CRITICAL-PATH ANALYSIS FOR NETWORK SCHEDULING

From studying this section, you will be able to:

- Perform CPM and PDM analyses for AOA and AON networks;
- Calculate the early / late times that an activity can start / finish;
- Determine the total project duration, activity floats, and the path of critical activities;
- Represent the schedule using Bar charts (Gantt charts);
- Use Microsoft Project Software to schedule projects; and
- Experiment with a spreadsheet model for network analysis.

Scheduling = Planning + Time.

The schedule is very important for the contractor to know when and how much labor is needed; vendors to know when to deliver materials; and subcontractors to know when they can do their work.

Critical-Path Method (CPM) for AOA Networks

The CPM is a systematic scheduling method for AOA network. The CPM involves 4 main steps:
- A forward pass to determine activities early-start times;
- A backward pass to determine activities late-finish times;
- Float calculations; and
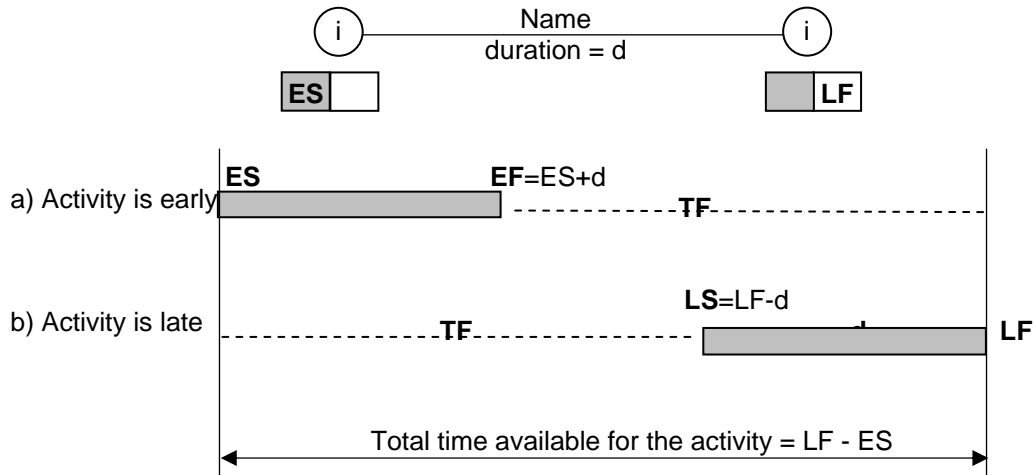- Identifying critical activities.

Forward Pass & Backward Pass

The forward pass determines the early-start times of activities, while the backward pass determines the late-finish (LF) times.
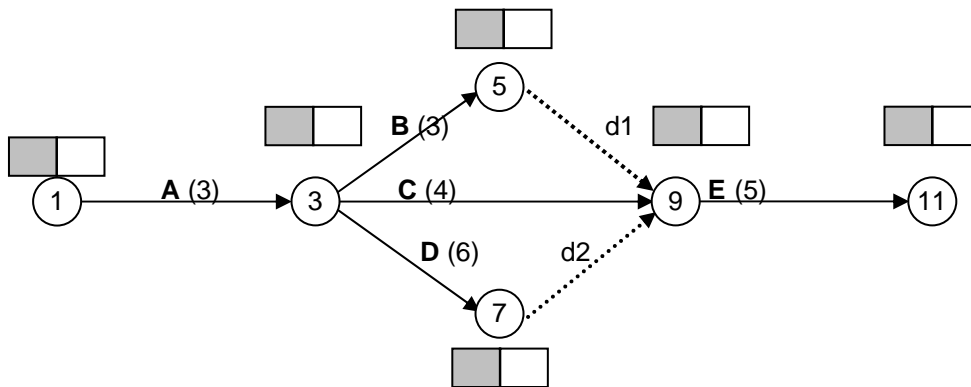
Float Calculations

Activity	Duration (d)	Results of Forward & Backward Pass		Calculations of Other Activity Times		Total Float & Criticality Calculations	
		(ES)	(LF)	LS = LF - d	EF = ES + d	TF = LF- ES - d	Critical (Y/N)
A	3						
B	3						
C	4						
D	6						
E	5						

Total Float (TF) = Total Slack = LF – EF = LS – ES = LF – ES – d

Another type of float often used in network analysis is the Free Float, which can be calculated as:

Free Float = Es (of succeeding activity) – EF (of activity in question)

The free float defines the amount of time that an activity can be delayed without taking float away from any other activity. With free float available for an activity, a project manager knows that the float can be used without changes the status of any non-critical activity to become critical.
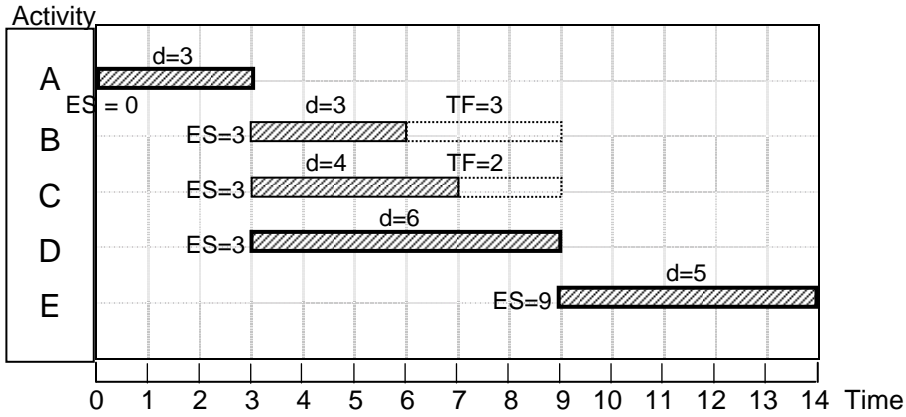
Identifying Critical Activities

Critical activities are the ones having TF = 0. They form a continuous path of the critical activities that is the longest in the network (Critical Path).

