ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA
DEPARTAMENTO DE ORGANIZACIÓN INDUSTRIAL

Project Management

Universidad Pontificia Comillas

Agenda

- ❑ Introduction to Project Management
- ❑ Tools for Project Management
  - ✓ CPM
  - ✓ PERT
- ❑ Case Study: CPM
  - ✓ Context
  - ✓ Project Network
  - ✓ Microsoft Project
  - ✓ Finding the Critical Path
- ❑ Management of randomness in duration: PERT
  - ✓ Risk and Uncertainty
- ❑ Cost Management
  - ✓ Application of Linear Programming

Introduction to Project Management

- Definition
  - The coordination of numerous activities with the potential use of many organizations, both internal and external to the business in order to conduct a large-scale project from beginning to end.
- Characteristics of projects:
  - Unique, one-time operations
  - Involve large number of activities that must be coordinated
  - Long time-horizon
  - Goals of meeting completion deadlines and budgets
- Examples of projects:
  - Construction of a new plant
  - Research and Development of a new product
  - Relocation of a facility

Techniques

- CPM (Critical Path Method): to examine projects from the standpoint of costs
- PERT (Program Evaluation and Review Technique): to examine projects from the standpoint of uncertainty
- Both techniques have been combined over time
- Both heavily rely on the use of networks to help plan and display the coordination of all the activities for a project

CASE STUDY The Reliable Construction Co. Project

- The Reliable Construction Company has just made the winning bid of $5.4 million to construct a new plant for a major manufacturer.
- The contract includes the following provisions:
  - A *penalty* of $300,000 if Reliable has not completed construction within 47 weeks.
  - A *bonus* of $150,000 if Reliable has completed the plant within 40 weeks.

Questions:

1. How can the project be displayed graphically to better visualize the activities?
2. What is the total time required to complete the project if no delays occur?
3. When do the individual activities need to start and finish?
4. What are the critical bottleneck activities?
5. For other activities, how much delay can be tolerated?
6. What is the probability the project can be completed in 47 weeks?
7. What is the least expensive way to complete the project within 40 weeks?
8. How should ongoing costs be monitored to try to keep the project within budget?

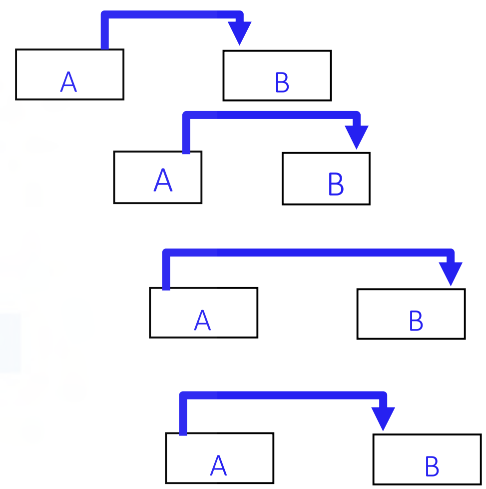
Activity List for Reliable Construction

Activity	Activity Description	Immediate Predecessors	Estimated Duration (Weeks)
A	Excavate	—	2
B	Lay the foundation	A	4
C	Put up the rough wall	B	10
D	Put up the roof	C	6
E	Install the exterior plumbing	C	4
F	Install the interior plumbing	E	5
G	Put up the exterior siding	D	7
H	Do the exterior painting	E, G	9
I	Do the electrical work	C	7
J	Put up the wallboard	F, I	8
K	Install the flooring	J	4
L	Do the interior painting	J	5
M	Install the exterior fixtures	H	2
N	Install the interior fixtures	K, L	6

Precession and Succession

- Immediate Predecessors:
  - Activities that must be completed by no later than the start time of the given activity
- Immediate Successors:
  - Given the immediate predecessor of an activity, this becomes the immediate successor of each of these immediate predecessors.
  - If an immediate successor has multiple immediate predecessors. Then all must be finished before an activity can begin.

- TYPES OF LINKS:
  - ✓ End - Start: Activity B can only start after activity A has finished
  - ✓ End-End: Activity B can only finish after Activity A has finished.
  - ✓ Start-End: Activity B can only finish once Activity A has started.
  - ✓ Start-Start: Activity B can only start after Activity A has started.



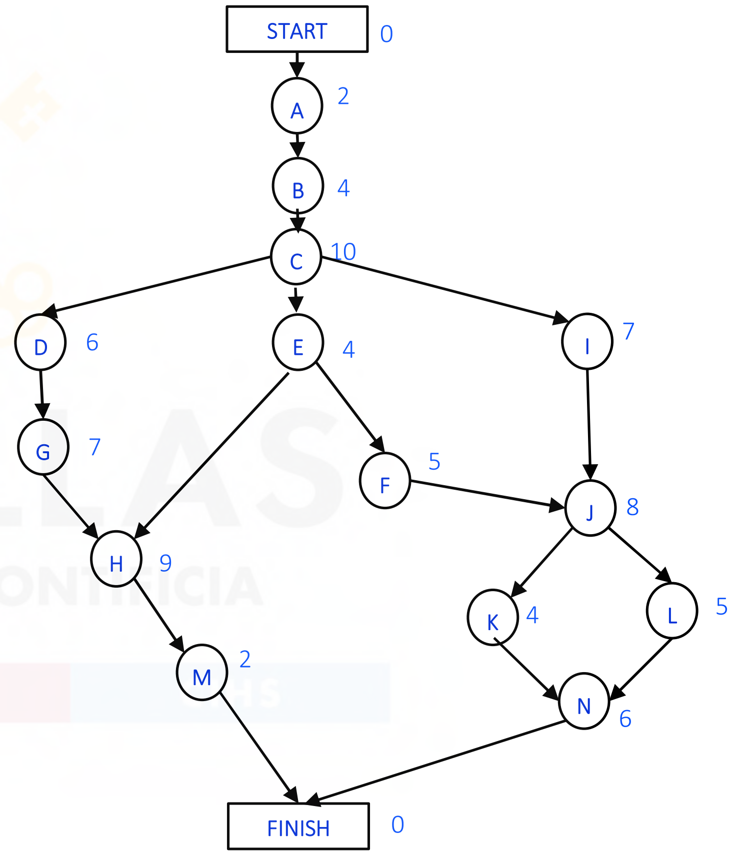
Project Networks

- A network used to represent a project is called a **project network**.
- A project network consists of several *nodes* connected by several *arcs*.

