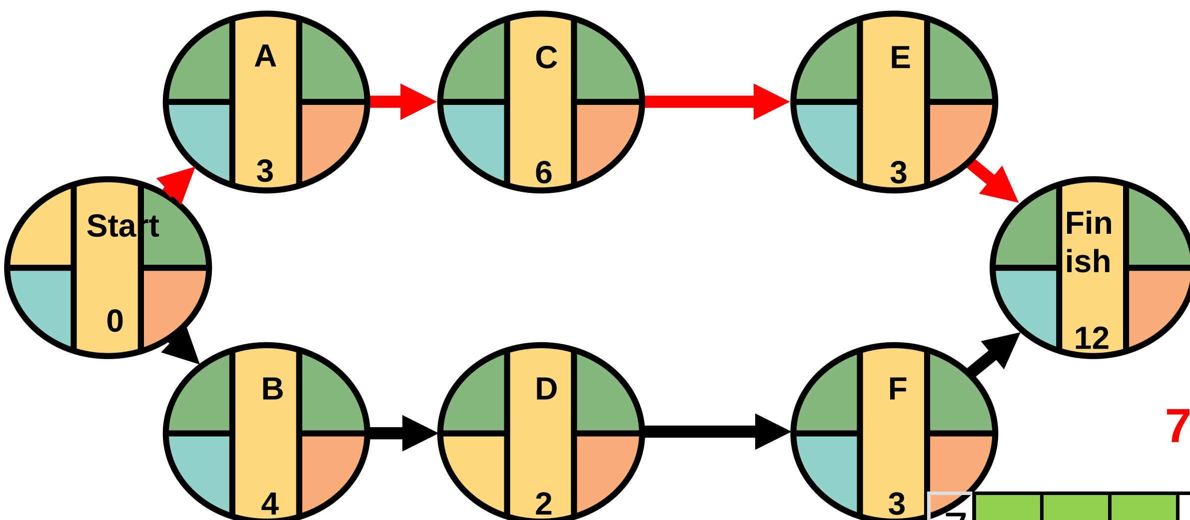
$t = (a + 4m + b)/6$

Add up to 6

ID		Task Name	Duration	Start	Finish	Predecessors	Optimistic Duration	Most Likely Duration	Pessimistic Duration	Optimistic Weight	Most Likely Weight	Pessimistic Weight	PERT State
1		**Christmas Carol TV Movie**	**0 days**	**Tue 13/08/20**	**Tue 13/08/20**		**0 days**	**0 days**	**0 days**	**1**	**3**	**2**	**Duration Calc'd: 2014/05/26 04:40:50 PM**
3		**Film**	**0 days**	**Tue 13/08/27**	**Tue 13/08/27**		**0 days**	**0 days**	**0 days**	**0**	**0**	**0**	**Duration Calc'd: 2014/05/26 04:40:50 PM**
4		**Develop Screenplay**	**0 days**	**Tue 13/08/27**	**Tue 13/08/27**		**0 days**	**0 days**	**0 days**	**0**	**0**	**0**	**Duration Calc'd: 2014/05/26 04:40:50 PM**
5		Drafts and Revisions	4.17 wks	Tue 13/08/27	Tue 13/09/24	2	3 wks	4 wks	5 wks	0	0	0	Duration Calc'd: 2014/05/26 04:40:50 PM
26		**Shooting of Scenes**	**0 days**	**Wed 13/09/11**	**Wed 13/09/11**		**0 days**	**0 days**	**0 days**	**0**	**0**	**0**	**Duration Calc'd: 2014/05/26 04:40:50 PM**
27		Interior scenes (Studio)	4.17 wks	Wed 13/09/11	Wed 13/10/09	15,24	3 wks	4 wks	5 wks	0	0	0	Duration Calc'd: 2014/05/26 04:40:50 PM
30		Editing	1.58 wks	Fri 13/11/29	Tue 13/12/10	29	1 wk	1.5 wks	2 wks	0	0	0	Duration Calc'd: 2014/05/26 04:40:50 PM
34		**Promotions**	**0 days**	**Fri 13/11/22**	**Fri 13/11/22**		**0 days**	**0 days**	**0 days**	**0**	**0**	**0**	**Duration Calc'd: 2014/05/26 04:40:50 PM**
35		**Commercials**	**0 days**	**Fri 13/11/29**	**Fri 13/11/29**		**0 days**	**0 days**	**0 days**	**0**	**0**	**0**	**Duration Calc'd: 2014/05/26 04:40:50 PM**
36		Produce 60 second slot	0.93 wks	Fri 13/11/29	Thu 13/12/05	29	3 days	5 days	1 wk	0	0	0	Duration Calc'd: 2014/05/26 04:40:50 PM
37		Produce 30 second slot	0.93 wks	Fri 13/11/29	Thu 13/12/05	29	3 days	5 days	1 wk	0	0	0	Duration Calc'd: 2014/05/26 04:40:50 PM

