GSOE9820 – Engineering Project Management

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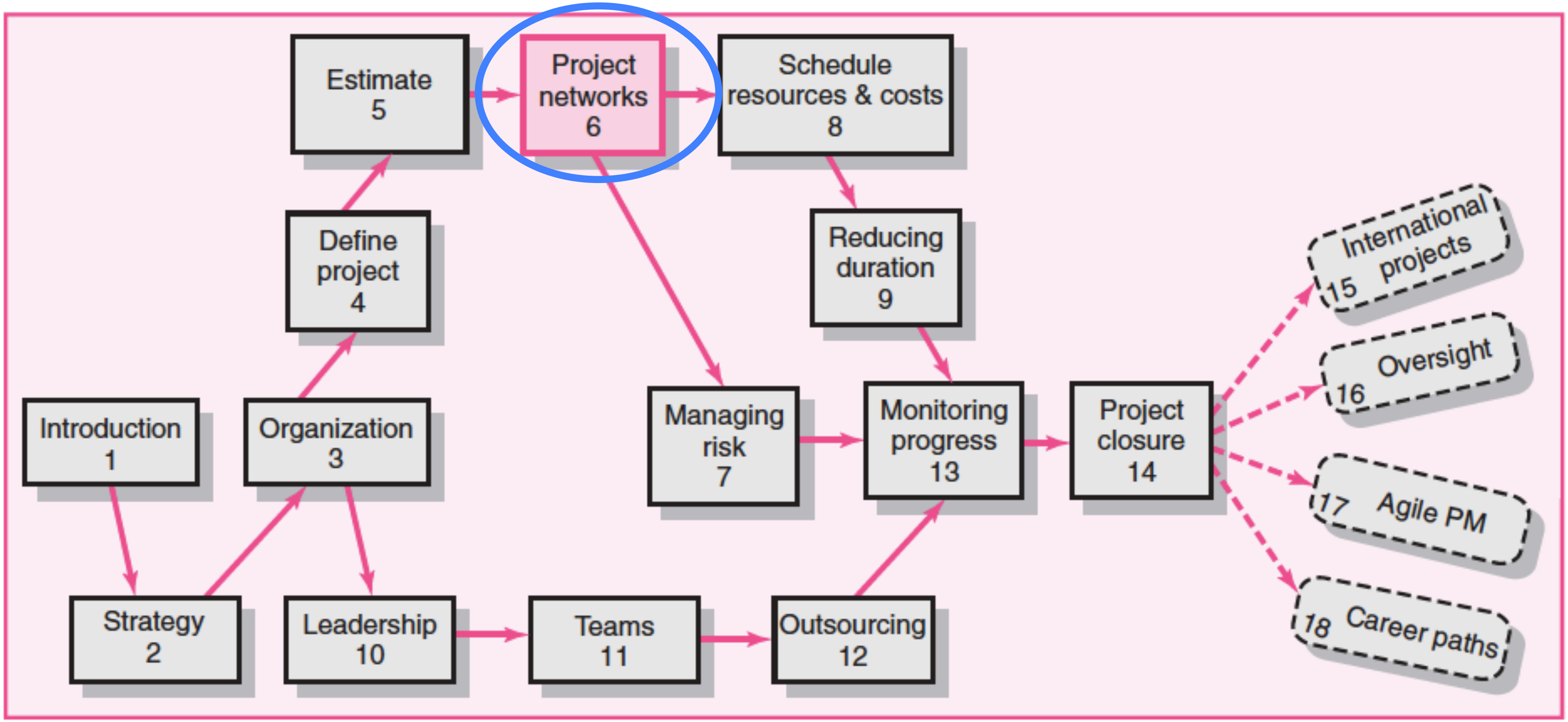
Week 6

Developing a project network

Course Roadmap



Reference: Gray, C & Larson, E, Project Management, 5th Ed. McGraw-Hill

Project Management Process Map (PMBOK Guide 5th Edition)