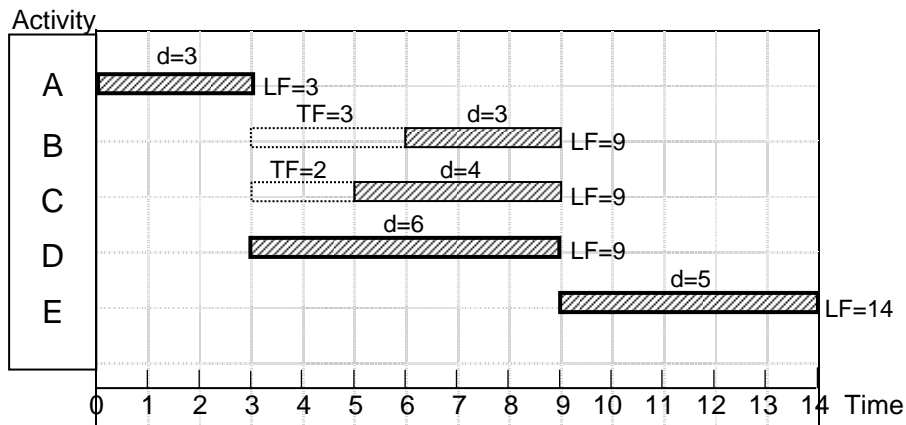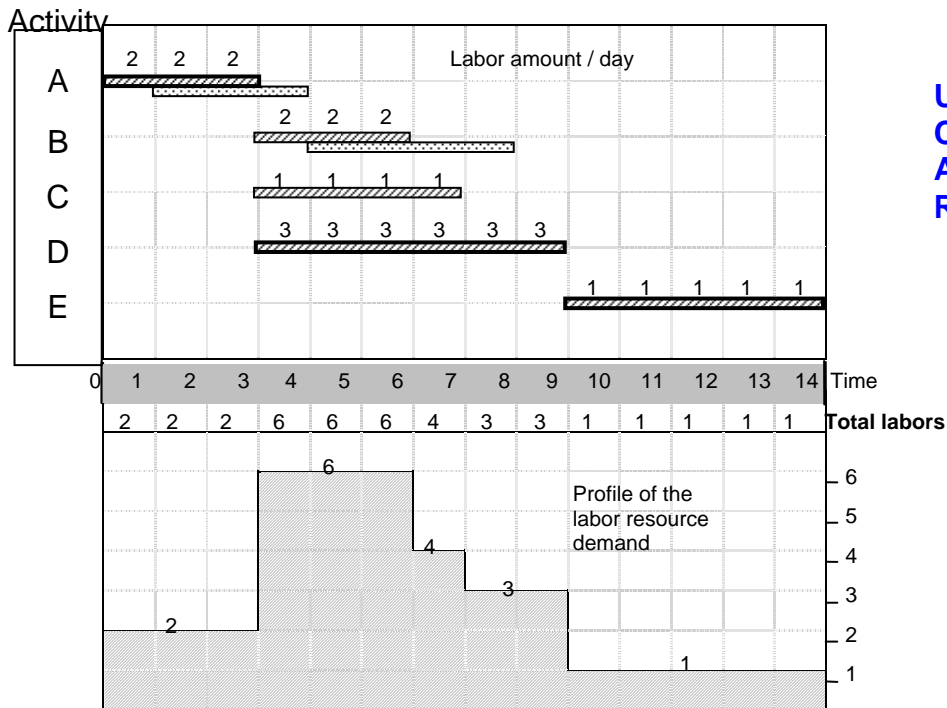## Precedence Diagram Method (PDM) for AON Networks
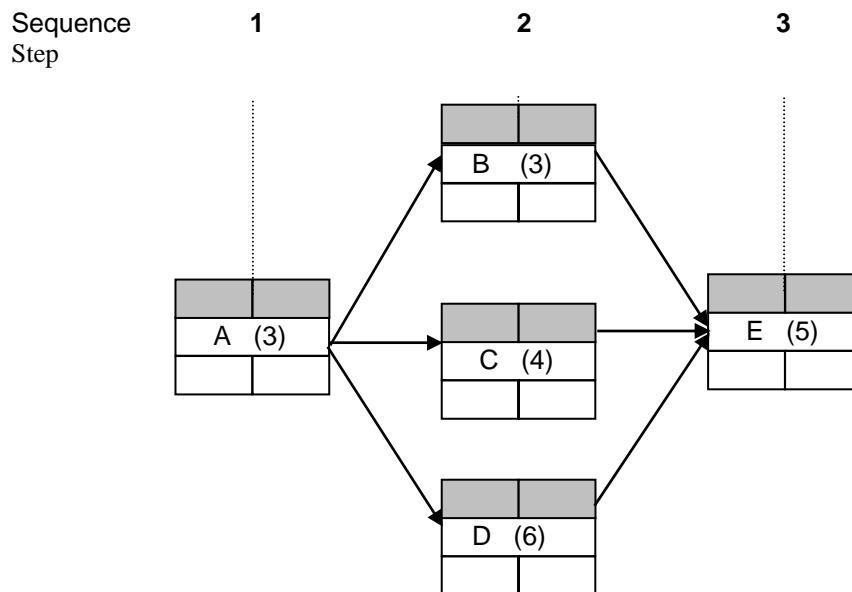
Schedule Presentation

Early Bar Chart

Late Bar Chart

Using Bar Chart to Accumulate Resources

Example
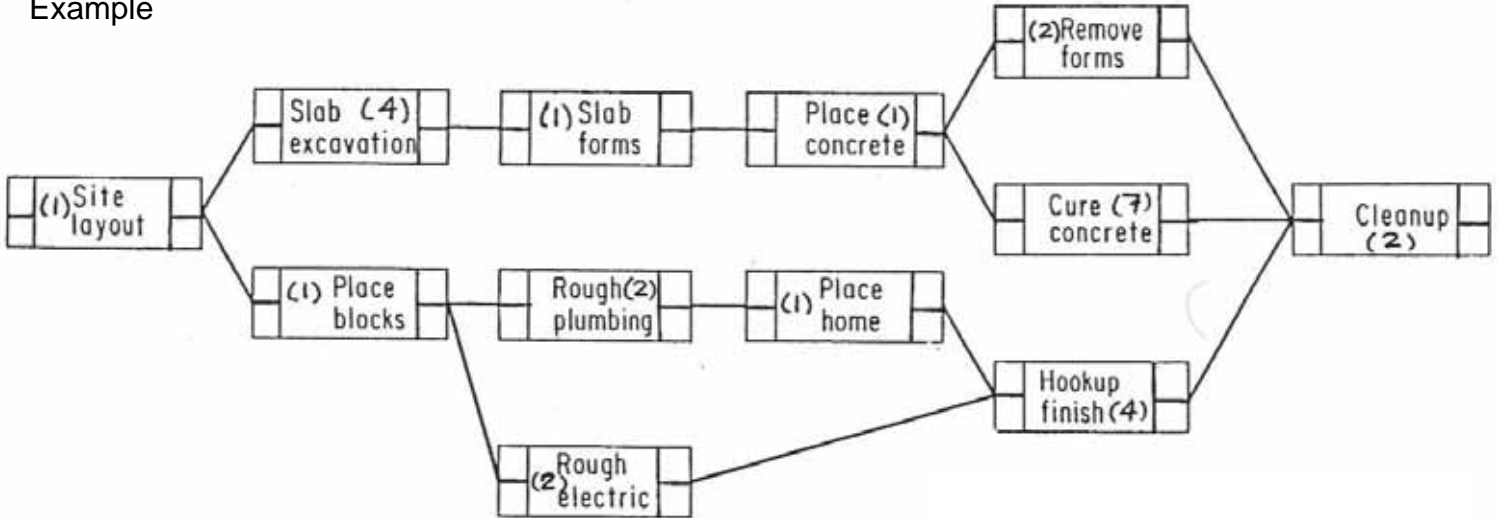
Solved Example

Perform PDM calculations for the small AON network shown here. Pay special attention to the different relationships and the lag times shown on them.
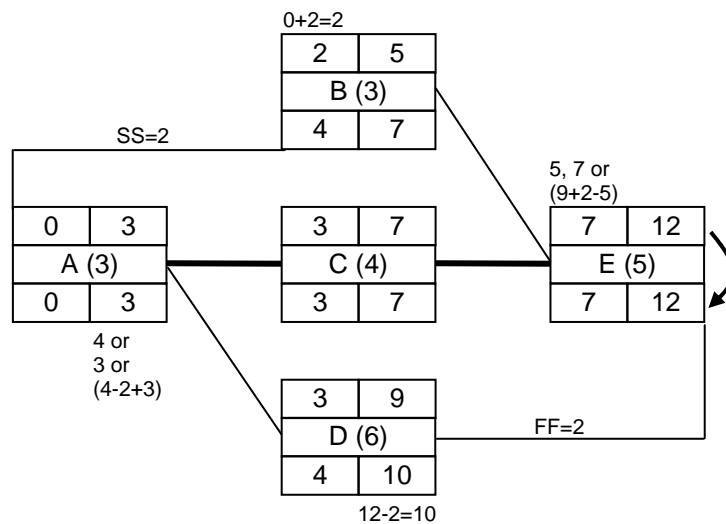
Criticisms to Network Techniques

- Assume all required resources are available
- Can result in large resource fluctuations
- Ignore project deadline
- Ignore project costs
- Use deterministic durations
- Do not consider realistic productivity factors

Back to Our Case Study Project

We need to do the following:
- Calculate ES, LF, & TF for all activities. Identify critical ones. Draw a Late Bar Chart for the project.
- What is the effect of delaying activity H by two days on project duration?
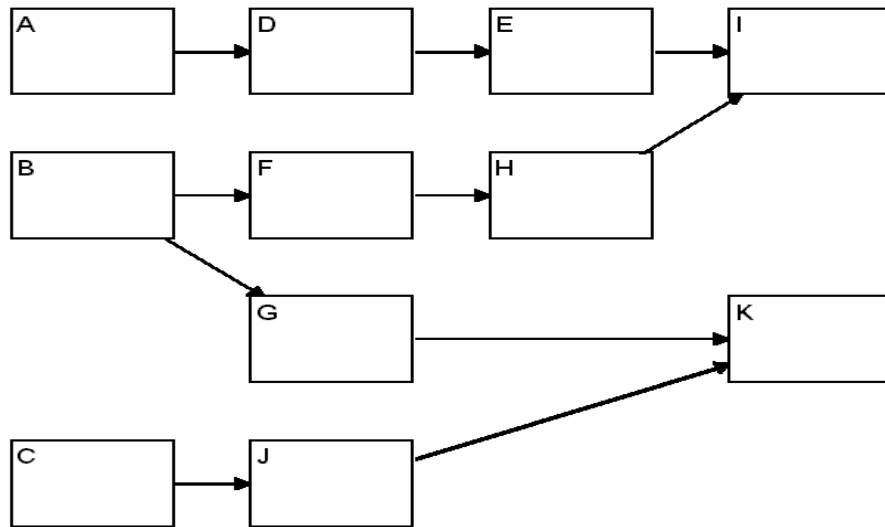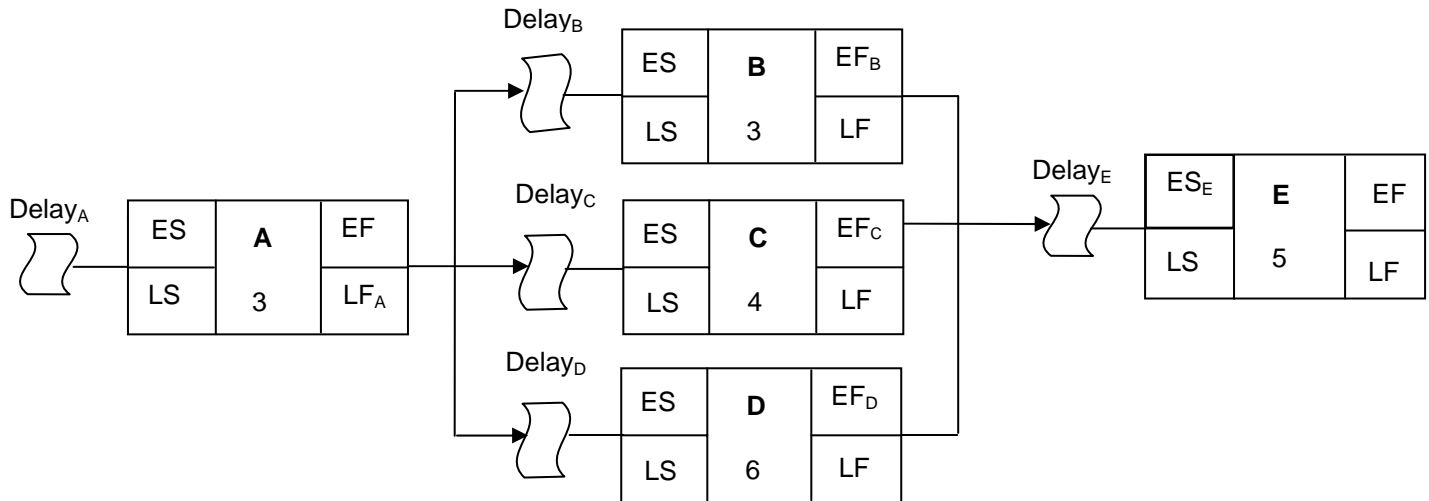