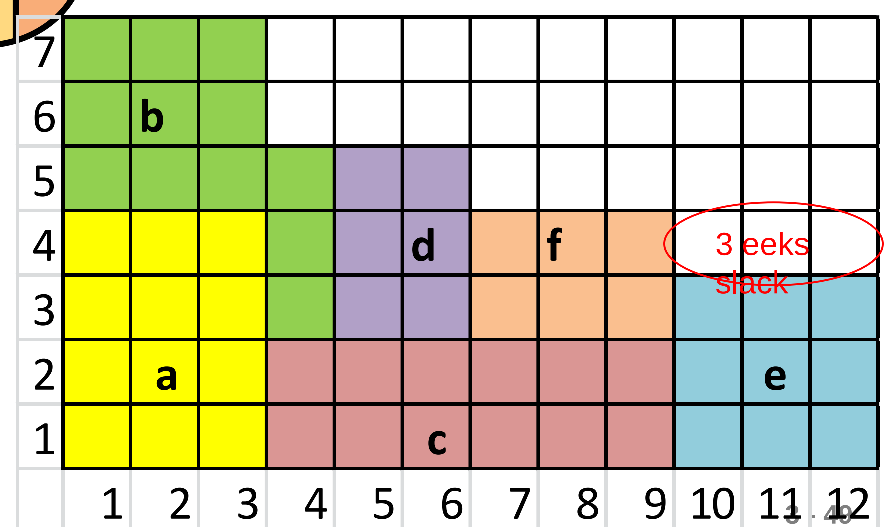
Resource Constraints

Figure 16.22 Resource profile of a network assuming that all activities are started as soon as possible

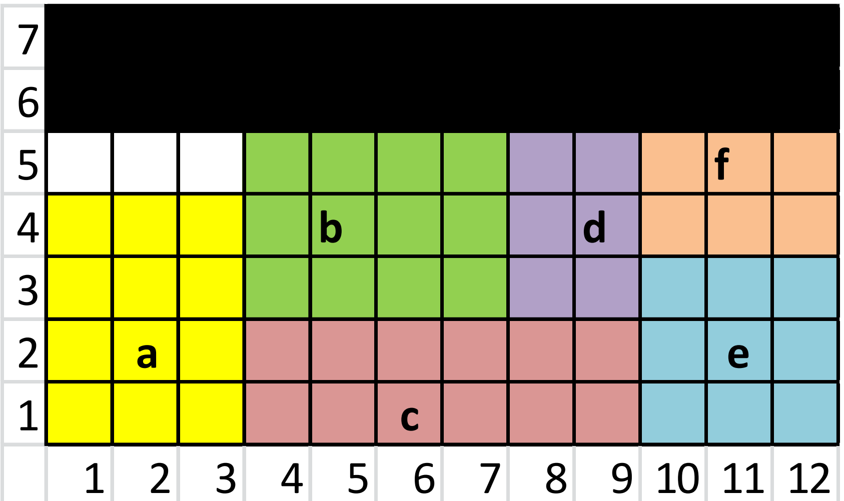


Activity	Duration (days)	Resources (staff)
a	3	4
b	4	3
c	6	2
d	2	3
e	3	3
f	3	2

7 staff available



The main idea of resource leveling is to **improve work efficiency and minimize cost** during the life of the project



