1 Project Time Management

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2 Project Scheduling Basics

Henry Gantt

Henry Gantt

H. L. Gantt, A.B, M.E. (1861- 1919) was a mechanical engineer and management consultant. H. L. Gantt is most recognized for creating a visual scheduling and control diagram in the second decade of the 20th century that we know today as the Gantt chart.

Gantt charts are created to show scheduled and actual project progress. Accepted as a commonplace project management tool today, it was an innovation of world-wide importance in the 1920s, based on H. L. Gantt's work while ship building during WWI.

Gantt charts were used to schedule and control large construction projects like the Hoover Dam started in 1931 and the US interstate highway network started in 1956.

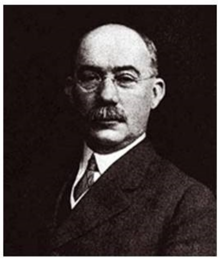
Henry Gantt Biography

Henry Gantt was born in Calvert County, Maryland, USA.

After working as a teacher and draftsman, he pursued mechanical engineering.

In 1887, he joined Frederick W. Taylor in the scientific management of Midvale Steel and Bethlehem Steel, working together there until 1893.

Later in his career he devised the 'task and bonus' method of wage payment and created methods of monitoring worker efficiency and productivity.



Henry Gantt
(1861-1919)

Basic Gantt Chart

ID	Task	Duration	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
1	A	2									
2	B	2									
3	C	4									
4	D	1									
5	E	6									
6	F	3									
7	G	2									
8	H	1									

Basic Gantt Chart - Resources

ID	Task	Duration	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
1	A	2									
2	B	2									
3	C	4									
4	D	1									
5	E	6									
6	F	3									
7	G	2									
8	H	1									

							E	F	F	G	
	Resources Levels Required			B	E	E	D	E	E	F	G
			A	A	B	C	C	C	C	E	H

		Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
						E	F	F	G	
	Resources Levels Required		B	E	E	D	E	E	F	G
		A	A	B	C	C	C	C	E	H

From the above you can very quickly see that *at least* two persons will be required for the duration of the project.

- Averaging (21 man-days/9 days) gives 2.33 persons.

So, we assign Jim & Bob to the project

Resource Allocation

ID	Task	Duration	Resource	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
1	A	2	Jim									
2	B	2	Bob									
3	C	4	Bob									
4	D	1	Jim									
5	E	6	Jim									
6	F	3	Bob									
7	G	2	Bob									
8	H	1	Jim									
								Jim	Bob	Bob	Bob	
					Bob	Jim	Jim	Jim	Jim	Jim	Bob	Bob
	Resources Levels Required			Jim	Jim	Bob	Bob	Bob	Bob	Bob	Jim	Jim
								Jim				
	Days Jim is required			Jim	Jim	Jim	Jim	Jim	Jim	Jim	Jim	Jim
									Bob	Bob	Bob	
	Days Bob is required				Bob	Bob	Bob	Bob	Bob	Bob	Bob	Bob

Resource Allocation

- Clearly we have a problem……
  - Jim is over-allocated on Day 5
  - Bob is over allocated on Days 6, 7, & 8, but not required on Day 1.
- Some of the options available:
  - Add another person for these days
  - Extend the Project
  - Change who is allocated to tasks
  - Move tasks around
  - Use Overtime or Non-Working Days (weekends)
  - Any combination of the above

Progress Tracking

- Progress can easily be tracked on a Gantt Chart by changing a colour or shading in another 'bar'

Approx 75% completion

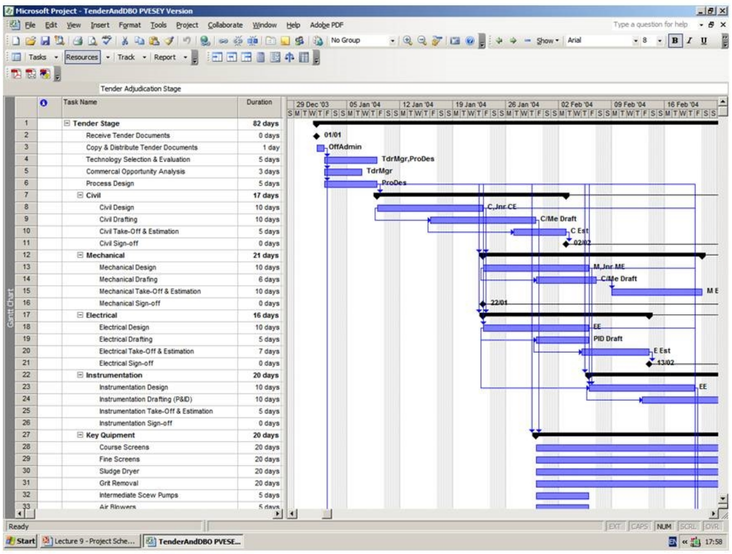
ID	Task	Duration	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9
1	A	2									
2	B	2									
3	C	4									
4	D	1									
5	E	6									
6	F	3									
7	G	2									
8	H	1									

Gantt Charts

- Advantages
  - Wide Acceptance and Popularity
  - Relatively Easy to prepare and understand
  - No 'theory' or complicated calculations required
  - Anyone can understand them
  - Can be prepared anywhere; with just a pen and some paper
  - Increases in computing power, and the availability of 'retail' project management software such as MS Project has greatly widened the usage and general acceptance of Gantt Charts

Gantt Charts

- Disadvantages
  - Lack logical representation (task relationships)
    - Why did a particular task start on a particular date
    - When attempts are made to depict these relationships, the results can be unclear
  - Bar charts may not always be practical for complex projects with large numbers of tasks
    - Software Implementation Plan
    - This can be addressed in two ways
      - Show details of critical activities only and summarize others
      - Show summary bars (a summary bar is a collection of other tasks, based on a common factor)
  - Most Software packages have addressed these issues with varying success.
    - MS Project Example Slide 11:
      - Cannot see entire plan
      - Relationships look complicated
      - Too much information?



Network Analysis

Network Analysis

- A network is a logical and chronological graphic representation of the activities of a project
- Networks are normally one of two types:
  - Arrow Networks
  - Node Networks
- Arrow Networks were popular in the 1960's and 1970's
- Precedence Diagrams (an advanced form of node diagrams) became more popular after this time
- Network Analysis is a **deterministic** method of estimating project duration
  - PERT is a probabilistic method

Arrow Networks

- Arrow networks are also called the Arrow Diagramming Method (ADM), Activity on Arrow Networks (AOA), or the I-J method
  – AOA is the most popular description; I-J is not very well known anymore

AOA Example

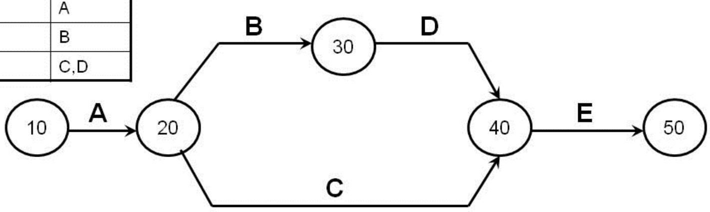
- Draw the arrow network for the project shown below

Activity	IPA
A	-
B	A
C	A
D	B
E	C,D

- IPA = Immediately Preceding Activity

Activity	IPA
A	-
B	A
C	A
D	B
E	C,D

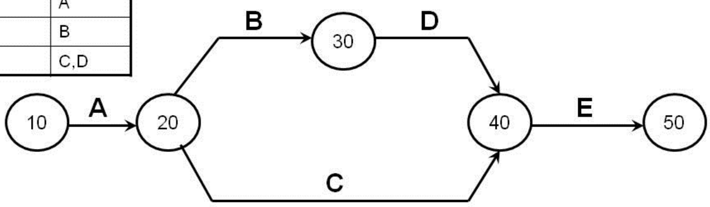
AOA Example



- Each Activity is represented by an arrow
- Each Arrow connects two nodes (shown by circles with numbers in them)
- These nodes are called the 'from node' and the 'to node'
- These nodes represent 'events'; an **event** is a point in time when an activity starts or ends
- Events of significance are called milestones; they can be a start milestone (such as authorization to proceed) or an end milestone (such as substantial completion)

Activity	IPA
A	-
B	A
C	A
D	B
E	C,D

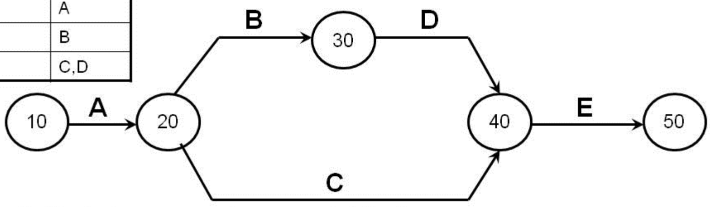
AOA Logic



- Activity A starts the project, B & C follow, but independently of each other.
- Activity D cannot start until the completion of B
- Once both C and D are complete, E can commence.
- Activity A precedes B & C; A is a **predecessor** of B & C
- Conversely, B&C are **successors** of A

Activity	IPA
A	-
B	A
C	A
D	B
E	C,D

AOA Logic

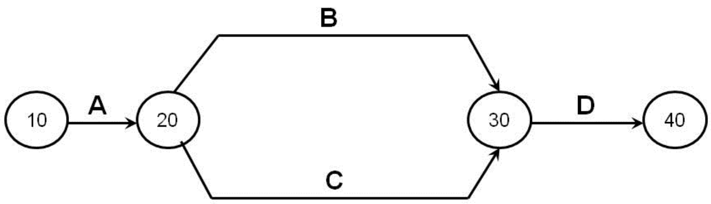


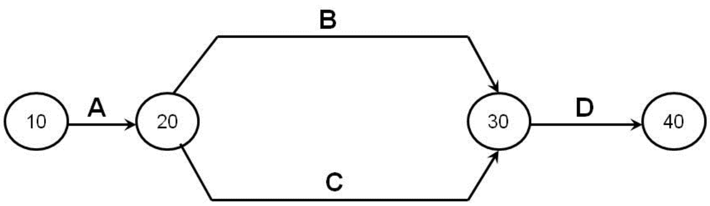
- A Node is an event or a point in time
- Node 10 represents the start of activity A;
- Node 20 the end of activity A **and** the start of activity B and activity C
- These diagrams are also called the **I-J method** because each activity can also be identified by two nodes
  - Activity C could also be identified as 20-40

AOA 'Dummy' Activities

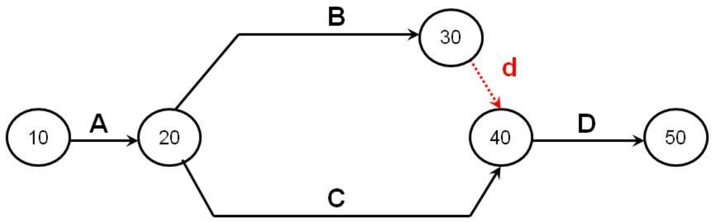
- Consider the following project

Activity	IPA
A	-
B	A
C	A
D	B, C

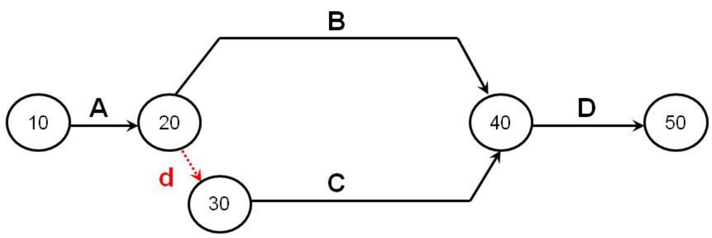


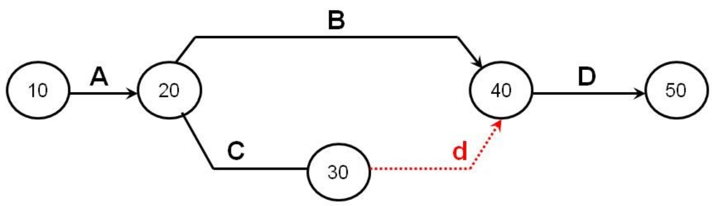


- We have a problem; both B and C start at node 20 and finish at node 30
- This means that both could be identified as 20-30.
- In order to resolve this ambiguity we insert what is known as a **dummy activity**

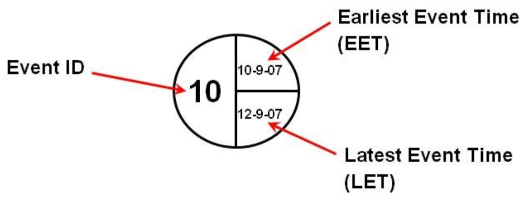


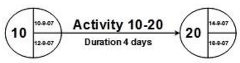
- This fictitious dummy activity ***'d'*** solves the problem of identification
  - Activity B is now 20-30 and C is 20-40
- The dummy activity d is treated, to all intents and purposes, as a real activity. It is treated in the CPM (Critical Path Method) and in computer programs as a real activity even though it is not.
- Note that the dummy activity could have been inserted in other locations to have the same effect





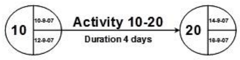
AOA with more details





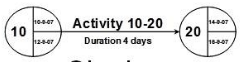
Key Terms

- Event
  - An event is a point in time
  - An event is achieved when all preceding activities with which it is connected are completed
  - It indicates that no subsequent activity can be started until that event is achieved
  - It is normally identified by a number and a circle



Key Terms

- Activity
  - An activity is an actual process or operation which leads to the completion of an event
  - In almost all cases represents the passage of time and the use of resources
  - It is represented by an arrow between the two events with which it is associated
  - The nodes can be named as the ‘from node’ and the ‘to node’; they may also be called the ‘head event’ and the ‘tail event’

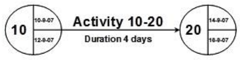


Key Terms

- Slack
  - It is the spare time on an event
    - The difference between the EET and the LET
  - For node 10 the slack is 2 days
- Float is the spare time on an activity
  - It can be considered **3 ways**
    - Total float is the maximum spare time on an activity and is the difference between the latest and earliest start (or finish) times of that activity
    - Free float is that part of the total float which does not effect subsequent activities
    - Independent Float is that part of the total float which does not affect previous or subsequent activities

Free Float = Total Float – Head Slack

Independent Float = Total Float – Head Slack – Tail Slack



Key Terms

- Dummy Activity
  - A Dummy Activity is indicated by a dotted line
  - It does not consume any resources, or time.
  - Normally, its purpose is to maintain the logic of the network
  - **However, It can sometimes be used to indicate a required delay** (such as time for concrete to cure)

3 Activity on Arrow

Basic Project Scheduling
Activity on Arrow

Project Management
Year 4

AOA and Critical Path Analysis

- Consider the Project Below

ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

AOA and Critical Path Analysis

- The first thing we need to do is to determine the events associated with each activity.
  - Insert two columns and assign I and J values

ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A		5	-
2		B		7	A
3		C		4	A
4		D		3	A
5		E		3	C
6		F		2	B
7		G		5	D
8		H		8	E,G
9		I		6	F,H

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2		B		7	A
3		C		4	A
4		D		3	A
5		E		3	C
6		F		2	B
7		G		5	D
8		H		8	E,G
9		I		6	F,H

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5		E		3	C
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4	20	D		3	A
5		E		3	C
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5		E		3	C
6	30	F		2	B
7		G		5	D
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9		I		6	F,H

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ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D		3	A
5		E		3	C
6	30	F		2	B
7		G		5	D
8		H		8	E,G
9		I		6	F,H

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6	30	F		2	B
7		G		5	D
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2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E		3	C
6	30	F		2	B
7		G		5	D
8		H		8	E,G
9		I		6	F,H

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1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E		3	C
6	30	F		2	B
7	50	G		5	D
8		H		8	E,G
9		I		6	F,H

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- The first thing we need to do is to determine the events associated with each activity.
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ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F		2	B
7	50	G		5	D
8		H		8	E,G
9		I		6	F,H

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1	10	A	20	5	-
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3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F		2	B
7	50	G		5	D
8	60	H		8	E,G
9		I		6	F,H

AOA and Critical Path Analysis

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  - Insert two columns and assign I and J values

ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G		5	D
8	60	H		8	E,G
9		I		6	F,H

AOA and Critical Path Analysis

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ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G		5	D
8	60	H		8	E,G
9	70	I		6	F,H

AOA and Critical Path Analysis

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ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60, 80	H		8	E,G
9	70	I		6	F,H

AOA and Critical Path Analysis

- The first thing we need to do is to determine the events associated with each activity.
  - Insert two columns and assign I and J values

ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
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3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60, 80	H	90	8	E,G
9	70, 90	I		6	F,H

AOA and Critical Path Analysis

- The first thing we need to do is to determine the events associated with each activity.
  - Insert two columns and assign I and J values

ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60, 80	H	90	8	E,G
9	70, 90	I	100	6	F,H

AOA and Critical Path Analysis

- We have a problem
  - H and I have two IPA's each.
  - To fix this we add dummy activities to the network

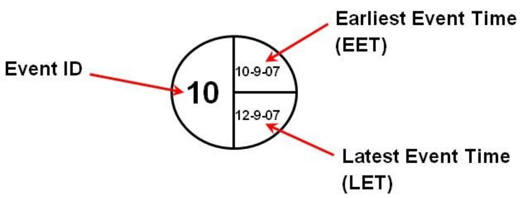
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60, 80	H	90	8	E,G
9	70, 90	I	100	6	F,H

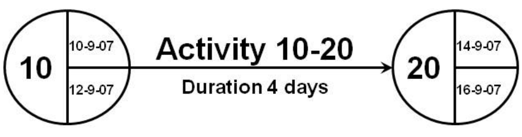
AOA and Critical Path Analysis

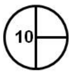
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

- In this instance we add dummy activities between the two predecessors of H and the two predecessors of I
- Check to ensure there are no ID issues associated with the network and add further dummy activities if necessary

Remember…..







ID	'I' value	Activity	'j' value	Duration	IPA
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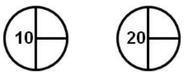
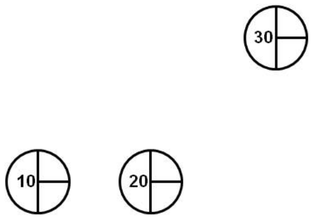
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Draw the first event and mark it off on the table



ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Then draw the next event
Hold off on drawing in the arrows for the moment



ID	'I' value	Activity	'j' value	Duration	IPA
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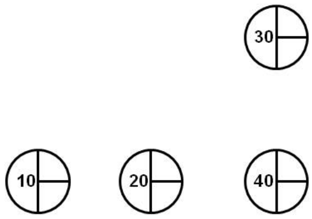
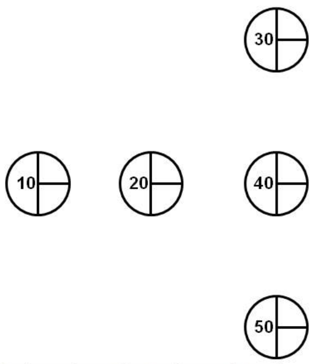
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Event 20 has three other events associated with it; so draw them in order



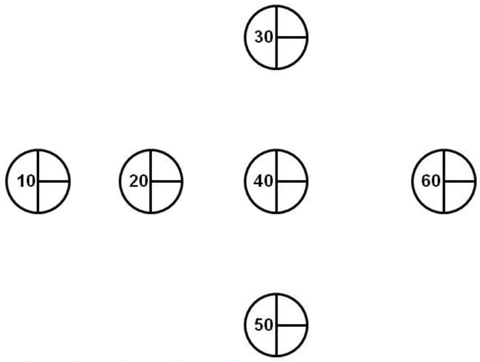
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Event 20 has three other events associated with it; so draw them in order



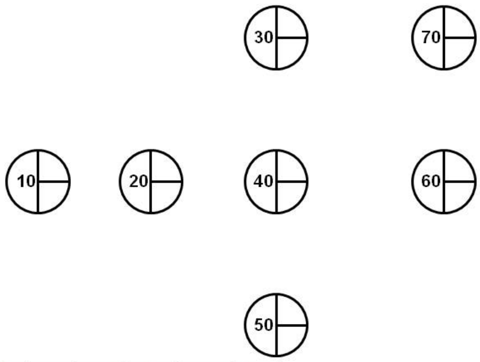
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Event 20 has three other events associated with it; so draw them in order



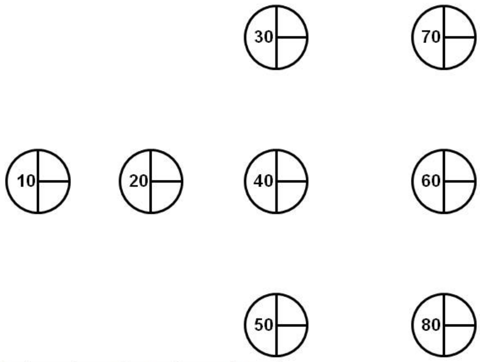
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

The next event is 60, which is preceded by 40



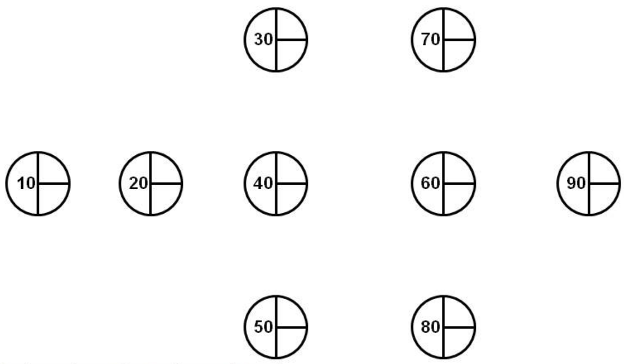
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

70 is preceded by 30



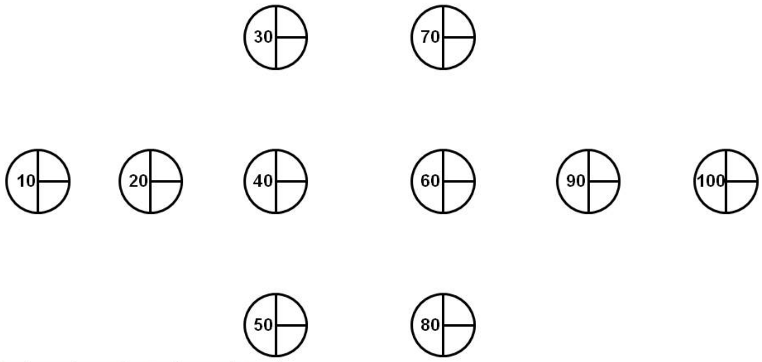
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

And 80 by 50



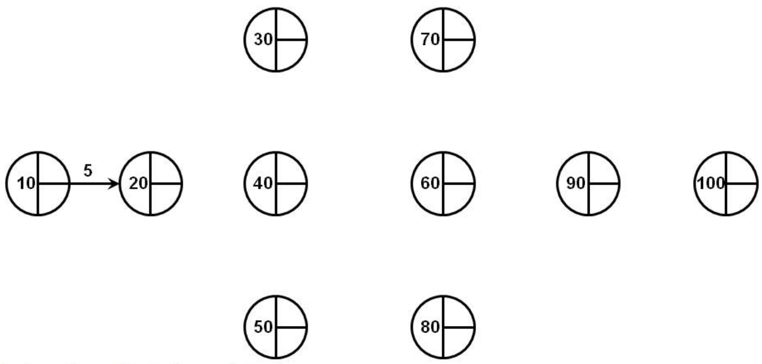
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

90 by 60



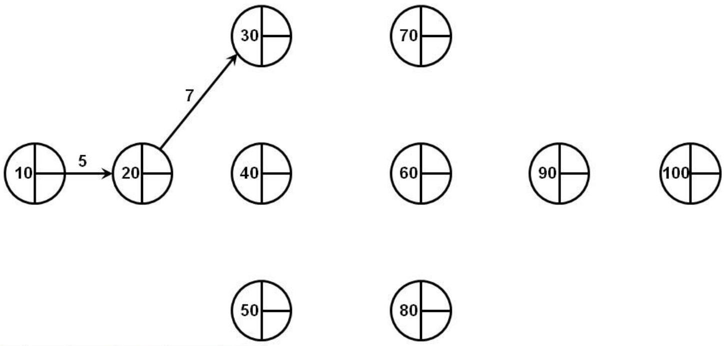
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

100 by 90



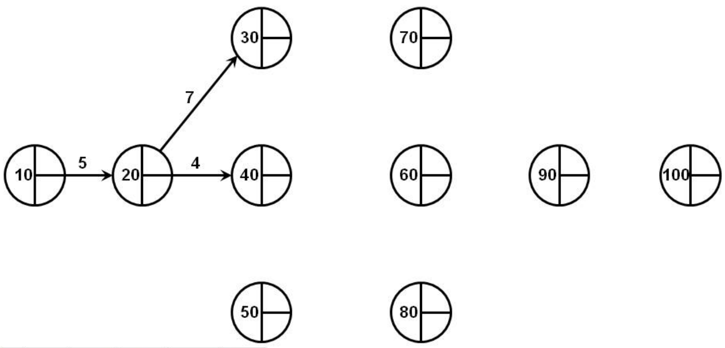
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Now draw in the arrows, and the durations associated with each



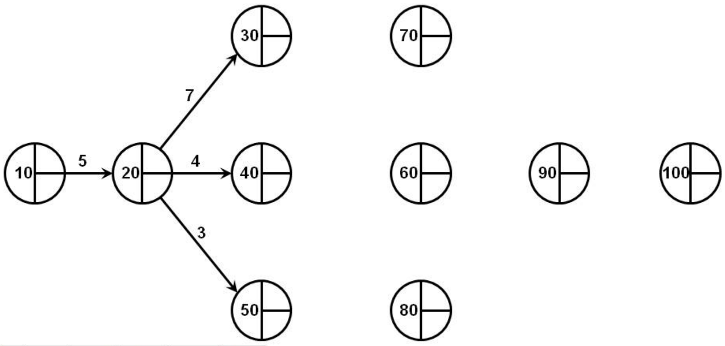
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Now draw in the arrows, and the durations associated with each



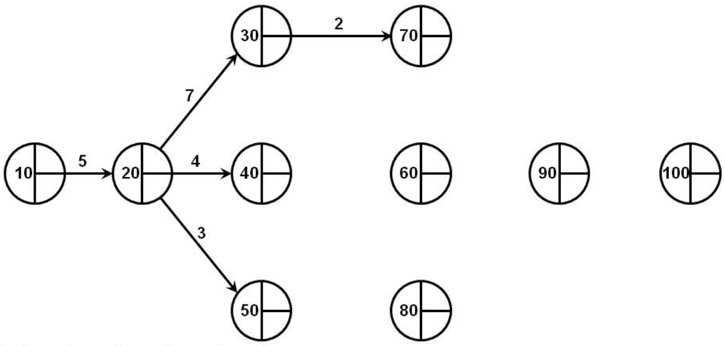
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Now draw in the arrows, and the durations associated with each



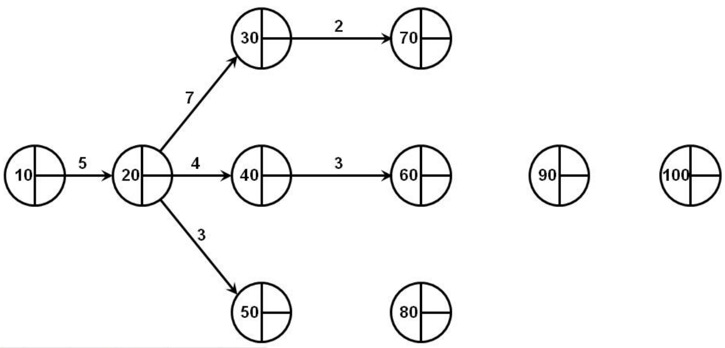
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Now draw in the arrows, and the durations associated with each



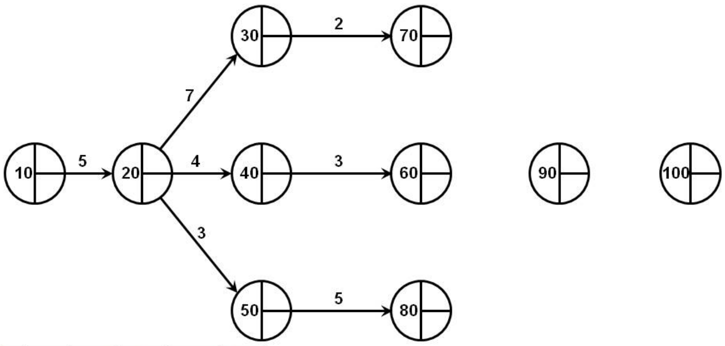
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Now draw in the arrows, and the durations associated with each