Solution:

Activity	Duration	ES	LF	TF=LF-ES-d	Critical
A	4				
B	6				
C	2				
D	8				
E	4				
F	10				
G	16				
H	8				
I	6				
J	6				
K	10				

ACTIVITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
A																																
B																																
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Critical Path Model on a Spreadsheet

The spreadsheet file ("**CPM.xls**") represents a template for CPM analysis with one row for each activity. The data for an activity are represented in columns. The shaded cells include formulas while the white cells are user inputs pertaining to the activity ID, Name, Duration, Cost, IDs of 3 predecessors, IDs of 3 successors, and a Delay value. The total project duration (32 days) is also included in a separate cell at the top of the spreadsheet.

ID	Name	Activity Duration	Cost x$1,000	P1	P2	P3	S1	S2	S3	Delay	F1	F2	F3	T1	T2	T3	ES	EF	LS	LF	TF
1	A	4					4							14	32	32		4	10	14	10
2	B	6					6	7						8	6	32		6		6	
3	C	2					10							16	32	32		2	14	16	14
4	D	8		1			5				4			22	32	32	4	12	14	22	10
5	E	4		4			9				12			26	32	32	12	16	22	26	10
6	F	10		2			8				6			18	32	32	6	16	8	18	2
7	G	16		2			11				6			22	32	32	6	22	6	22	
8	H	8		6			9				16			26	32	32	16	24	18	26	2
9	I	6		5	8						16	24		32	32	32	24	30	26	32	2
10	J	6		3			11				2			22	32	32	2	8	16	22	14
11	K	10		7	10						22	8		32	32	32	22	32	22	32	

Duration = 32.0 days

Predec-cessors / Succ-essors / CPM Calculations

Notes:
- Shaded and colored cells are lables or include formulas and calculations. White cells are user inputs.
- Cell "C1" is named "**dur**"
- The whole data range (A4:V14) is named "**data**"

Sheets: CPM / CPM-BarChart / CPM-Res1 / CPM-Res2 / CPM-Res-TCT / Schedule

Any change in the duration of any activity or the logical relationships automatically changes the project duration along with all the CPM data regarding the activities' early and late times as well as the total floats, which identify critical and non-critical activities. Experiment with different option and see their impact on the schedule.

SCHEDULING REPETITIVE & LINEAR PROJECTS

Repetitive Projects: Highways, Multiple Houses, Multiple Bridge Maintenance, etc.