	Integration	Scope	Time	Cost	Quality	Human Resources	Communicat on	Risk	Procurement	Stakeholder
Initiating	Develop Project Charter									Identify Stakeholders
Planning	Develop Project Management Plan	Plan Scope Management Collect Requirements Define Scope Create WBS	Plan Schedule Management Define Activities Sequence Activities Estimate Activity Resources Estimate Activity Durations Develop Schedule	Plan Cost Management Estimate Costs Determine Budget	Plan Quality Management	Plan HR Management	Plan Communication Management	Plan Risk Management Identify Risks Perform Qualitative Risk Analysis Perform Quantitative Risk Analysis Plan Risk Responses	Plan Procurement Management	Plan Stakeholder Management
Executing	Direct and Manage Project Work				Perform Quality Assurance	Acquire Project Team Develop Project Team Manage Project Team	Manage Communications		Conduct Procurements	Manage Stakeholder Engagement
Controlling	Monitor & Control Project work Perform Integrated Change Control	Validate Scope Control Scope	Control Schedule	Control Costs	Control Quality		Control Communications	Control Risks	Control Procurements	Control Stakeholder Engagement
Closi ng	Close Project or Phase								Close Procurements	

Source: PMBOK 5th Edition

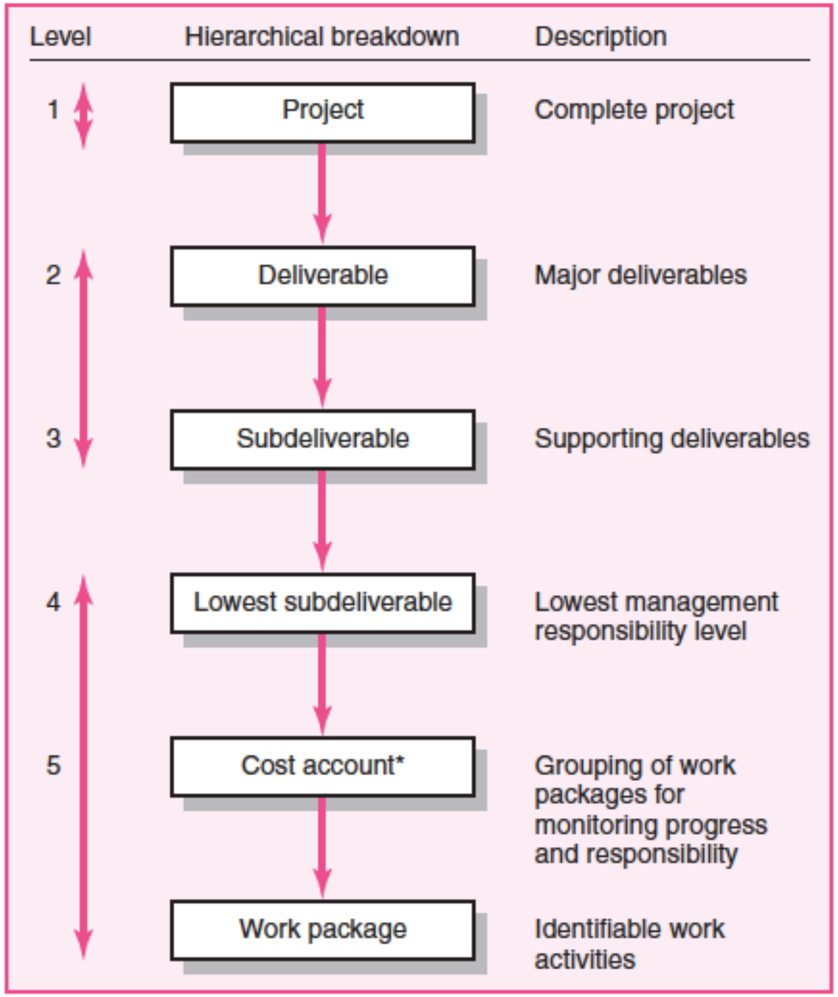
Review of WBS

Work Breakdown Structure (WBS)