Staff levelling for organisational convenience or due to **restriction of only 5 staff** available

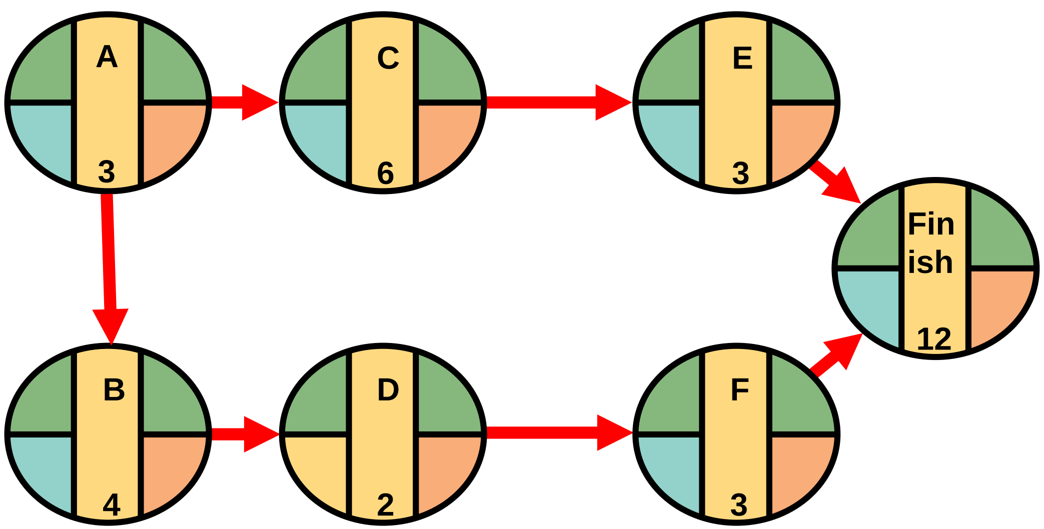


Figure 16.23 Resource profile of a network with non-critical activities delayed to fit resource constraints; in this case this **effectively changes the network logic to make all activities critical**

Availability of resources -> constraints => relationship between activities

https://www.pmi.org/learning/library/scheduling-resource-leveling-project-progression-8006

Fast tracking and Crashing

Why?

- your project is late, and you are running around to bring your project back on track. A delay in the project may happen due to many reasons, including:
  - – An unrealistic schedule
  - – You did not get the promised resources
  - – An unforeseen incident occurred
  - – Due to force majeure.

- **you intentionally want to shorten the duration of the project, although your project is on track**
  – The client wants to complete the project early.
  – You see an opportunity to get another project if you are able complete the project early.
  – Your competitor is about to launch a new product; therefore you have to hasten the launch your product.

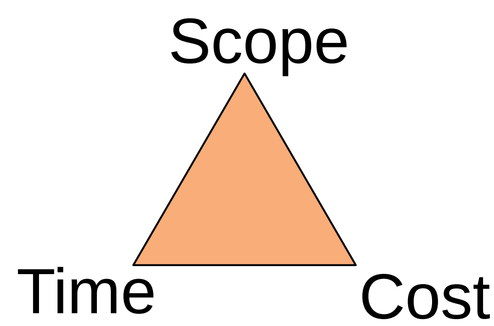
In project management you can use two techniques, i.e. **fast tracking, and crashing**, to shorten the schedule when no change in scope is required