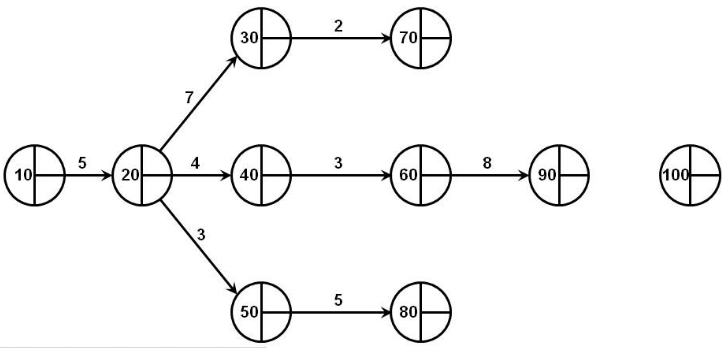
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Now draw in the arrows, and the durations associated with each



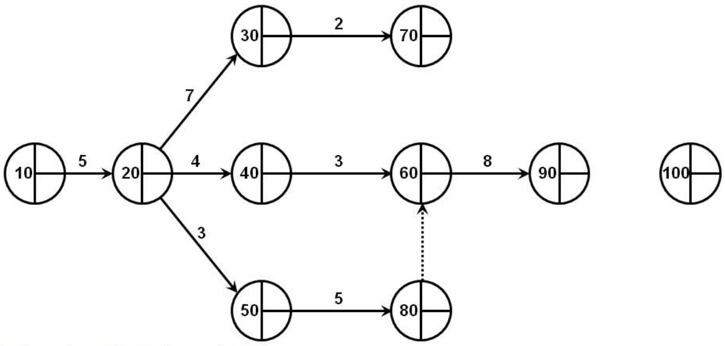
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Now draw in the arrows, and the durations associated with each



ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

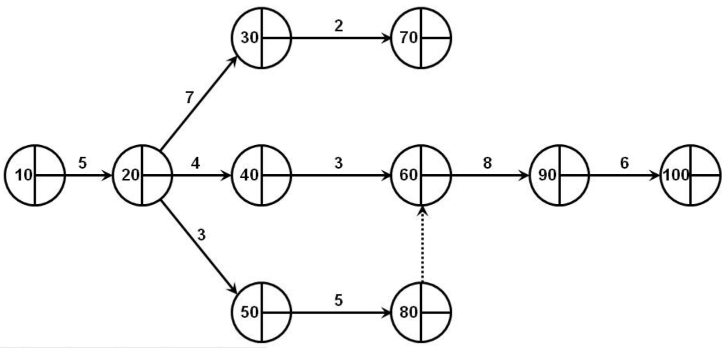
Now draw in the arrows, and the durations associated with each



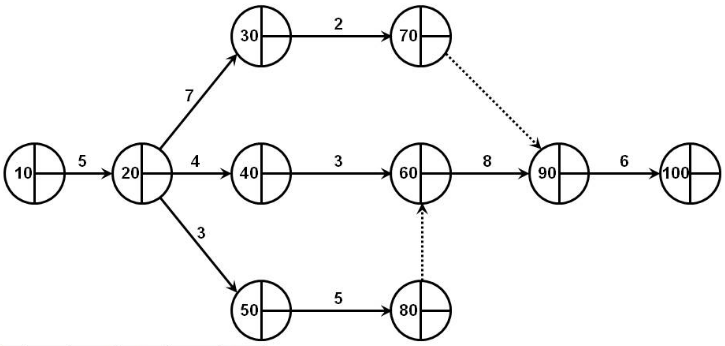
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Draw in dummy activities using a dotted line

When constructing the table we set up this task as 60-80, but logically it is 80-60, so draw it this way



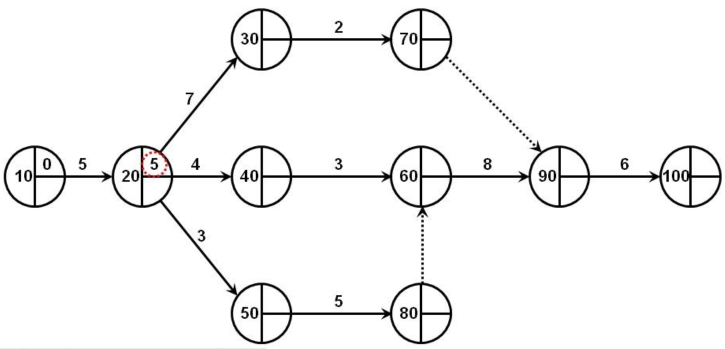
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	



ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

The final activity was 70-90

This was correct on the table



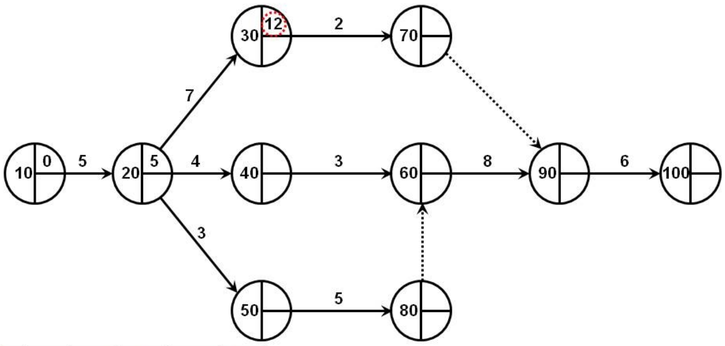
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Now we need to determine the activities EET's and LET's

We use 'End of Day' convention

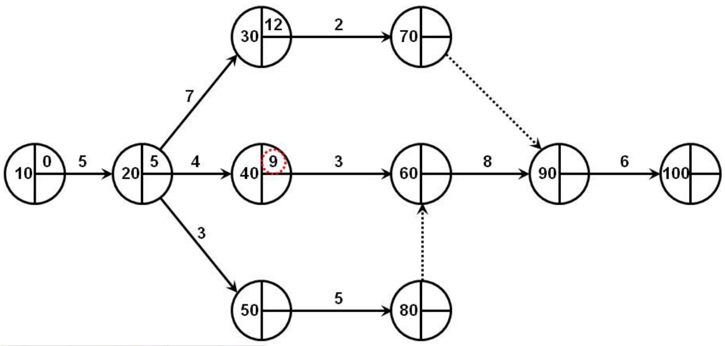
So, start of day 1, is stated as end of day 0 (Remember PERT)

Therefore 0 + 5 = 5 ; enter this in as the EET of event 20



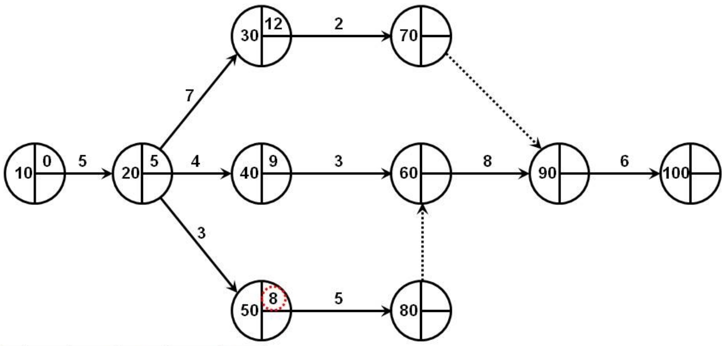
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

5 + 7 = 12



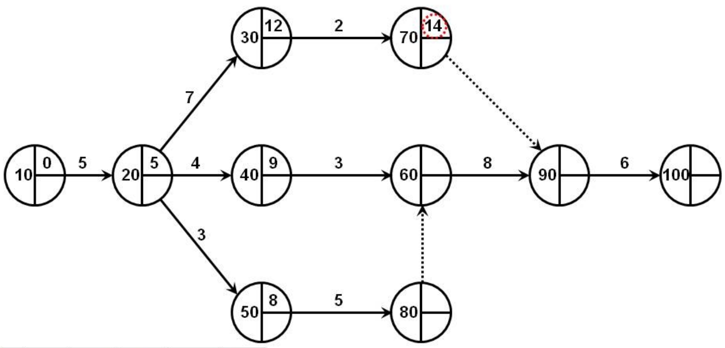
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

5 + 4 = 9



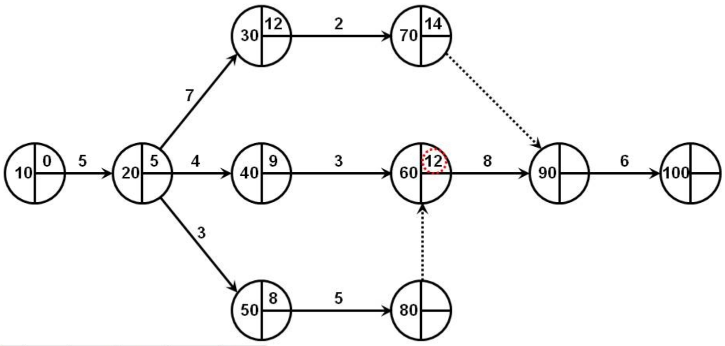
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

5 + 3 = 8



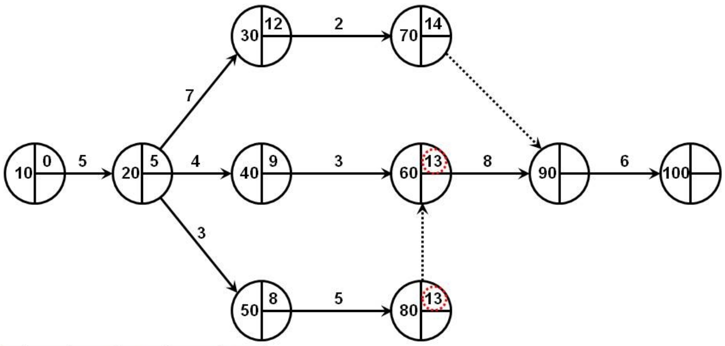
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

12 + 2 = 14



ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

$9 + 3 = 12$

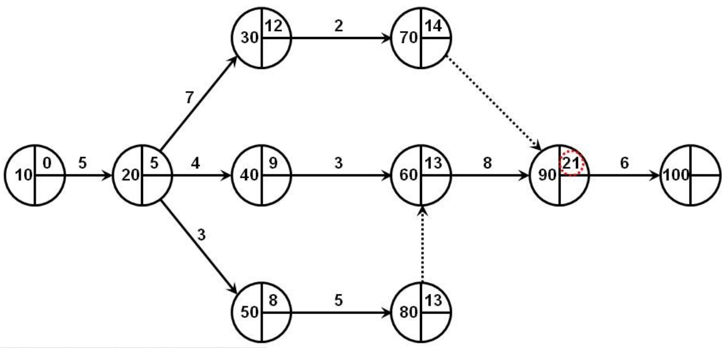


ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

8 + 5 = 13

We had previously calculated the EET of event 60 as day 12.

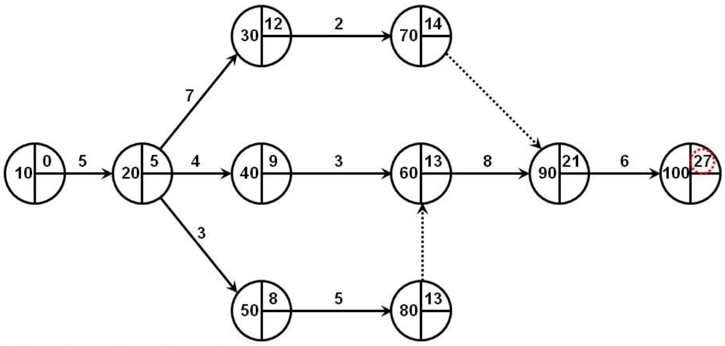
However event 80 is a predecessor of 60; 60 cannot start until 80 is completed therefore the EET of 60 needs to be changed to 13



ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Event 90 can also have two possible EET's, 14 or 21.

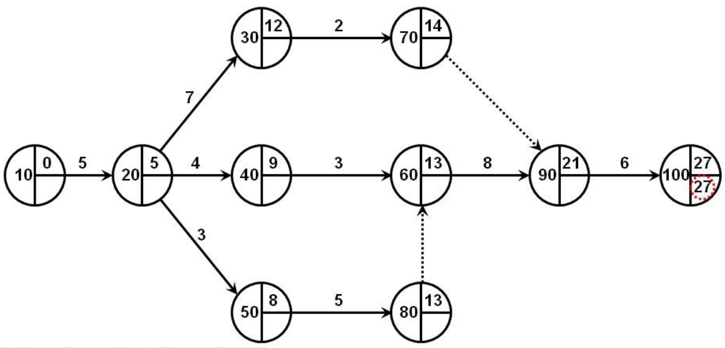
Again, we apply the rules and select Day 21



ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

21 + 6 = 27

We have now determined that the project will finish at the end of Day 27



ID	'I' value	Activity	'j' value	Duration	IPA
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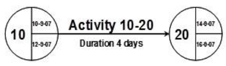
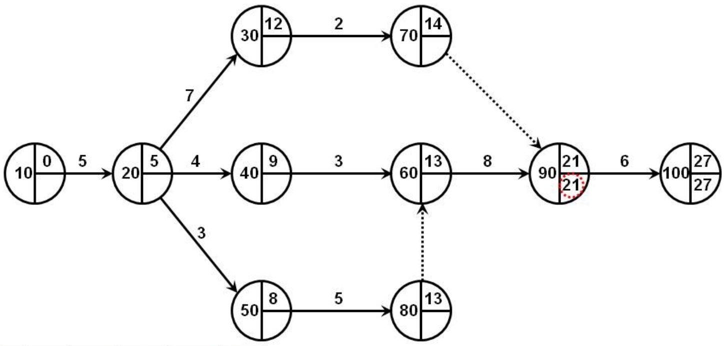
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

We now run the backwards-pass

To do this in minimum time we take the LET of event 100 as EoD 27





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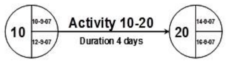
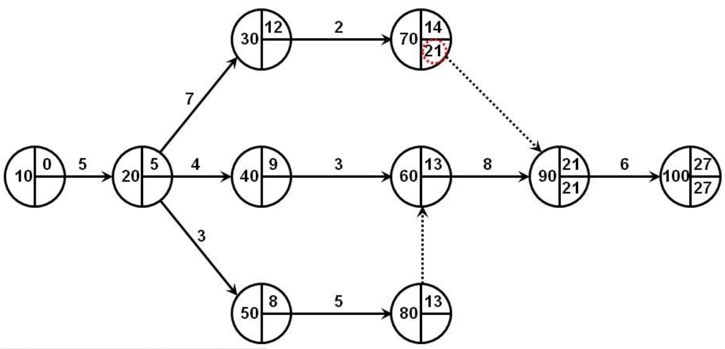
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

27 – 6 = 21





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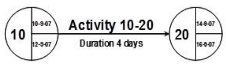
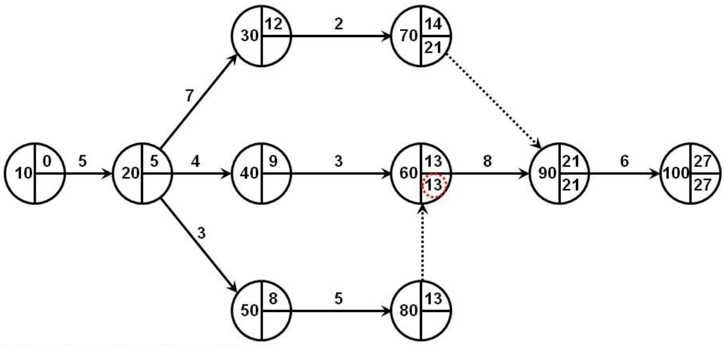
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

The dummy task does not have any duration therefore 21 is the LET of event 70





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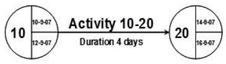
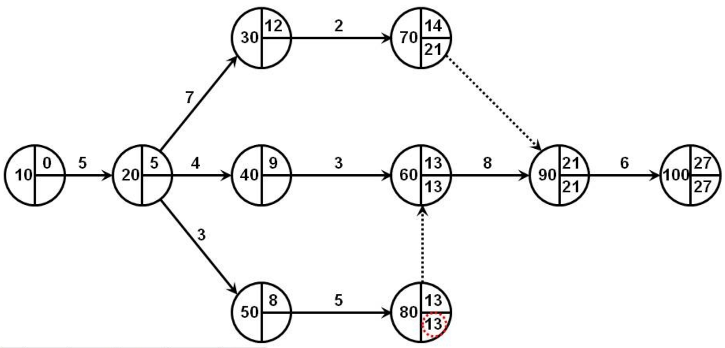
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

21 – 8 = 13





ID	'I' value	Activity	'j' value	Duration	IPA
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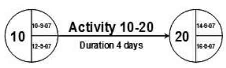
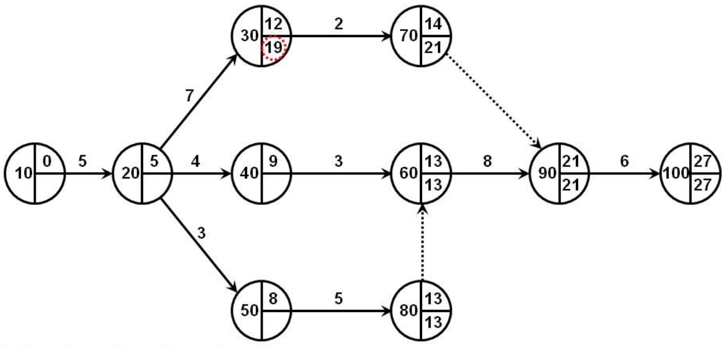
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Again, the dummy does not have a duration therefore the LET of event 80 is 13





ID	'I' value	Activity	'j' value	Duration	IPA
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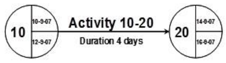
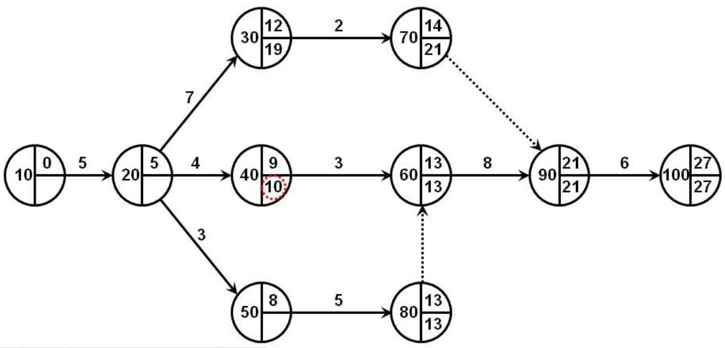
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

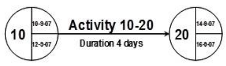
21 – 2 = 19

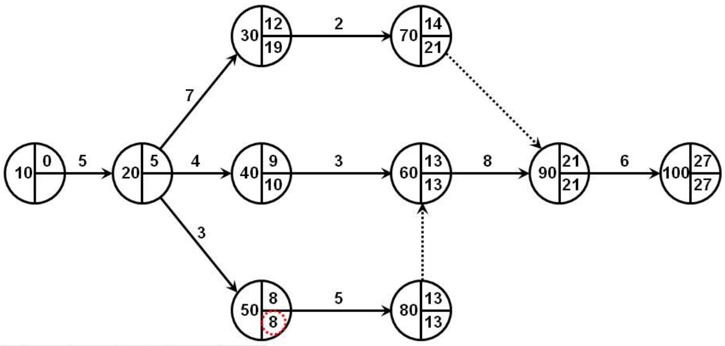




ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

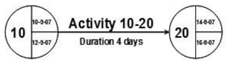
13 – 3 = 10





ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

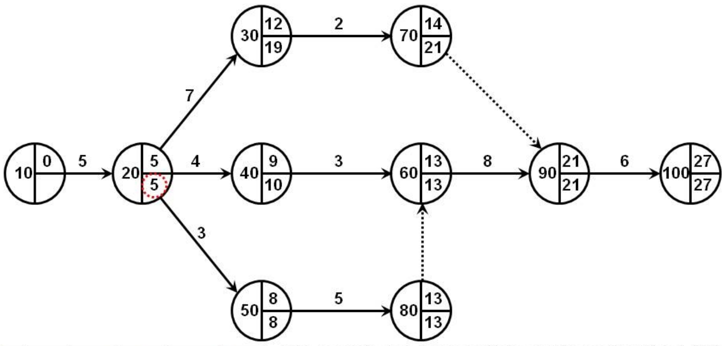
$$13 - 5 = 8$$



4 Activity on Node

Additional Resources

Support Material Powerpoint Download Powerpoint View Online



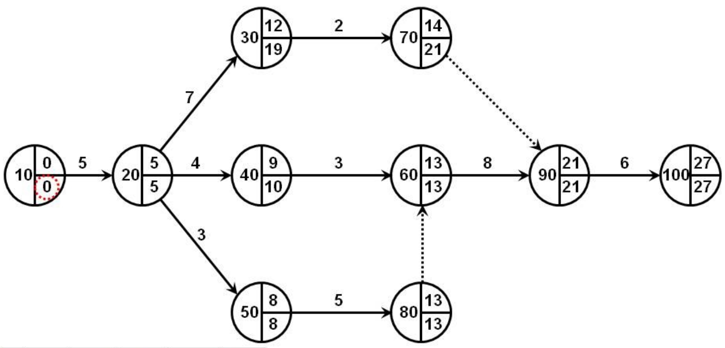
ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

We now have 3 possible options for the LET of 20

They are 12, 6 or 5.

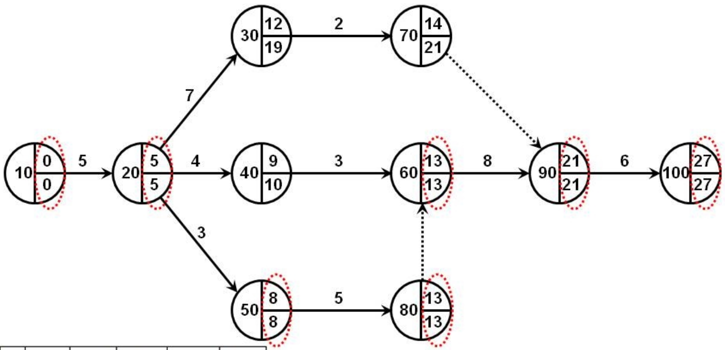
12 or 6 cannot be selected because they would violate the LET of 50

When tasks converge in this manner on the backwards pass, the earliest of the LET options is selected



ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

5 – 5 = 0



ID	'I' value	Activity	'j' value	Duration	IPA
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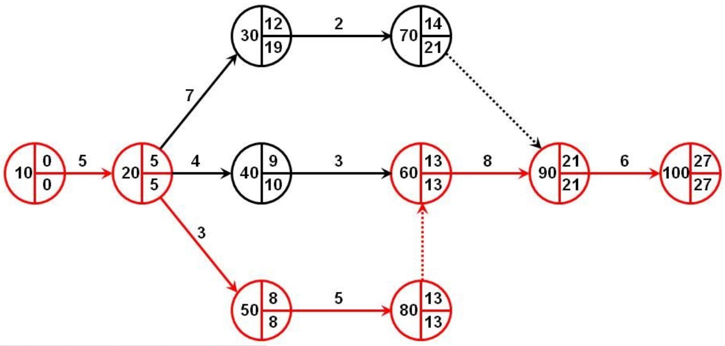
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

Slack on an event is the difference between the EET and the LET.

If we examine the network, we find that for some events the slack is zero



ID	'I' value	Activity	'j' value	Duration	IPA
1	10	A	20	5	-
2	20	B	30	7	A
3	20	C	40	4	A
4	20	D	50	3	A
5	40	E	60	3	C
6	30	F	70	2	B
7	50	G	80	5	D
8	60	H	90	8	E,G
	60	dH	80	0	
9	90	I	100	6	F,H
	70	dI	90	0	

The zero slack path is A-D-G-H-dH-I

As the dH is a dummy, the Critical path is A-D-G-H-I

Project Scheduling Basics

Activity on Node

Precedence Diagrams

Project Management

Year 4

Precedence Diagrams

ES	D	EF
	Activity	
LS	**TF**	**LF**

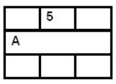
ES = Earliest Start Time
EF = Earliest Finish Time
LS = Latest Start Time
LF = Latest Finish Time
D = Activity Duration
TF = Total Float

- **Activity Box may state:**
  1. Activity Name
  2. Activity Description
  3. Resources Required
  4. Etc.