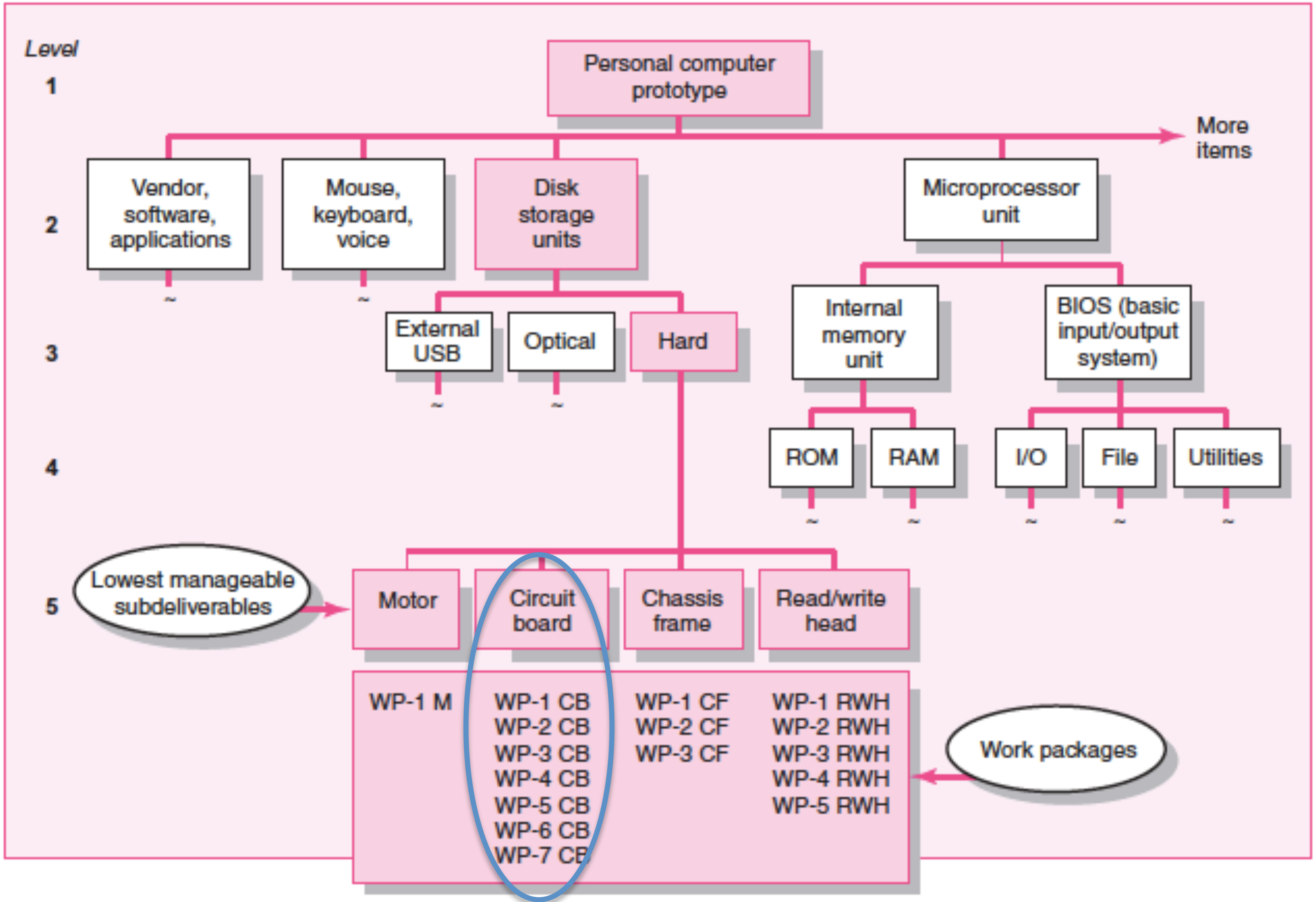
– An hierarchical outline (map) that identifies **ALL** the products and work elements involved in a project.

– Defines the relationship of the final deliverable (the project) to its sub-deliverables, and in turn, their relationships to **work packages**.

Building a WBS Hierarchy



Example – From WBS to project



Template WP Description

Activities are listed in WP Description

Project Title: ______________________ **Date Prepared:** ______________________

Work Package Name: ***From the WBS***					WBS ID: ***From the WBS***					
Description of Work: *Description of the work to be delivered in sufficient detail to ensure a common understanding by stakeholders.*										
Milestones: 1. *List any milestones associated with the work package.* 2. 3.					Due Dates: *List the due dates of the milestones.*					
ID	Activity	Resource	Labor			Material			Total Cost
			Hours	Rate	Total	Units	Cost	Total	
	From Activity list or schedule	*From Resource requirements*	*Total effort.*	*Labor rate.*	*Hours X rate.*	*Amount*	*Cost*	*Units X cost.*	*Labor + Material.*
Quality Requirements: *Quality metrics used to verify the deliverable.*									
Acceptance Criteria: *Criteria that will be used to accept the WBS element.*									
Technical Information: *Technical information or reference to technical documentation that contains technical information.*									
Contract Information: *Relevant contract information that contains constraints, resource information, or other relevant information.*									

The project network

Is a flow chart that graphically depicts the sequence, interdependencies and start and finish times of the project job plan of activities.

Difference

Project Definition (WBS)

- identifies all the work elements involved in a project.

Project Network

- Places the activities in the right sequence

Benefits of developing the project network

- Provides the basis for scheduling labour and equipment;
- Enhances communication among project participants;
- Provides an estimate of the project's duration;
- