

MacroEconometric Forecasting



Topic:
Bringing It All Together

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Network Planning Techniques



- **Program Evaluation & Review Technique (PERT):**
 - Developed to manage the Polaris missile project
 - Many tasks pushed the boundaries of science & engineering (tasks' duration = probabilistic)
- **Critical Path Method (CPM):**
 - Developed to coordinate maintenance projects in the chemical industry
 - A complex undertaking, but individual tasks are routine (tasks' duration = deterministic)



Both PERT and CPM

- Graphically display the precedence relationships & sequence of activities
- Estimate the project's duration
- Identify critical activities that cannot be delayed without delaying the project
- Estimate the amount of slack associated with non-critical activities



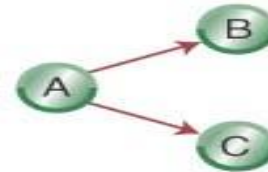
Network Diagrams

- **Activity-on-Node (AON):**

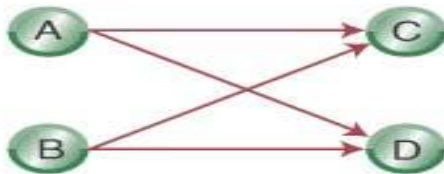
- Uses nodes to represent the activity
- Uses arrows to represent precedence relationships



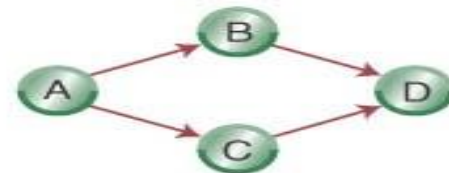
a. Activity A precedes activity B, which precedes activity C



b. Activity A must be completed before activities B and C can begin.



c. Activities A and B must both be completed before activity C or D can begin.



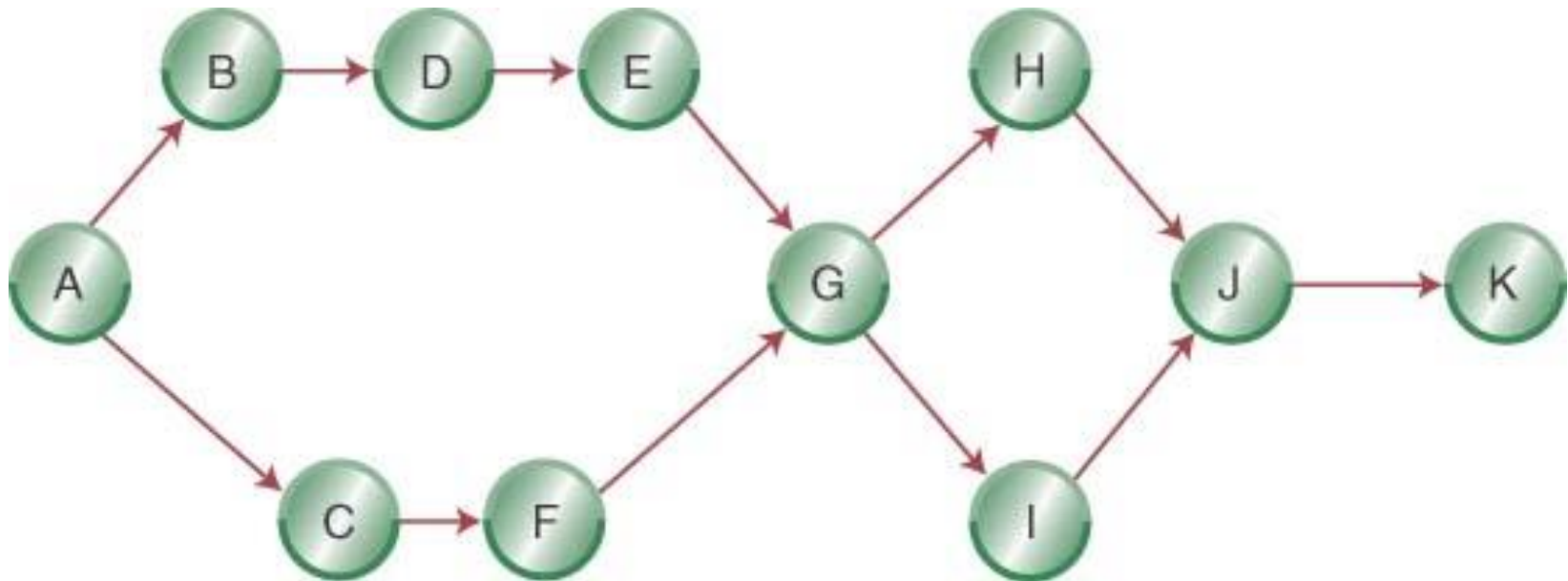
d. Activities B and C can begin once activity A has been completed; activity D cannot begin until both B and C are completed.

Step 1-Define the Project: Cables By Us is bringing a new product on line to be manufactured in their current facility in existing space. The owners have identified 11 activities and their precedence relationships. Develop an AON for the project.



Activity	Description	Immediate Predecessor	Duration (weeks)
A	Develop product specifications	None	4
B	Design manufacturing process	A	6
C	Source & purchase materials	A	3
D	Source & purchase tooling & equipment	B	6
E	Receive & install tooling & equipment	D	14
F	Receive materials	C	5
G	Pilot production run	E & F	2
H	Evaluate product design	G	2
I	Evaluate process performance	G	3
J	Write documentation report	H & I	4
K	Transition to manufacturing	J	2

Step 2- Diagram the Network for Cables By Us

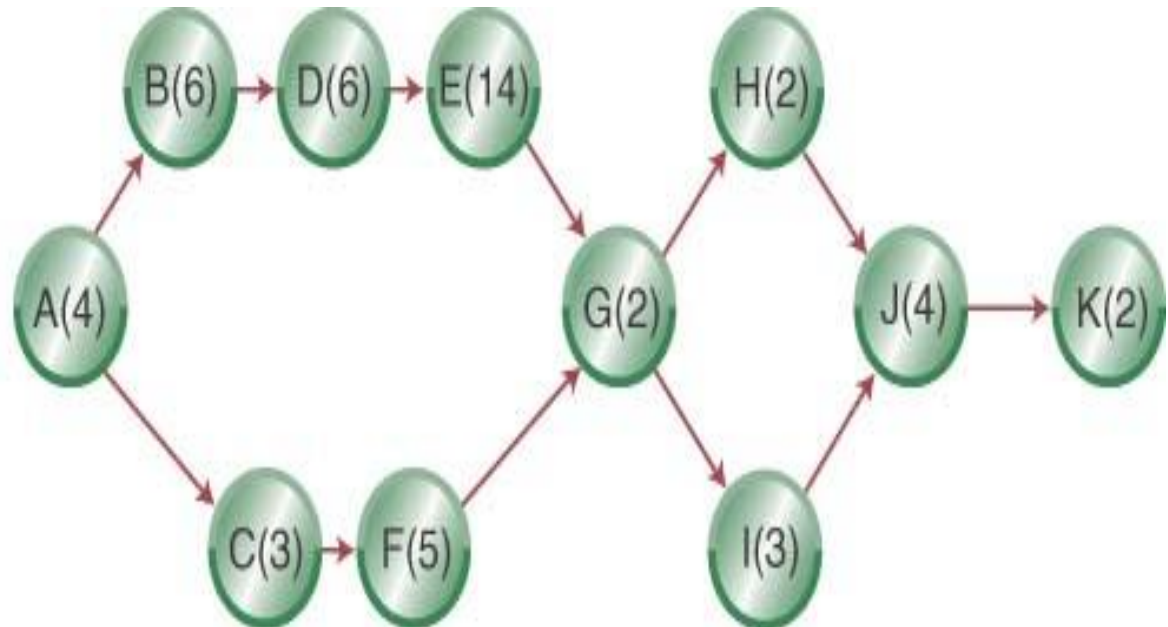


Step 3 (a)- Add Deterministic Time Estimates and Connected Paths



Connected paths

1. A, B, D, E, G, H, J, K
2. A, B, D, E, G, I, J, K
3. A, C, F, G, H, J, K
4. A, C, F, G, I, J, K



Step 3 (a) (con't): Calculate the Project Completion Times



Paths	Path duration
ABDEGHJK	40
ABDEGIJK	41
ACFGHJK	22
ACFGIJK	23

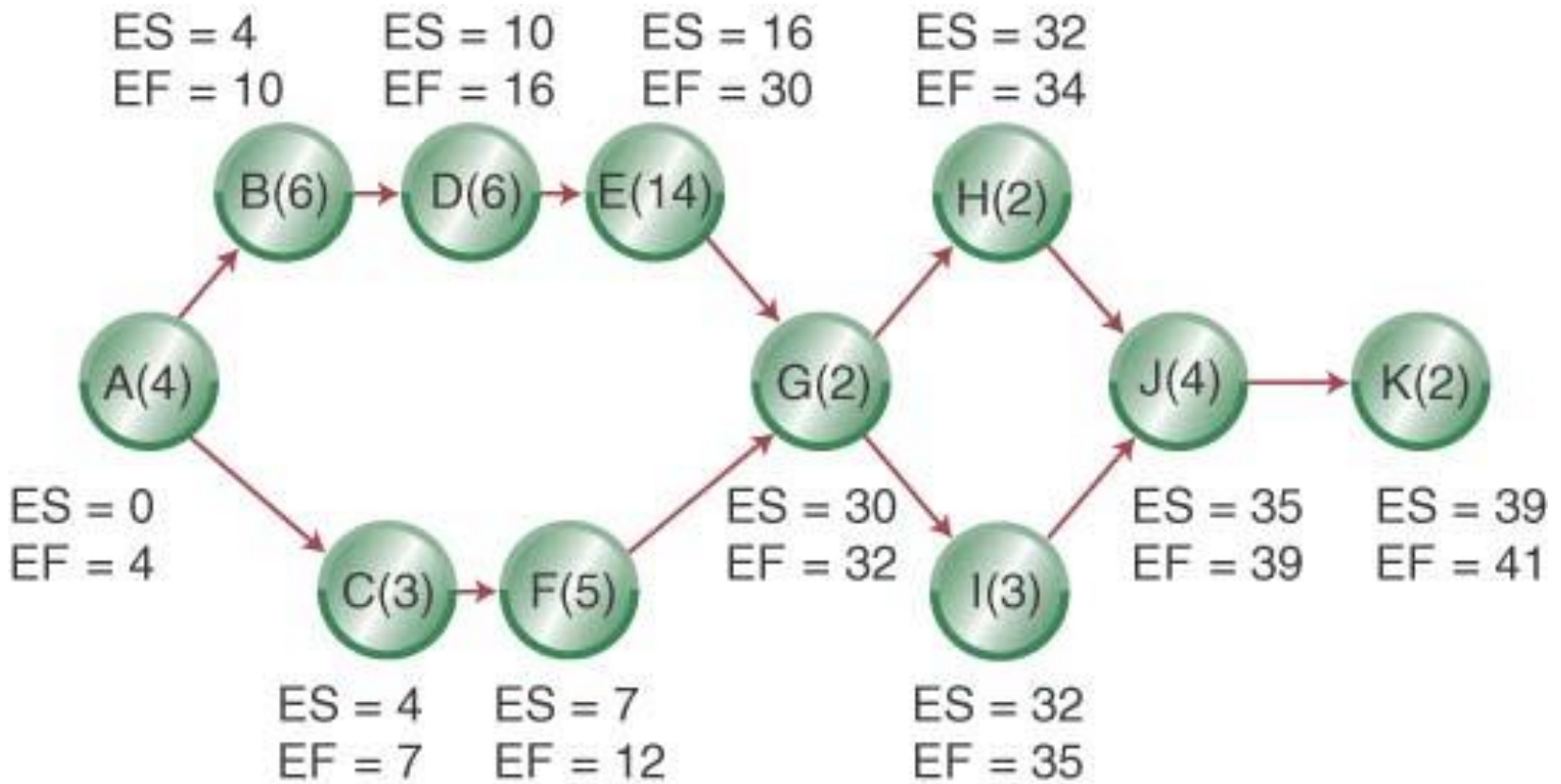
- The longest path (ABDEGIJK) limits the project's duration (project cannot finish in less time than its longest path)
- **ABDEGIJK is the project's critical path**



Some Network Definitions

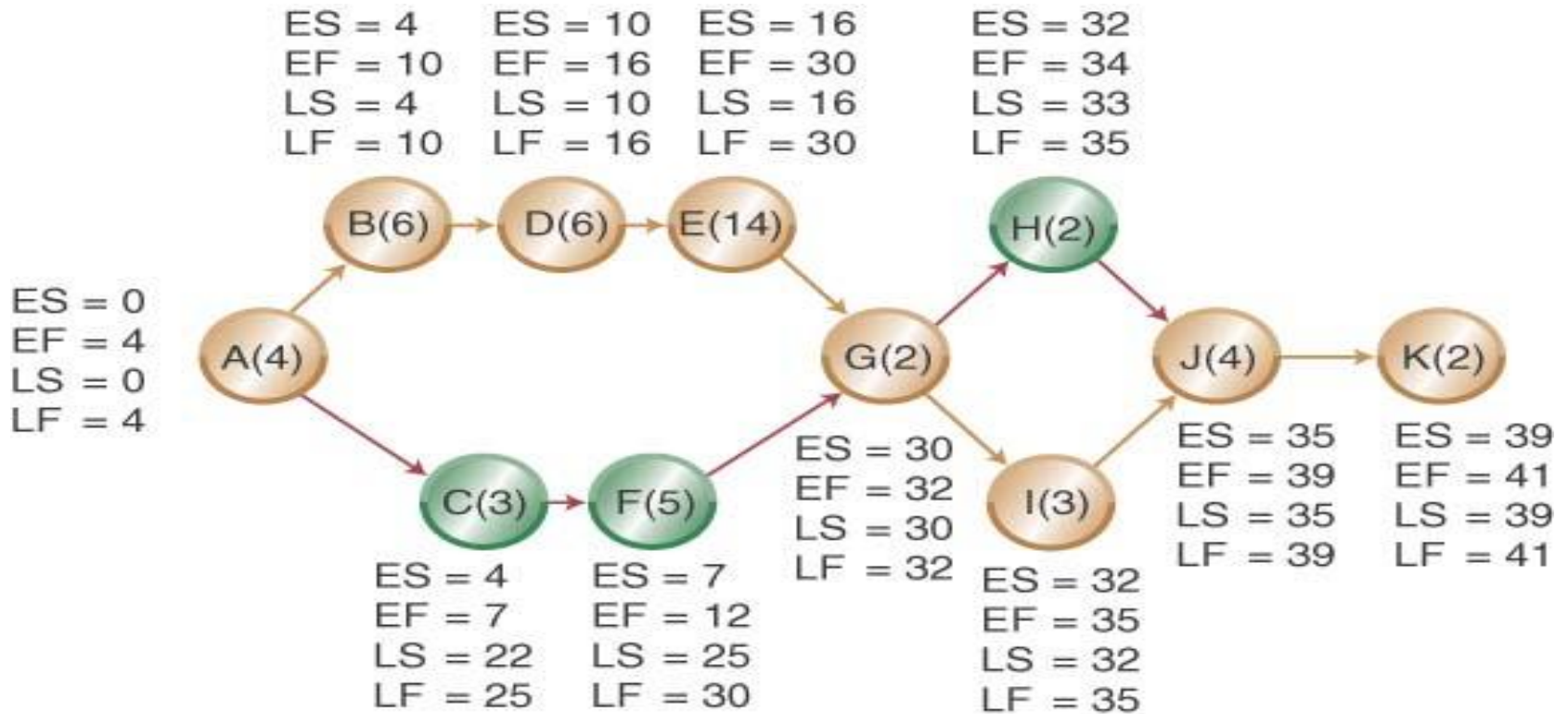
- All **activities** on the **critical path** have **zero slack**
- **Slack** defines how long **non-critical activities** can be **delayed without delaying the project**
- **Slack** = the activity's **late finish minus its early finish** (or its **late start minus its early start**)
- Earliest Start (**ES**) = the earliest finish of the immediately preceding activity
- Earliest Finish (**EF**) = is the **ES plus the activity time**
- Latest Start (**LS**) and Latest Finish (**LF**) = the latest an activity can start (LS) or finish (LF) without delaying the project completion

ES, EF Network





LS, LF Network



Critical path is
A-B-D-E-G-I-J-K

Calculating Slack



Activity	Late Finish	Early Finish	Slack (weeks)
A	4	4	0
B	10	10	0
C	25	7	18
D	16	16	0
E	30	30	0
F	30	12	18
G	32	32	0
H	35	34	1
I	35	35	0
J	39	39	0
K	41	41	0

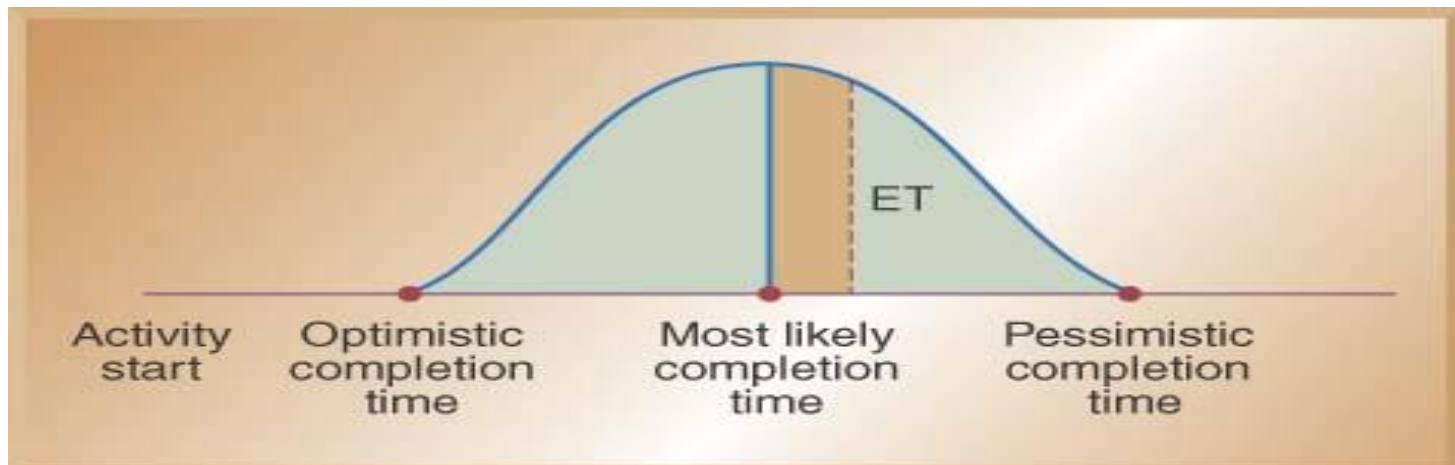
Revisiting Cables By Us Using Probabilistic Time Estimates



Activity	Description	Optimistic time	Most likely time	Pessimistic time
A	Develop product specifications	2	4	6
B	Design manufacturing process	3	7	10
C	Source & purchase materials	2	3	5
D	Source & purchase tooling & equipment	4	7	9
E	Receive & install tooling & equipment	12	16	20
F	Receive materials	2	5	8
G	Pilot production run	2	2	2
H	Evaluate product design	2	3	4
I	Evaluate process performance	2	3	5
J	Write documentation report	2	4	6
K	Transition to manufacturing	2	2	2

Using Beta Probability Distribution to Calculate Expected Time Durations

- A typical beta distribution is shown below, note that it has definite end points
- The expected time for finishing each activity is a weighted average



$$\text{Exp. time} = \frac{\text{optimistic} + 4(\text{most likely}) + \text{pessimistic}}{6}$$

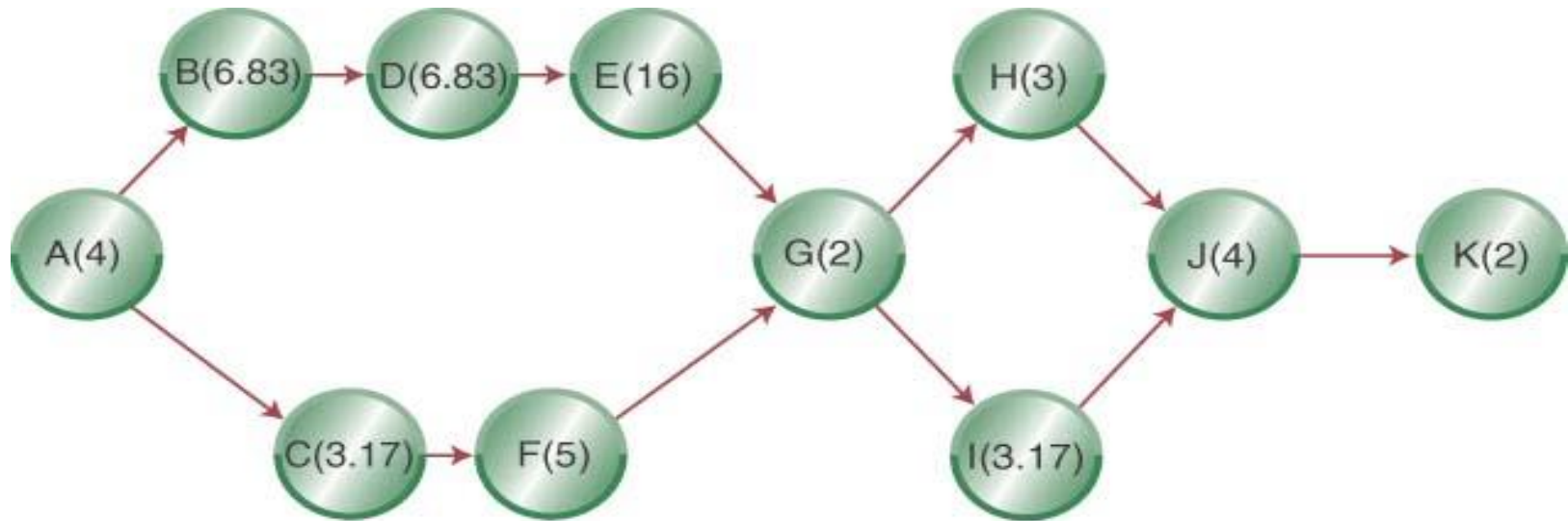
Calculating Expected Task Times



$$\text{Expected time} = \frac{\text{optimistic} + 4(\text{most likely}) + \text{pessimistic}}{6}$$

Activity	Optimistic time	Most likely time	Pessimistic time	Expected time
A	2	4	6	4
B	3	7	10	6.83
C	2	3	5	3.17
D	4	7	9	6.83
E	12	16	20	16
F	2	5	8	5
G	2	2	2	2
H	2	3	4	3
I	2	3	5	3.17
J	2	4	6	4
K	2	2	2	2

Network Diagram with Expected Activity Times



Connected paths

1. A, B, D, E, G, H, J, K
2. A, B, D, E, G, I, J, K
3. A, C, F, G, H, J, K
4. A, C, F, G, I, J, K

Estimated Path Durations through the Network

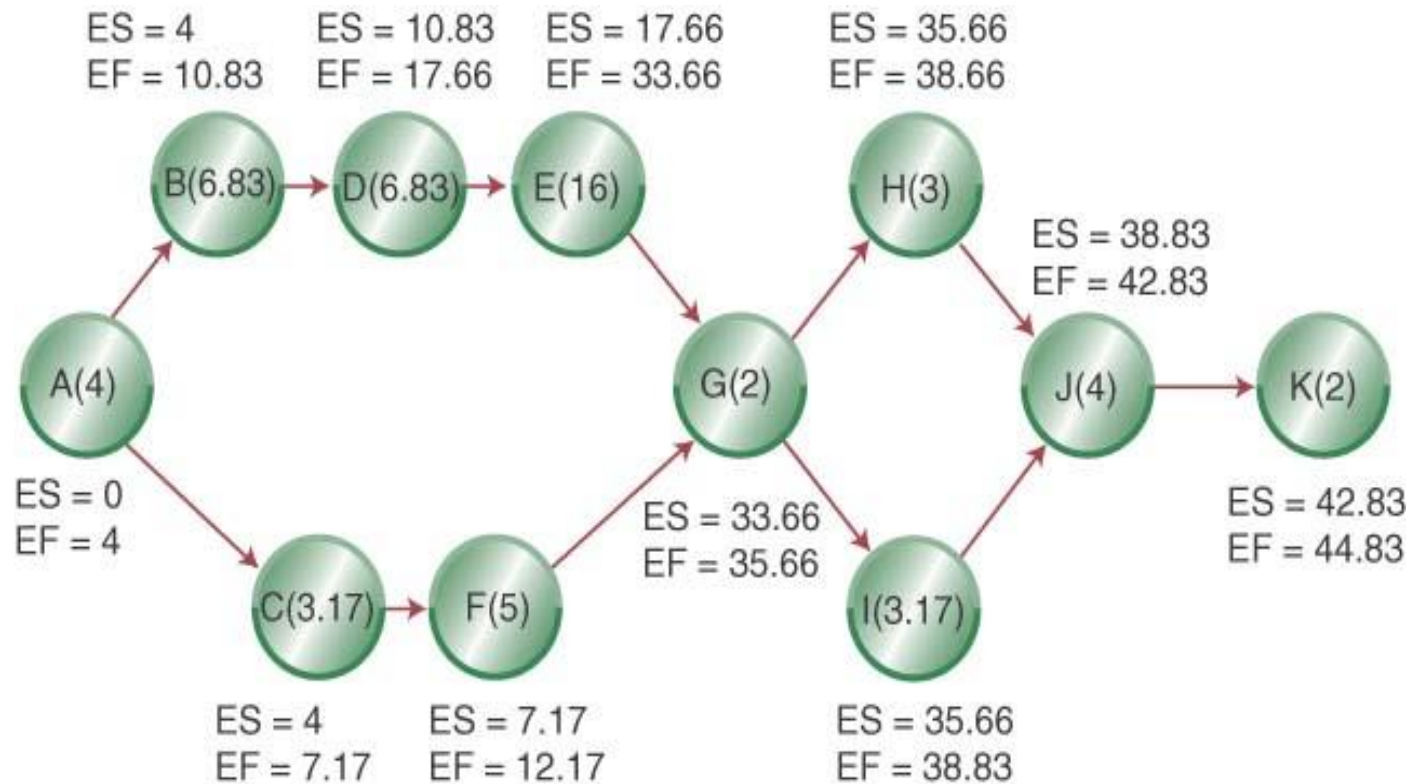


Activities on paths	Expected duration
ABDEGHJK	44.66
ABDEGIJK	44.83
ACFGHJK	23.17
ACFGIJK	23.34

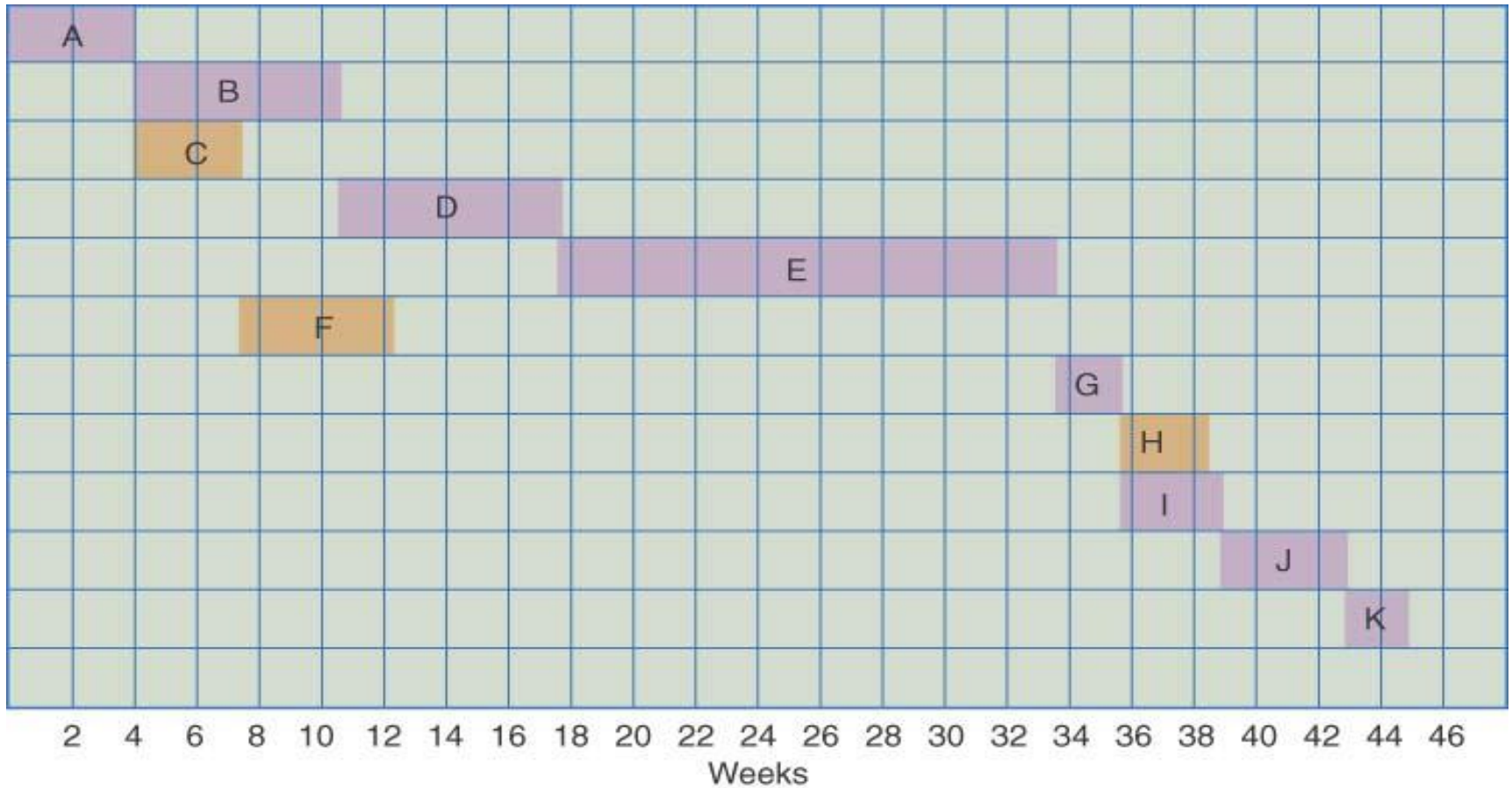
- **ABDEGIJK** is the expected critical path & the project has an expected duration of **44.83 weeks**



Adding ES and EF to Network

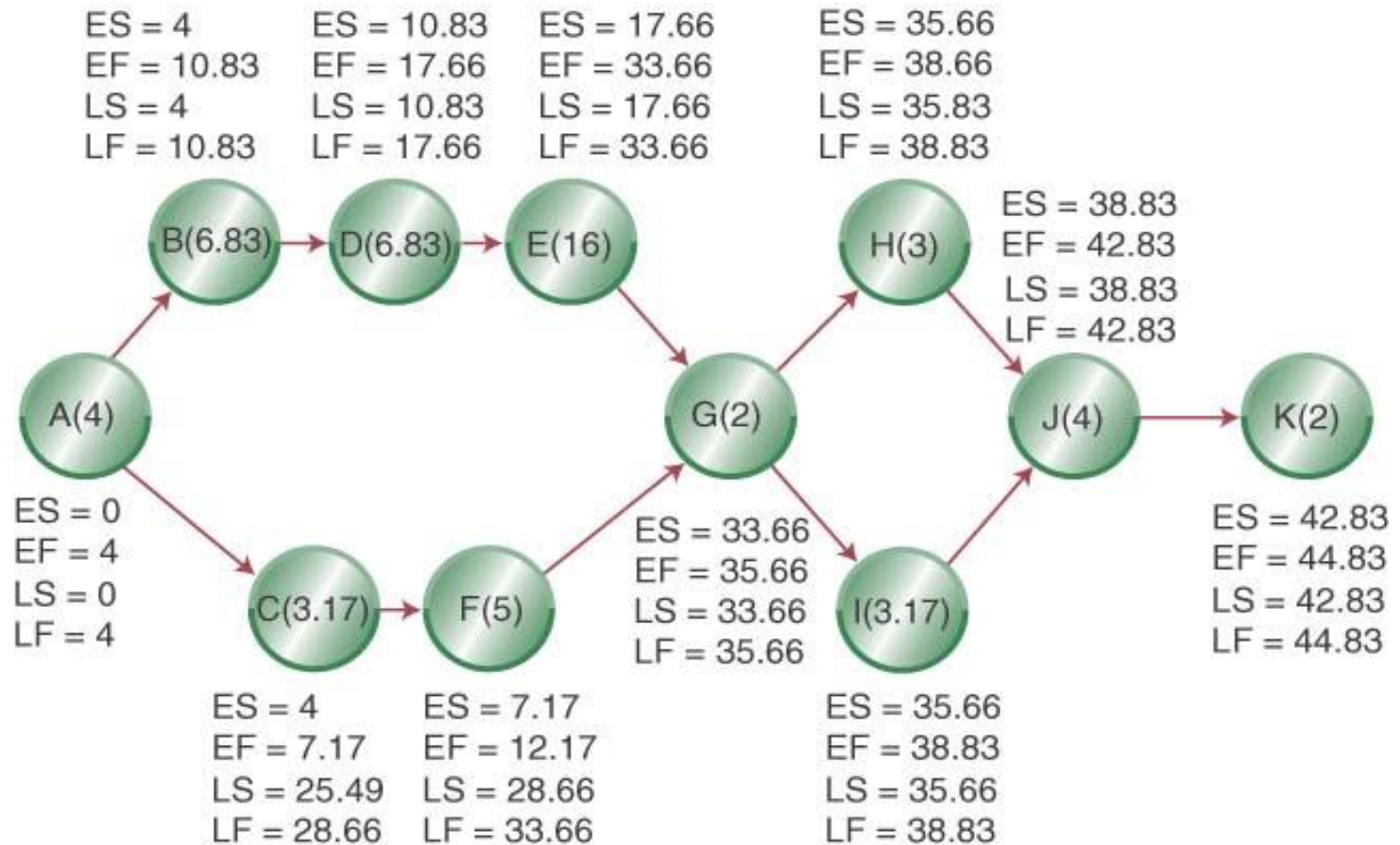


Finished at the Earliest Possible Start Date

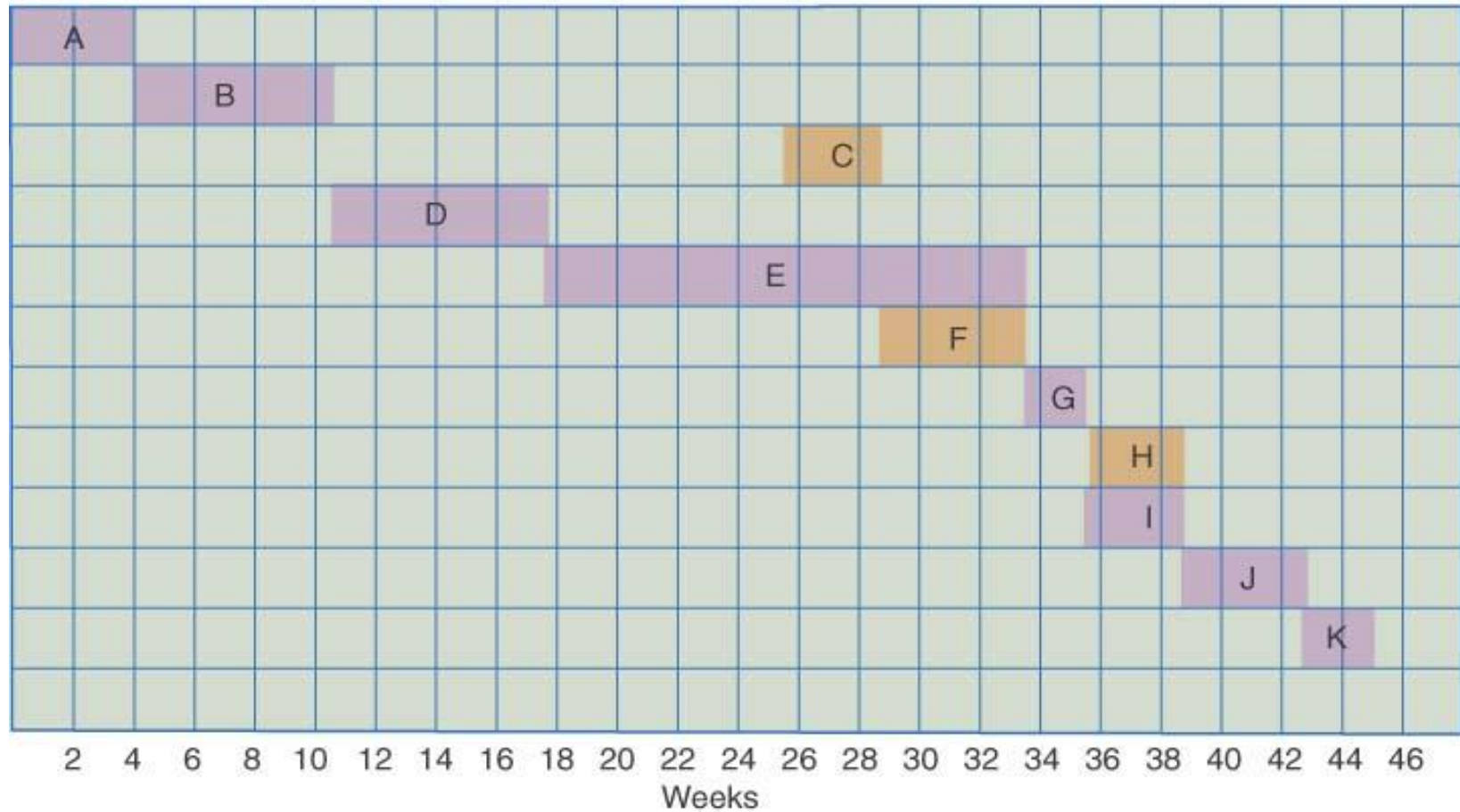




Adding LS and LF to Network



Start Times if the Project Is to Be Completed in 44.83 Weeks





Estimating the Probability of Completion Dates

- Using probabilistic time estimates offers the advantage of predicting the probability of project completion dates
- We have already calculated the expected time for each activity by making three time estimates
- Now we need to calculate the variance for each activity
- The variance of the beta probability distribution is:

$$\sigma^2 = \left(\frac{\mathbf{p} - \mathbf{o}}{\mathbf{6}} \right)^2$$

- where p=pessimistic activity time estimate
o=optimistic activity time estimate



Project Activity Variance

Activity	Optimistic	Most Likely	Pessimistic	Variance
A	2	4	6	0.44
B	3	7	10	1.36
C	2	3	5	0.25
D	4	7	9	0.69
E	12	16	20	1.78
F	2	5	8	1.00
G	2	2	2	0.00
H	2	3	4	0.11
I	2	3	5	0.25
J	2	4	6	0.44
K	2	2	2	0.00

Variations of Each Path through the Network



Path Number	Activities on Path	Path Variance (weeks)
1	A,B,D,E,G,H,J,k	4.82
2	A,B,D,E,G,I,J,K	4.96
3	A,C,F,G,H,J,K	2.24
4	A,C,F,G,I,J,K	2.38



Calculating the Probability of Completing the Project in Less Than a Specified Time

- **When you know:**
 - The expected completion time
 - Its variance
- **You can calculate the probability of completing the project in “X” weeks with the following formula:**

$$z = \frac{\text{specified time} - \text{path expected time}}{\text{path standard time}} = \left(\frac{D_T - EF_P}{\sqrt{\sigma_P^2}} \right)$$

Where D_T = the specified completion date

EF_{Path} = the expected completion time of the path

σ_{Path}^2 = variance of path



Example: Calculating the probability of finishing the project in 48 weeks

- Use the z values in Appendix B to determine probabilities

- e.g. probability for path 1 is
$$z = \left(\frac{48 \text{ weeks} - 44.66 \text{ weeks}}{\sqrt{4.82}} \right) = 1.52$$

Path Number	Activities on Path	Path Variance (weeks)	z-value	Probability of Completion
1	A,B,D,E,G,H,J,k	4.82	1.5216	0.9357
2	A,B,D,E,G,I,J,K	4.96	1.4215	0.9222
3	A,C,F,G,H,J,K	2.24	16.5898	1.000
4	A,C,F,G,I,J,K	2.38	15.9847	1.000



Reducing Project Completion Time

- Project completion times may need to be shortened because:
 - Different deadlines
 - Penalty clauses
 - Need to put resources on a new project
 - Promised completion dates
- Reduced project completion time is “crashing”



Reducing Project Completion Time – con't

- Crashing a project needs to balance
 - Shorten a project duration
 - Cost to shorten the project duration
- Crashing a project requires you to know
 - Crash time of each activity
 - Crash cost of each activity

Crash cost/duration = (crash cost-normal cost)/(normal time – crash time)



Reducing the Time of a Project (crashing)

Activity	Normal Time (wk)	Normal Cost (\$)	Crash Time	Crash Cost (\$)	Max. weeks of reduction	Reduce cost per week
A	4	8,000	3	11,000	1	3,000
B	6	30,000	5	35,000	1	5,000
C	3	6,000	3	6,000	0	0
D	6	24,000	4	28,000	2	2,000
E	14	60,000	12	72,000	2	6,000
F	5	5,000	4	6,500	1	1500
G	2	6,000	2	6,000	0	0
H	2	4,000	2	4,000	0	0
I	3	4,000	2	5,000	1	1,000
J	4	4,000	2	6,400	2	1,200
K	2	5,000	2	5,000	0	0

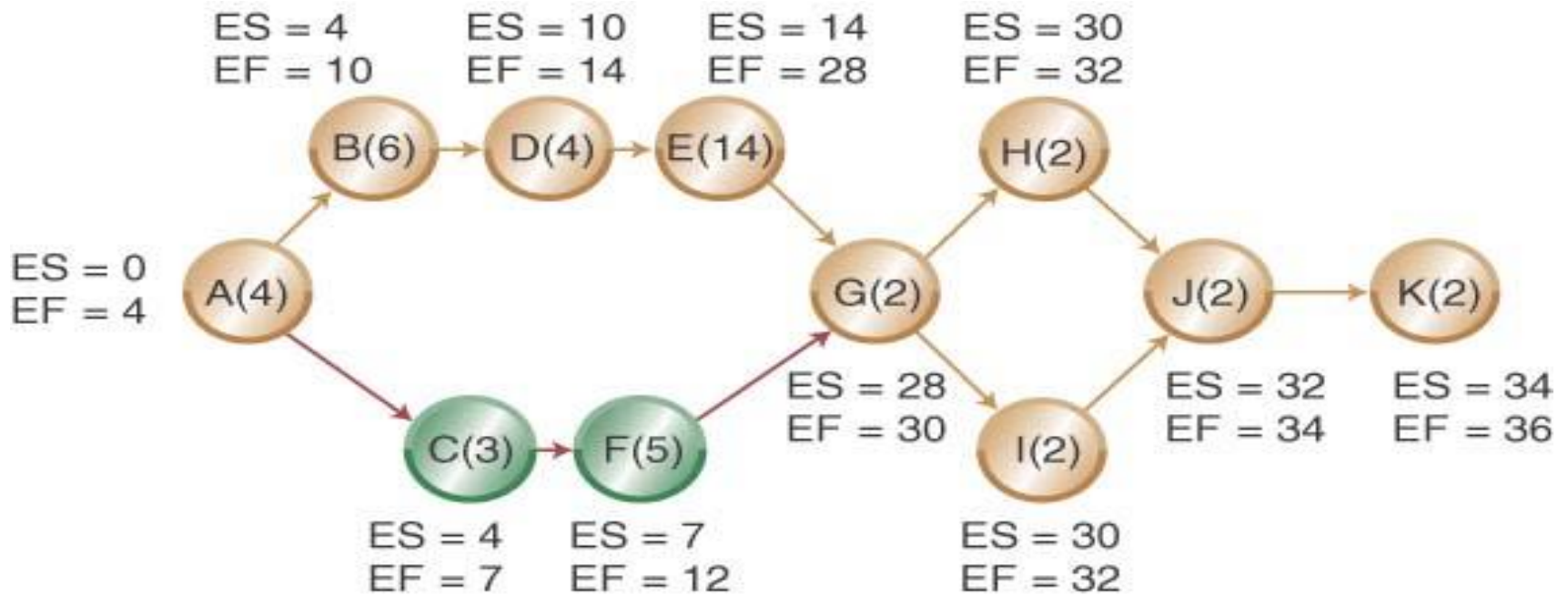


Crashing Example: Suppose the *Cables By Us* project manager wants to reduce the new product project from 41 to 36 weeks.