Precedence Diagram Example

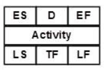
- Consider the Project Below

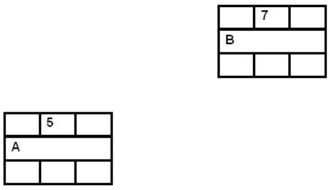
ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H



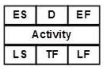
ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

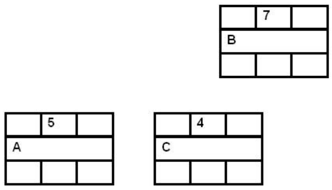
1. **Draw the network**
2. **Enter the Durations**





ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H





ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
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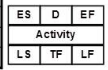
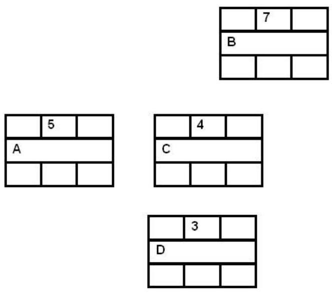
7	G	5	D
8	H	8	E,G
9	I	6	F,H





ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
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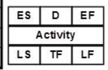
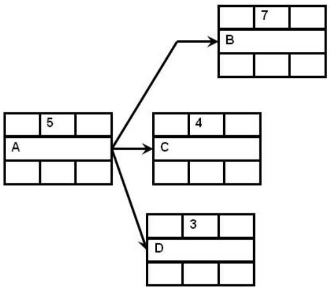
8	H	8	E,G
9	I	6	F,H





ID	Activity	Duration	IPA
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2	B	7	A
3	C	4	A
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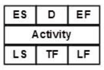
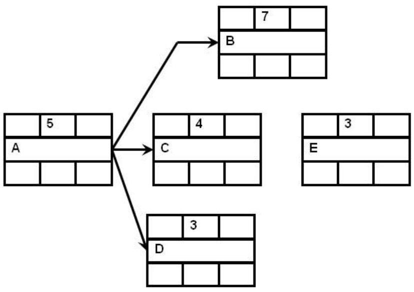
8	H	8	E,G
9	I	6	F,H





ID	Activity	Duration	IPA
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2	B	7	A
3	C	4	A
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5	E	3	C
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7	G	5	D
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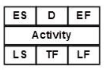
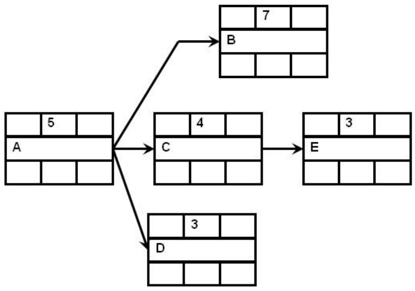
9	I	6	F,H





ID	Activity	Duration	IPA
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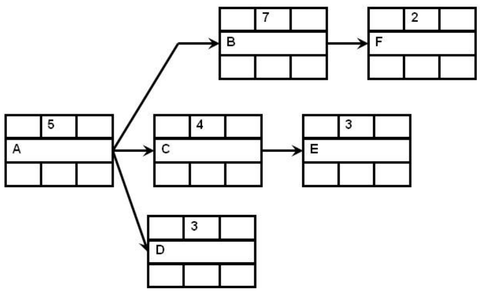
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF



ID	Activity	Duration	IPA
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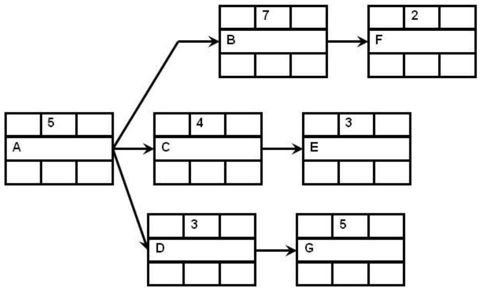
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF



ID	Activity	Duration	IPA
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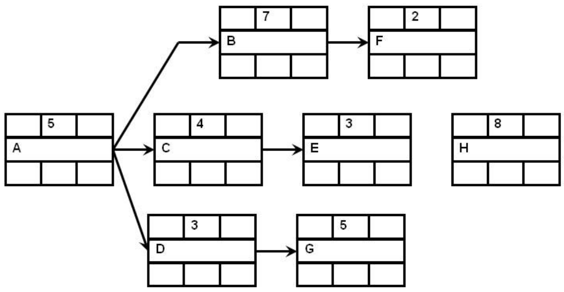
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
	Activity	
LS	TF	LF



ID	Activity	Duration	IPA
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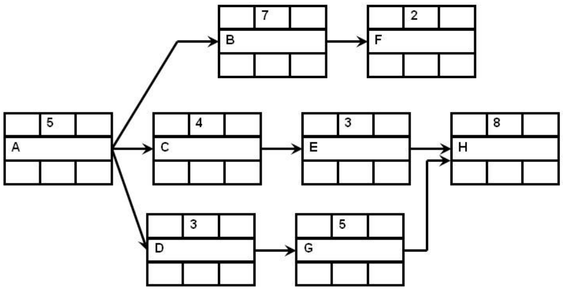
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
	Activity	
LS	TF	LF



ID	Activity	Duration	IPA
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2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
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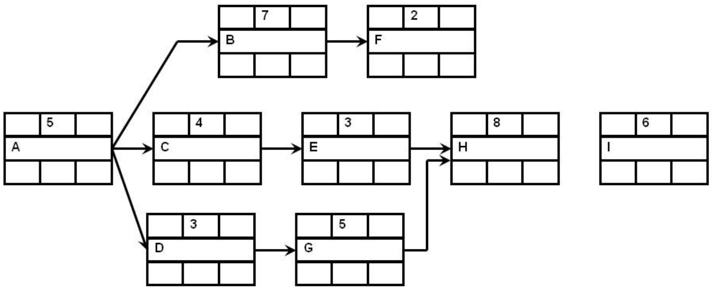
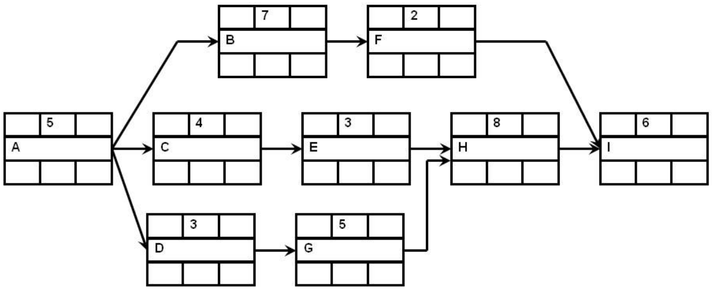
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF



ID	Activity	Duration	IPA
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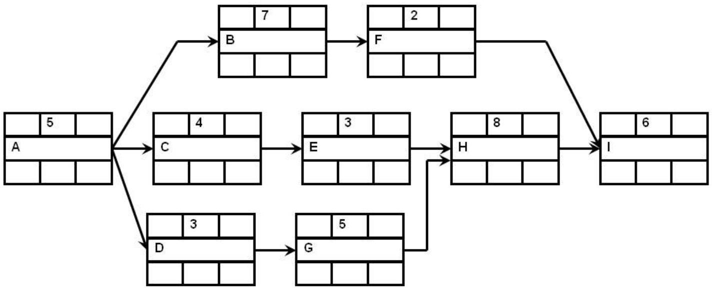
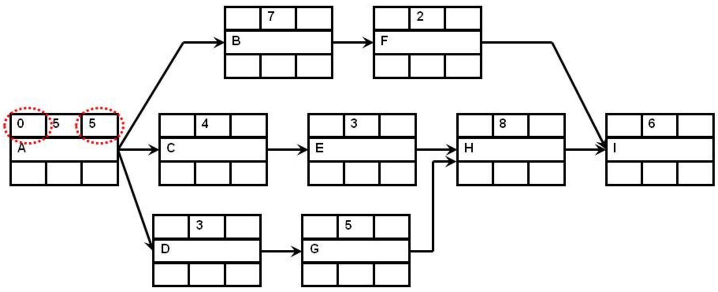
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
	Activity	
LS	TF	LF

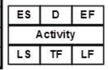


ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

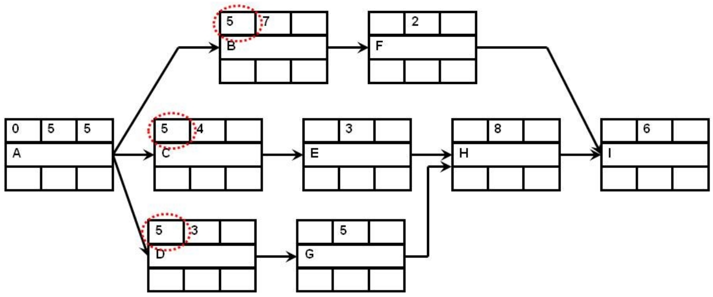
ES	D	EF
	Activity	
LS	TF	LF



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H



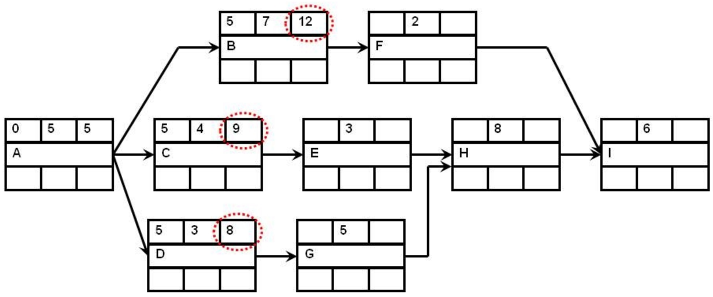
1. **The Earliest Start Time is Time 0 (start of Day 1)**
2. **Add the ES to the Duration (D) to get the Earliest Finish Time**



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF

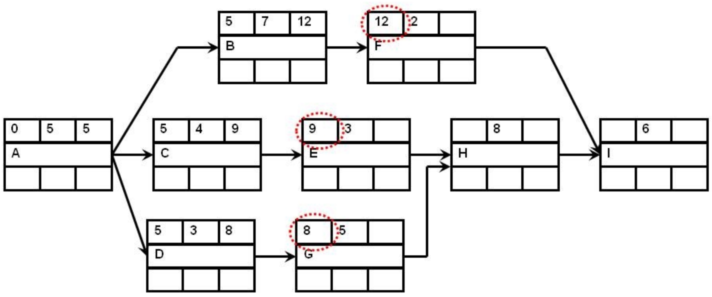
The EF Time of Activity A now becomes the ES Time of Activities B, C, and D



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF

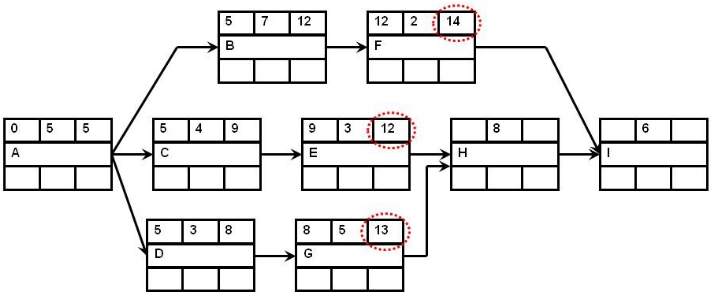
As before, add the ES to the D to get the EF of each activity



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
	Activity	
LS	TF	LF

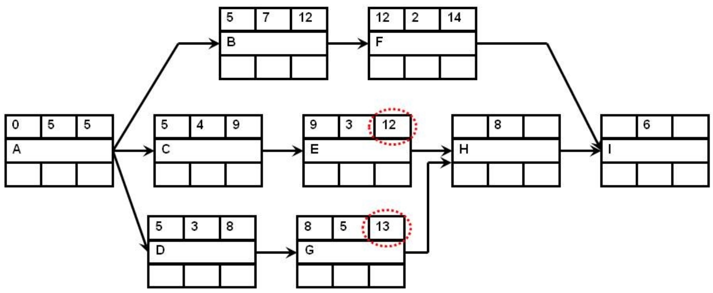
As before, the EF becomes the ES of the following activity



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
	Activity	
LS	TF	LF

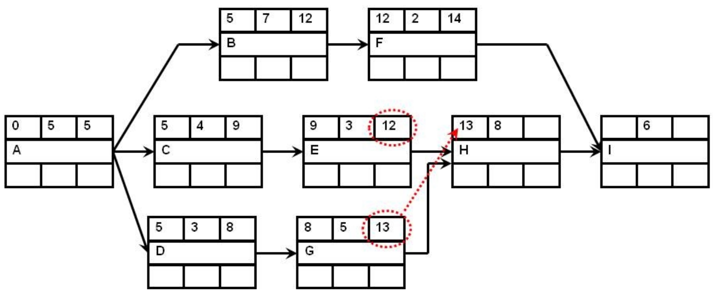
Calculate the EF



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF

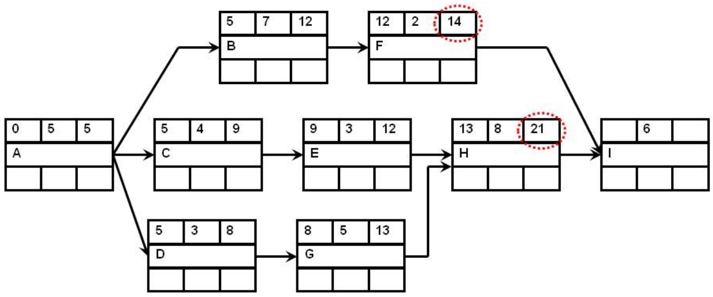
1. **This time we have 2 different EF's.**
2. **Activity 'H' cannot commence until both E and G are complete**
3. **The earliest time that this will happen is upon completion of Activity G (i.e. Day 13)**



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF

So Day 13, the EF of Activity 'G' becomes the ES of Activity 'H'

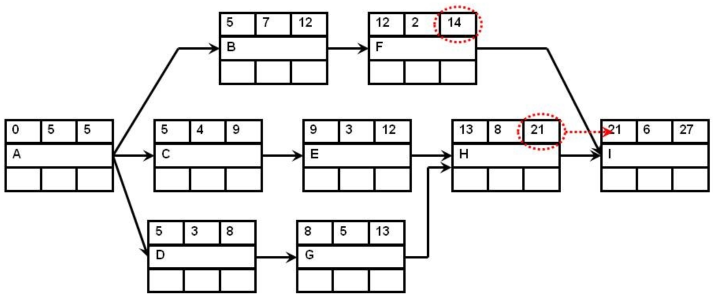


ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF

Again, two activities are converging. In this case 'H' and 'F' onto 'I'

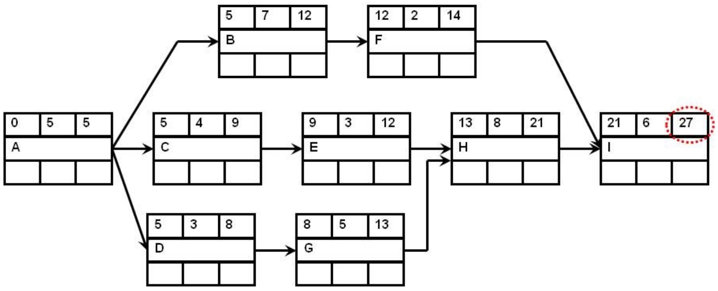
The same rules are applied



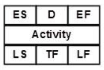
ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF

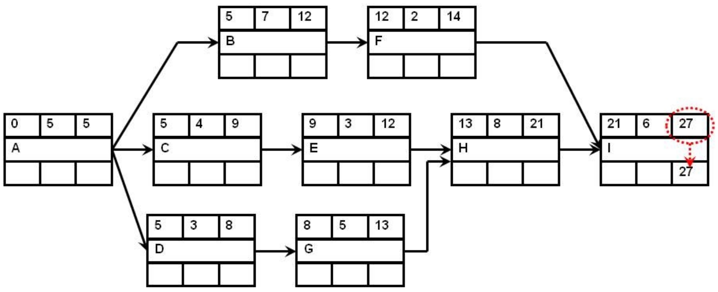
So, Day 21 becomes the ES of Activity 'I'



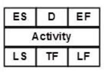
ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H



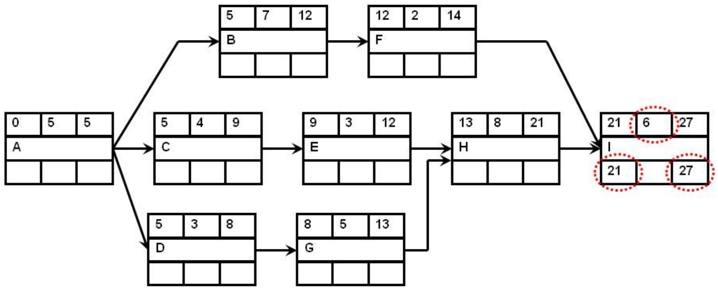
- **We have now determined that the duration of the project will be 27 days**
- **Precedence Diagrams are a *Deterministic Method* of estimating Project Duration**



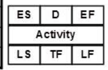
ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H



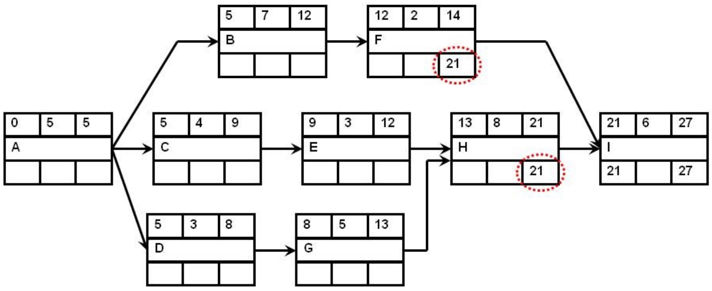
We now use the EF as the LF of the final activity to commence what is known as the ‘backwards pass’



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H



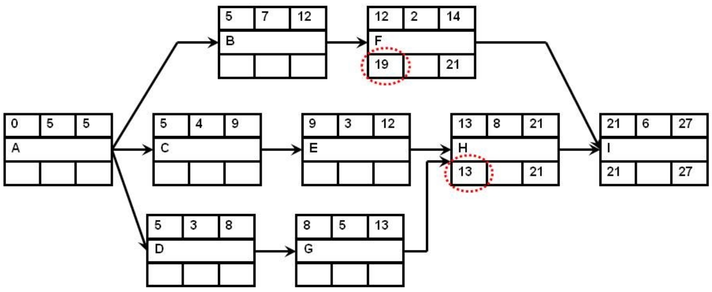
This time we subtract the duration (6 days) from our LF to give the LS



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF

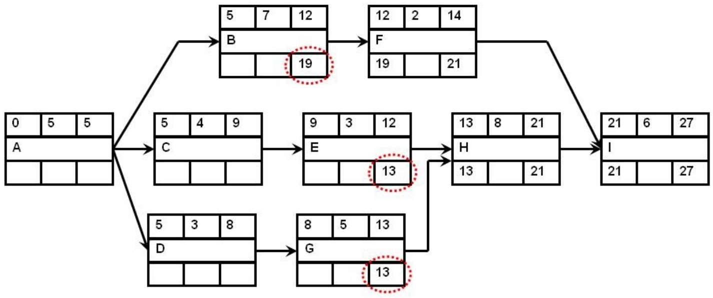
And, as before we use the LS of the successor (I) to determine the LF of its immediate predecessors (F and H)



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

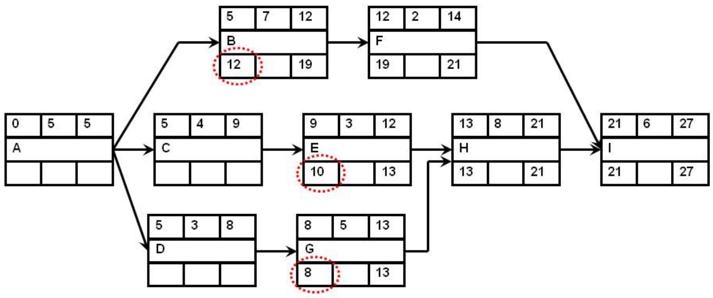
ES	D	EF
Activity		
LS	TF	LF

Again, we calculate the LS values



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

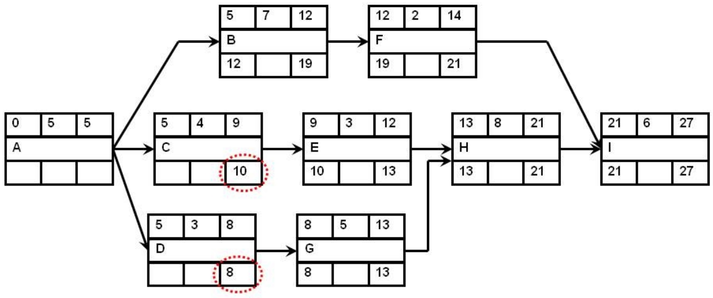
ES	D	EF
Activity		
LS	TF	LF



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

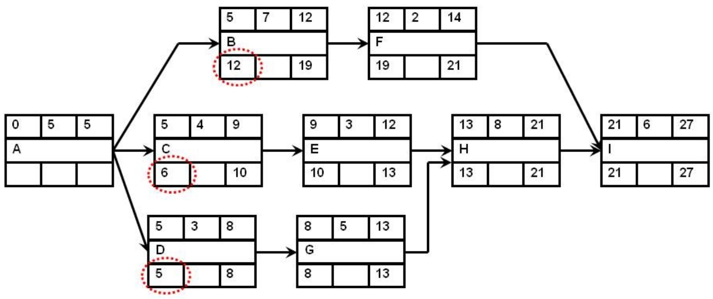
- Now we are starting to converge on an activity. This time Activity A.
- We do not transfer in the LS until we have calculated all the LS values that could be associated with a predecessor

ES	D	EF
Activity		
LS	TF	LF



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

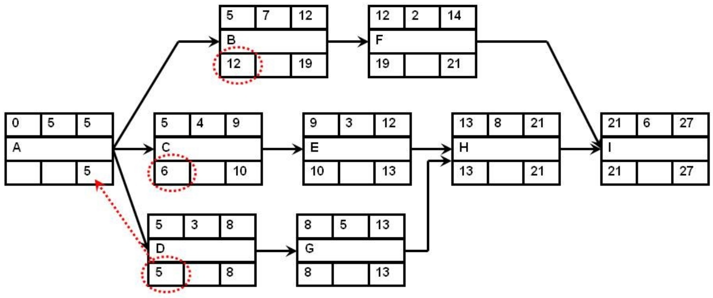
ES	D	EF
Activity		
LS	TF	LF



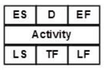
ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

- **Now that all of the values are calculated we can see that they differ**

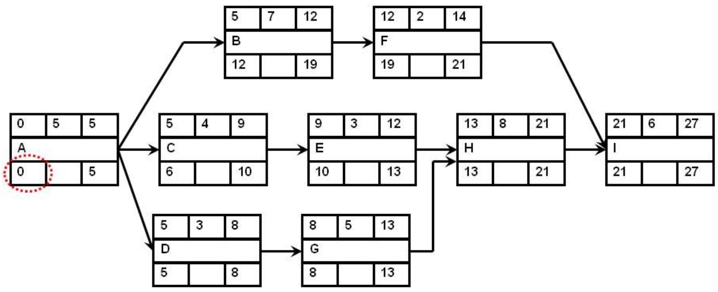
ES	D	EF
Activity		
LS	TF	LF



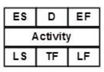
ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H



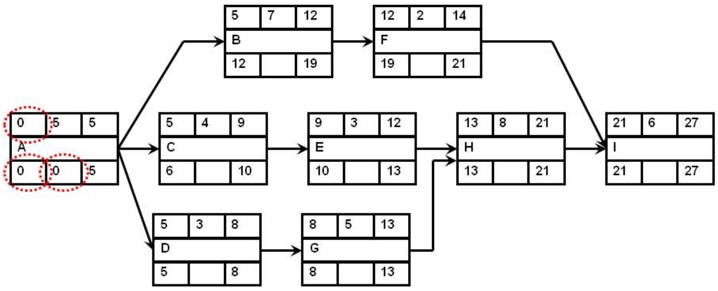
- **The lowest value of the three alternatives is selected.**
- **If one of the others is selected, it would violate the LS date of Activity 'C'**



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

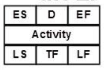


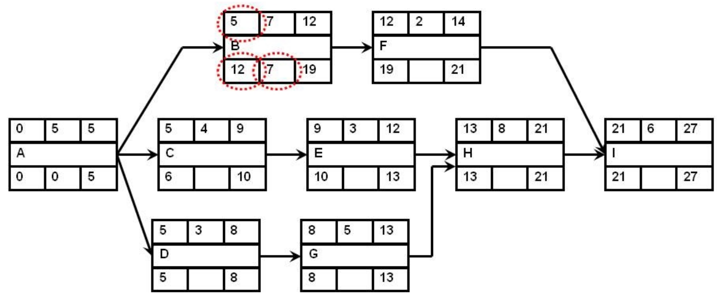
Again we calculate the LS for the activity



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

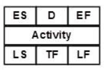
- **The next item that we are interested in is the Total Float associated with each activity**
- **This is calculated by subtracting the ES from the LS (LS-ES = TF)**
- **It can also be calculated by subtracting the EF from the LF (or LF – EF = TF)**

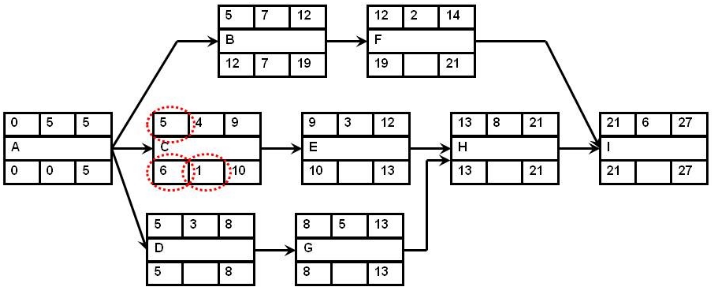




ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

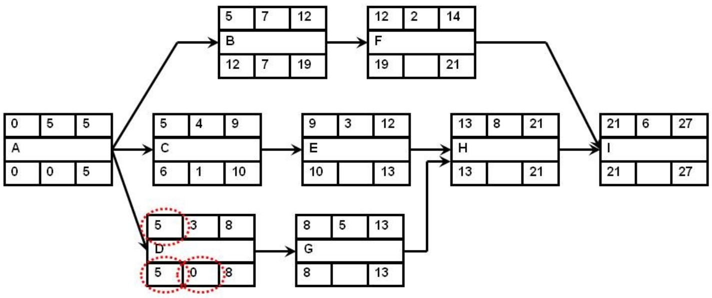
So we parse the network going calculating the TF values for each activity





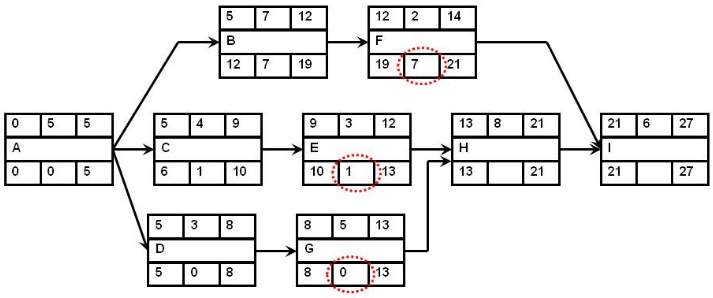
ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF



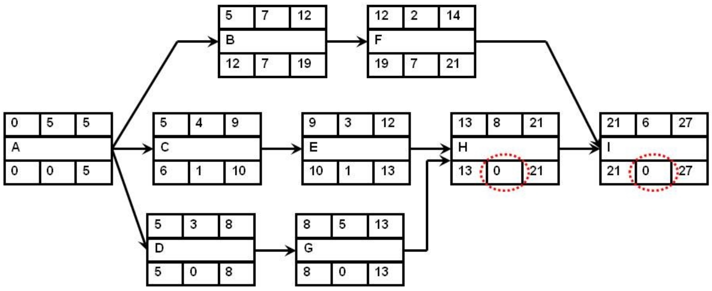
ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

ES	D	EF
Activity		
LS	TF	LF



ID	Activity	Duration	IPA
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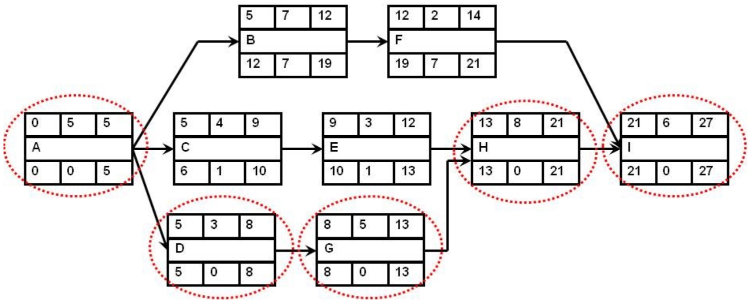
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

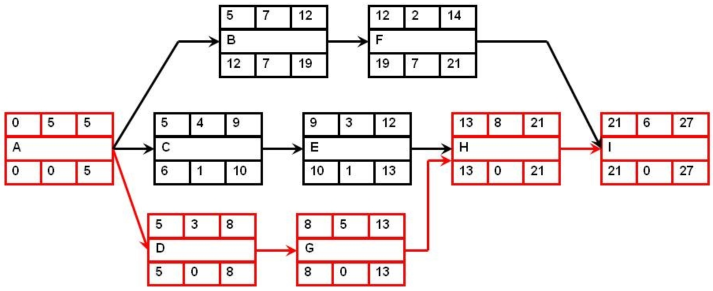
ES	D	EF
Activity		
LS	TF	LF



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

Next, identify all activities that have a TF of zero

ES	D	EF
Activity		
LS	TF	LF



ID	Activity	Duration	IPA
1	A	5	-
2	B	7	A
3	C	4	A
4	D	3	A
5	E	3	C
6	F	2	B
7	G	5	D
8	H	8	E,G
9	I	6	F,H

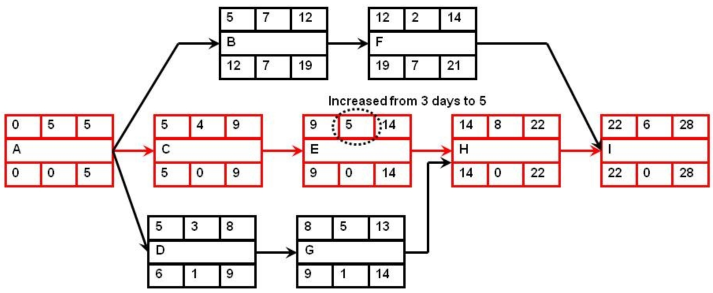
ES	D	EF
Activity		
LS	TF	LF

Activities with Zero float make up the critical path

Therefore the Critical Path is A-D-G-H-I

Critical Path

- In the example, activities ADGHI are driving the duration of the project. A delay in any of these activities will extend the duration of the project
  - i.e if activity H is delayed by 2 days the overall project will not be completed until Day 29
  - The project will not be delayed if activities B and F are delayed by 2 days
  - There are limits. If activities C or E are delayed by 2 days, they will become critical, and the new critical path will be ACEHI

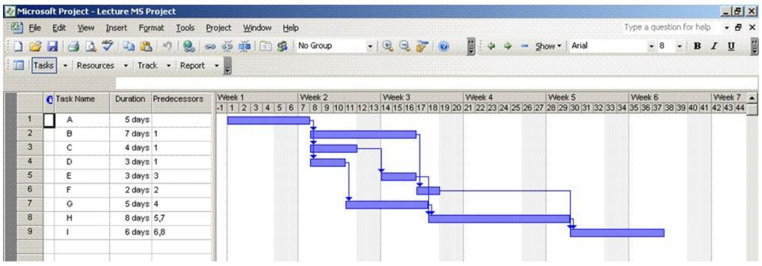


- Increasing the duration of Task E from 3 days to 5 days changes the critical path of the network
- This would likely occur on a project during execution, and highlights the importance of ensuring **all** activities are managed and controlled – not just those on the critical path

Critical Path

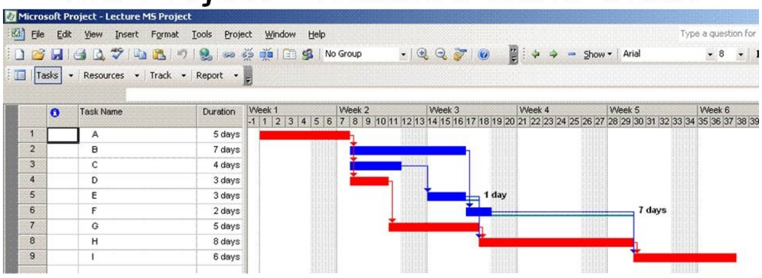
- General Observations
  - In every network at least 1 critical path must exist
  - More then one critical path may exist
  - Any critical path must be continuous from the start to the end of the project
  - Unless a constraint is imposed, a path cannot be partially critical. The entire path is either critical or non critical
  - If all paths go through a particular activity, then that activity must be critical, ie ‘A’ and ‘I’ in the example
  - Sometimes the critical path is defined as ‘the path with zero float’. This definition is only correct if there is no imposed finish date in the backwards pass calculations
  - **We will define the Critical Path as ‘the longest path in the network’. It always holds true.**

Microsoft Project – Gantt Chart

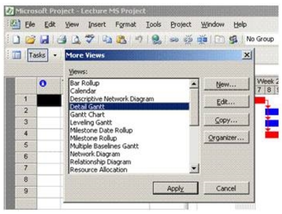


View | Gantt Chart

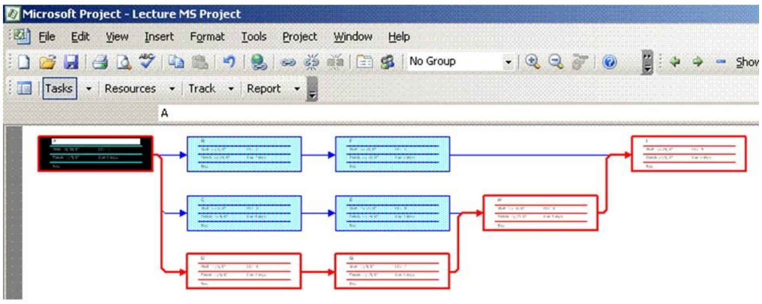
MS Project – Detailed Gantt Chart



View | More Views | Detail Gantt



MS Project – Network Diagram

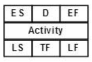


View | Network Diagram

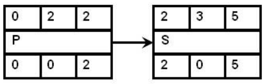
Task Relationships

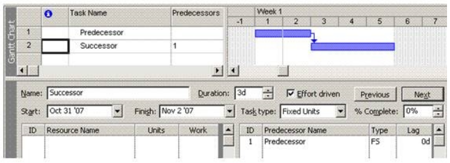
- So far we have assumed that a preceding task needs to be completed before a successor can start. This is known as a Finish-Start (FS) relationship

- However, there are in fact 4 task relationships
    1. Finish-Start (FS)
    2. Start-Start (SS)
    3. Finish-Finish (FF)
    4. Start-Finish (SF)

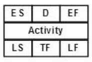


Finish-Start (FS)

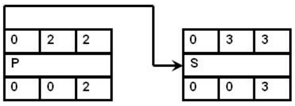


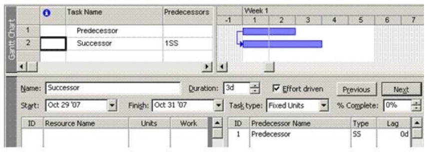


- Most common relationship
- Default relationship for most project scheduling software
- Concrete cannot be poured until formwork is in place
- Block work cannot start until foundation is complete

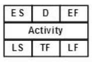


Start-Start (SS)

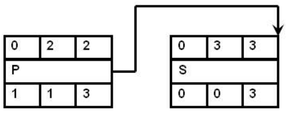


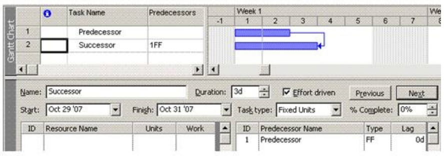


- Commonly used; very useful
- Often used with a lag
- Commence landscaping when snag-list is starting
- Commence laying underground pipe 3 days (lag) after excavation has started

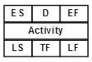


Finish-Finish (FF)

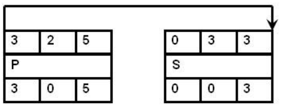


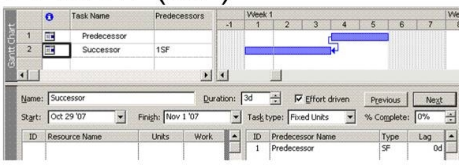


- Again, commonly used and very useful
- Beware when running forward and backwards pass
  - See above, LF of ‘S’ becomes LF of ‘P’
- As-Built drawings and substantial completion must finish together



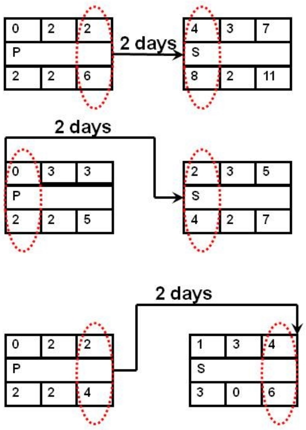
Start-Finish (SF)





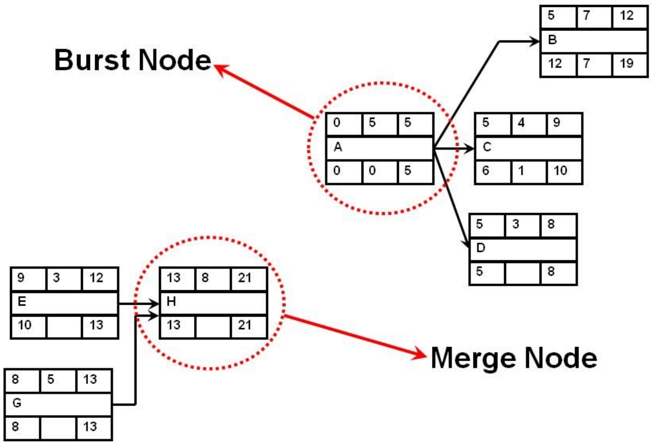
- Rarely (if ever) used; avoid if possible
  - Creates complexity; ‘end of day’ and ‘start of day’ become vital for correct analysis.
  - Rarely makes logical sense.
- Can be used to schedule backwards from a specific event, such as a submission of a tender. However it is better to use a constraint.

Lags



- Lag is not the same as ‘Float’
- Lag is minimum delay between the end (or start) of an activity and the start (or end) of is successor
- The delay can exceed the minimum, provided it does not violate some other logic or constraint
- Lags can be introduced to cater for non-resource associated times, such as the time allowed for concrete to cure.

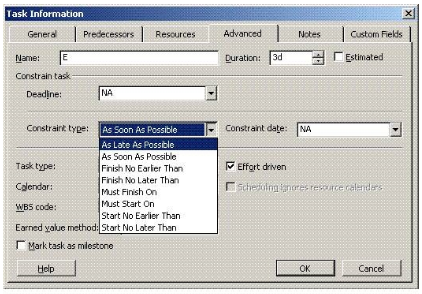
'Burst Node' and 'Merge Node'



Scheduling Constraints

- There are 8 scheduling constraints available in MS Project

	Name		**Type**
1	As Soon as Possible	ASAP	Flexible
2	As Late as Possible	ALAP	Flexible
3	Finish No Earlier Than	FNET	Semi-Flexible
4	Finish No Later Than	FNLT	Semi-Flexible
5	Start No Earlier Than	SNET	Semi-Flexible
6	Start No Later Than	SNLT	Semi-Flexible
7	Must Start On	MSO	Inflexible
8	Must Finish On	MFO	Inflexible



Scheduling Constraints

- ***One of the most misunderstood aspects of Project Management Software***

- Inexperienced users will often use Must-Finish-On constraints in an attempt to ensure that the software will meet a contractual completion date
- What they are actually doing is forcing the system to finish on that date **<u>and only that date</u>**
- Better to use Finish-No-Later-Than; this constraint allows for completion before the specified date

Scheduling Constraints

- As Soon As Possible (ASAP)
  - Software will attempt to schedule the activity task to finish as soon as possible
  - It is the default setting of Activities on most PM software
  - It is ‘Flexible’ because the start and finish dates can be brought forward or pushed back in time in accordance with schedule logic only
- As Late As Possible (ALAP)
  - Software will attempt to schedule the activity to finish as late as possible
  - Useful for Landscaping activities etc where it is preferable to start and finish ALAP in order to avoid damage
  - It too is ‘Flexible’ because the start and finish dates can be brought forward or pushed back in time in accordance with schedule logic

Scheduling Constraints

- Finish No Earlier Than (FNET)
  - Software will attempt to schedule the activity to finish no earlier than a specified date; it will allow the task to finish after the specified date
- Finish No Later Than (FNLT)
  - Software will attempt to schedule the activity to finish no later than a specified date; it will allow the task to finish before the specified date
  - i.e. construction of a pump plinth. It must finish no later than the date the pump is delivered to site, but can finish before this

Scheduling Constraints

- Start No Earlier Than (SNET)
  - Software will attempt to schedule the activity so that it starts no earlier than a specified date. It will allow the start date to be scheduled after this date, and is therefore considered semi-flexible
- Start No Later Than (SNLT)
  - Software will attempt to schedule the activity so that it will start no later than a specified date

Scheduling Constraints

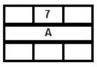
- Must Start On (MSO)
  - Software will schedule the activity such that it starts on a specified date
  - It is an inflexible constraint as it does not allow for any change to the start date whatsoever.
- Must Finish On (MFO)
  - Software will schedule the activity such that it will finish on a specified date
  - It is an inflexible constraint as it does not allow for any change to the finish date.

General Comment on Scheduling Constraints

- A flexible constraint **sets a preference** for either late or early completion
- Semi-Flexible constraints will allow an activity to be started (or finished) **either earlier or later, but not both**
- Inflexible constraints will not allow the activity's start (or finish) date to change in any way.
- Semi-Flexible and Inflexible constraints should never be used unless absolutely necessary
- Semi-Flexible and Inflexible should never be used to 'drive' a project plan – that is for the PM team to do.
  - i.e. Set SNLT on a task in an attempt to ensure task completion. (logic should do this for you)
- Overuse of Semi and Inflexible constraints will force tasks onto the critical path that otherwise would not have to be critical

Typical Example

Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS



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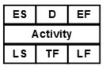
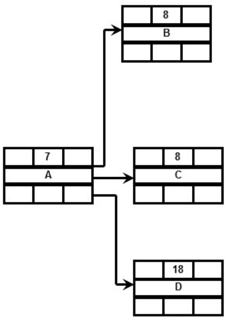
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS





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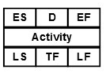

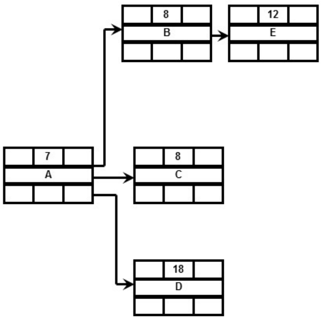

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J	8	K	FS
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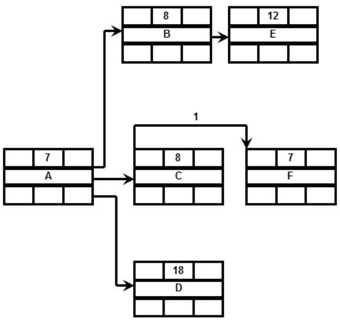
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



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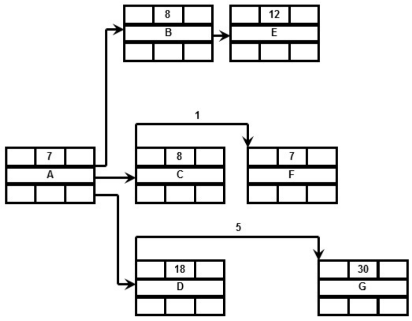

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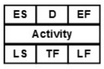

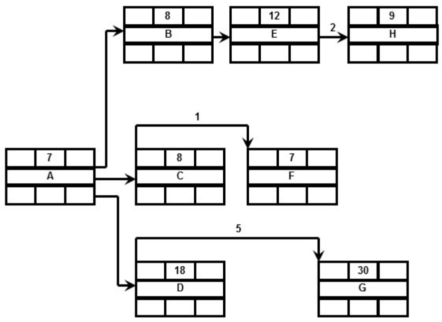

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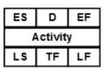

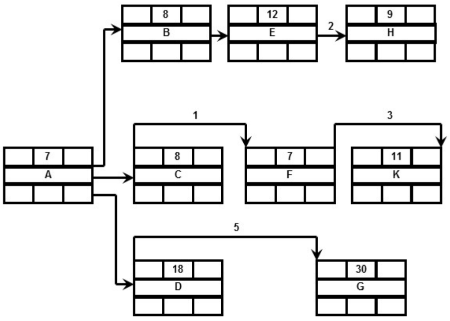

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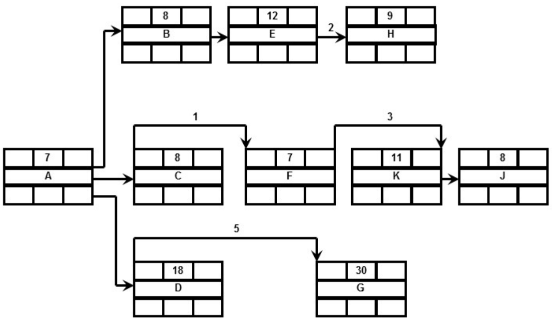
		L	FS
N	4	M	FS

ES	D	EF
	Activity	
LS	TF	LF



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M	6	J	FS
		L	FS
N	4	M	FS

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	Activity	
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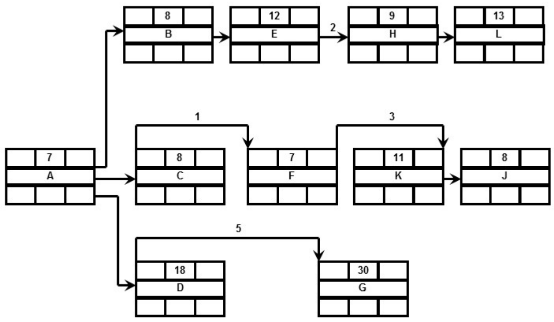

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		L	FS
N	4	M	FS

ES	D	EF
Activity		
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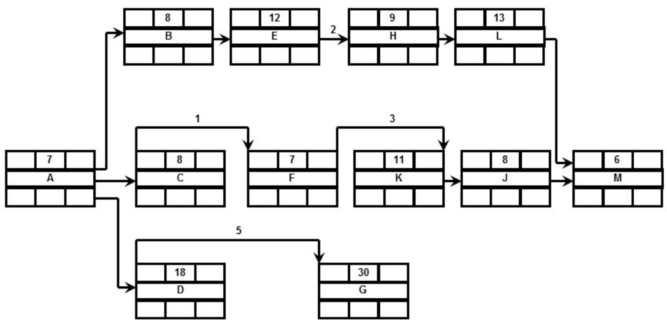

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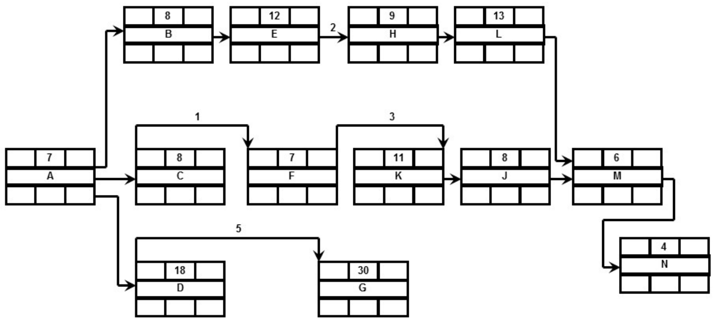

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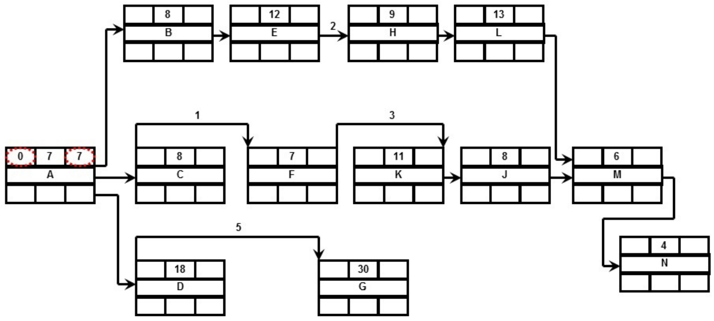

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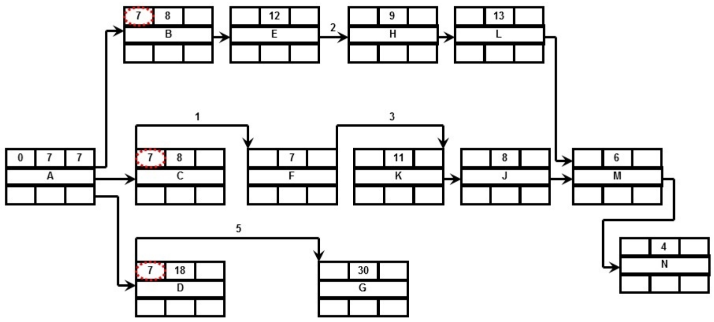

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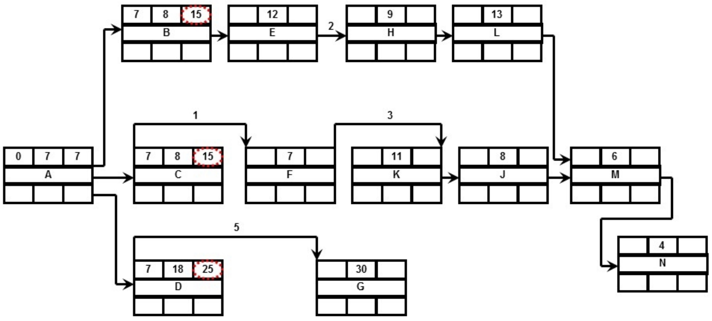

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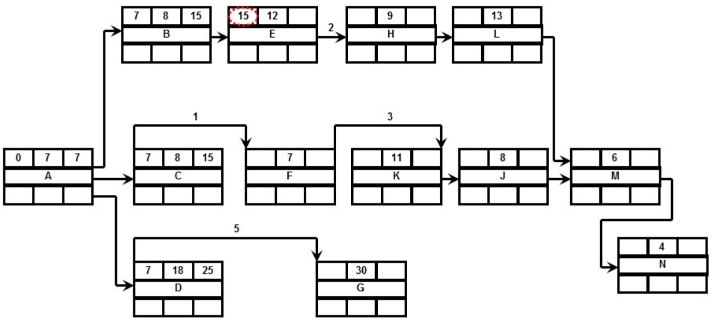

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		L	FS
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ES	D	EF
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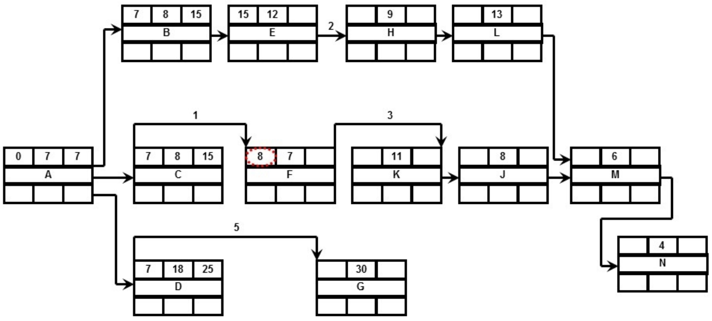

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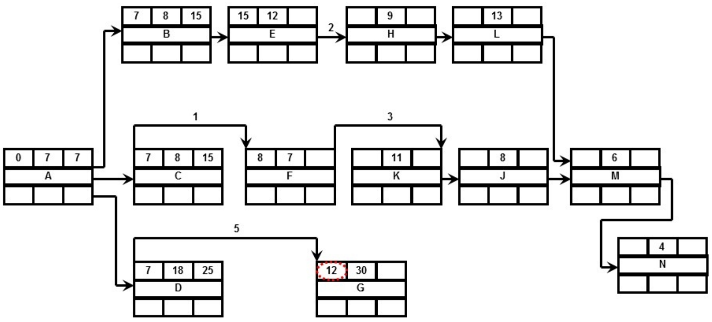
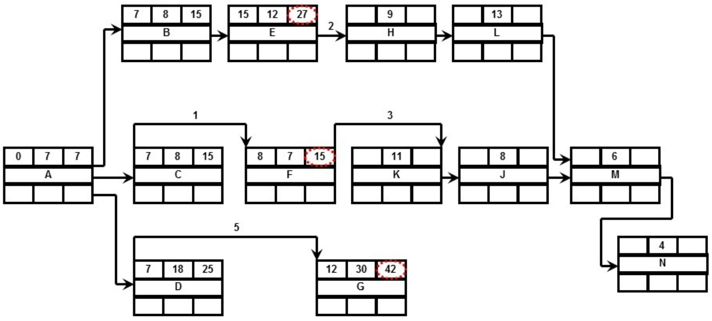


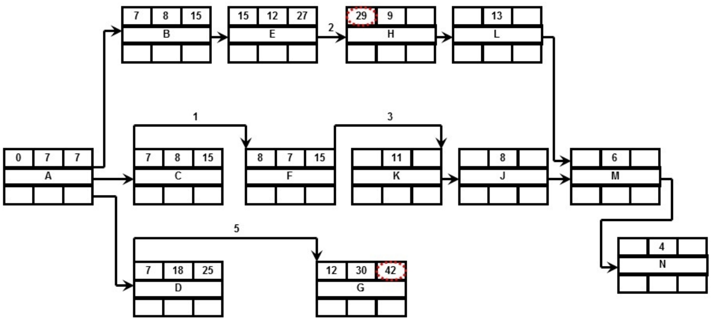
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



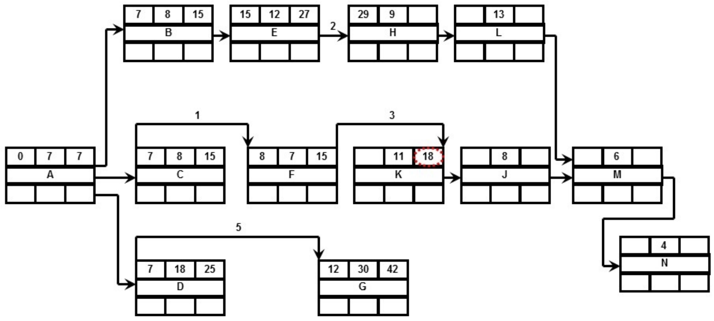
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



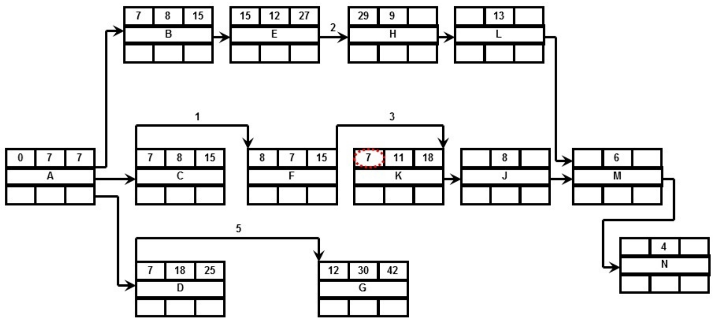
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



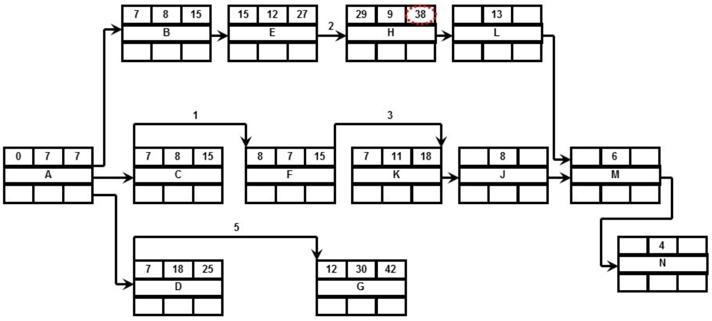
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



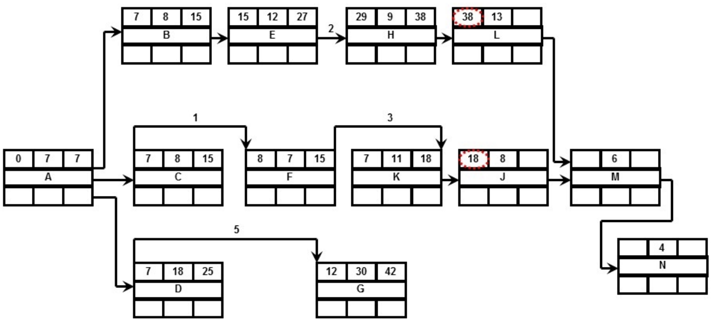
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



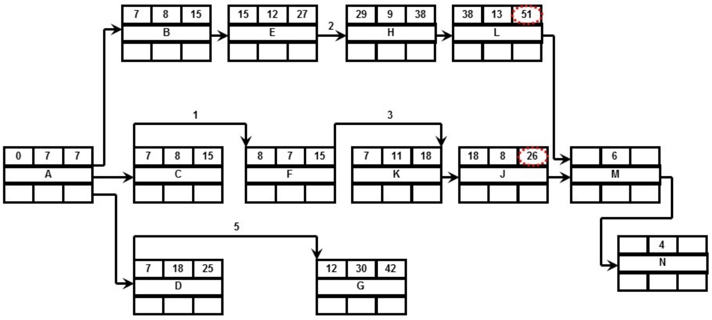
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF

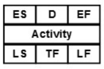


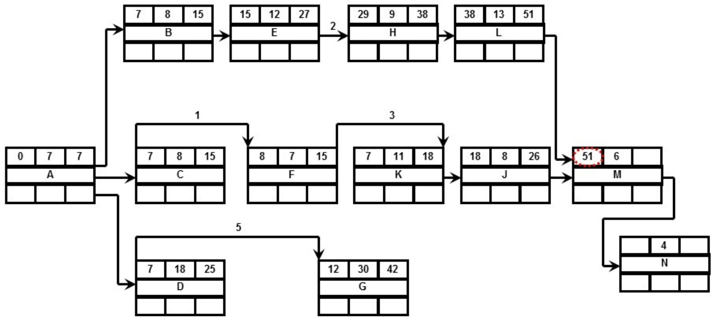
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



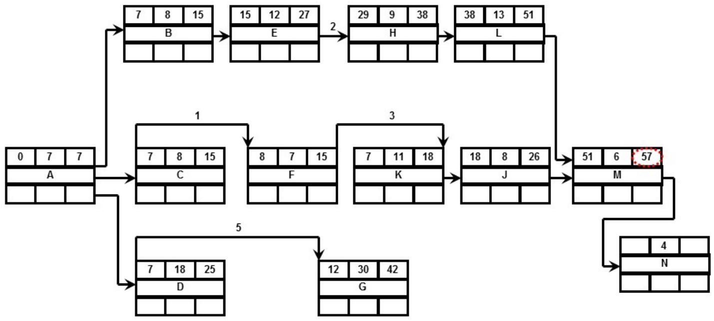
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS





Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
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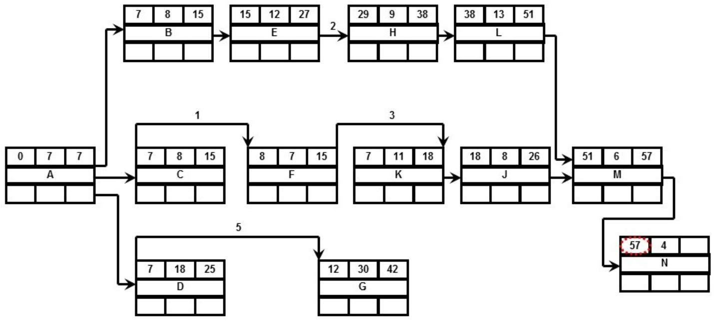
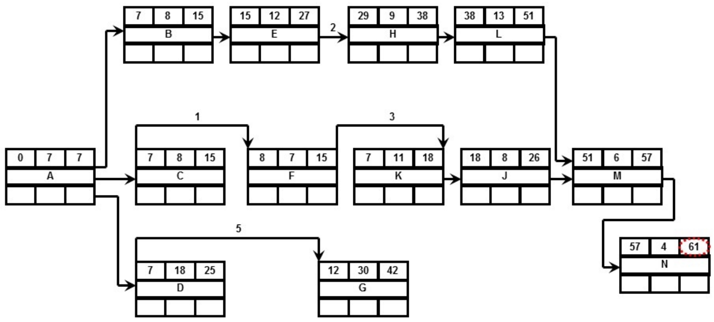
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
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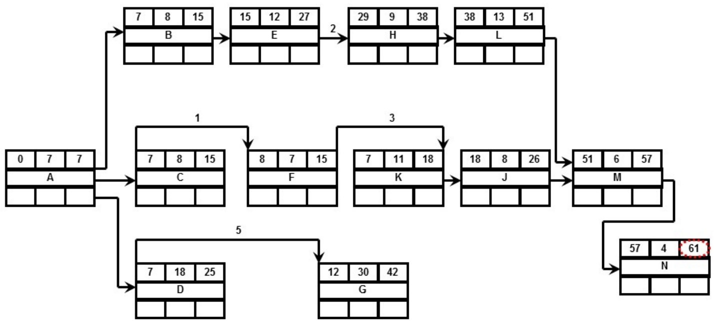
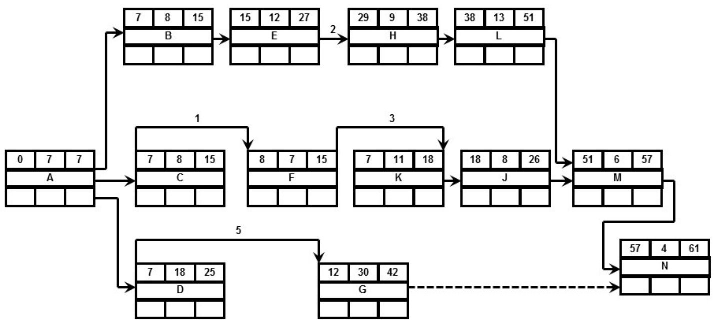
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



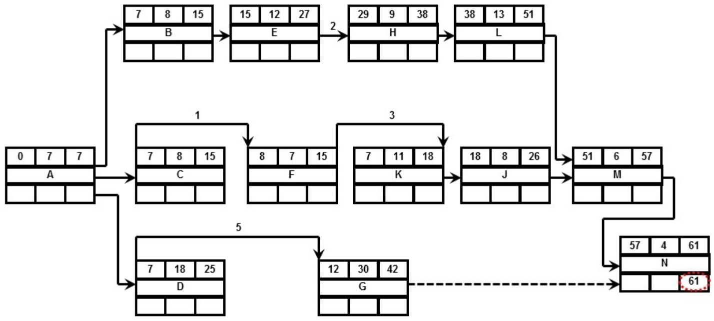
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



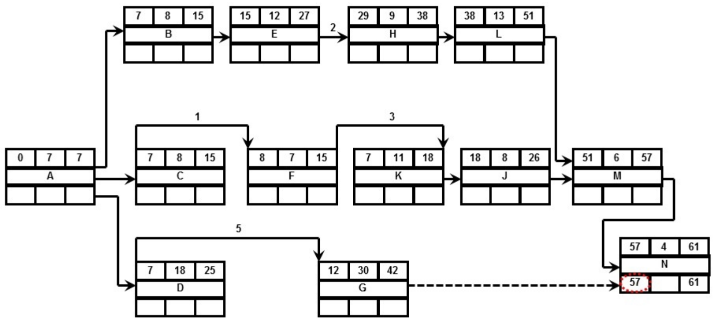
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
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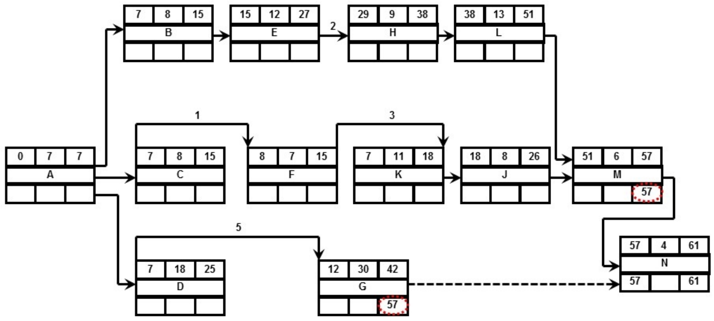
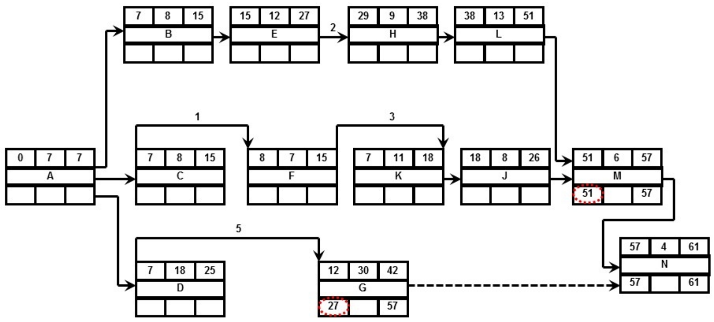
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



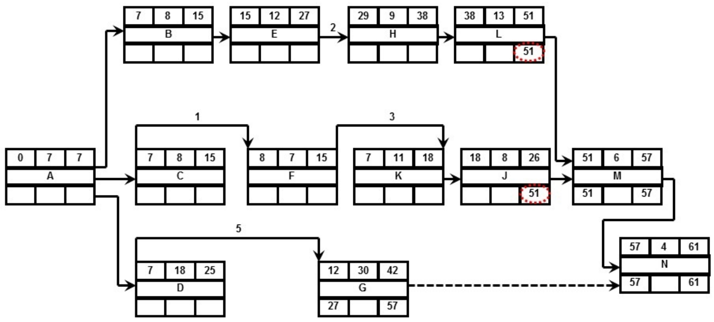
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



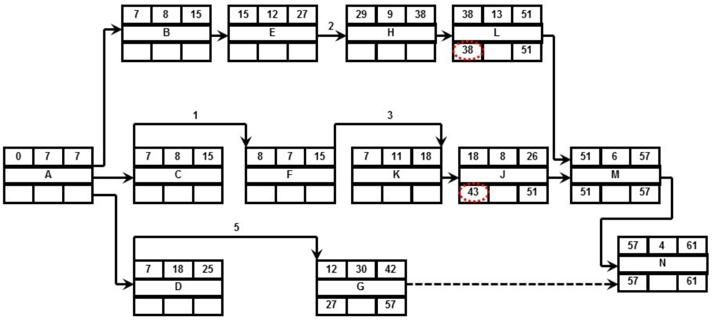
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
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B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
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G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
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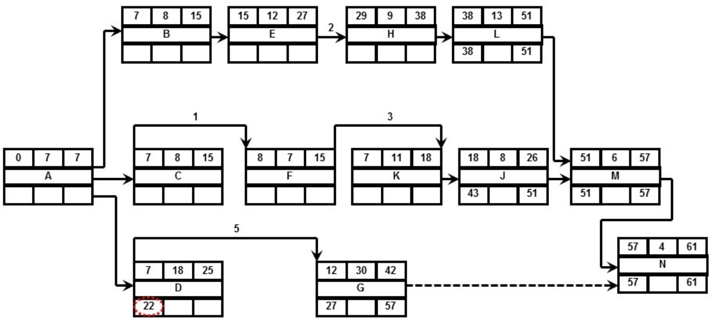
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
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G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
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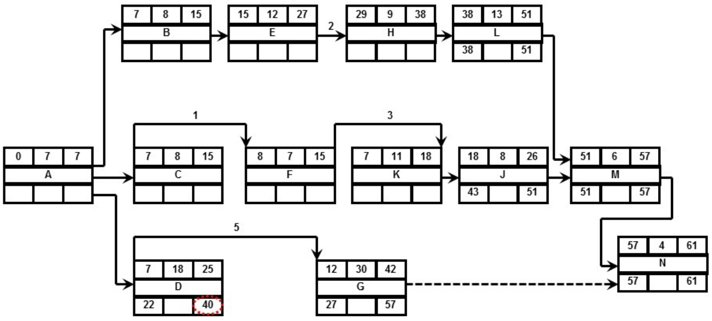
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
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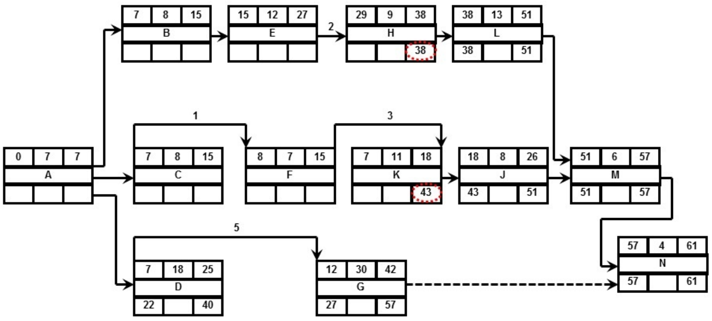
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
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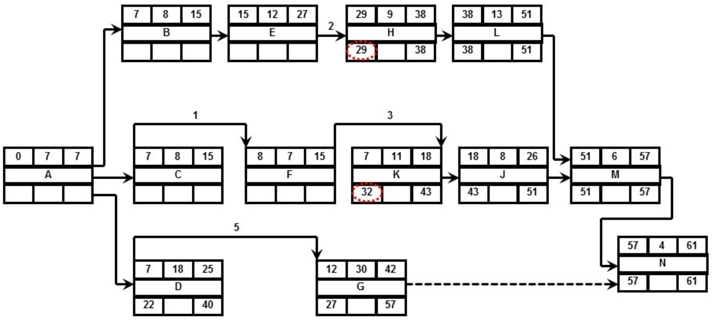
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
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G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
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M	6	J	FS
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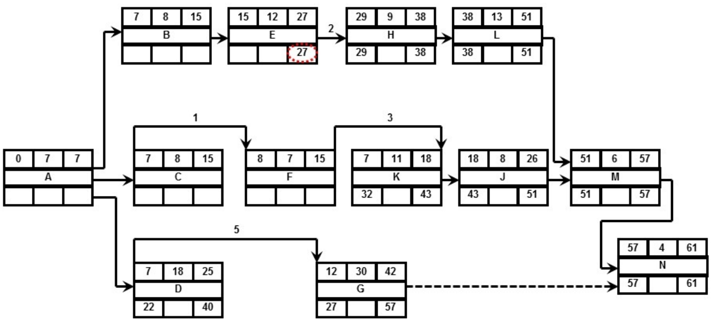
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
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B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
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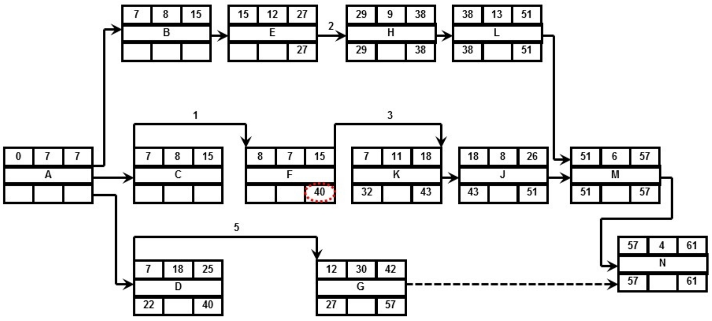
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
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G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
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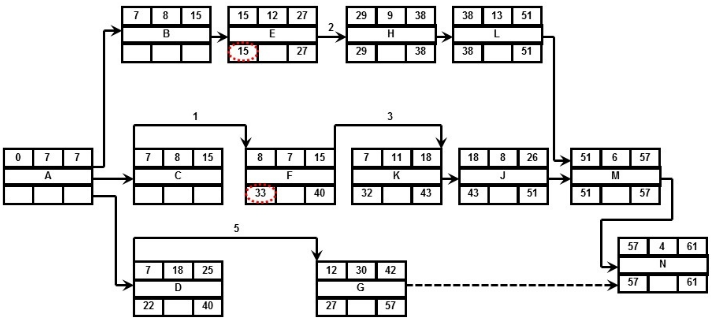
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
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G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
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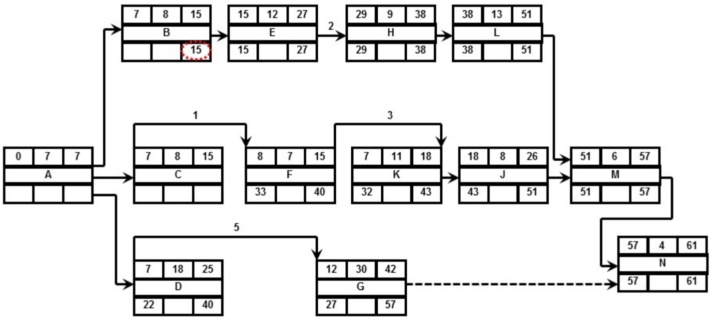
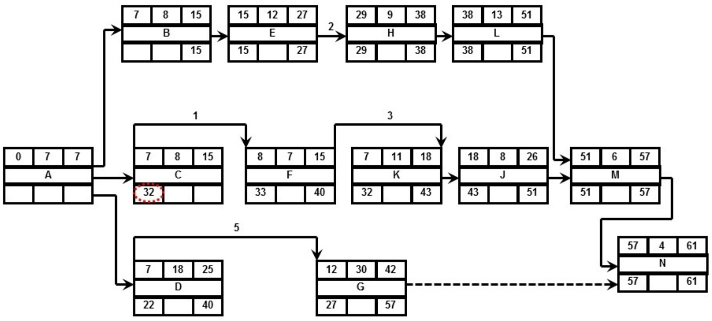
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
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B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
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G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
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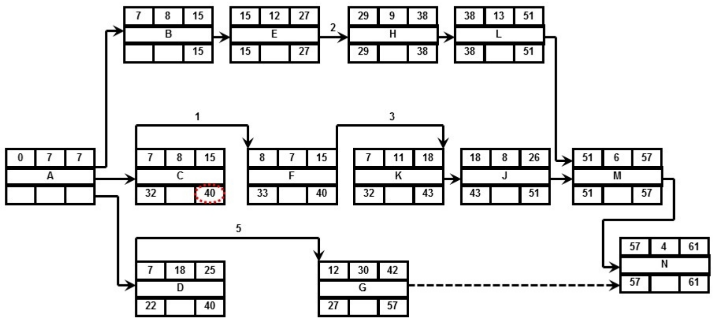
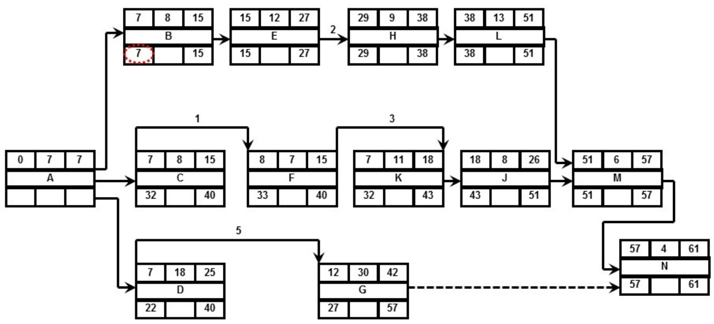
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



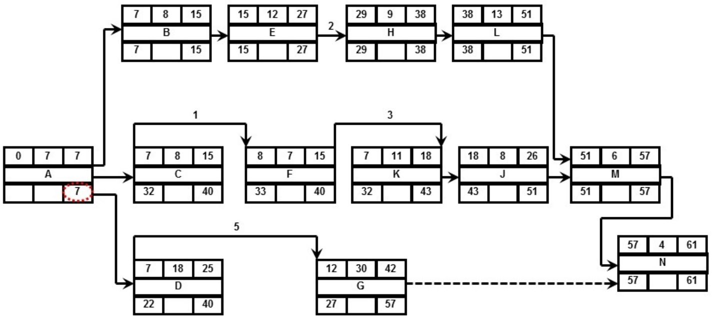
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF

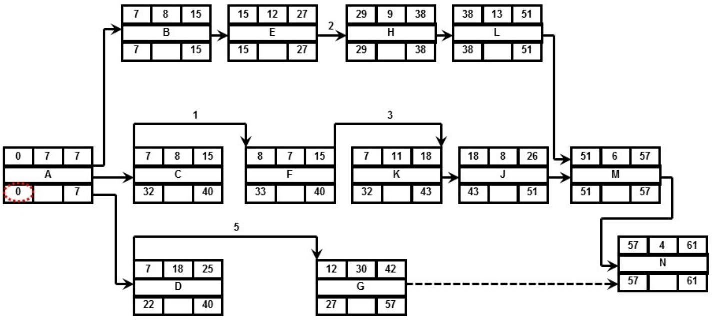


Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF

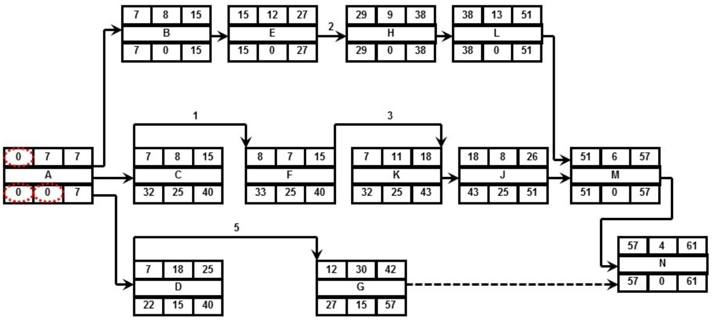
5 PERT

PERT
Program Evaluation & Review Technique



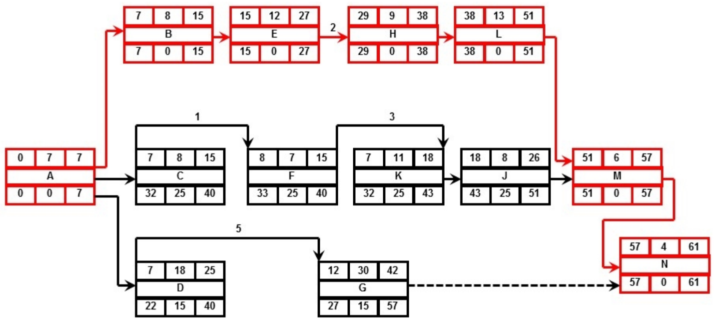
Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF

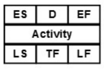


Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS

ES	D	EF
Activity		
LS	TF	LF



Activity	Duration	Predecessor	Type & Lag
A	7	-	-
B	8	A	FS
C	8	A	FS
D	18	A	FS
E	12	B	FS
F	7	C	SS +1
G	30	D	SS +5
H	9	E	FS +2
J	8	K	FS
K	11	F	FF +3
L	13	H	FS
M	6	J	FS
		L	FS
N	4	M	FS



What is PERT?

Program Evaluation and Review Technique

- Event Orientated Network Analysis
- Used where individual activity durations are highly uncertain
- PERT applies weighted average duration estimates to the Critical Path Method (CPM)
- PERT is a probabilistic or stochastic method

History of PERT

1950's - US Navy had huge cost overruns on the Polaris Missile System Project, primarily due to the lack of historical data. The project team (USN, Lockheed, Allen Hamilton) began to research effort to develop a tool to assist the planning of the Polaris Project. Objective was to devise a method that can predict a completion date and assign a probability to meeting that date. June 1962; Department of Defence and NASA officially adopt system.

Concept of PERT

PERT is a probabilistic approach that requires a duration frequency distribution for each activity. Each Activity is given:

- T_O - Optimistic Duration
- T_M - Most Likely Duration
- T_P - Pessimistic Duration

Paint Room, expect 3 days, maybe 2, but could be 5 days if paint runs out.

- T_O = 2 days; T_M = 3 days; T_P = 5 days;

Concept of PERT

These 3 durations give a 'distribution' for the activity, therefore we can produce a statistical mean and variance for the duration of the activity. PERT treats the means of these activity durations as a normal distribution, and then using normal statistical methods, a mean duration, and variance (or standard deviation) of the time required to complete the chain of activities. The result is that completion can be calculated as a probability that it will occur by a particular day.

Mathematics of PERT

The Mean Weighted Average of these three durations is called the Expected Duration T_e

$$T_e = \frac{T_o + 4T_m + T_p}{6} \tag{PERT-1}$$

Where:

- T_o is the Optimistic Duration
- T_m is the Most Likely Duration
- T_p is the Pessimistic Duration
- T_e is the Expected Duration

In order to avoid confusion when referring to the entire path or the individual tasks, uppercase letters are used to refer to the entire path i.e. T_E, and lowercase letters are used to refer to the individual tasks, i.e. T_e

Mathematics of PERT

Values for T_o ,T_m and T_p, are determined through experience, judgement, knowledge etc. The weights assigned to T_o ,T_m and T_p can be adjusted; however the denominator of Eqn. (PERT-1) must equal the sum of the weights. i.e. $1 + 4 + 1 = 6$ This arithmetic average is sometimes referred to as μ or $\overline{X}$

Mathematics of PERT

The standard deviation (SD) of the expected duration is:

$$\sigma = \frac{T_p - T_o}{6} \tag{PERT-2}$$

The variance (V_e)is given by:

$$V_e = \sigma_e^2 \tag{PERT-3}$$

Mathematics of PERT

Now, add the expected durations for all activities on the studied path (T_E):

$$T_E = \sum_{i=1}^{n} (T_e)i \tag{PERT-4}$$

Following on, the Variance (V_E) for the entire path can be calculated from:

$$V_E = \sum_{i=1}^{n} (\sigma_e^2)i \tag{PERT-5}$$

Mathematics of PERT

And the Standard Deviation (σ_E) for the entire path can be calculated from:

$$\sigma_E = \sqrt{V_E} \tag{PERT-6}$$

Mathematics of PERT

Using the previous calculations, it is possible to calculate the probability that a certain event will occur on or by a certain date (T_S) by using the normal distribution formulas:

$$Z = \frac{T_S - T_E}{\sigma_E} \tag{PERT-7}$$

Where Z (called the Z function) represents the standard deviations (σ_E) away from the mean (T_E)

By rearranging Eqn. PERT-7 we can obtain an equation that will predict the date by which completion will occur with a known level of confidence (probability).

$$T_S = \sigma_E Z + T_E \tag{PERT-8}$$

Activity	Optimistic Duration (T_o)	Most Likely Duration (T_m)	Pessimistic Duration (T_P)
A	2	4	7
C	5	8	14
F	4	6	8
J	2	2	2
K	7	10	21

You will be expected to remember these equations. The second equation is simply a rearrengement of the first.

$$Z = \frac{T_S - T_E}{\sigma_E} \tag{1}$$

bring up σ_E

$$\sigma_E Z = T_S - T_E$$

bring over T_E

$$\sigma_E Z + T_E = T_S$$

and swapping sides:

$$T_S = \sigma_E Z + T_E$$

5.1 Example

PERT Calculations

Example: By using the Critical Path Method (CPM) the following critical path has been determined.

PERT Calculations

Example (cont.) Calculate the following Values:

1. The probability that the project will finish by the end of day 32
2. The probability that the project will finish by the end of day 34
3. The probability that the project will finish before day 30
4. The probability that the project will finish on the 32nd day
5. The probability that the project will finish no later than the 35th day
6. The probability that the project will finish at least 2 days early
7. The probability that the project will finish at least 2 days late
8. The probability that the project will finish on the 32nd day ±1 day
9. The completion date with at least 90% confidence level

Activity	Optimistic Duration (T_o)	Most Likely Duration (T_m)	Pessimistic Duration (T_P)	Expected Duration	Std. Dev σ_e	Variance $V_e = \sigma_e^2$
A	2	4	7	4.167	0.833	0.694
C	5	8	14	8.500	1.500	2.250
F	4	6	8	6.000	0.667	0.444
J	2	2	2	2.000	0.000	0.000
K	7	10	21	11.333	2.333	5.444
				T_E = **32.000**		V_E =**8.833**

Z	0.00	0.01	0.02
0.0	0.5000	0.5040	0.5080
0.1	0.5398	0.5438	0.5478
0.2	0.5793	0.5832	0.5871

PERT Calculations

Example (cont.) Before going any further, we need to calculate the expected duration (T_E) and the standard deviation (σ_E) of the path ACFJK. So, for every activity we calculate the expected duration (T_e) and the standard deviation (σ_e) by using equations (PERT-1) and (PERT-2).

NOTE: When you are doing these calculation make sure you work to 3 places of decimal. These calculations are very sensitive, particularly when σ_E is small, i.e. less than 2.0.

PERT Calculations

Now that we have determined: T_E = 32.000 days V_E = 8.833 days we can calculate the standard deviation of the entire path (σ_E) from:

$$\sigma_E = \sqrt{V_E}$$

to give:

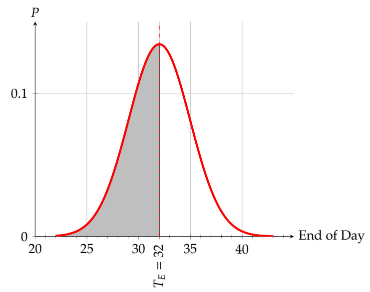
$$\sigma_E = 2.972 \text{ days}$$

PERT Calculations Example 1

The probability that the project will finish by the end of day 32. Z is calculated using Eqn (PERT-7). For this case T_S = 32, so inserting the values we get

$$Z = \frac{T_S - T_E}{\sigma_E} = \frac{32 - 32}{2.972} = 0.000$$

We then need to look-up the Z-tables at value 0.00 From the table we can see that the probability that the project will complete on day 32 is 0.50 or 50%



Z	0.06	0.07	0.08
0.5	0.7123	0.7157	0.719
0.6	0.7454	0.7486	0.7517
0.7	0.7764	0.7794	0.7823

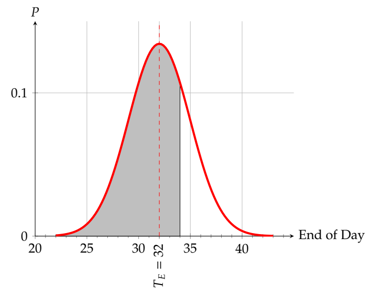
Z	0	0.01	0.02
0.9	0.8159	0.8186	0.8212
1	0.8413	0.8438	0.8461
1.1	0.8643	0.8665	0.8686

PERT Calculations Example 2

The probability that the project will finish by the end of day 34 Z is calculated using Eqn (PERT-7). For this case $T_S = 34$, so inserting the values we get:

$$Z = \frac{T_S - T_E}{\sigma_E} = \frac{34 - 32}{2.972} = 0.672$$

We then need to look-up the Z-tables at value 0.67 From the table we can see that the probability that the project will complete by the end of day 34 is 0.7486 or 74.9%

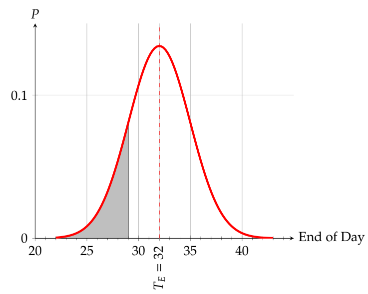


PERT Calculations Example 3

The probability that the project will finish before day 30 Note: this is the same as the probability of finishing by the end of day 29, so $T_S = 29$.

$$Z = \frac{29 - 32}{2.972} = \frac{-3}{2.972} = -1.009$$

In this case Z is less than Zero. For values of Z less than zero, lookup the absolute value of Z as derived, and subtract from 1.00 So, subtracting 0.8438 from 1 we get 0.1562 or 15.6%

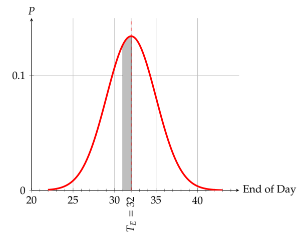


PERT Calculations Example 4

The probability that the project will finish on the 32nd day From part 1. we have already calculated the probability that the project will finish by the end of day 32. i.e. $\Pr(T_S \leq 32)$=0.50 or 50%, so now we need to calculate $\Pr(T_S \leq 31)$.

$\Pr(T_S \leq 31) = 1 - 0.633 = 0.367 = 36.7\%$ (note: check the logic) so, $\Pr(T_S = 32) = \Pr(T_S \leq 32) - \Pr(T_S \leq 31) = 50\% - 36.7\% = 13.3\%$

$$Z = \frac{29 - 32}{2.972} = \frac{-3}{2.972} = -1.009$$



Day 32 runs from End of Day 31 to End of Day 32. Think of it like running from midnight to midnight; the end of one day is the start of the next. Now, when we calculate the probability of completion by the end of any particular day, say 32, we are calculating the sub of all probabilitues (the area under the curve) upto that point in time. This means that the probability of completion by end of day 32, also includces the probability of completion by end of day 31, 30, 29, etc. all the way to zero. In order to get a specific day we get the sum of all probabilites to the end of the day we are interested in (32), and subtract the sum of all probabilites to the start of that day, which happens to be the same as the end of the day before (31). In the diagram below the sum of all probabilites upto end of day 31 is shown in cyan.

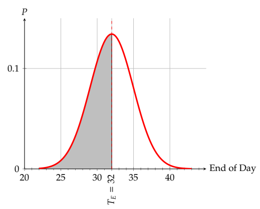


Figure 1: $T_S \leq 32$

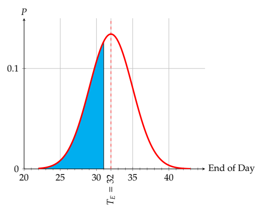


Figure 2: $T_S \leq 32$

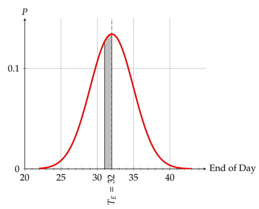


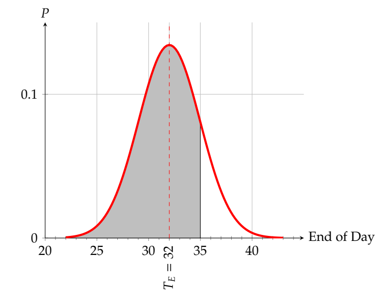
Figure 3: $T_S = 32$

PERT Calculations Example 5

The probability that the project will finish no later than the 35th day This is the same as the probability that the project will finish by the end of day 35.

$$Z = \frac{35 - 32}{2.972} \approx 1.01$$

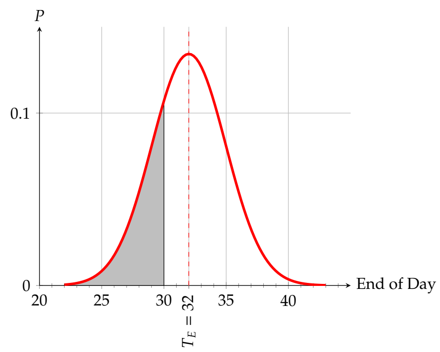
so $\Pr(T_S \leq 35) = 0.8438 = 84.4\%$



PERT Calculations Example 6

The probability that the project will finish at least 2 days early This is the same as the probability of finishing on the 30th day or earlier; or the same as the probability of finishing at the end of day 30.

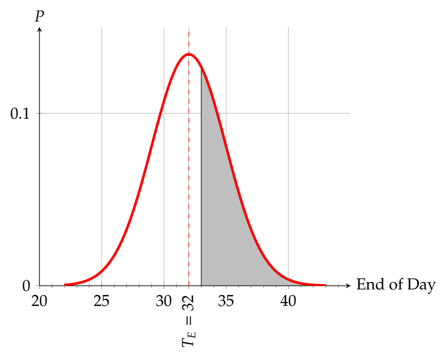
so Z= -0.67 therefore $\Pr(T_S \leq 30)$ = 1-0.7486 = 0.2514 = 25.1%



PERT Calculations Example 7

The probability that the project will finish at least 2 days late This is the same as the probability of finishing on the 34th day or later, or the same as finishing by the end of day 33 or later.

$\Pr(T_S > 33) = 1 - \Pr(T_S \leq 33)$ = 1-.633 = 36.7%

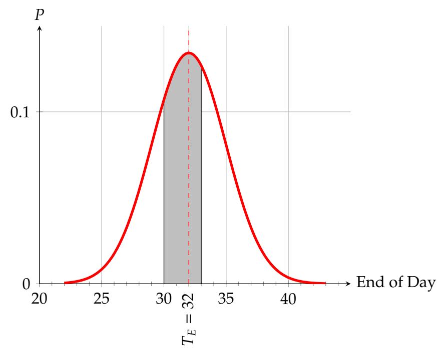


Z	0.07	0.08	0.09
1.1	0.879	0.881	0.883
1.2	0.898	0.8997	0.9015
1.3	0.9147	0.9162	0.9177

PERT Calculations Example 8

The probability that the project will finish on the 32nd day ±1 day. This means finishing on day 31, 32 or 33

Pr(Ts = 31, 32, 33)= Pr($T_S \leq 33$) - Pr($T_S \leq 30$) = 0.633 -0.251 = 38.2%



End of Day convention is very important here. Recall that day 32 will run from end of day 31 to end of day 32. So, one day before will be $31 - 1 = 30$ and one day after will be $32 + 1 = 33$. To confirm your are correct with your two values of T_S, subtract one from the other. This will give $33 - 30 = 3$, so you have 3 days of probabilites.

PERT Calculations Example 9

The completion date with at least 90% confidence level Go to Z-table and look up the value nearest to (but not less than) 0.9000.

From the table Z=1.29, and insert into (PERT-8):

$$T_S = \sigma_E Z + T_E = 2.972(1.29) + 32 = 35.834$$

As the answer is over 35.0, we are infact in Day 36. Answer Day 36.

Z Table: Cumulative probability for the Standard Normal Distribution (0.00 to 2.00)

Microsoft Project 2007

PERT analysis was available on MS Project 2007; it was dropped for 2010. View—Toolbars—PERT Analysis

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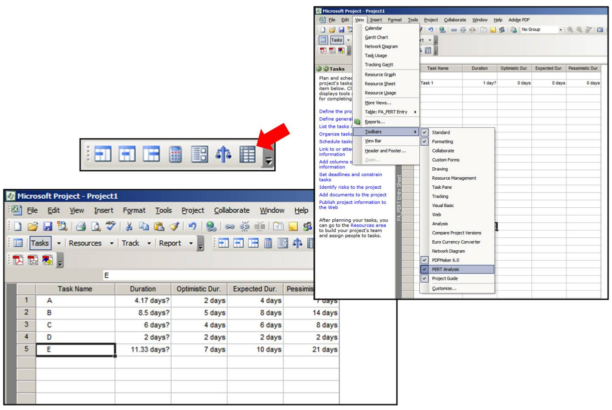
Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817



Z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1.0	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2.0	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3.0	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998
3.5	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998	0.9998

Table 1: Cumulative probability for the Standard Normal Distribution: Positive Value of Z

5.2 Z Table: Cumulative probability for the Standard Normal Distribution: Positive Values of Z

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6 Activity on Arrow

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7 Line of Balance

Additional Resources

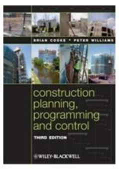
Support Material Powerpoint Show Download

Basic Project Scheduling
Activity on Arrow

Project Management
Year 4

Basic Project Scheduling
Line of Balance

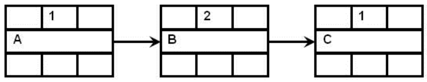
Project Management
Year 4



Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition,* Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2

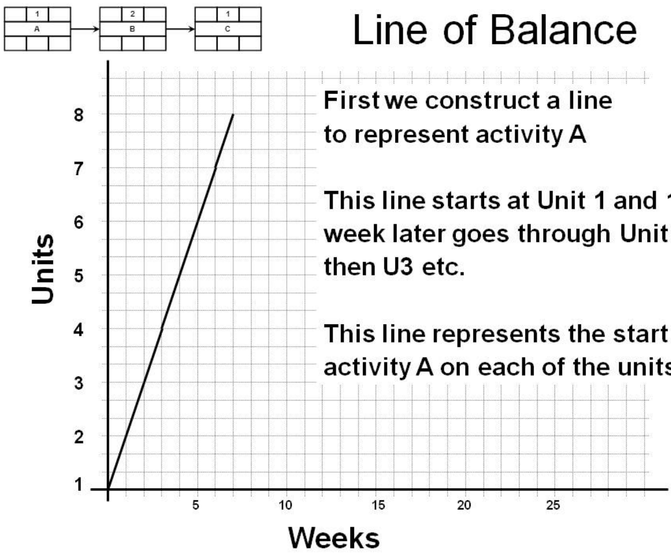
Line of Balance

- Consider the construction sequence below



- Suppose this process is repeated over 8 similar or identical units (for instance houses)
- Clearly it would be inefficient to have 8 versions of the construction sequence, all with their own EST's, LST's, etc.
- For these types of project, 'Line of Balance' is selected.
- LOB does not replace network logic; it supplements it

Line of Balance

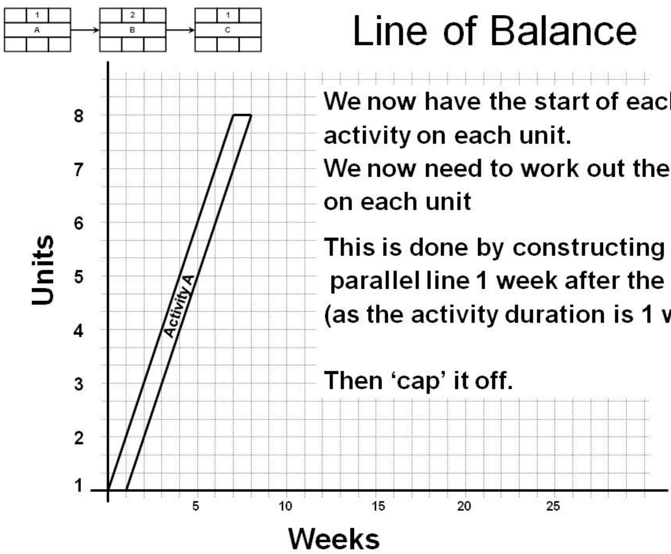


First we construct a line
to represent activity A

This line starts at Unit 1 and 1
week later goes through Unit 2,
then U3 etc.

This line represents the start of
activity A on each of the units

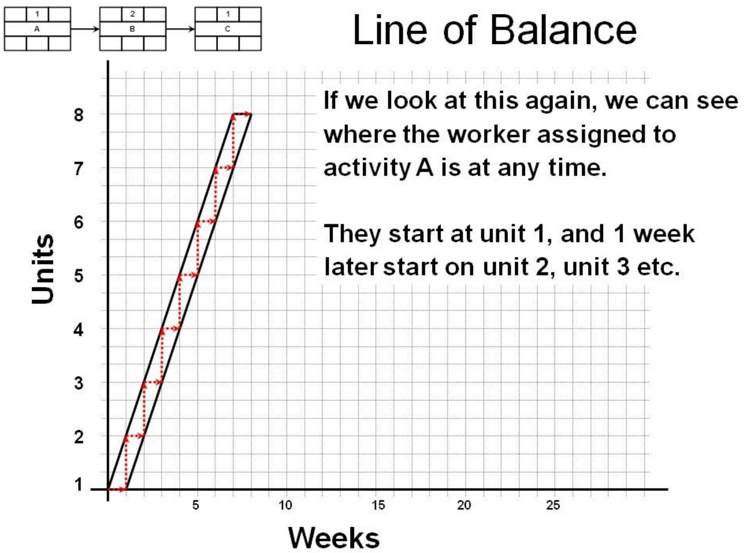
Line of Balance

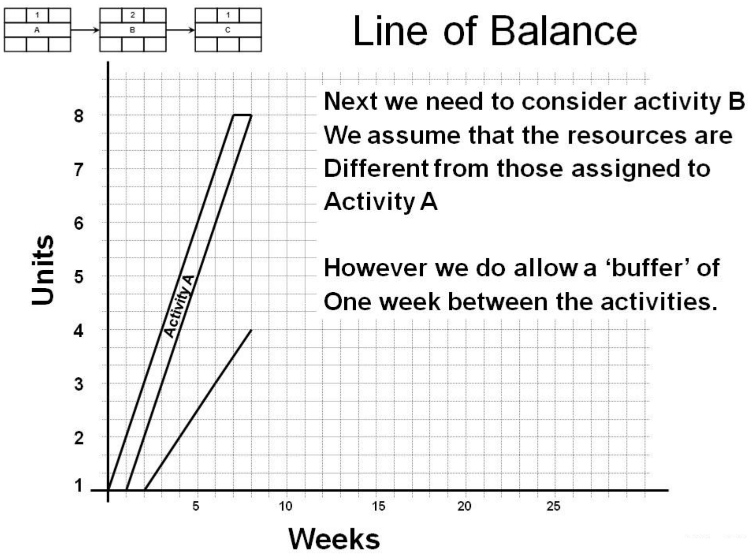


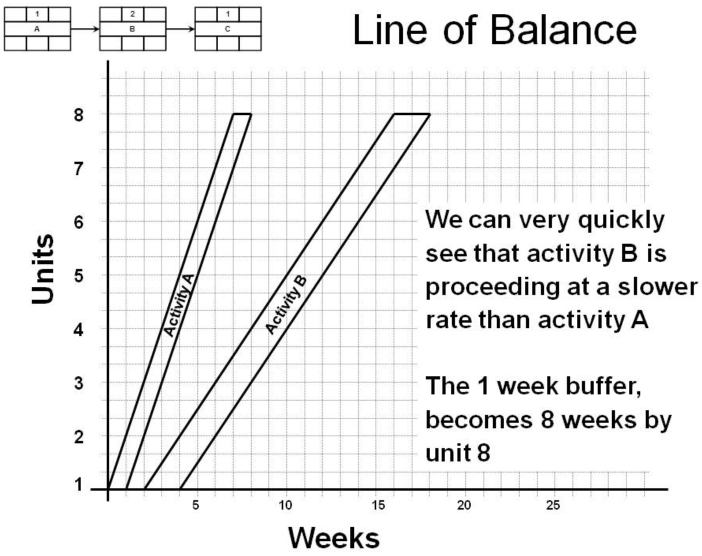
We now have the start of each
activity on each unit.
We now need to work out the finish
on each unit

This is done by constructing a
parallel line 1 week after the start
(as the activity duration is 1 week)

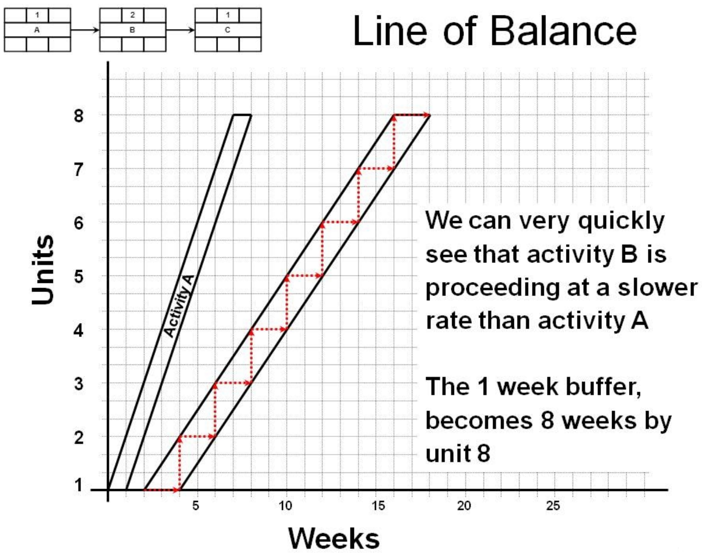
Then 'cap' it off.


1
A
2
B
1
C
Line of Balance
If we look at this again, we can see where the worker assigned to activity A is at any time.
They start at unit 1, and 1 week later start on unit 2, unit 3 etc.
Units
8
7
6
5
4
3
2
1
5
10
15
20
25
Weeks

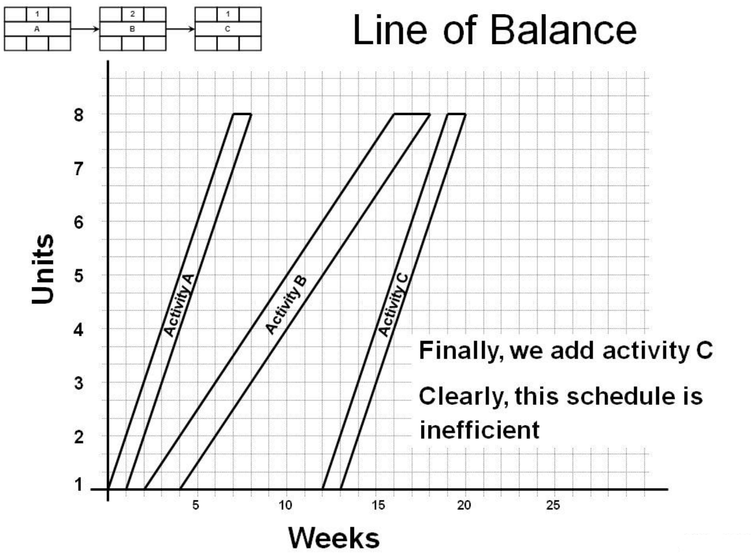

1
A
2
B
1
C
Line of Balance
Next we need to consider activity B
We assume that the resources are Different from those assigned to Activity A
However we do allow a 'buffer' of One week between the activities.
Activity A
Units
8
7
6
5
4
3
2
1
5
10
15
20
25
Weeks



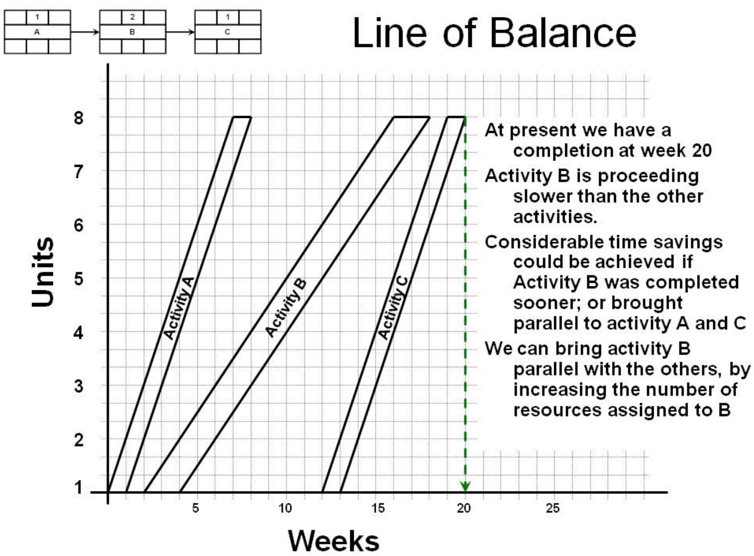
1
A
2
B
1
C
Line of Balance
Units
8
7
6
5
4
3
2
1
Activity A
Activity B
We can very quickly see that activity B is proceeding at a slower rate than activity A
The 1 week buffer, becomes 8 weeks by unit 8
5
10
15
20
25
Weeks



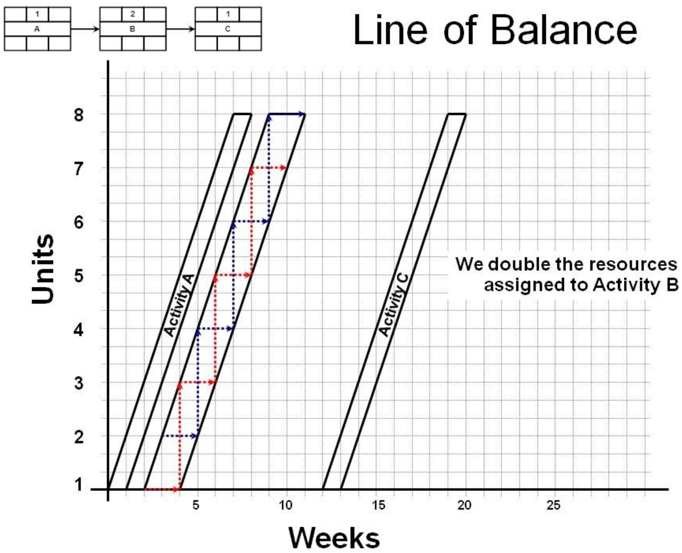
1
A
2
B
1
C
Line of Balance
Units
8
7
6
5
4
3
2
1
Activity A
We can very quickly see that activity B is proceeding at a slower rate than activity A
The 1 week buffer, becomes 8 weeks by unit 8
5
10
15
20
25
Weeks

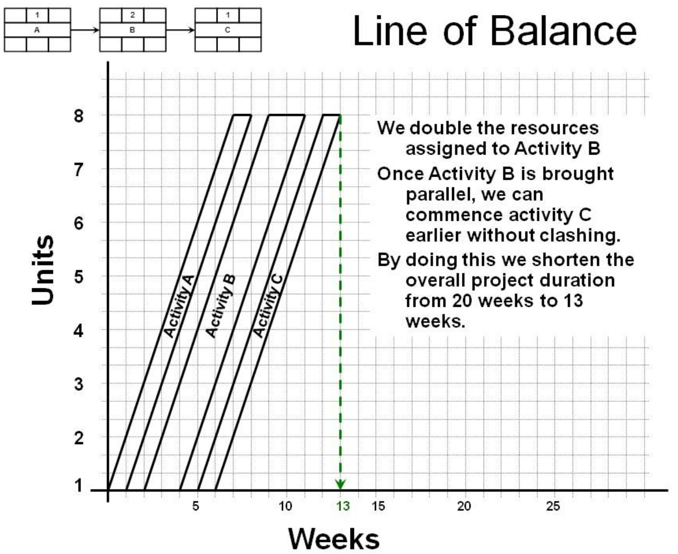


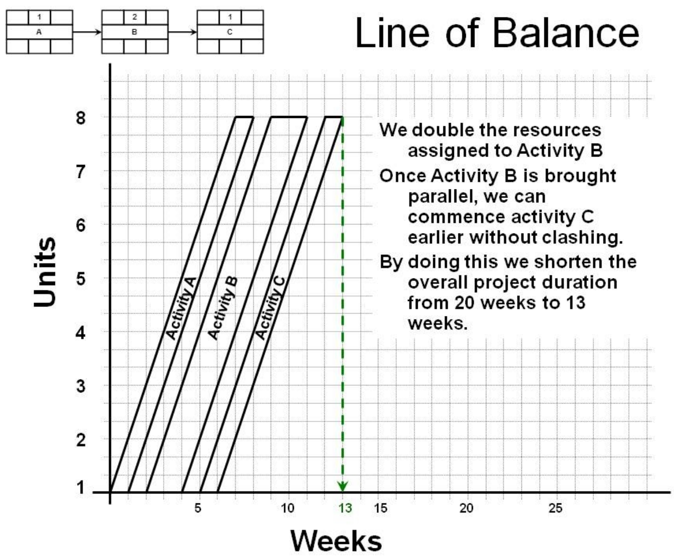
1
A
2
B
1
C
Line of Balance
Units
8
7
6
5
4
3
2
1
Activity A
Activity B
Activity C
Finally, we add activity C
Clearly, this schedule is inefficient
5
10
15
20
25
Weeks

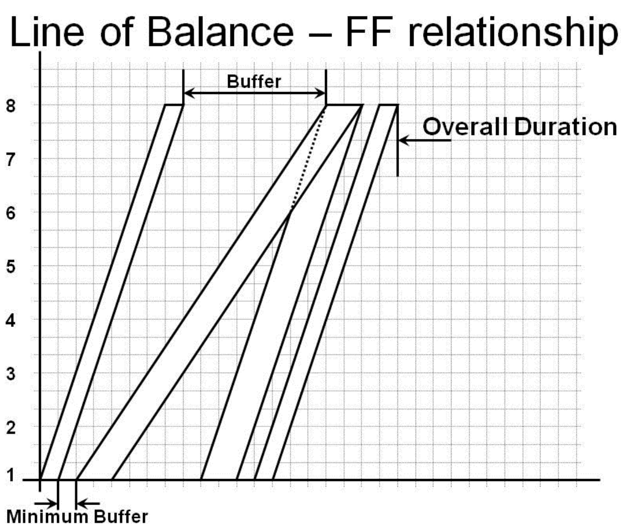


1
A
2
B
1
C
Line of Balance
Units
8
7
6
5
4
3
2
1
Activity A
Activity B
Activity C
At present we have a completion at week 20
Activity B is proceeding slower than the other activities.
Considerable time savings could be achieved if Activity B was completed sooner; or brought parallel to activity A and C
We can bring activity B parallel with the others, by increasing the number of resources assigned to B
5
10
15
20
25
Weeks


1
A
2
B
1
C
Line of Balance
Units
8
7
6
5
4
3
2
1
Activity A
Activity C
We double the resources assigned to Activity B
5
10
15
20
25
Weeks


1
A
2
B
1
C
Line of Balance
Units
8
7
6
5
4
3
2
1
Activity A
Activity B
Activity C
We double the resources assigned to Activity B
Once Activity B is brought parallel, we can commence activity C earlier without clashing.
By doing this we shorten the overall project duration from 20 weeks to 13 weeks.
5
10
13
15
20
25
Weeks

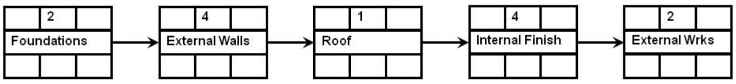

1
A
2
B
1
C
Line of Balance
Units
8
7
6
5
4
3
2
1
Activity A
Activity B
Activity C
5
10
13
15
20
25
Weeks
We double the resources assigned to Activity B
Once Activity B is brought parallel, we can commence activity C earlier without clashing.
By doing this we shorten the overall project duration from 20 weeks to 13 weeks.


Line of Balance – FF relationship
Buffer
Overall Duration
8
7
6
5
4
3
2
1
Minimum Buffer

Line of Balance Example 2

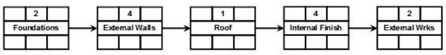
- Consider the project below which consists of 5 construction activities

Activity	Duration (weeks)	Number of Gangs
Foundations	2	2
External Walls	4	3
Roof Construction	1	1
Internal Finishes	4	3
External Works	2	2



- The contractor will be constructing 10 houses in the above sequence

Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition*, Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2



Activity	Duration (weeks)	Number of Gangs
Foundations	2	2
External Walls	4	3
Roof Construction	1	1
Internal Finishes	4	3
External Works	2	2

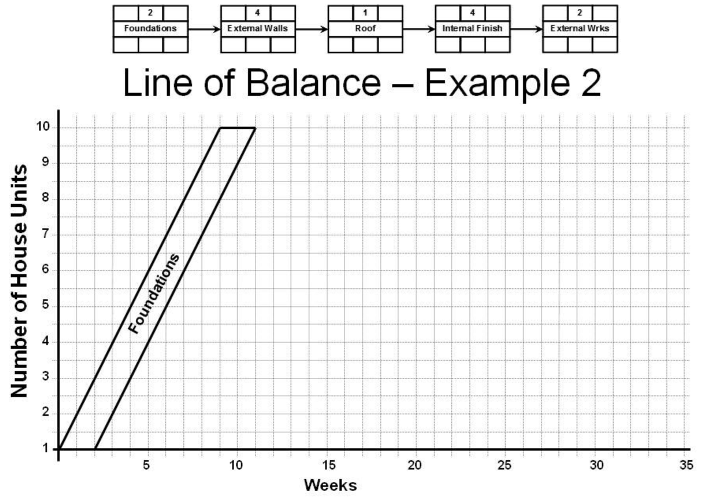
The mathematical relationship between the duration of an activity and the number of crews can be expressed as:

$$\frac{(Units - 1)(duration)}{resource}$$

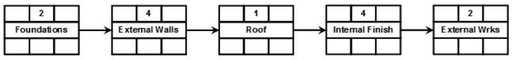
For Activity ‘Foundations’ this is

$$\frac{(10-1)(2)}{2} = 9$$

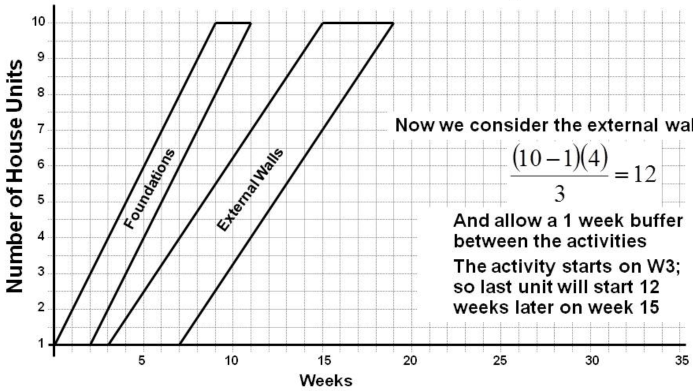
Which means that the last start of ‘Foundations’ is on week 9



Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition*, Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2



Line of Balance – Example 2



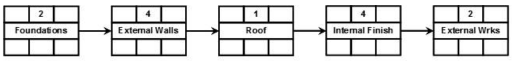
Now we consider the external walls

$$\frac{(10-1)(4)}{3} = 12$$

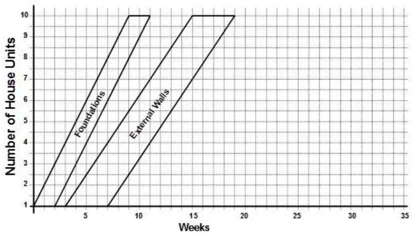
And allow a 1 week buffer between the activities

The activity starts on W3; so last unit will start 12 weeks later on week 15

Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition*, Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2



Line of Balance – Example 2



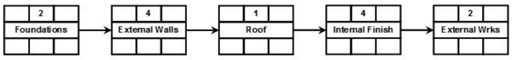
We now need to consider the roof.

It is good practice to run a quick test to determine if the buffer should be applied at the start or end of the activity

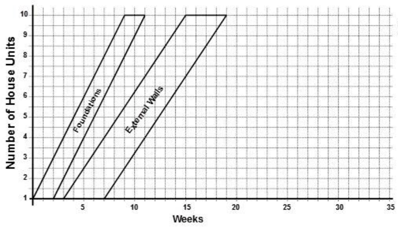
- We examine the slope of the lines for the External Walls and the Roof

$$\text{Slope of Balance Line} = \frac{\text{Duration}}{\text{Num of Gangs}}$$

External walls: $\frac{4}{3} = 1.33$ **Roof:** $\frac{2}{2} = 1$



Line of Balance – Example 2



$$\text{Slope of Balance Line} = \frac{\text{Duration}}{\text{Num of Gangs}}$$

External walls: $\frac{4}{3} = 1.33$

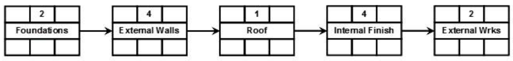
Roof: $\frac{2}{2} = 1.00$

- The slope of the 'External Walls' activity is 1.33
- The slope of the 'Roof' activity is 1.00

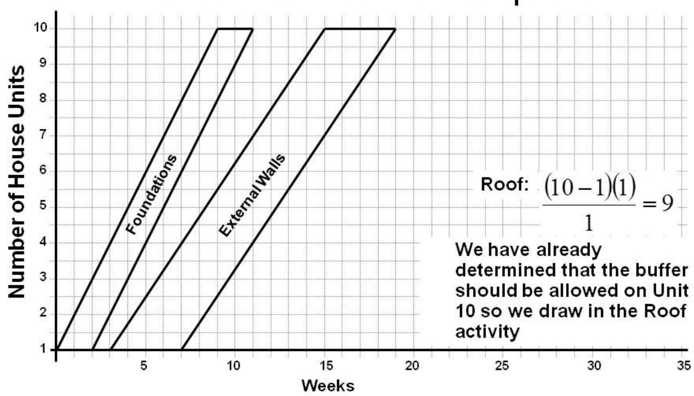
The lower the number the faster the rate of progress

So in this case we can see that the Roof will progress at a faster rate than the External Walls

Because of this, we need to allow the 1 week buffer at the start of Unit 10; otherwise the program will clash



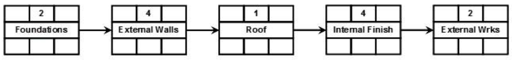
Line of Balance – Example 2



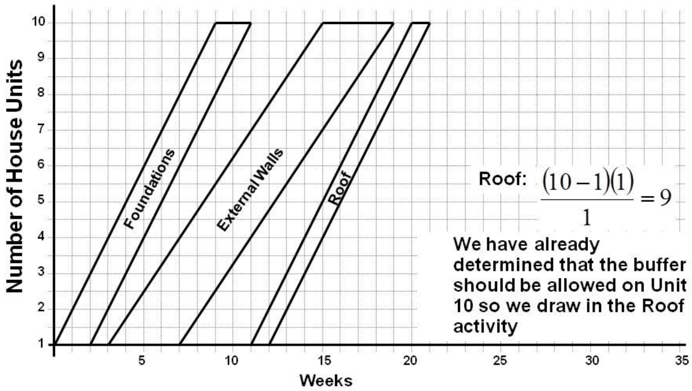
Roof: $\frac{(10-1)(1)}{1} = 9$

We have already determined that the buffer should be allowed on Unit 10 so we draw in the Roof activity

Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition*, Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2



Line of Balance – Example 2



Roof: $\dfrac{(10-1)(1)}{1} = 9$

We have already determined that the buffer should be allowed on Unit 10 so we draw in the Roof activity

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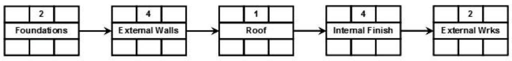
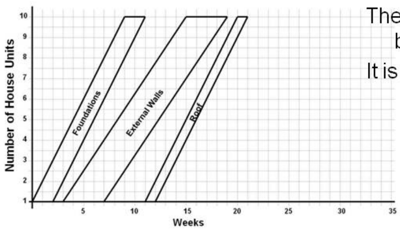


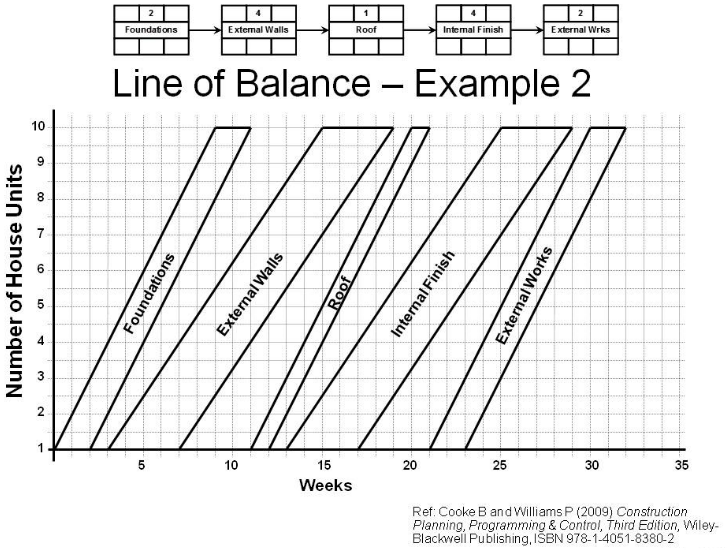
Line of Balance – Example 2

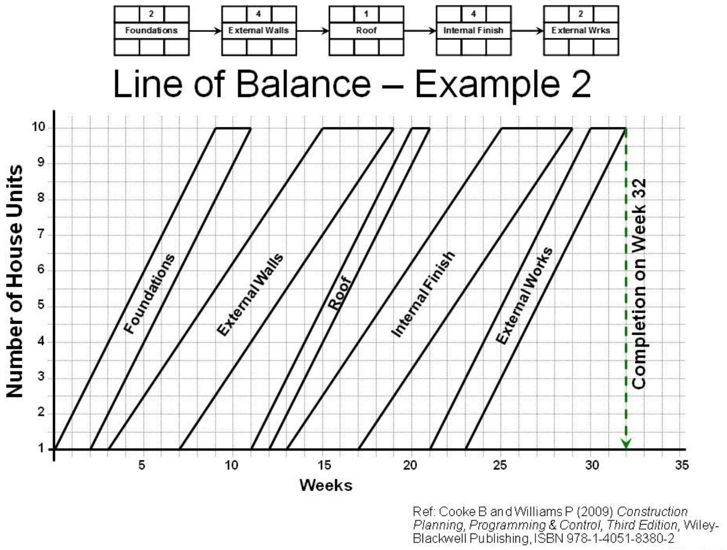


The calculations for each activity can be run at the start of the analysis

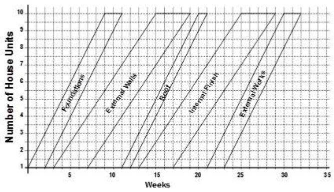
It is in fact normal practice to do so..

- slope of ‘Roof’: 1.00
- slope of ‘Internal Finish’: 1.33; therefore buffer at Unit 1
- slope of ‘External Works’: 1.00; therefore buffer at Unit 10
- Duration of ‘Internal Finish’: 12 weeks
- Duration of ‘External Works’: 9 weeks


2
Foundations
4
External Walls
1
Roof
4
Internal Finish
2
External Wrks
Line of Balance – Example 2
Number of House Units
Weeks
Foundations
External Walls
Roof
Internal Finish
External Works
Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition*, Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2


2
Foundations
4
External Walls
1
Roof
4
Internal Finish
2
External Wrks
Line of Balance – Example 2
Number of House Units
Weeks
Foundations
External Walls
Roof
Internal Finish
External Works
Completion on Week 32
Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition*, Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2

What else can we determine?



- We have determined that completion of unit 10 should occur at the end of week 32

We also have start and end times for all of the activities

Foundations – start week 0: finish week 11

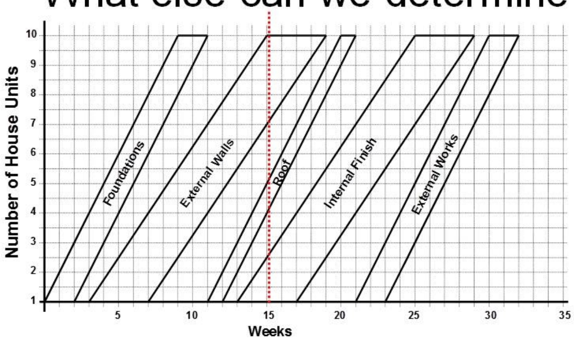
External Walls – start week 3: finish week 19

Roof – start week 11: finish week 21

Internal Finish - start week 13: finish week 29

External Works - start week 21: finish week 32

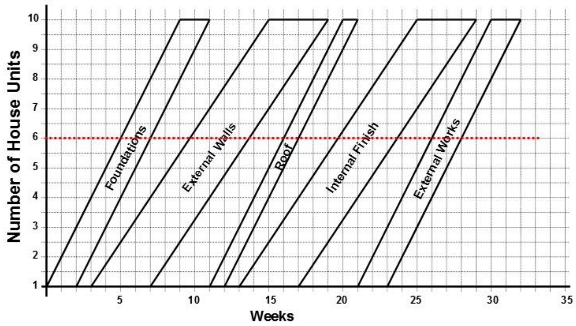
What else can we determine?



We can also pin-point progress at any point in time:

For instance at week 15 all foundations should be complete; the last of the external walls should be starting, the roof should be complete on Unit 4, and internal finishes should be 50% complete on Unit 1 and 25% complete on Unit 2

What else can we determine?



We can also examine the schedule on a particular unit:

Unit 6 should commence on week 5 and be complete by week 28; the roof should be complete by week 17, and any decisions in relation to paint colour etc. must be made by the purchaser before week 19

Mathematical Method

- The solutions presented use a graphical method
- Line of balance can also be solved using a mathematical method or algorithm

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2									
External Walls	4	3									
Roof	1	1									
Internal Finishes	4	3									
External Works	2	2									

Construct the Table as shown

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00								
External Walls	4	3	1.33								
Roof	1	1	1.00								
Internal Finishes	4	3	1.33								
External Works	2	2	1.00								

Calculate the slope of each balance line using the equation

$$\text{Slope of Balance Line} = \frac{\text{Duration}}{\text{Gangs}}$$

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00								
External Walls	4	3	1.33								
Roof	1	1	1.00								
Internal Finishes	4	3	1.33								
External Works	2	2	1.00								

Compare the slopes

In this case 1.33 is larger than 1.00, therefore the slope goes to the bottom of the graph

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00								
					Buffer at Bottom						
External Walls	4	3	1.33								
Roof	1	1	1.00								
Internal Finishes	4	3	1.33								
External Works	2	2	1.00								

An easy way to remember is:

'the buffer goes to the location of the larger of the two numbers being compared'

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00								
					Buffer at Bottom						
External Walls	4	3	1.33								
Roof	1	1	1.00								
Internal Finishes	4	3	1.33								
External Works	2	2	1.00								

In this case the larger number is on the top

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00								
					Buffer at Bottom						
External Walls	4	3	1.33								
					Buffer at Top						
Roof	1	1	1.00								
Internal Finishes	4	3	1.33								
External Works	2	2	1.00								

So the buffer goes to the top

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00								
					Buffer at Bottom						
External Walls	4	3	1.33								
					Buffer at Top						
Roof	1	1	1.00								
					Buffer at Bottom						
Internal Finishes	4	3	1.33								
External Works	2	2	1.00								

And so on

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00								
					Buffer at Bottom						
External Walls	4	3	1.33								
					Buffer at Top						
Roof	1	1	1.00								
					Buffer at Bottom						
Internal Finishes	4	3	1.33								
					Buffer at Top						
External Works	2	2	1.00								

And so on…

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9					
					Buffer at Bottom						
External Walls	4	3	1.33			12					
					Buffer at Top						
Roof	1	1	1.00			9					
					Buffer at Bottom						
Internal Finishes	4	3	1.33			12					
					Buffer at Top						
External Works	2	2	1.00			9					

Add in the total activity durations using

$$\frac{(Units - 1)(Duration)}{Gangs}$$

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9					
					Buffer at Bottom						
External Walls	4	3	1.33			12					
					Buffer at Top						
Roof	1	1	1.00			9					
					Buffer at Bottom						
Internal Finishes	4	3	1.33			12					
					Buffer at Top						
External Works	2	2	1.00			9					

This is the same as:

$$(Units - 1) \times Slope$$

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9					
					Buffer at Bottom		1				
External Walls	4	3	1.33			12					
					Buffer at Top		1				
Roof	1	1	1.00			9					
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

Now insert the buffers

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00		
					Buffer at Bottom		1				
External Walls	4	3	1.33			12					
					Buffer at Top		1				
Roof	1	1	1.00			9					
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

Foundations start at time 0.00 and finishes 2 days later

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	
					Buffer at Bottom		1				
External Walls	4	3	1.33			12					
					Buffer at Top		1				
Roof	1	1	1.00			9					
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

Foundations on Unit 10 will start 9 days after the start of Unit 1

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12					
					Buffer at Top		1				
Roof	1	1	1.00			9					
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

Foundations on Unit 1 will finish 2 days later

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00			
					Buffer at Top		1				
Roof	1	1	1.00			9					
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

We have already determined that the buffer between 'Foundations' and 'External Walls' goes to the bottom

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00			
					Buffer at Top		1				
Roof	1	1	1.00			9					
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

Therefore 'External Walls' will commence one day after the finish of 'Foundations' on Unit 1; which is Day 3

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00	7.00		
					Buffer at Top		1				
Roof	1	1	1.00			9					
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

'External Walls' will take 4 days. As this commenced on Day 3, it will be finished 4 days later on Day 7

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00	7.00	15.00	19.00
					Buffer at Top		1				
Roof	1	1	1.00			9					
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

Unit 10 will start 12 days later on Day 15
And will finish on Day 19

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00	7.00	15.00	19.00
					Buffer at Top		1				
Roof	1	1	1.00			9				20.00	
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

Next we have the roof. The buffer goes to the 'top' Therefore we start unit 10 on Day 20 and complete 1 days later on Day 21

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00	7.00	15.00	19.00
					Buffer at Top		1				
Roof	1	1	1.00			9				20.00	21.00
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

Construct the Table as shown

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00	7.00	15.00	19.00
					Buffer at Top		1				
Roof	1	1	1.00			9		11.00	12.00	20.00	21.00
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12					
					Buffer at Top		1				
External Works	2	2	1.00			9					

We can now work backwards to determine when Unit 1 should start and finish

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00	7.00	15.00	19.00
					Buffer at Top		1				
Roof	1	1	1.00			9		11.00	12.00	20.00	21.00
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12		13.00			
					Buffer at Top		1				
External Works	2	2	1.00			9					

And the process continues on.

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00	7.00	15.00	19.00
					Buffer at Top		1				
Roof	1	1	1.00			9		11.00	12.00	20.00	21.00
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12		13.00	17.00	25.00	29.00
					Buffer at Top		1				
External Works	2	2	1.00			9					

And the process continues on.

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00	7.00	15.00	19.00
					Buffer at Top		1				
Roof	1	1	1.00			9		11.00	12.00	20.00	21.00
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12		13.00	17.00	25.00	29.00
					Buffer at Top		1				
External Works	2	2	1.00			9				30.00	

And the process continues on.

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00	7.00	15.00	19.00
					Buffer at Top		1				
Roof	1	1	1.00			9		11.00	12.00	20.00	21.00
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12		13.00	17.00	25.00	29.00
					Buffer at Top		1				
External Works	2	2	1.00			9		21.00	23.00	30.00	32.00

And the process continues on.

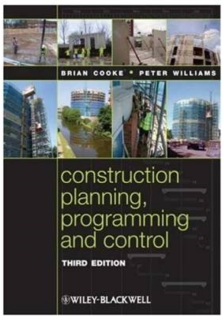
8 Time Chainage

Mathematical Method

Activity	Duration	Gang	Slope			Activity Duration	Buffer	Start of Unit 1	Finish of Unit 1	Start of Unit 10	Finish of Unit 10
								Bottom		Top	
Foundations	2	2	1.00			9		0.00	2.00	9.00	11.00
					Buffer at Bottom		1				
External Walls	4	3	1.33			12		3.00	7.00	15.00	19.00
					Buffer at Top		1				
Roof	1	1	1.00			9		11.00	12.00	20.00	21.00
					Buffer at Bottom		1				
Internal Finishes	4	3	1.33			12		13.00	17.00	25.00	29.00
					Buffer at Top		1				
External Works	2	2	1.00			9		21.00	23.00	30.00	32.00

Once complete each of the 4 points of the Balance Line have been determined, so the diagram can be constructed

Further Reading



Cooke B. and Williams P. (2009) *Construction Planning, Programming & Control, Third Edition,* Wiley-Blackwell Publishing, Chapter 9

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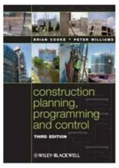
Basic Project Scheduling
Time-Chainage Charts

Project Management

Year 4



Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition,* Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2

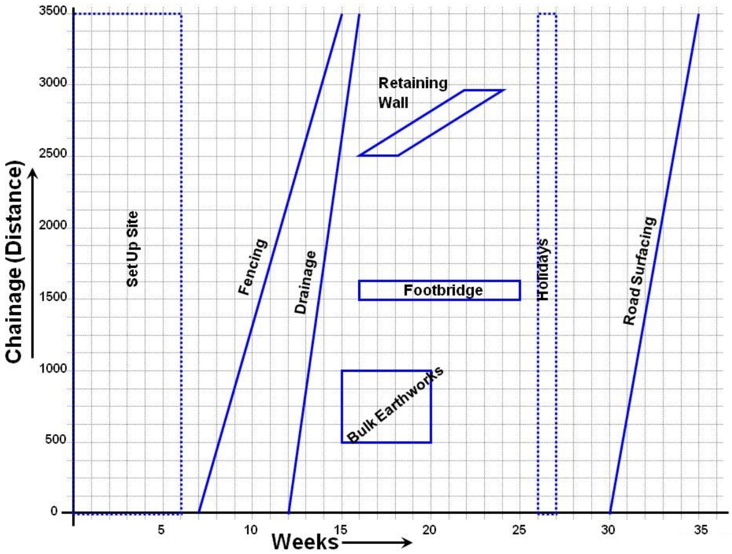
Time-Chainage Charts

- AKA
  - Time-Distance diagrams (or charts)
  - Time-Location diagrams (or charts)
  - Location-Time diagrams (or charts)
  - Etc.
- Time-chainage diagrams are a combination of the bar-chart and line of balance schedules.

History

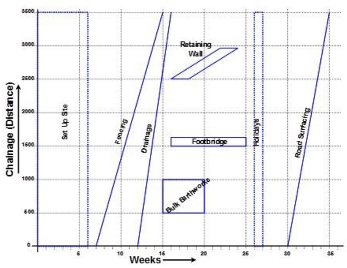
- Relatively new tool for scheduling projects
- TC charts have gained wide acceptance in:
  - Motorway construction
  - Railway construction
  - Pipeline work
  - Tunnel construction
  - Bridges
- The technique was used for tunnelling and fixed equipment installation on the channel tunnel project

- Time-chainage diagrams are only appropriate for certain types of project, and therefore is not as widely used as bar charts (Gantt) or network techniques.
  - It is not available on MS Project…
- Time chainage has distinct attributes and advantages on projects where it is important to depict
  - The order of activities or operations
  - The location of activities
  - How activites must progress in relation to direction and distance
  - Time, Key dates, holidays, etc.



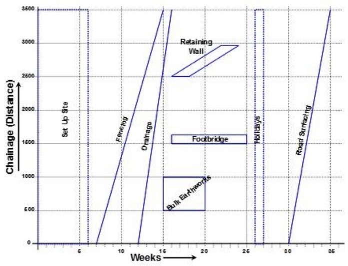
Example

- Consider a project to improve a 3.5km stretch of motorway. The activities are as follows
  1. Fencing
  2. Drainage
  3. Bulk Earthworks -
  4. Footbridge
  5. Retaining wall
  6. Road surfacing



Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition*, Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2

- Further information
  - Set-up Site
    - starts at time 0,
    - duration 6 weeks
  - Fencing
    - Starts week 7
    - Duration 9 weeks, therefore finish week 15
    - Full 3.5 km to be fenced
  - Holiday Period
    - Starts week 26 for 1 week



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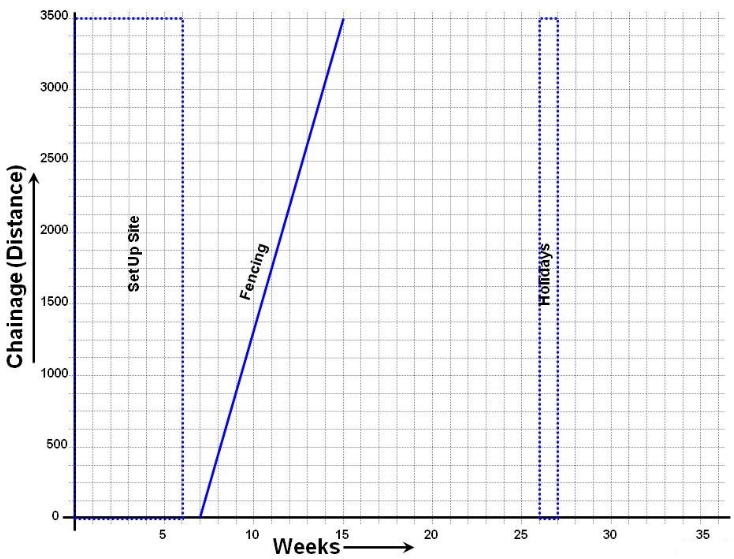
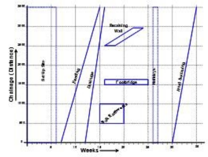
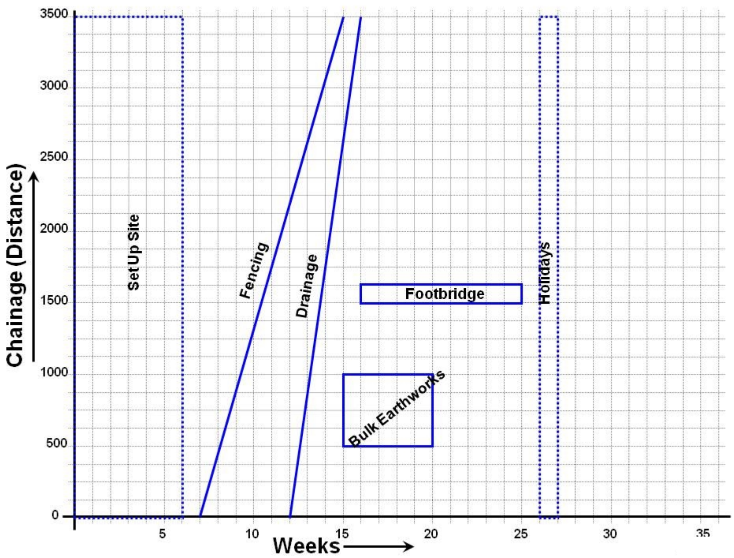
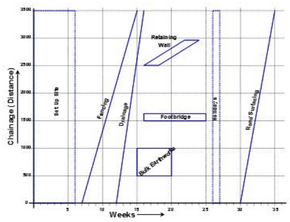




- Further information
  - Drainage
    - starts week 12
    - duration 4 weeks, therefore finish week 16
    - Drainage required for full 3.5km
  - Bulk Earthworks
    - Starts week 15
    - Duration 5 weeks, therefore finish week 20
    - Required from 500m to 1000m
  - Footbridge
    - Starts week 16 for 9 weeks, therefore finish week 25
    - Required 1500m

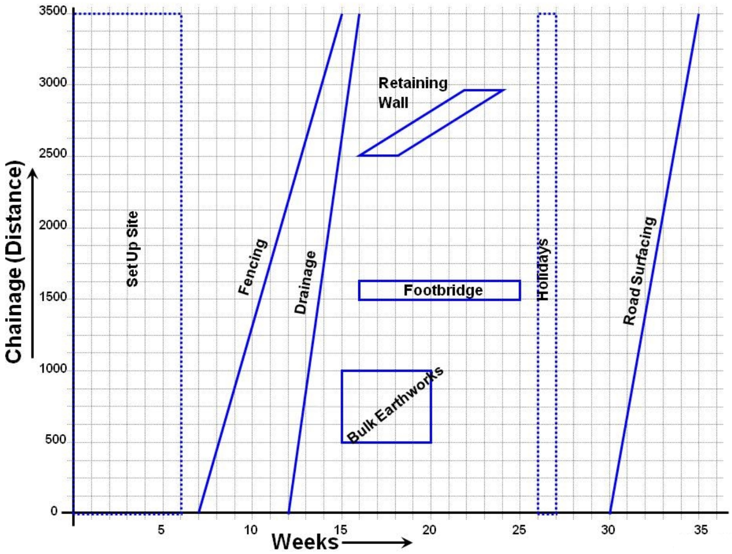
Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition*, Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2





- Further information
  - Retaining Wall
    - starts week 16
    - duration 8 weeks, therefore finish week 24
    - Required from 2500m to 2900m
    - Progresses at a rate of 50m per week
  - Road Surfacing
    - Starts week 30
    - Duration 5 weeks, therefore finish week 35
    - Entire 3.5km to be surfaced

Ref: Cooke B and Williams P (2009) *Construction Planning, Programming & Control, Third Edition*, Wiley-Blackwell Publishing, ISBN 978-1-4051-8380-2



Tips for Constructing Time Chainage Diagrams

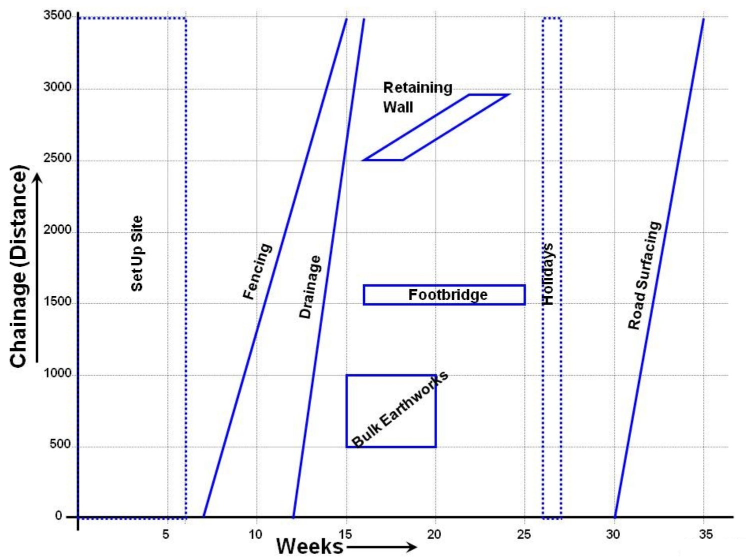
– Examine Layout Drawings etc and determine locations of important features

– Draw a sketch of the diagram, and include holidays etc.

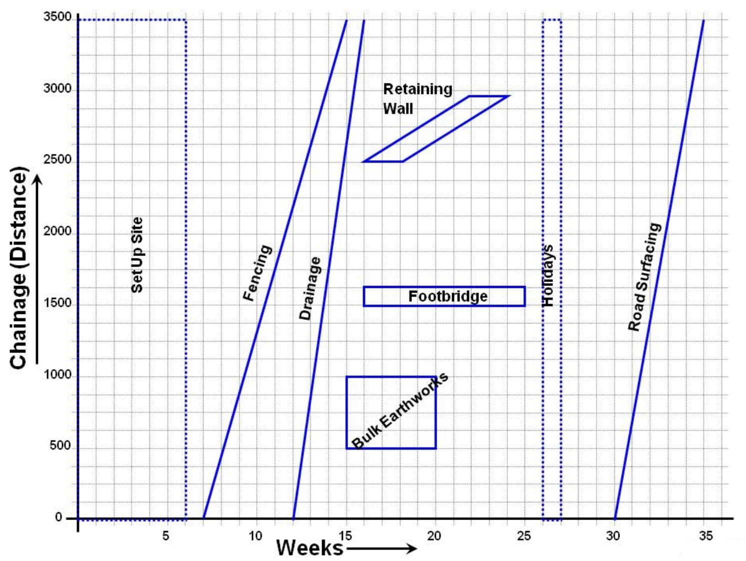
– List main activities in approximate sequence. Include site setup and clearance

– For static activities (footbridge), 'block out' the location, distance, and the correct duration

– **Beware of changes in axis**: time chainage is relatively new and conventions have yet to take hold



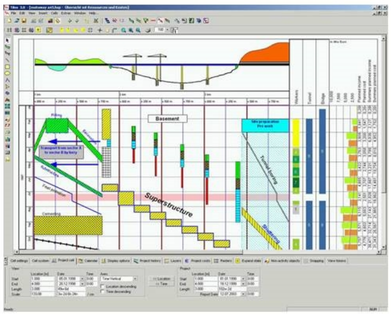
Chainage (Distance)
Weeks
Set Up Site
Fencing
Drainage
Retaining Wall
Footbridge
Bulk Earthworks
Holidays
Road Surfacing

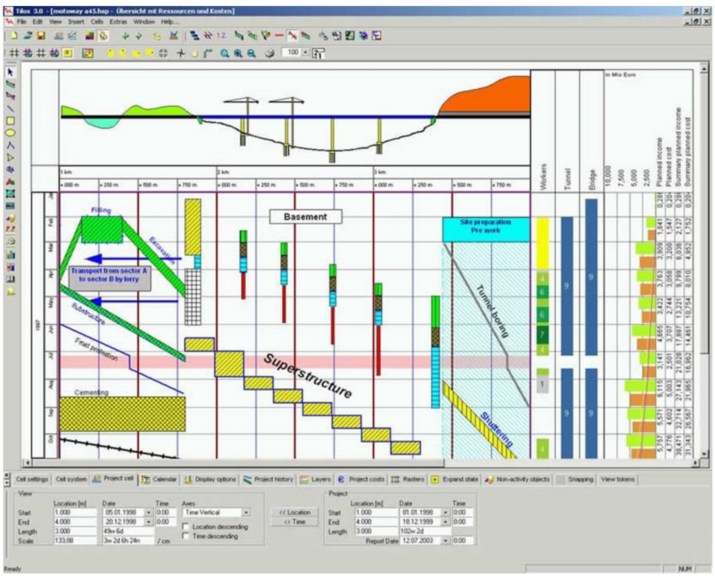


Chainage (Distance)
Weeks
Set Up Site
Fencing
Drainage
Retaining Wall
Footbridge
Bulk Earthworks
Holidays
Road Surfacing

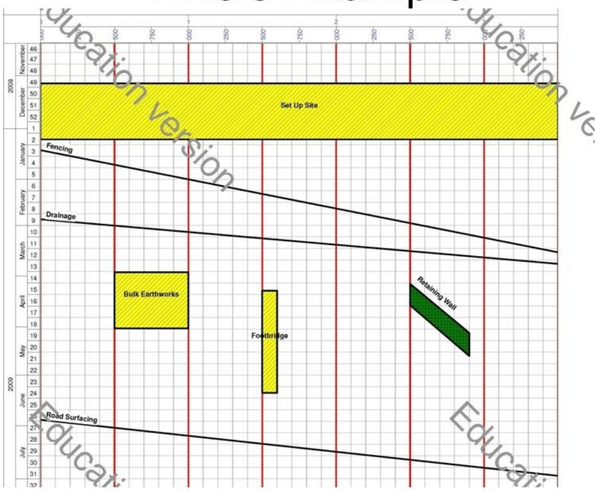
TILOS

- Commercial Software Package for Time Chainage Diagrams
- Free demo version available on website
  - http://www.astadev.com/software/tilos/index.asp
- Installed in 4C02 and 4C03

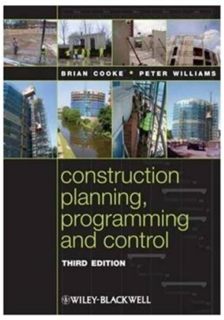




TILOS Example



Further Reading



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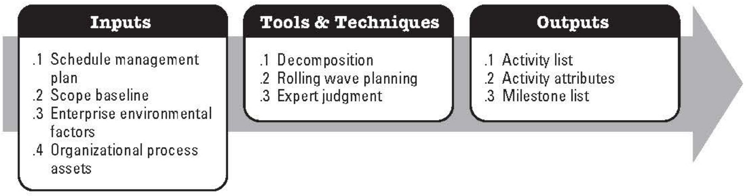


Figure 6-5. Define Activities: Inputs, Tools & Techniques, and Outputs

9 PMBOK Processes

Project Time Management

- Define Activities
- Sequence Activities
- Estimate Activity Resources
- Estimate Activity Durations
- Develop Schedule
- Control Schedule

We have already covered some of the material for Time Management, namely:

- Gantt Charts, Network Diagrams, Line of Balance, Time Chainage, PERT

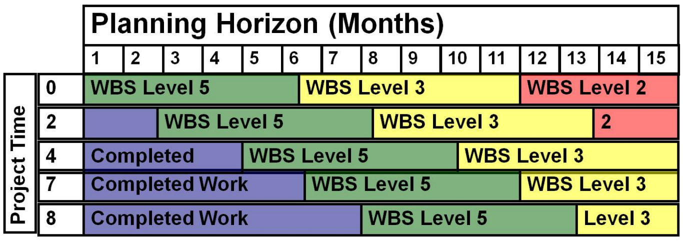
Define Activities
Part of the Planning Process Group

Define Activities

- Generally, Activity definition involves identifying and documenting schedule activities at the lowest level of the WBS i.e. work packages
- There is an overlap between WBS, WBS Dictionary and Activity Definition
- The main difference is that the WBS decomposes the project in terms of **deliverables**, and 'Activity Definition' decomposes the project in terms of **schedule activities Ideally, 'WBS', 'WBS Dictionary', and 'Activity Definition' should be carried out in parallel.**

Tools and Techniques **Rolling Wave Planning**
AKA **Moving Window** planning

- Rolling Wave planning is a form of progressive elaboration, whereby work to be accomplished in the near future is planned in detail at low levels of the WBS



WBS		Estimate Accuracy	
Level	Description	Low Risk Projects	High Risk Projects
1	Program	±35%	±75-100%
2	Project	±20%	±50-60%
3	Task	±10%	±20-30%
4	Subtask	±5%	±10-15%
5	Work Package	±2%	±5-10%

Table 2: Kerzner (2009), P569

- Elements further into the future are only planned to the upper levels in the WBS
- Increases the risks associated with the project
- For complex projects, it is often the only way to execute

Two key points to consider:

1. How far out you can plan in detail will vary considerably from project to project
2. **It works best when client and upper management understand how the technique works**

If the client or senior managers are not aware of the effects of progressive elaboration, there can be serious effects.

- Project budgets are normally set at the early stages of the project. Where PE is being used, a probability should be assigned to estimated costs to ensure funding will be available.

Cost Estimate Accuracy

This partially explains why tender prices can vary as much as 30% between highest and lowest

Define Activities **Outputs**

- Activity List
  - Comprehensive list of all schedule activities
- Activity Attributes

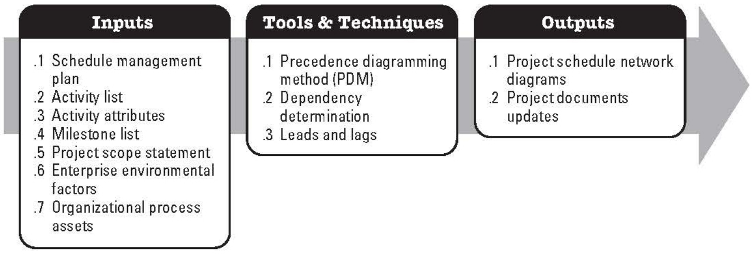
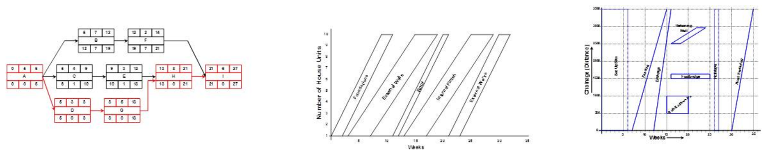


Figure 6-7. Sequence Activities: Inputs, Tools & Techniques, and Outputs



  - Activity identifier
  - Predecessors Successors
  - Logic Relationships
  - Leads Lags
  - Resource Requirements

- Milestone List
  - Mandatory or otherwise

Sequence Activities
Part of the Planning Process Group

Sequence Activities

- Activity Sequencing Involves identifying and documenting the logical relationship amongst schedule activities
- The logical relationships between schedule activities must be considered when determining project schedules
- Tools and techniques for this have already been covered :

Tools and Techniques
Precedence Diagrams

- Already covered

Dependency Determination

- Mandatory or **Hard Logic**, Inherent in the nature of the work being done
- Discretionary, Preferred Logic, **Soft Logic** e.g. Landscaping
- External: Usually driven by dependencies between project activities and non-project activities such as Planning Permission, IPC Licence, etc.

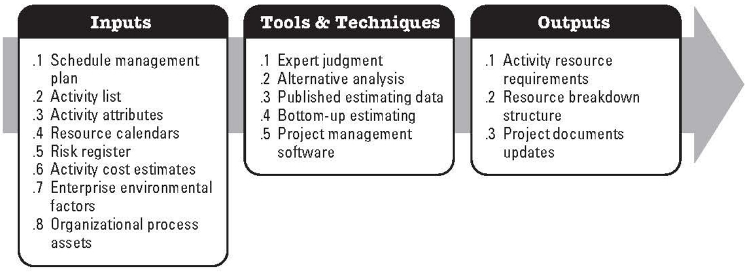


Figure 6-12. Estimate Activity Resources: Inputs, Tools & Techniques, and Outputs

Tools and Techniques
Leads and Lags

- Concrete set time typically creates a Lag
- Refer to book

Schedule Network Templates

- Entire project or portions of the project
- Allows transfer of information from project to project (Knowledge Management)
- Lessens the likelihood of errors of omission

Estimate Activity Resources
Part of the Planning Process Group

Estimate Activity Resources
Inputs

- Refer to Book..
- Resource calendars: Concerned with resource availability
  - People, Equipment, Materials
  - People: are appropriate skill sets available?
  - Equipment: Own or Hire
  - Materials: Availability, Storage, lead times, etc.

Tools and Techniques
Alternatives Analysis

- Machine Types, Size, etc.
- Make or Buy?

Published Estimating Data

- e.g. Spons Guides - Contains time and money data

Time	
Locate existing stop-tap	5 min
Setup equipment	15 min
Excavate	10 min
Cut and Remake Connections	10 min
Fill and Compact	10 min
Concrete Collar	10 min
Total Time	60 min
Cost	
Van, Tools & equip	€ 200 p/h
Labour	€ 120 p/h
Total Cost	€ 320 p/h

Bottom Up Estimating

- Most difficult and time consuming, however if done properly is highly accurate

Project Management Software

- MS Project Resource Sheets, etc.

Bottom-Up Estimating Example

Installation of a water meter box

This example works out direct cost and time only

Estimate Activity Durations

Part of the Planning Process Group

Estimate Activity Durations

Activity Duration Estimating involves:

- Estimating the amount of work required to complete an activity
- The level and type of resources that must be applied to complete an activity
- By using the above information, an estimate of the time taken to complete the task can be derived.

All data and assumptions that support the duration estimate are documented for each activity

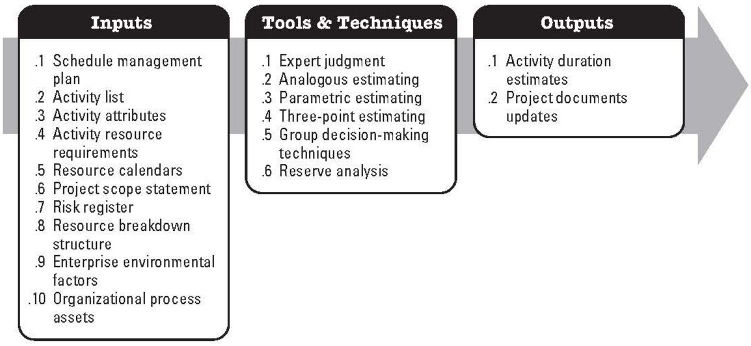


Figure 6-14. Estimate Activity Durations: Inputs, Tools & Techniques, and Outputs

Estimate Activity Durations

Work, Time, Resource relationship

$$\text{Time Required} = \frac{\text{Work Required}}{\text{Resources Applied}}$$

Note: this is a pseudo-mathematical relationship.

- The actual mathematical relationship will depend on how the 3 elements (work, time, resource) are defined.

The mathematical relationship is better described below:

$$t = f(w, r)$$

Tools & Techniques

Expert Judgment

- Refer to Book
- Very common, but not accurate enough; should be combined with one or more other methods to improve accuracy

Analogous Estimating

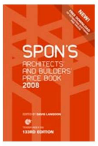
- Means using the actual duration of a previous similar activity as the basis for estimating the duration of a future schedule activity
- Very common method.

Tools & Techniques

Parametric Estimating

- Using the work, time, resource relationship

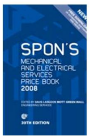
$$t = f(w, r)$$



268 *Prices for Measured Works – Major Works*

L WINDOWS/DOORS/STAIRS

Item	PC £	Labour hours	Labour £	Material £	Unit	**Total rate £**
L20 DOORS/SHUTTERS/HATCHES – cont'd						
Doors; standard flush; softwood Composition – cont'd						
Flush door; one-hour fire resisting; Iroko veneer; hardwood lipping all edges; Leaderflush" type B60 or other equal and approved; including groove and "Leaderseal" intumescent strip						
457 mm x 1981 mm x 54 mm	136.46	1.94	33.80	146.86	nr	**180.67**
533 mm x 1981 mm x 54 mm	137.97	1.94	33.80	148.49	nr	**182.29**
610 mm x 1981 mm x 54 mm	142.26	1.94	33.80	153.11	nr	**186.91**
686 mm x 1981 mm x 54 mm	143.32	1.94	33.80	154.25	nr	**188.06**
762 mm x 1981 mm x 54 mm	153.41	1.94	33.80	165.11	nr	**198.92**
838 mm x 1981 mm x 54 mm	154.69	1.94	33.80	166.49	nr	**200.29**
526 mm x 2040 mm x 54 mm	138.14	1.94	33.80	148.67	nr	**182.48**
626 mm x 2040 mm x 54 mm	142.97	1.94	33.80	153.87	nr	**187.67**
726 mmx 2040 mm x 54 mm	144.56	1.94	33.80	155.58	nr	**189.38**
826 mm x 2040 mm x 54 mm	155.18	1.94	33.80	167.01	nr	**200.81**
Flush door; external quality; skeleton or cellular core; plywood faced both sides; lipped on all four edges						
762 mm x 1981 mm x 54 mm	37.08	1.62	28.23	39.90	nr	**68.13**
838 mm x 1981 mm x 54 mm	38.41	1.62	28.23	41.34	nr	**69.56**
Flush door; external quality with standard glass opening; skeleton or cellular core; plywood faced both sides; lipped on all four edges; including glazing beads						
762 mm x 1981 mm x 54 mm	46.59	1.62	28.23	50.14	nr	**78.36**
838 mm x 1981 mm x 54 mm	47.81	1.62	28.23	51.45	nr	**79.68**



Material Costs/Prices for Measured Works – Mechanical Installations 413

U:VENTILATION/AIR CONDITIONING SYSTEMS

Item	Net Price £	Material £	Labour hours	Labour £	Unit	**Total rate £**
Modular air handling unit with supply and extract sections. Supply side; inlet with motorised damper, LTHW frost coil (at -5°C to 5°C), panel filter (EU4), bag filter (EU6), cooling coil at 28°Cdb/20°Cwb to 12°Cdb/11.5°C wb), LTHW heating coil (at 5°C to 21°C), supply fan, outlet plenum. Extract side; inlet with motorised damper, extract fan; includes access sections; placing in position and fitting of sections together; electrical work elsewhere.						
2 m³/s at 350 Pa	5793.90	7420.77	50.00	1133.92	nr	**8554.69**
2 m³/s at 700 Pa	6074.25	7779.84	50.00	1133.92	nr	**8913.76**
5 m³/s at 350 Pa	9985.50	12789.33	86.00	1950.34	nr	**14739.67**
5 m³/s at 700 Pa	10172.92	13029.38	86.00	1950.34	nr	**14979.72**
8 m³/s at 350 Pa	13866.30	17759.82	105.00	2381.23	nr	**20141.05**
8 m³/s at 700 Pa	14199.15	18186.13	105.00	2381.23	nr	**20567.36**
10 m³/s at 350 Pa	16011.45	20507.31	120.00	2721.41	nr	**23228.71**
10 m³/s at 700 Pa	16356.38	20949.08	120.00	2721.41	nr	**23670.49**
13 m³/s at 350 Pa	20069.18	25704.40	130.00	2948.19	nr	**28652.59**
13 m³/s s at 700 Pa	20698.65	26510.62	130.00	2948.19	nr	**29458.82**
15 m³/s at 350 Pa	22425.90	28722.87	145.00	3288.37	nr	**32011.24**
15 m³/s at 700 Pa	22989.22	29444.37	145.00	3288.37	nr	**32732.74**
18 m³/s at 350 Pa	25092.37	32138.06	160.00	3628.54	nr	**35766.61**
18 m³/s at 700 Pa	25679.85	32890.50	160.00	3628.54	nr	**36519.04**
20 m³/s at 350 Pa	27424.95	35125.60	175.00	3968.72	nr	**39094.32**
20 m³/s at 700 Pa	28378.35	36346.71	175.00	3968.72	nr	**40315.43**

- Parametric Estimating is a process by which the duration of an activity can be quantitatively determined by multiplying the quantity of work to be performed by the productivity rate
- Can be highly accurate. However, beware of inaccurate base data, or improperly used base data.

Standard rate of progress for laying a pipe in a greenfield site usually bears no resemblance to laying a pipe in a built up area with existing services.

SPON's Architects & Builders

SPON's Mech & Elec

Three-Point Estimates

The accuracy of a duration estimate can be improved by considering the amount of risk in the original estimate. Three types of estimate are produced:

- Most Likely
- Optimistic

- Pessimistic

The average of these three estimates is taken

Average Duration

$$t_e = \frac{t_o + t_m + t_p}{3}$$

Weighted Average Duration (as per PERT)

$$t_e = \frac{t_o + 4t_m + t_p}{6}$$

Reserve Analysis

Reserve analysis means adding time to a previously determined (or estimated) activity duration to account for:

- Potential Data inaccuracies (analogous, parametric etc.)
- Schedule risks (resource availability etc.)

Contingencies can be based on %age of estimated activities, fixed durations, etc. Contingency reserves can be utilised, reduced or eliminated as the project progresses and more information becomes available All aspects of contingency reserves should be documented

Activity Duration Estimating Outputs

Activity Durations Estimates: quantitative assessments of the work periods (time) that will be required to complete schedule activities

- 2 weeks ± 2 days
- 85% probability of 12 days

Project Document Updates

- Refer to book and previous lectures

Develop Schedule

Part of the Planning Process Group

Develop Schedule

Schedule Development is an iterative process to determine the planned start and planned completion dates for project activities Duration Estimates and Resource Estimates may need to be revised in order to develop an accurate schedule against which project progress can be tracked The initial Project Schedule is known as the 'Baseline Schedule'. Schedule Development continues throughout the course of the project.

- Risk Events may occur, or may not occur
- Resource Availabilities may change
- Scope may change
- Etc.

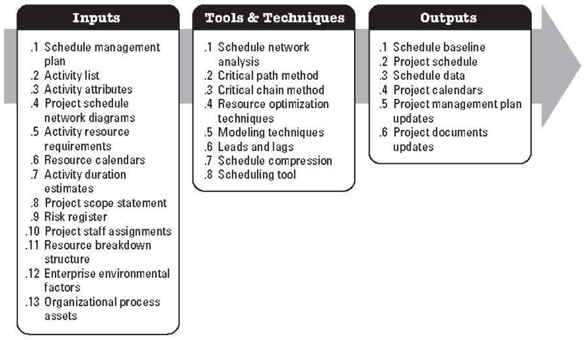


Figure 6-16 Develop Schedule: Inputs, Tools & Techniques, and Outputs

Tools & Techniques

Network Analysis, CPM, Critical Chain

- Already covered in lectures
- Refer to Book for further details

Schedule Compression

- Crashing
- Fast Tracking

What-if Scenario Analysis Resource Leveling

Schedule Compression

Schedule Compression shortens the project schedule without changing the project scope.

- Crashing: shortening activity durations, in order to shorten the overall project duration
- Fast-Tracking: commencing phases (or activities) before their logical predecessor is completed.

Crashing

Shortening Activity durations in order to shorten overall project duration.

- Usually involves shortening durations on the critical path.
- Shortening durations on the Critical Path may change the Critical Path
- Crashing normally involves increased costs

Crashing involves increasing the resources (labour and/or equipment) assigned to an activity.

- Remember:

$$\text{Time Required} = \frac{\text{Work Required}}{\text{Resources Applied}}$$

- You cannot change the work; the scope must remain unchanged

Crashing

NEVER crash a project at planning stage

- At planning stage you should be looking at building in schedule contingency.
- If you are crashing at planning stage then you have underestimated resources or resource availability (need to re-plan, not crash)
- Better to look at:
  - Sequence of Activities
  - Internal v. External Resources
  - Modification of Scope (requires stakeholder approval)

Crashing

A correctly planned and executed project should not require crashing Crashing a project should be looked upon as the last resort for bringing a project back on schedule Not all activities can be crashed

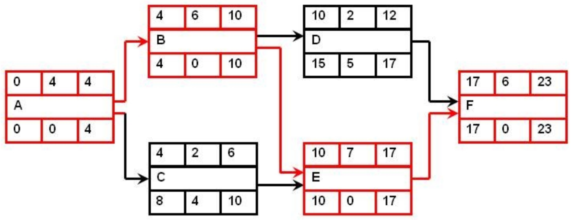
- *It takes one woman nine months to have a baby. It cannot be done in one month by impregnating nine women.*

Crashing an activity will always be subject to some form of constraint

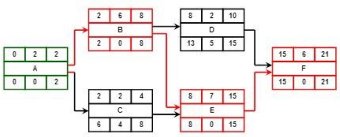
Crashing **Trade-offs**

- Increased Cost
- Increased Risk
  - Not just Schedule Risk; Health & Safety may be compromised, H&S should never be compromised.
- Typically increased management effort is required
- Crashing one project may have a detrimental effect on other projects (or operations) being undertaken by the organization

Crash Costing

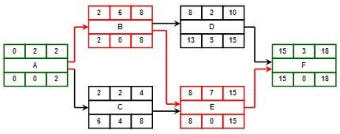


			Duration (weeks)		Cost €		Crash Cost per week
ID	Activity	IPA	Normal	Crash	Normal	Crash	
1	A	-	4	2	10,000	14,000	2,000
2	B	A	6	5	30,000	42,500	12,500
3	C	A	2	1	8,000	9,500	1,500
4	D	B	2	1	12,000	18,000	6,000
5	E	B,C	7	5	40,000	52,000	6,000
6	F	D,E	6	3	20,000	29,000	3,000



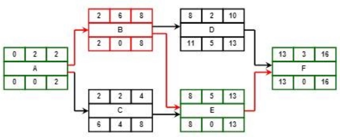
			Duration (weeks)		Cost €		Crash Cost per week
ID	Activity	IPA	Normal	Crash	Normal	Crash	
1	A	-	4	2	10,000	14,000	2,000
2	B	A	6	5	30,000	42,500	12,500
3	C	A	2	1	8,000	9,500	1,500
4	D	B	2	1	12,000	18,000	6,000
5	E	B,C	7	5	40,000	52,000	6,000
6	F	D,E	6	3	20,000	29,000	3,000

- Activity C has lowest crash cost per week
  - Crashing C at this stage will have no effect as it is not on the critical path
- Next lowest crash cost per week is A at €2,000 per week.
  - On critical path so will effect overall project duration
  - Crashing A reduces the overall project duration by 2 weeks to give new project duration of 21 weeks



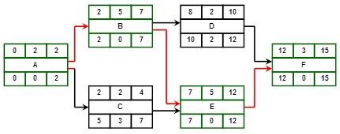
			Duration (weeks)		Cost €		Crash Cost per week
ID	Activity	IPA	Normal	Crash	Normal	Crash	
1	A	-	4	2	10,000	14,000	2,000
2	B	A	6	5	30,000	42,500	12,500
3	C	A	2	1	8,000	9,500	1,500
4	D	B	2	1	12,000	18,000	6,000
5	E	B,C	7	5	40,000	52,000	6,000
6	F	D,E	6	3	20,000	29,000	3,000

- Next lowest crash cost per week is ‘F’ at €3,000 per week.
  - On critical path therefore it will effect overall project duration.
  - Crashing F reduces the overall project duration by 3 weeks to give new project duration of 18 weeks.
- Now we need to look at E and B.
  - ‘E’ has a crash cost of €6,000 per week as opposed to B at €12,500 per week
  - Therefore Crash E



			Duration (weeks)		Cost €		Crash Cost per week
ID	Activity	IPA	Normal	Crash	Normal	Crash	
1	A	-	4	2	10,000	14,000	2,000
2	B	A	6	5	30,000	42,500	12,500
3	C	A	2	1	8,000	9,500	1,500
4	D	B	2	1	12,000	18,000	6,000
5	E	B,C	7	5	40,000	52,000	6,000
6	F	D,E	6	3	20,000	29,000	3,000

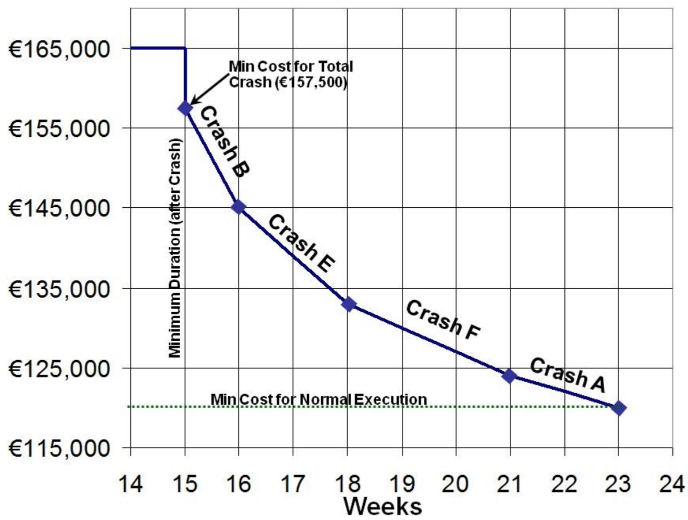
- Crash E
  - Overall Project Duration is now 16 weeks
  - Total Project Costs, €145,000
- Activities C and D are still not on the critical path, therefore crashing C and D will have no effect on the overall project duration.
- B can be crashed by 1 week for €12,500



			Duration (weeks)		Cost €		Crash Cost per week
ID	Activity	IPA	Normal	Crash	Normal	Crash	
1	A	-	4	2	10,000	14,000	2,000
2	B	A	6	5	30,000	42,500	12,500
3	C	A	2	1	8,000	9,500	1,500
4	D	B	2	1	12,000	18,000	6,000
5	E	B,C	7	5	40,000	52,000	6,000
6	F	D,E	6	3	20,000	29,000	3,000

- Crash B
  - Overall Project Duration is now 15 weeks
  - Total Project Costs, €157,500

- Activities C and D can each be crashed to 1 week. However as they are not on the critical path, crashing these activities will have no effect on the overall project duration; the only effect will be to increase costs.



Additional Resources

Support Material Excel File Download View File Online

More on Crashing

If you must crash a project, consider the following:

- If you are crashing to bring a project back on schedule:
  - Don't crash too early; If you need to crash early activities then chances are that the schedule is wrong in the first place, or there has been a delay. Better to get an EOT.
  - You cant crash what you have already done, or what is already in progress. Crashing tasks while in progress tends to lead to confusion. Better to look ahead and plan the crashing of an activity.
  - Crashing a construction project can put too many people in the same physical location, thus impeding progress and reducing productivity

More on Crashing

If you must crash a project, consider the following:

- Financial Aspects
  - If LD clause exists, then compare crash costs against LDs. It may be cheaper to pay the LDs
  - Make sure you understand the effects of crashing on the financial aspects of the project. i.e. if 25% is added to the project cost, will it still be financially viable?