- Two types of project networks:
  - Activity-on-arc (AOA): each activity is represented by an *arc*. A node is used to separate an activity from its predecessors. The sequencing of the arcs shows the precedence relationships.
  - Activity-on-node (AON): each activity is represented by a *node*. The arcs are used to show the precedence relationships.
- Advantages of AON (we will use this one):
  - considerably easier to construct
  - easier to understand
  - easier to review when there are changes

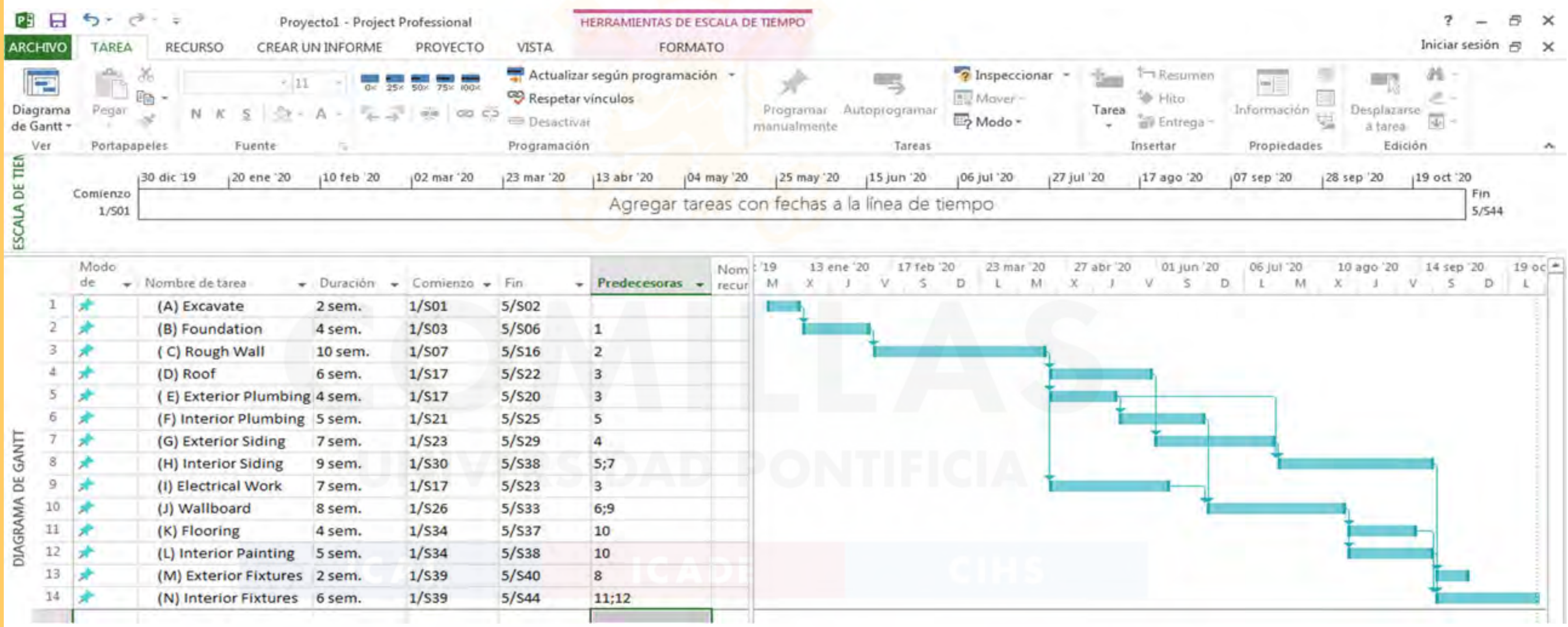
Using a Network to visually display a project

Activity	Immediate Predecessors	Estimated Duration (Weeks)
A	—	2
B	A	4
C	B	10
D	C	6
E	C	4
F	E	5
G	D	7
H	E, G	9
I	C	7
J	F, I	8
K	J	4
L	J	5
M	H	2
N	K, L	6



Using Microsoft Project

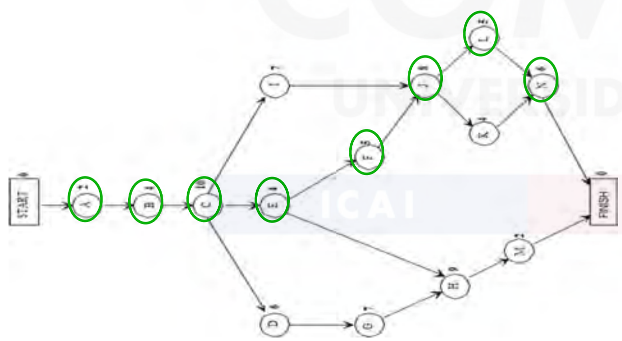
Creating a Gantt Chart:



	Nombre de tarea	Duración	Comienzo	Fin	Predecesoras
1	(A) Excavate	2 sem.	1/S01	5/S02	
2	(B) Foundation	4 sem.	1/S03	5/S06	1
3	(C) Rough Wall	10 sem.	1/S07	5/S16	2
4	(D) Roof	6 sem.	1/S17	5/S22	3
5	(E) Exterior Plumbing	4 sem.	1/S17	5/S20	3
6	(F) Interior Plumbing	5 sem.	1/S21	5/S25	5
7	(G) Exterior Siding	7 sem.	1/S23	5/S29	4
8	(H) Interior Siding	9 sem.	1/S30	5/S38	5;7
9	(I) Electrical Work	7 sem.	1/S17	5/S23	3
10	(J) Wallboard	8 sem.	1/S26	5/S33	6;9
11	(K) Flooring	4 sem.	1/S34	5/S37	10
12	(L) Interior Painting	5 sem.	1/S34	5/S38	10
13	(M) Exterior Fixtures	2 sem.	1/S39	5/S40	8
14	(N) Interior Fixtures	6 sem.	1/S39	5/S44	11;12

The Critical Path

- ❑ A path through a network is one of the routes following the arrows (arcs) from the start node to the finish node.
- ❑ The length of a path is the *sum* of the (estimated) *durations* of the activities on the path.
- ❑ The (estimated) project duration equals the *length of the longest path* through the project network.
- ❑ This longest path is called the critical path. (If more than one path tie for the longest, they all are critical paths.)



The Paths for Reliable's Project Network

Path	Length (Weeks)
Start→A→B→C→D→G→H→M→Finish	2 + 4 + 10 + 6 + 7 + 9 + 2 = 40
Start→A→B→C→E→H→M→Finish	2 + 4 + 10 + 4 + 9 + 2 = 31
Start→A→B→C→E→F→J→K→N→Finish	2 + 4 + 10 + 4 + 5 + 8 + 4 + 6 = 43
Start→A→B→C→E→F→J→L→N→Finish	2 + 4 + 10 + 4 + 5 + 8 + 5 + 6 = 44
Start→A→B→C→I→J→K→N→Finish	2 + 4 + 10 + 7 + 8 + 4 + 6 = 41
Start→A→B→C→I→J→L→N→Finish	2 + 4 + 10 + 7 + 8 + 5 + 6 = 42

Method to find the Critical Path

Earliest Start and Earliest End Times (FORWARD):

- The starting and finishing times of each activity if no delays occur anywhere in the project are called the **earliest start time** and the **earliest finish time**.
  - ES = Earliest start time for an activity
  - EF = Earliest finish time for an activity

Earliest Start Time Rule:
ES = Largest EF of the immediate predecessors
EF = ES + Duration of Activity

Procedure for obtaining earliest times for all activities:

1. For each activity that starts the project (including the start node), set its ES = 0.
2. For each activity, whose ES has just been obtained, calculate EF = ES + duration.
3. For each new activity, whose immediate predecessors now have EF values, obtain its ES by applying the *earliest start time rule*. Apply step 2 to calculate EF.
4. Repeat step 3 until ES and EF have been obtained for *all* activities.

ES and EF Values for Reliable Construction

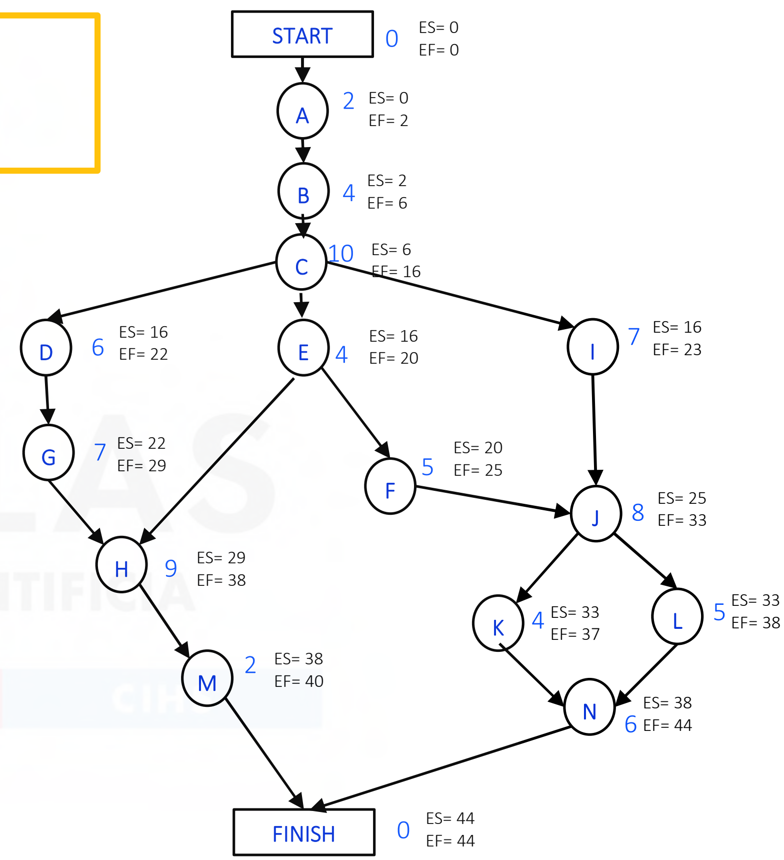
Earliest Start Time Rule:
ES = Largest EF of the immediate predecessors
EF = ES + Duration of Activity

<u>With only one predecessor:</u>

- Start: ES= 0
  EF= 0
- A: ES= 0
  EF= 0+2 =2
- B: ES= 2
  EF= 2+4=6
- C: ES= 6
  EF= 6+10=16
- D: ES= 16
  EF= 16+6

<u>With numerous predecessors:</u>

- H: ES= 29
  EF= 29+9=38



Latest Start and Latest Finish Times (BACKWARD):

- The **latest start time for an activity** is the latest possible time that it can start without delaying the completion of the project (so the finish node still is reached at its earliest finish time). The **latest finish time** has the corresponding definition with respect to finishing the activity..
  - LS = Latest start time for an activity
  - LF = Latest finish time for an activity

Latest Finish Time Rule:

LF = Smallest LS of the immediate successors

LS = LF – Duration of Activity

- **Procedure for obtaining latest times for all activities:**
  1. For each of the activities that together complete the project (including the finish node), set LF equal to EF of the finish node.
  2. For each activity, whose LF value has just been obtained, calculate LS = LF – duration.
  3. For each new activity, whose immediate successors now have LS values, obtain its LF by applying the *latest finish time rule*. Apply step 2 to calculate its LS.
  4. Repeat step 3 until LF and LS have been obtained for *all* activities.

LS and LF Values for Reliable Construction

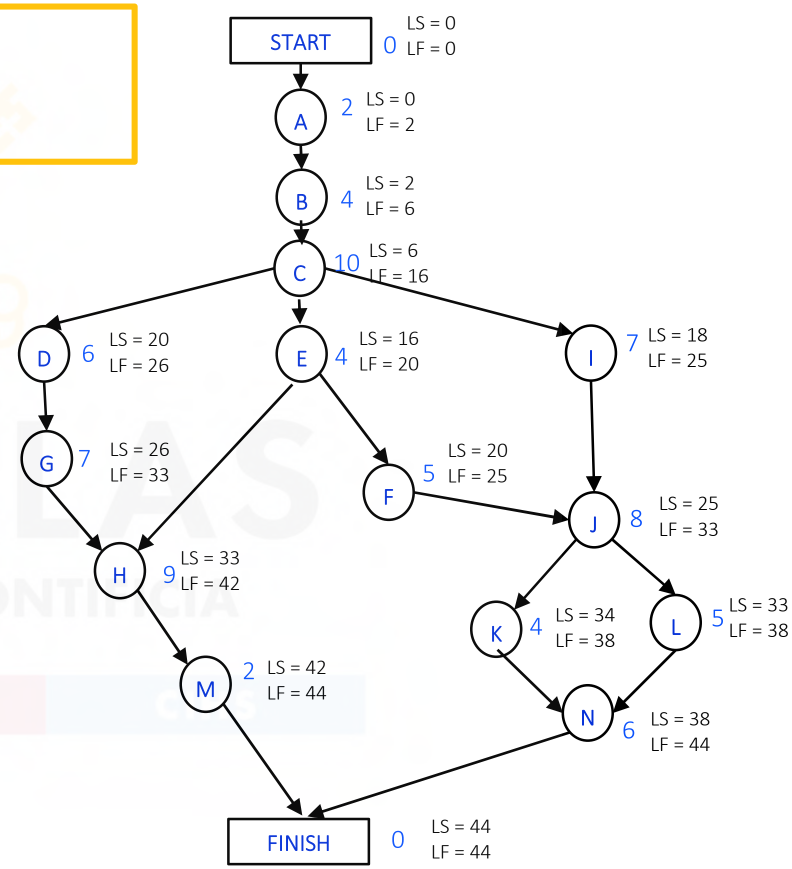
Latest Finish Time Rule:
LF = Smallest LS of the immediate successors
LS = LF – Duration of Activity

With only one successor:

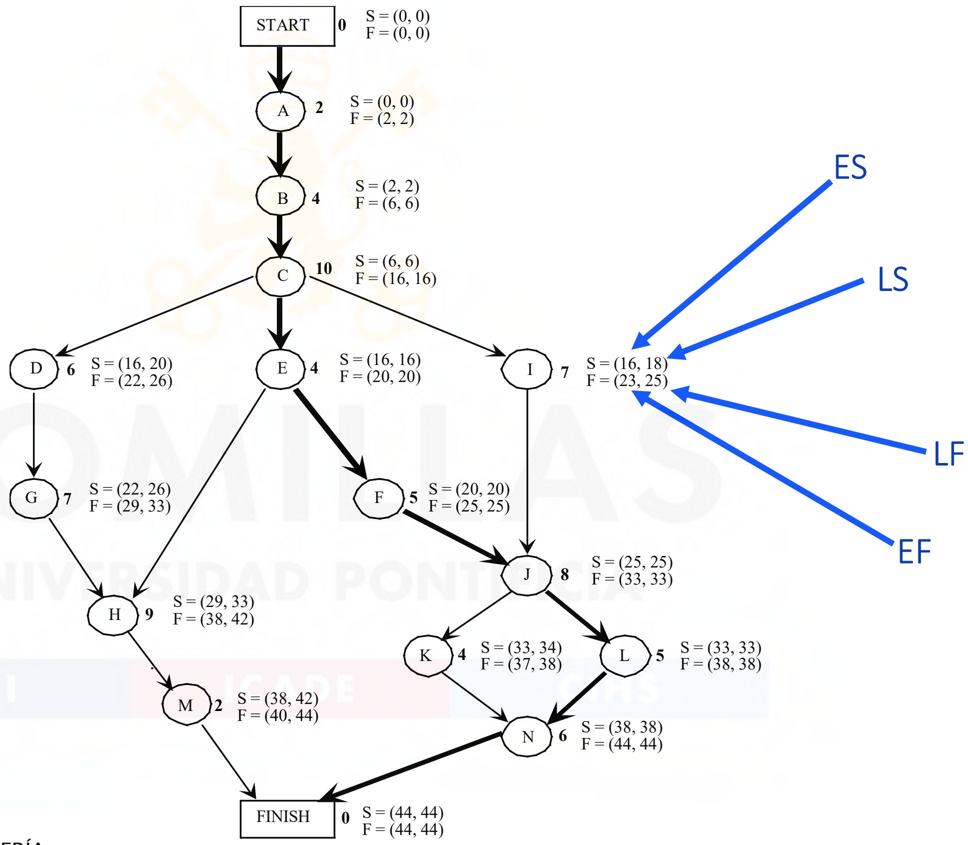
- Finish: LF: 44
  LS: 44
- N: LF: 44
  LS: 44 – 6 = 38
- L: LF: 38
  LS: 38 – 5 = 33
- K: LF: 38
  LS: 38 – 4 = 34

With multiple successors:

- J: LF: 33
  LS: 33 – 8 = 25



The Complete Project Network



Slack (How much an activity can be delayed without affecting finish time)

SLACK =
LF – EF = LS - ES

Activity	Slack (LF–EF)	On Critical Path?
A	0	Yes
B	0	Yes
C	0	Yes
D	4	No
E	0	Yes
F	0	Yes
G	4	No
H	4	No
I	2	No
J	0	Yes
K	1	No
L	0	Yes
M	4	No
N	0	Yes

SLACK= 0 ⟷ ON CRITICAL PATH

Time-Cost Trade-Offs

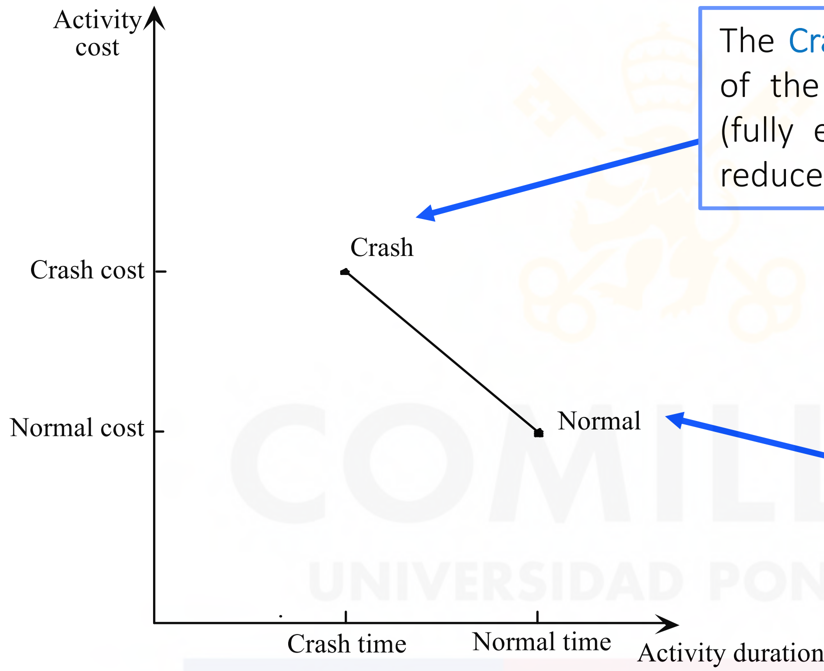
Question: If extra money is spent to expedite the project, what is the least expensive way of attempting to meet the target completion time (40 weeks)?

CPM Method of Time-Cost Trade-Offs:

- Crashing an activity refers to taking special costly measures to reduce the duration of an activity below its normal value. Special measures might include overtime, hiring additional temporary help, using special time-saving materials, obtaining special equipment, etc.

- Crashing the project refers to crashing several activities to reduce the duration of the project below its normal value.

Time-Cost Graph for an Activity



The Crash Point shows the time and cost of the activity when it is fully crashed (fully expedited with no cost spared to reduce its duration as much as possible).

The Normal Point on the time-cost graph for an activity shows the time (duration) and cost of the activity when it is performed the normal way.

Assumption: Partially Crashed Activities will lie on the line segment between the Crash and Normal points.

Time-Cost Trade-Off Data

Activity A:
- Normal Point:
  - Time= 2 weeks
  - Cost=$180,000
- Crash Point:
  - Time= 1 week
  - Cost= $280,000
- Max Reduction in Time
  = 2-1= 1 week
- Crash Cost per week saved
  = (280,000-180,000)/1
  =$100,000

	Time (weeks)		Cost		Maximum Reduction in Time (weeks)	Crash Cost per Week Saved
Activity	Normal	Crash	Normal	Crash		
A	2	1	$180,000	$280,000	1	$100,000
B	4	2	320,000	420,000	2	50,000
C	10	7	620,000	860,000	3	80,000
D	6	4	260,000	340,000	2	40,000
E	4	3	410,000	570,000	1	160,000
F	5	3	180,000	260,000	2	40,000
G	7	4	900,000	1,020,000	3	40,000
H	9	6	200,000	380,000	3	60,000
I	7	5	210,000	270,000	2	30,000
J	8	6	430,000	490,000	2	30,000
K	4	3	160,000	200,000	1	40,000
L	5	3	250,000	350,000	2	50,000
M	2	1	100,000	200,000	1	100,000
N	6	3	330,000	510,000	3	60,000

Marginal Cost Analysis

Goal: Find the least expensive way of reaching 40 weeks of Project duration

Step 1: Find the longest path

ABCEFJLN

Step 2: Find the Activity in the longest path which has the smallest Crash Cost Per Week (Last column in the previous table)

J

Step 3: Crash said Activity reducing its duration by 1 week

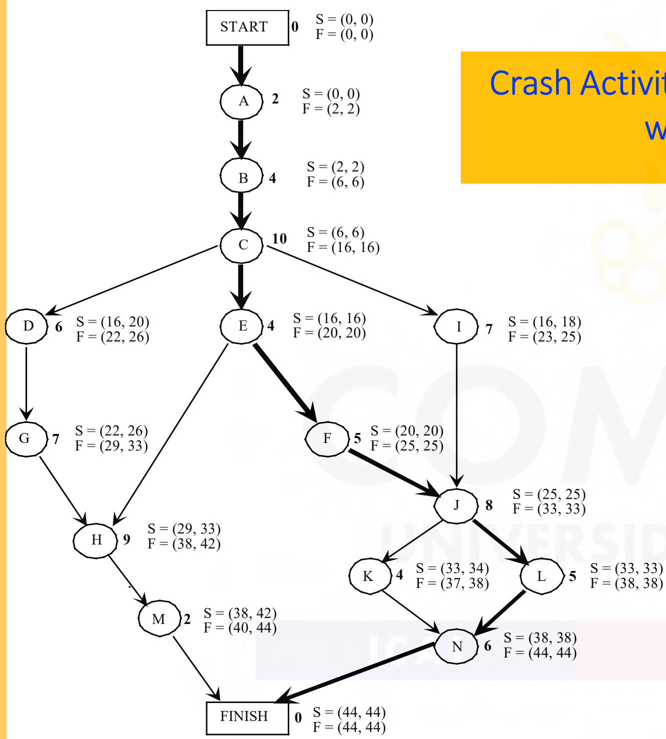
Step 4: Repeat the procedure

Activity to Crash	Crash Cost	Length of Path: ABCDGHM	ABCEHM	ABCEFJKN	ABCEFJLN	ABCIJKN	ABCIJLN
		40	31	43	44	41	42
J	$30,000	40	31	42	43	40	41
J	$30,000	40	31	41	42	39	40
F	$40,000	40	31	40	41	39	40
F	$40,000	40	31	39	40	39	40

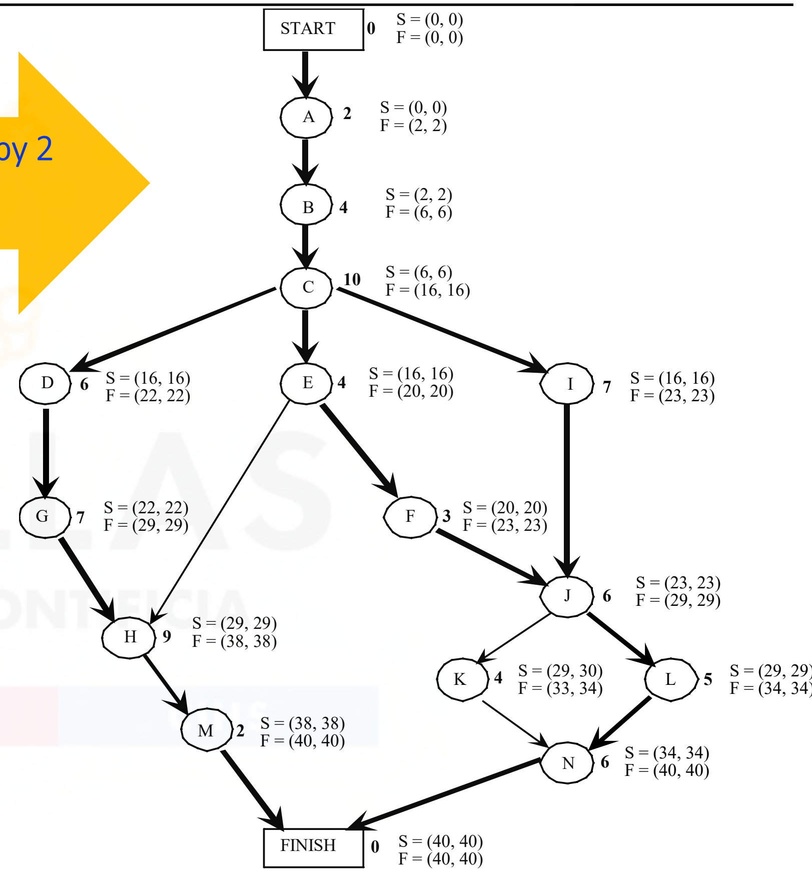
Conclusion:
Total Crashing Cost= sum of Crash Costs = $140,000

Should he do it? ....

New Project Network after Crashing



Crash Activities J and F by 2 weeks



Scheduling and Controlling Project Costs

Question: How should ongoing costs be monitored to try to keep the Project within Budget?

- PERT/Cost is a systematic procedure (normally computerized) to help the project manager plan, schedule, and control costs.
- Assumption: A common assumption when using PERT/Cost is that the costs of performing an activity are incurred at a constant rate throughout its duration.

Project Budget

Cost Per Week of Duration

=

$$\frac{\textbf{Estimated Cost}}{\textbf{Duration (weeks)}}$$

Activity	Estimated Duration (weeks)	Estimated Cost	Cost per Week of Its Duration
A	2	$180,000	$90,000
B	4	320,000	80,000
C	10	620,000	62,000
D	6	260,000	43,333
E	4	410,000	102,500
F	5	180,000	36,000
G	7	900,000	128,571
H	9	200,000	22,222
I	7	210,000	30,000
J	8	430,000	53,750
K	4	160,000	40,000
L	5	250,000	50,000
M	2	100,000	50,000
N	6	330,000	55,000

Weekly Schedule of Expenses (Earliest Start Times)

PERT/Cost Spreadsheet

= IF(AND(G5>E6,G5<=E6+C6),F6,0)

	B	C	D	E	F	G	H	I	J
3		Estimated							
4		Duration	Estimated	Start	Cost Per Week	Week	Week	Week	Week
5	Activity	(weeks)	Cost	Time	of Its Duration	1	2	3	4
6	A	2	$180,000	0	$90,000	$90,000	$90,000	$0	$0
7	B	4	$320,000	2	$80,000	$0	$0	$80,000	$80,000
8	C	10	$620,000	6	$62,000	$0	$0	$0	$0
9	D	6	$260,000	16	$43,333	$0	$0	$0	$0
10	E	4	$410,000	16	$102,500	$0	$0	$0	$0
11	F	5	$180,000	20	$36,000	$0	$0	$0	$0
12	G	7	$900,000	22	$128,571	$0	$0	$0	$0
13	H	9	$200,000	29	$22,222	$0	$0	$0	$0
14	I	7	$210,000	16	$30,000	$0	$0	$0	$0
15	J	8	$430,000	25	$53,750	$0	$0	$0	$0
16	K	4	$160,000	33	$40,000	$0	$0	$0	$0
17	L	5	$250,000	33	$50,000	$0	$0	$0	$0
18	M	2	$100,000	38	$50,000	$0	$0	$0	$0
19	N	6	$330,000	38	$55,000	$0	$0	$0	$0
20									
21					Weekly Project Cost	$90,000	$90,000	$80,000	$80,000
22					Cumulative Project Cost	$90,000	$180,000	$260,000	$340,000