Fast-Tracking

- **you review the critical path to find out which sequential activities can be performed parallel or partially parallel to each other.**
  - **sequential activities can be fast-tracked by 33%. This means if the previous activity is 66% completed, you can start next activity. Here, both activities will be overlapped partially. Although it will increase the risk, the level of risk impact should be within acceptable limits.**
  - **you should check other paths whose durations are near the critical path duration**

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**

Crashing networks

Crashing networks is the process of reducing time spans on critical path activities so that the project is completed in less time. Usually, crashing activities incurs extra cost. This can be as a result of:

- **overtime working;**
- **additional resources, such as manpower;**
- **subcontracting.**

Steps in Project Crashing

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

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

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

Rands/week

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
   (b) has the smallest crash cost per period.

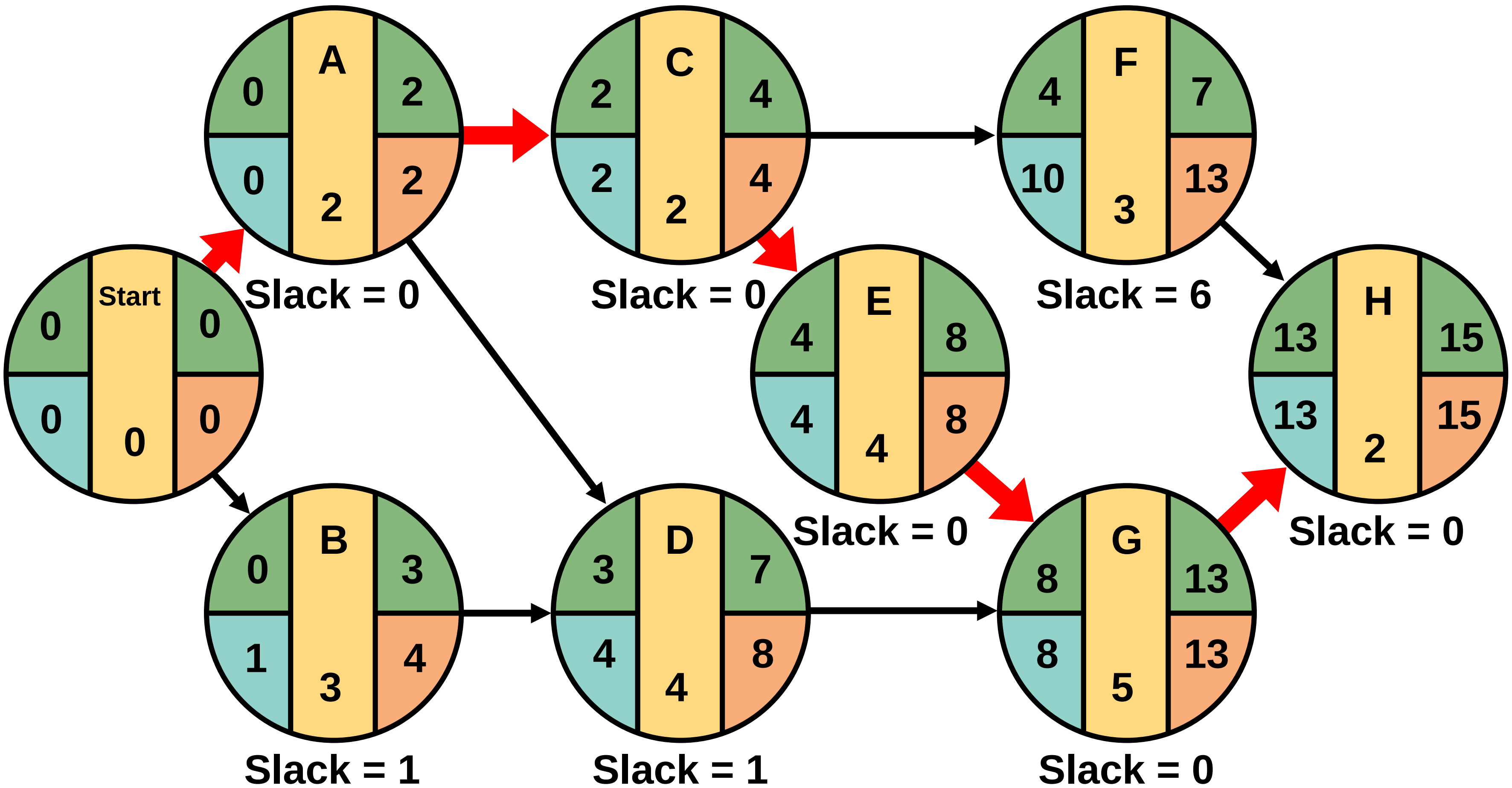
   If there is more than one critical path, then select one activity from each critical path such that
   (a) each selected activity can still be crashed
   (b) total crash cost of all selected activities is the smallest.