Characteristics: Multiple locations, complex, many resources

Challenges:
- Crew Work Continuity
- Learning Phenomenon
- Representing the large amount of data
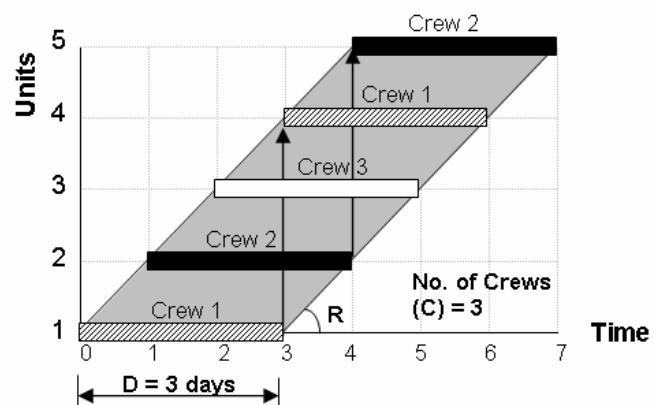
New Representation:
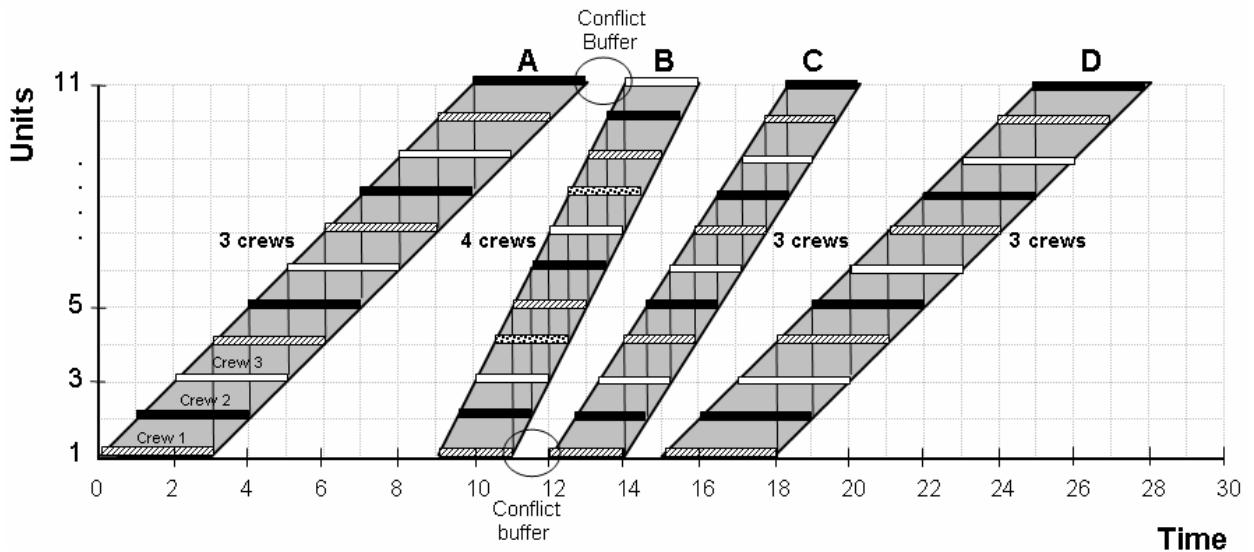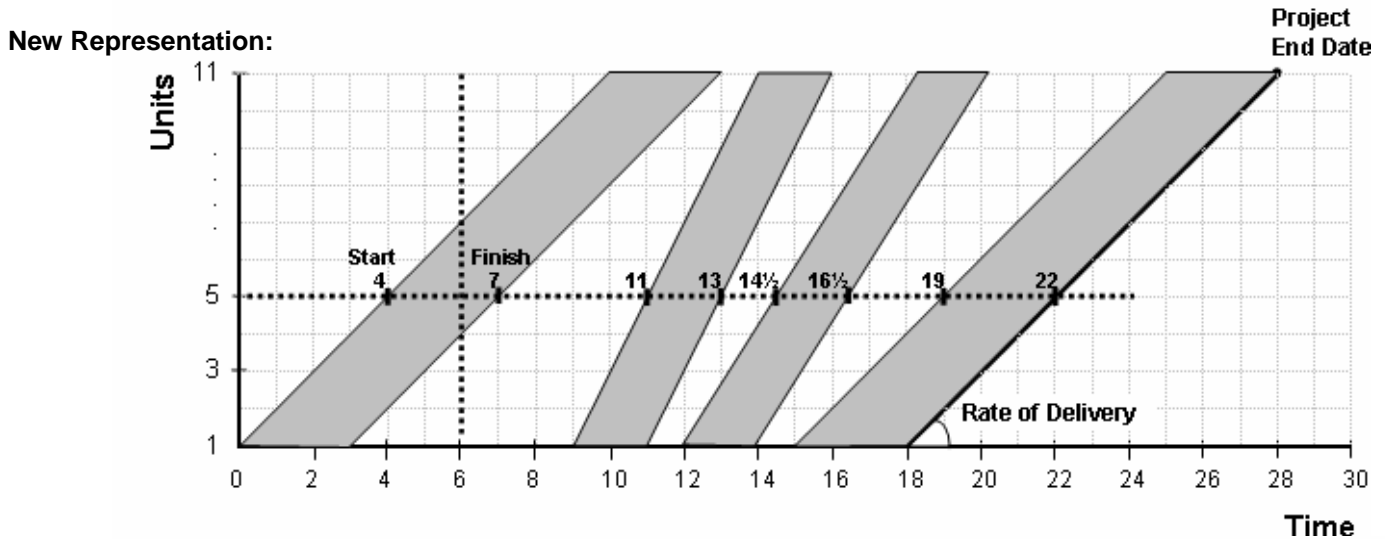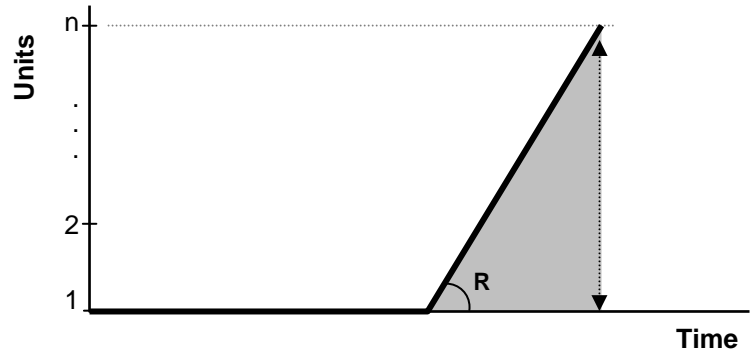

How to Design the Schedule:

- How many crews needed to meet deadline?
- How to arrange the crew assignment to maintain work continuity?

Crew Synchronization Calculations:

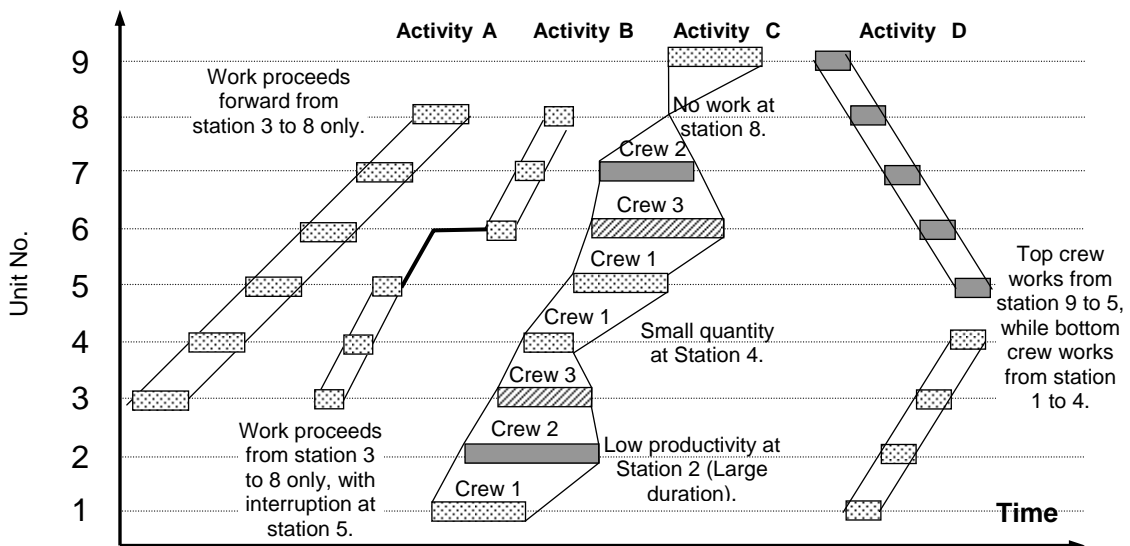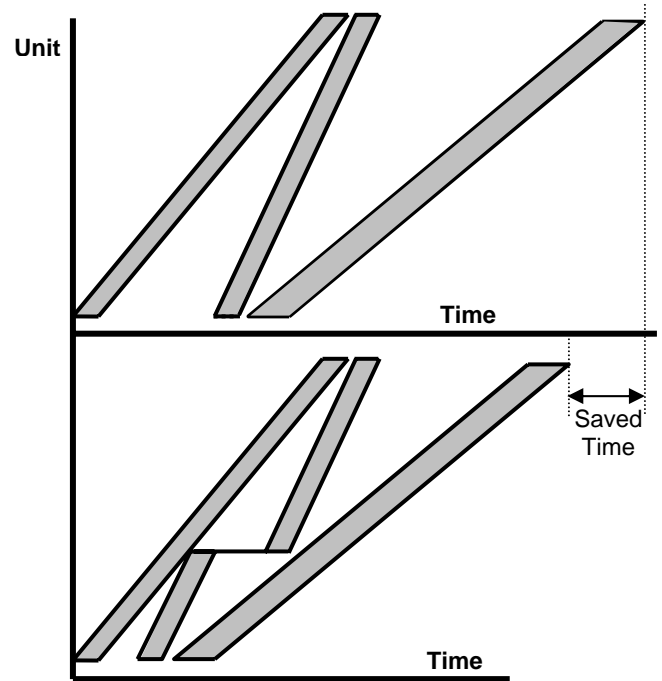$$\text{Crews } (\mathbf{C}) = (\mathbf{D}) \times (\mathbf{R})$$

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Calculating a Desired Progress Rate (R):

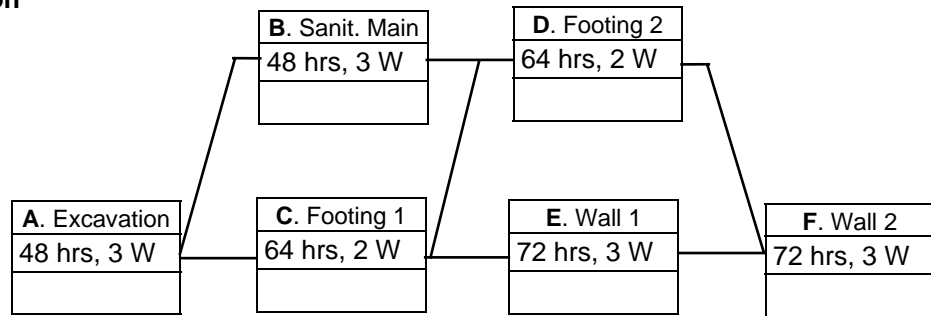## Advanced Scheduling Options

1. Use of interruption to save project time
2. Each activity has up to 3 methods of construction (e.g., normal work, overtime, or subcontractor) with associated time, cost, and crew constraints. The model can then be used to select the proper combination of methods that meet the deadline, cost, and crew constraints;
3. Activities can have non-standard durations and costs at selected units; and
4. Conditional methods of construction can be specified by the user.

Activity A — Work proceeds forward from station 3 to 8 only.

Work proceeds from station 3 to 8 only, with interruption at station 5.

Activity B — Crew 2, Crew 3, Crew 1, Crew 1, Crew 3, Crew 2, Crew 1

Low productivity at Station 2 (Large duration).

Activity C — No work at station 8. Small quantity at Station 4.

Activity D — Top crew works from station 9 to 5, while bottom crew works from station 1 to 4.

Example:

For this small project, the work hours and the number of workers for each activity are shown. if you are to construct these tasks for **5 houses in 21 days**, calculate the number of crews that need in each activity. Draw the schedule and show when each crew enters and leaves the site. **Use EasyPlan & compare your solution**.
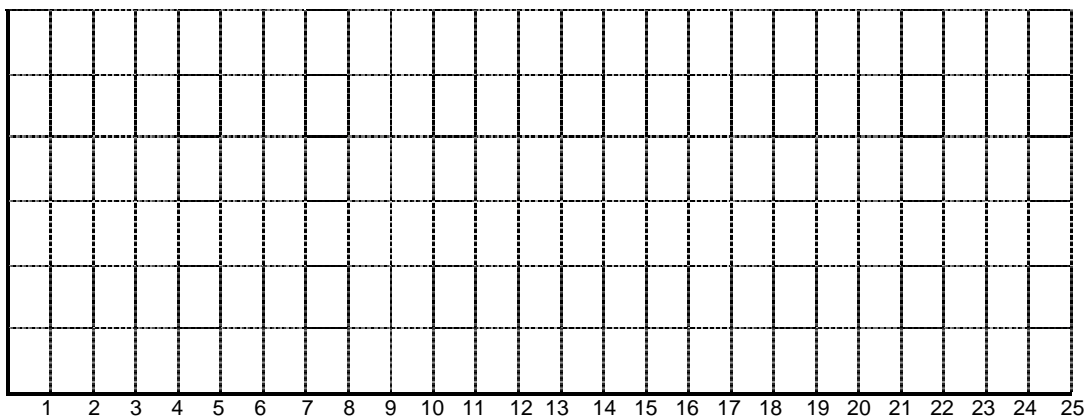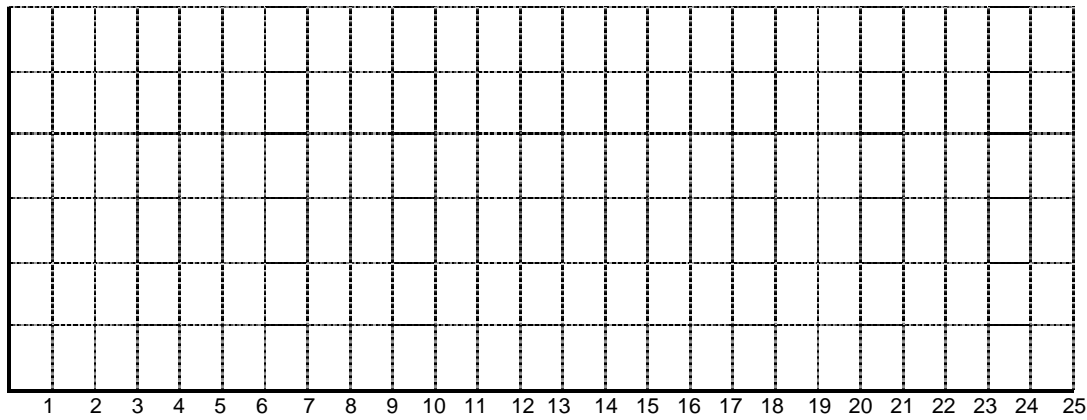
Step 1: CPM Calculation

B. Sanit. Main		**D**. Footing 2
48 hrs, 3 W		64 hrs, 2 W

A. Excavation	**C**. Footing 1	**E**. Wall 1	**F**. Wall 2
48 hrs, 3 W	64 hrs, 2 W	72 hrs, 3 W	72 hrs, 3 W

Step 2: LOB Calculations   Deadline $T_L = 21$; $T_1 =$ ___ ; $n = 5$

Activity	Duration (D)	Total Float (TF)	Desired Rate (R) $(n-1) / (T_L - T_1 + TF)$	Min. Crews (C) = D x R	Actual Crews (C_a)	Actual Rate (R_a) = C_a / D
A						
B						
C						
D						
E						
F						

Step 3: Draw the Schedule

Draw the critical path

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

Assume:

- Same no. of Crews

- Activity A in unit 2 has double the duration

- Unit 4 does not need excavation

Back to the Case Study Project

onsider that the project involves 5 typical units. The owner wants the contractor to finish all the work in 50 days. Compare manual solution to that of EasyPlan.

A(4)   F(10)   K(10)

B(6)   G(16)

C(2)   H(8)

D(8)   I(6)

E(4)   J(6)
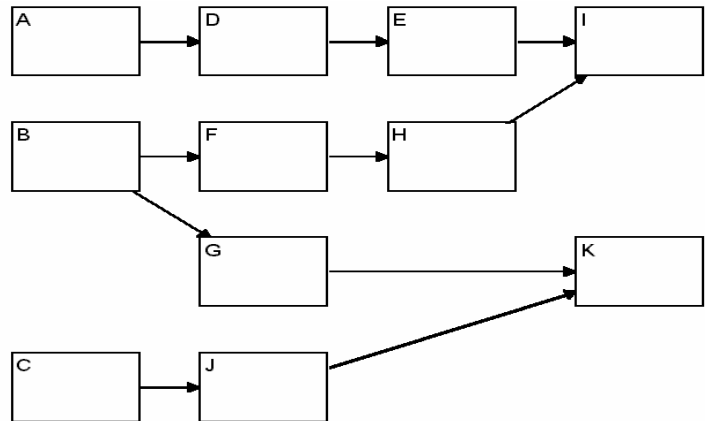
**Step 1:   CPM Calculations**

Step 2:   LOB Calculations

Activity	Activity Duration (D)	Total Float (TF)	Desired Rate (R) = (n-1) / (T_L-T_1+TF)	Required Crews (C) = D x R	Actual Crews (C_a)	Actual Rate (R_a) = C_a / D
A	4	10	0.143	0.572	1	0.25
*B	**6**	**0**	**0.222**	**1.332**	**2**	**0.333**
C	2	14	0.125	0.250	1	0.5
D	8	10	0.143	1.144	2	0.25
E	4	10	0.143	0.572	1	0.25
F	10	2	0.200	2	2	0.2
*G	**16**	**0**	**0.222**	**3.552**	**4**	**0.25**
H	8	2	0.200	1.6	2	0.25
I	6	2	0.200	1.2	2	0.333
J	6	14	0.125	0.75	1	0.167
*K	**10**	**0**	**0.222**	**2.22**	**3**	**0.3**