	B	E	W	X	Y	Z	AA	AB	AC	AD	AE
4		Start	Week	Week	Week	Week	Week	Week	Week	Week	Week
5	Activity	Time	17	18	19	20	21	22	23	24	25
6	A	0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	B	2	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	C	6	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	D	16	$43,333	$43,333	$43,333	$43,333	$43,333	$43,333	$0	$0	$0
10	E	16	$102,500	$102,500	$102,500	$102,500	$0	$0	$0	$0	$0
11	F	20	$0	$0	$0	$0	$36,000	$36,000	$36,000	$36,000	$36,000
12	G	22	$0	$0	$0	$0	$0	$0	$128,571	$128,571	$128,571
13	H	29	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	I	16	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$0	$0
15	J	25	$0	$0	$0	$0	$0	$0	$0	$0	$0
16	K	33	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	L	33	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	M	38	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	N	38	$0	$0	$0	$0	$0	$0	$0	$0	$0
20											
21			$175,833	$175,833	$175,833	$175,833	$109,333	$109,333	$194,571	$164,571	$164,571
22			$1,295,833	$1,471,667	$1,647,500	$1,823,333	$1,932,667	$2,042,000	$2,236,571	$2,401,143	$2,565,714

These tables show the amount of money Mr. Perty will need to cover each week's expenses as well as the total cumulative amount if we assume the **Project will stick to this Earliest Start Time schedule.**

Weekly Schedule of Expenses (Latest Start Times)

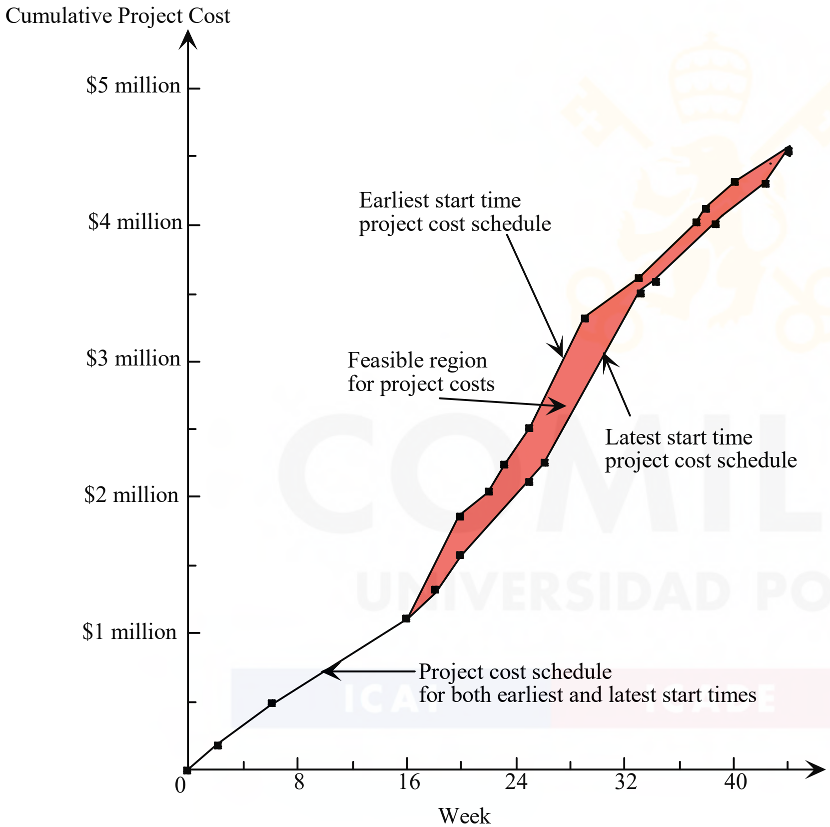
PERT/Cost Spreadsheet

	B	C	D	E	F	G	H	I	J
3		Estimated							
4		Duration	Estimated	Start	Cost Per Week	Week	Week	Week	Week
5	Activity	(weeks)	Cost	Time	of Its Duration	1	2	3	4
6	A	2	$180,000	0	$90,000	$90,000	$90,000	$0	$0
7	B	4	$320,000	2	$80,000	$0	$0	$80,000	$80,000
8	C	10	$620,000	6	$62,000	$0	$0	$0	$0
9	D	6	$260,000	20	$43,333	$0	$0	$0	$0
10	E	4	$410,000	16	$102,500	$0	$0	$0	$0
11	F	5	$180,000	20	$36,000	$0	$0	$0	$0
12	G	7	$900,000	26	$128,571	$0	$0	$0	$0
13	H	9	$200,000	33	$22,222	$0	$0	$0	$0
14	I	7	$210,000	18	$30,000	$0	$0	$0	$0
15	J	8	$430,000	25	$53,750	$0	$0	$0	$0
16	K	4	$160,000	34	$40,000	$0	$0	$0	$0
17	L	5	$250,000	33	$50,000	$0	$0	$0	$0
18	M	2	$100,000	42	$50,000	$0	$0	$0	$0
19	N	6	$330,000	38	$55,000	$0	$0	$0	$0
20									
21					Weekly Project Cost	$90,000	$90,000	$80,000	$80,000
22					Cumulative Project Cost	$90,000	$180,000	$260,000	$340,000

	B	E	W	X	Y	Z	AA	AB	AC	AD	AE
4		Start	Week	Week	Week	Week	Week	Week	Week	Week	Week
5	Activity	Time	17	18	19	20	21	22	23	24	25
6	A	0	$0	$0	$0	$0	$0	$0	$0	$0	$0
7	B	2	$0	$0	$0	$0	$0	$0	$0	$0	$0
8	C	6	$0	$0	$0	$0	$0	$0	$0	$0	$0
9	D	20	$0	$0	$0	$0	$43,333	$43,333	$43,333	$43,333	$43,333
10	E	16	$102,500	$102,500	$102,500	$102,500	$0	$0	$0	$0	$0
11	F	20	$0	$0	$0	$0	$36,000	$36,000	$36,000	$36,000	$36,000
12	G	26	$0	$0	$0	$0	$0	$0	$0	$0	$0
13	H	33	$0	$0	$0	$0	$0	$0	$0	$0	$0
14	I	18	$0	$0	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000
15	J	25	$0	$0	$0	$0	$0	$0	$0	$0	$0
16	K	34	$0	$0	$0	$0	$0	$0	$0	$0	$0
17	L	33	$0	$0	$0	$0	$0	$0	$0	$0	$0
18	M	42	$0	$0	$0	$0	$0	$0	$0	$0	$0
19	N	38	$0	$0	$0	$0	$0	$0	$0	$0	$0
20											
21			$102,500	$102,500	$132,500	$132,500	$109,333	$109,333	$109,333	$109,333	$109,333
22			$1,222,500	$1,325,000	$1,457,500	$1,590,000	$1,699,333	$1,808,667	$1,918,000	$2,027,333	$2,136,667