Note that the same activity may be common to more than one critical path.

Steps in Project Crashing

4. Update all activity times. If the desired due date has been reached, stop. If not, return to Step 2.

Critical Path and Slack Times

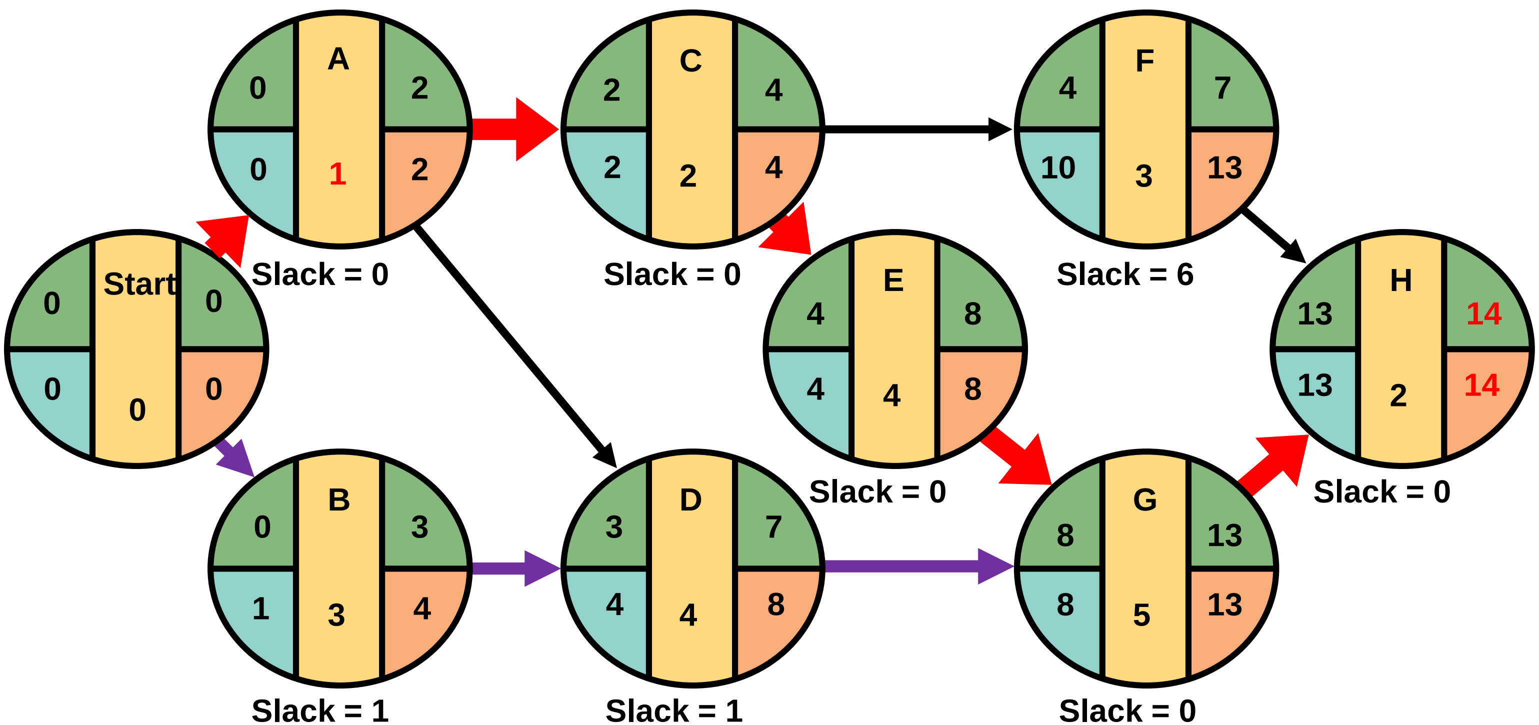


Crashing The Project

Suppose that the project must be completed in **14 weeks**. Given the information in the table below, determine which activity(ies) should be crashed and what additional cost this will add to be the project. Show all calculations and explain your answers.

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

- The current critical path (using normal times) is Start-A-C-E-G-H, in which Start is just a dummy, starting activity.
- Of these critical activities, activity A has the lowest crash cost per week of $750, therefore crash activity A by 1 week to reduce the project completion time to 14 weeks
- The cost is an additional $750. Note that activity A cannot be crashed any further, since it has reached its crash limit of 1 week.
- At this stage, the original path **Start-A-C-E-G-H** remains critical with a completion time of 14 weeks.
- However, a new path **Start-B-D-G-H** is also critical now, with a completion time of 14 weeks.



Suppose that the project must be completed in **13 weeks**. Given the information in the table below, determine which activity(ies) should be crashed and what additional cost this will add to be the project. Show all calculations and explain your answers.

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

- **Further crashing must be done to both critical paths.**
- ***On each of these critical paths, identify one activity that can still be crashed - want the total cost of crashing an activity on each path to be the smallest.***
- **Can pick the activities with the smallest crash cost per period in each path - > select activity C from the first path and activity D from the second path. The total crash cost would then be $2000 (= $1000 + $1000).**
- **But activity G is common to both paths -> by crashing activity G, we will simultaneously reduce the completion time of both paths.**
- **Even though the $1500 crash cost for activity G is higher than that for each of activities C and D.**
- **By crashing G, the total cost will now be only $1500 (compared with the $2000 if crash C and D).**
- **To crash the project down to 13 weeks from 15 weeks->**
  - **should crash activity A by 1 week, and**
  - **activity G by 1 week.**
  - **Total crash cost = $2250**
- **This is important because many contracts for projects include bonuses for early finishes and penalties for late finishes**

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

Advantages of PERT/CPM

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

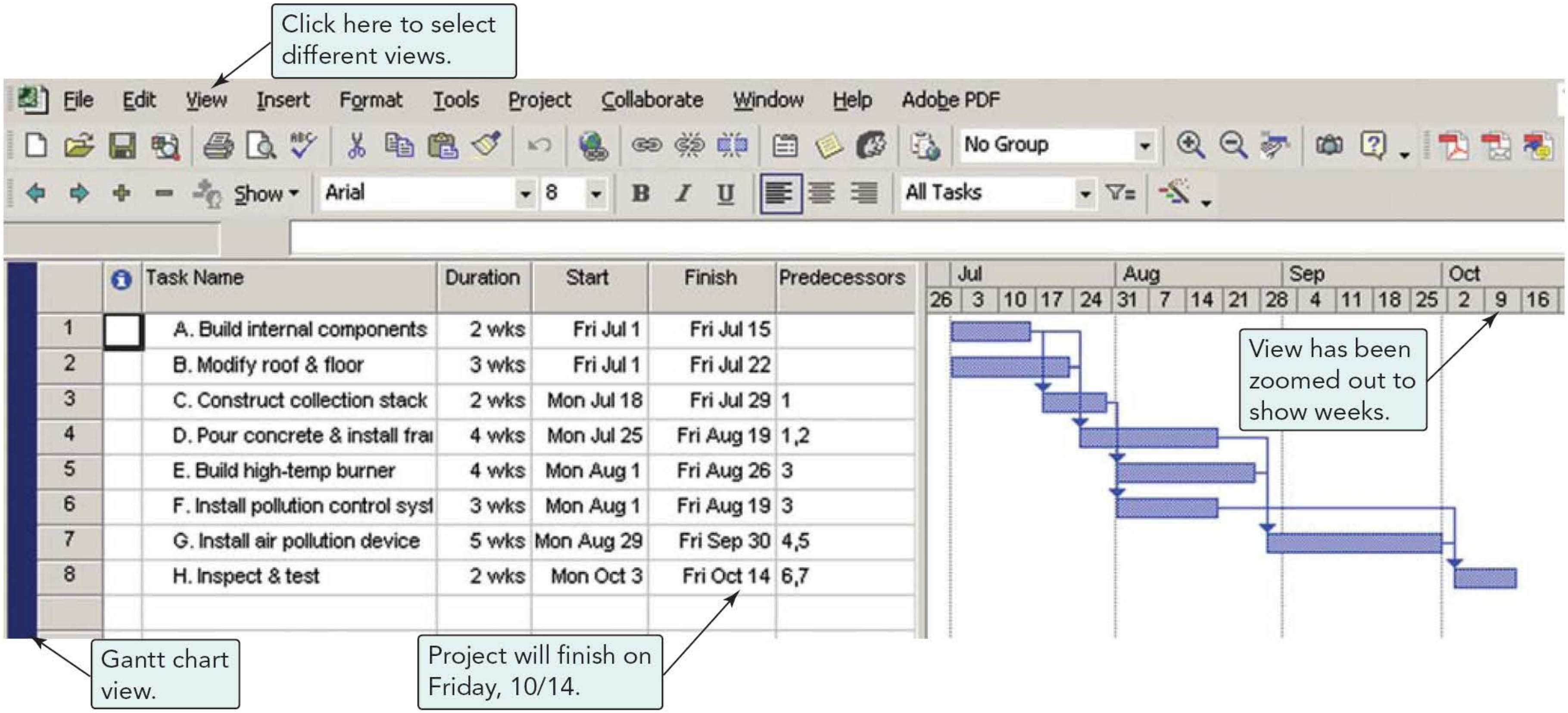
Limitations of PERT/CPM

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**
4. **There is an inherent danger of too much emphasis being placed on the longest, or critical, path**

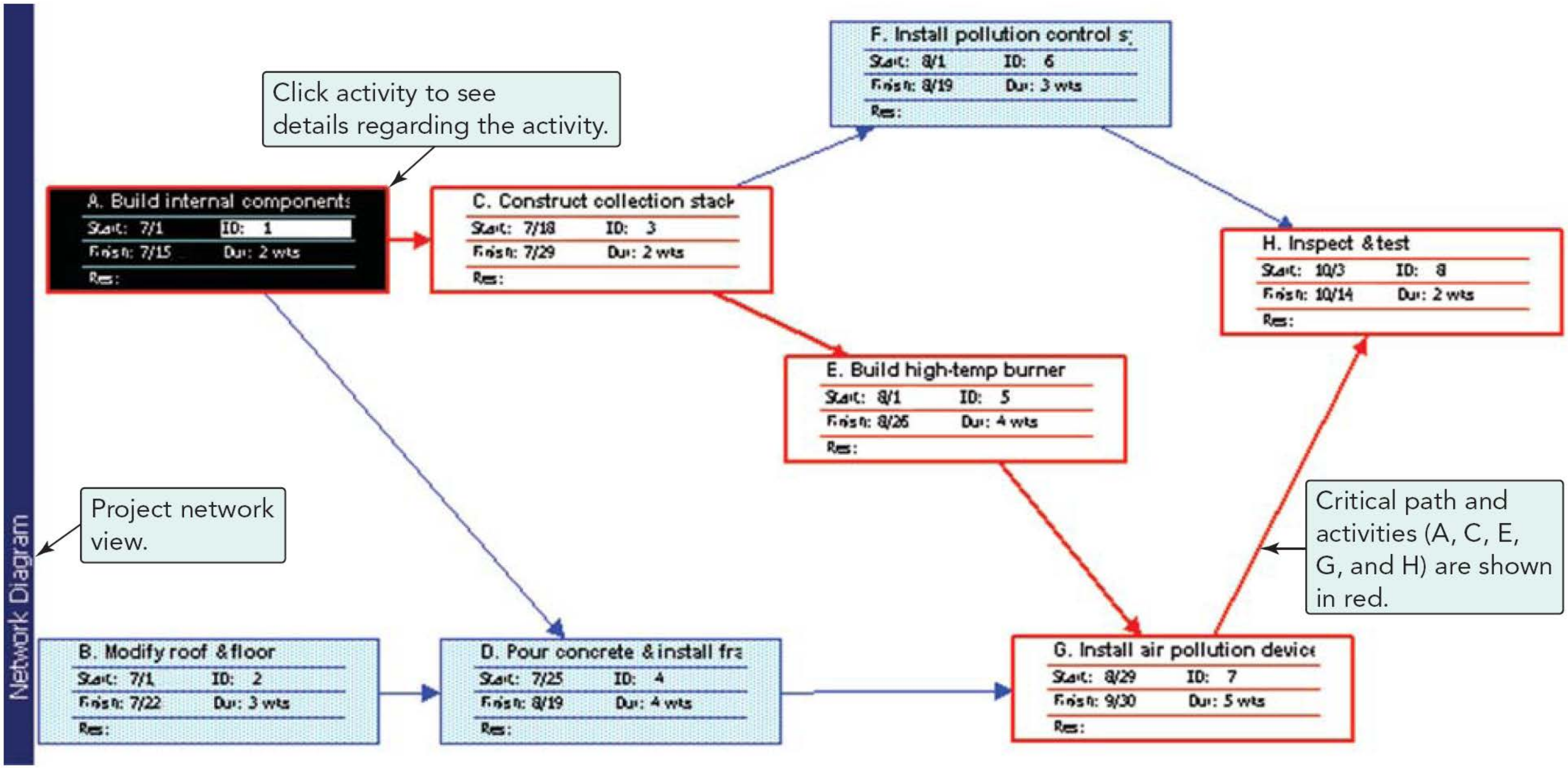
Project Management Software

- **There are several popular packages for managing projects**
  - **Primavera**
  - **MacProject**
  - **Pertmaster**
  - **VisiSchedule**
  - **Time Line**
  - **Microsoft Project**

Using Microsoft Project



Using Microsoft Project



Using Microsoft Project

Check mark indicates activity is 100% complete.

		Task Name	Duration	Start	Finish
1	✓	A. Build internal components	2 wks	Fri Jul 1	Fri Jul 15
2	✓	B. Modify roof & floor	3 wks	Fri Jul 1	Fri Jul 22
3	✓	C. Construct collection stack	2 wks	Mon Jul 18	Fri Jul 29
4		D. Pour concrete & install frai	4 wks	Mon Jul 25	Fri Aug 19
5		E. Build high-temp burner	4 wks	Mon Aug 1	Fri Aug 26
6		F. Install pollution control syst	3 wks	Mon Aug 1	Fri Aug 19
7		G. Install air pollution device	5 wks	Mon Aug 29	Fri Sep 30
8		H. Inspect & test	2 wks	Mon Oct 3	Fri Oct 14