- **Crashing Costs are considered to be linear**
- **Look to crash activities on the critical path**
- **Crash the least expensive activities on the critical path first (based on cost per week)**
 - Crash **activity I** from 3 weeks to 2 weeks **\$1000**
 - Crash **activity J** from 4 weeks to 2 weeks **\$2400**
 - Crash **activity D** from 6 weeks to 4 weeks **\$4000**
 - **Recommend Crash Cost** **\$7400**
- **Question: Will crashing 5 weeks return more in benefits than it costs?**



Crashed Network Diagram



Critical paths: A, B, D, E, G, H, J, K
A, B, D, E, G, I, J, K



The Critical Chain Approach

- The **Critical Chain Approach** focuses on project due dates rather than on individual activities and the following realities:
 - **Project time estimates are uncertain so we add safety time**
 - **Multi-levels of organization may add additional time to be “safe”**
 - **Individual activity buffers may be wasted on lower-priority activities**
 - **A better approach is to place the project safety buffer at the end**

Original critical path

Activity A

Activity B

Activity C

Activity D

Activity E

Critical path with project buffer

Activity A

Activity B

Activity C

Activity D

Activity E

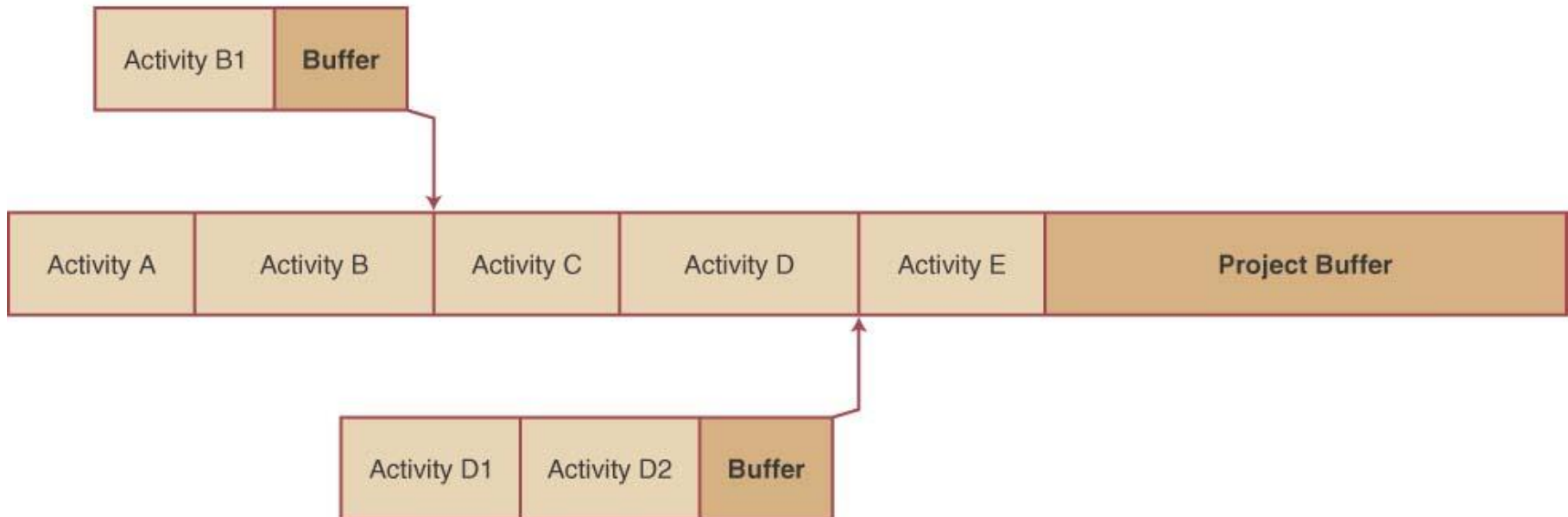
Project Buffer



Adding Feeder Buffers to Critical Chains

- The theory of constraints, the basis for critical chains, focuses on keeping bottlenecks busy.
- Time buffers can be put between bottlenecks in the critical path
- These feeder buffers protect the critical path from delays in non-critical paths

Example with Feeder Buffers



Project Management within OM: How it all fits together



- Project management techniques provide a structure for the project manager to track the progress of different activities required to complete the project. Particular concern is given to critical path (the longest connected path through the project network) activities.
- Any delay to a critical path activity affects the project completion time. These techniques indicate the expected completion time and cost of a project. The project manager reviews this information to ensure that adequate resources exist and that the expected completion time is reasonable.

Project Management OM Across the Organization



- Accounting uses project management (PM) information to provide a time line for major expenditures
- Marketing use PM information to monitor the progress to provide updates to the customer
- Information systems develop and maintain software that supports projects
- Operations use PM to information to monitor activity progress both on and off critical path to manage resource requirements



Highlights

- A project is a unique, one time event of some duration that consumes resources and is designed to achieve an objective in a given time period.
- Each project goes through a five-phase life cycle: concept, feasibility study, planning, execution, and termination.
- Two network planning techniques are PERT and CPM. Pert uses probabilistic time estimates. CPM uses deterministic time estimates.
- Pert and CPM determine the critical path of the project and the estimated completion time. On large projects, software programs are available to identify the critical path.



Highlights con't

- Pert uses probabilistic time estimates to determine the probability that a project will be done by a specific time.
- To reduce the length of the project (crashing), we need to know the critical path of the project and the cost of reducing individual activity times. Crashing activities that are not on the critical path typically do not reduce project completion time.
- The critical chain approach removes excess safety time from individual activities and creates a project buffer at the end of the critical path.

Reference and source



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