T_L = deadline duration = 50 days; T_1 = CPM duration of a single unit; * = Critical activity
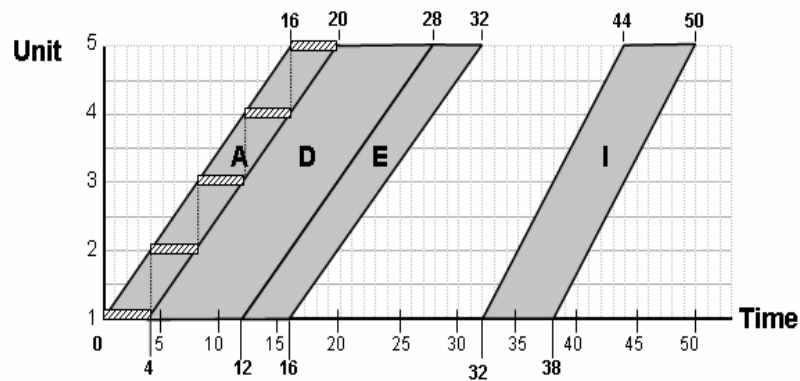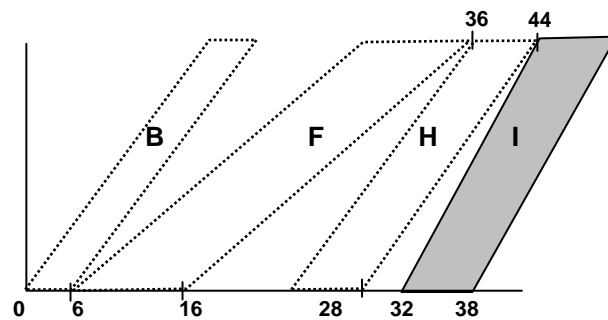
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Step 3:   Draw the Schedule
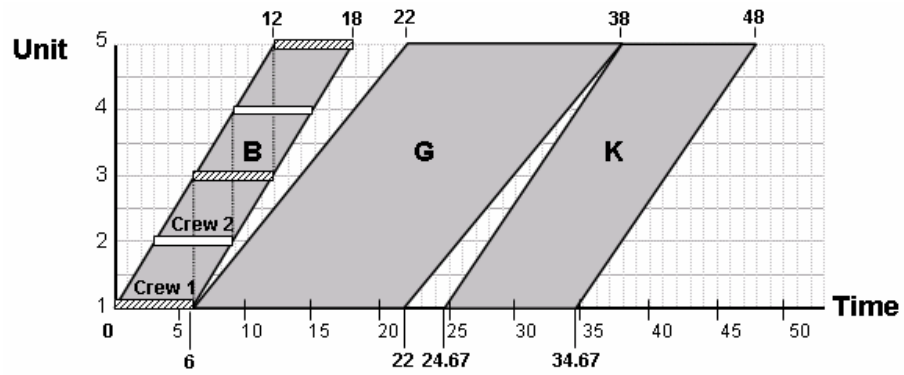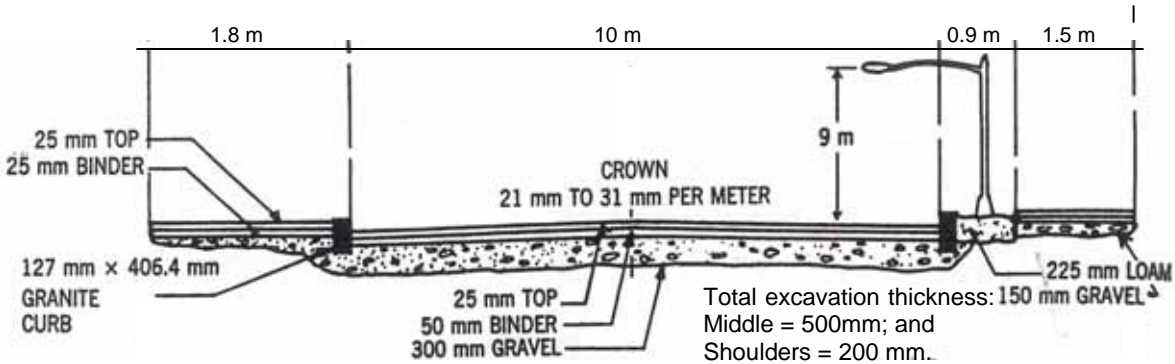

The Critical Path B-G-K
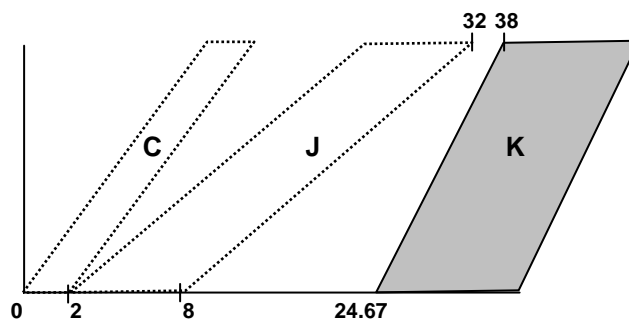
Path C-J-K

Path A-D-E-I

Path B-F-H-I

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A three-kilometer highway stretch is divided to ten sections for planning purposes. Each section is 300 meters. The cross section is shown below along with activities' details.

Activities' estimates are as follows:

Activity	Estimate 1		Estimate 2		Estimate 3	
	Cost ($)	Time (days)	Cost ($)	Time (days)	Cost ($)	Time (days)
1. Excavation	21,000	3	30,000	2	----	----
2. Sub-base	7,800	2	----	----	----	----
3. Base	72,000	10	80,000	8	100,000	5
4. Binder	30,000	1.2	----	----	----	----
5. Asphalt	14,400	1	----	----	----	----
6. Curbs	31,200	2	38,000	1	----	----
7. Lighting	19,245	2	25,000	1	----	----
8. Sidewalks	10,950	2	----	----	----	----

The logical relationships are shown. Also, for all activities, seasonal productivity factors are: Winter = 0.65; Spring = 1.0; and Fall = 0.85.

Requirements:

- Use the Repetitive Schedule feature of EasyPlan to develop an optimum schedule.

- Deadline = 30 days and the project starts June 1, 2006.

- How will your plan differ if you start the whole project on Feb. 1, 2006?

- How will your plan differ if you have a maximum of 3 crews for each activity?

- How will your plan differ if you start the whole project from one side as opposed to employing half the crews from each side?