These tables show the amount of money Mr. Perty will need to cover each week's expenses as well as the total cumulative amount if we assume the **Project will stick to this Latest Start Time schedule.**

Cumulative Project Costs



- Temporary Savings can be achieved by postponing start times
  - Helpful if Company is incurring cash shortages
  - Postponing would remove latitude for avoiding delays in completion of entire Project.
- End Cost is the same
- Shaded Area= feasible budgets
- Provides best forecast of Project costs per week
- Chosen Best Forecast = Budget

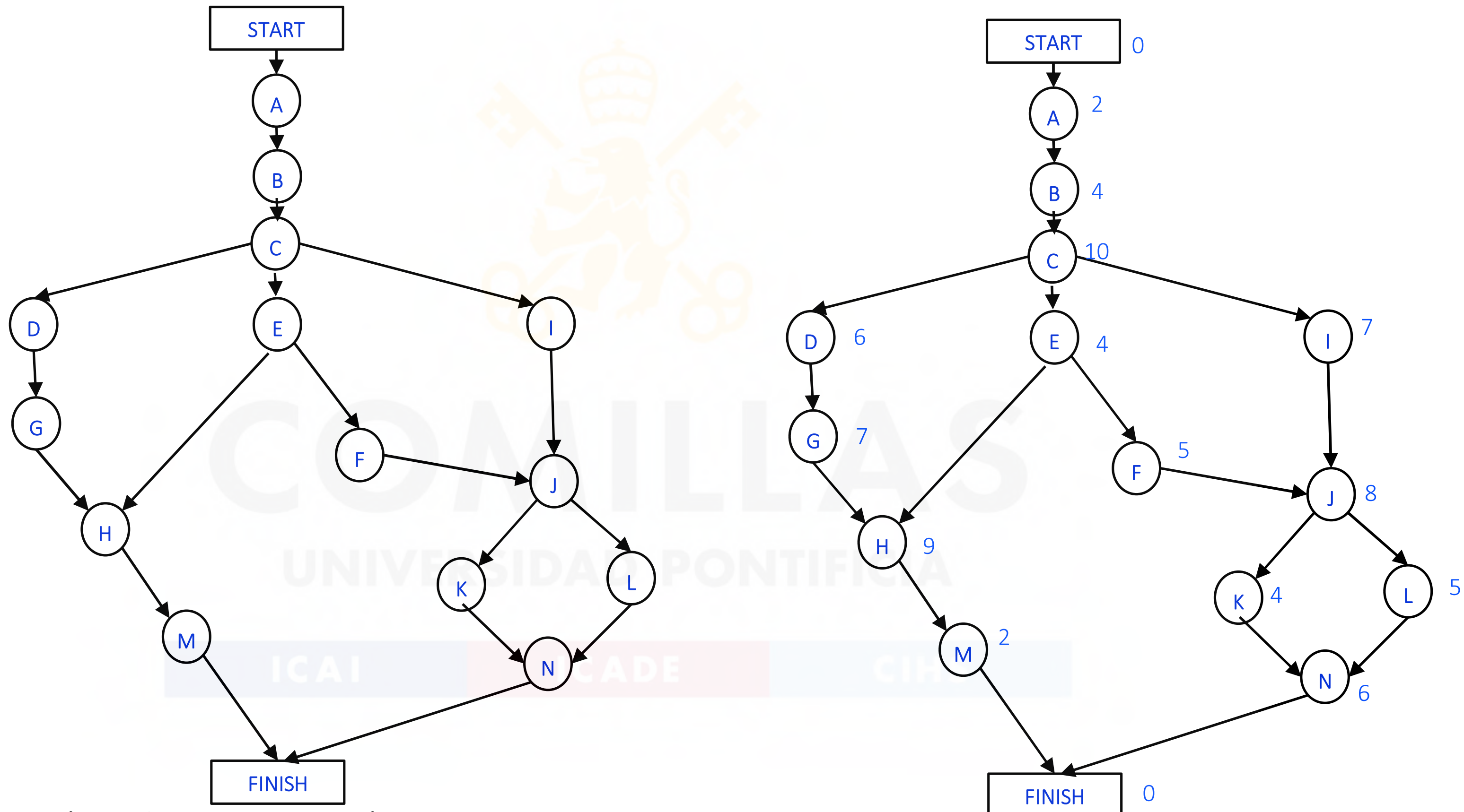
PERT/Cost Report after Week 22

We must constantly update our cost reports.

Activity	Budgeted Cost	Percent Completed	Value Completed	Actual Cost to Date	Cost Overrun to Date
A	$180,000	100%	$180,000	$200,000	$20,000
B	320,000	100	320,000	330,000	10,000
C	620,000	100	620,000	600,000	–20,000
D	260,000	75	195,000	200,000	5,000
E	410,000	100	410,000	400,000	–10,000
F	180,000	25	45,000	60,000	15,000
I	210,000	50	105,000	130,000	25,000
Total	$2,180,000		$1,875,000	$1,920,000	$45,000

Value Completed = Budgeted Cost x Percent Completed

Cost Overrun to Date = Actual Cost to Date – Value Completed


START
A
B
C
D
E
I
G
F
J
H
K
L
M
N
FINISH
START 0
A 2
B 4
C 10
D 6
E 4
I 7
G 7
F 5
J 8
H 9
K 4
L 5
M 2
N 6
FINISH 0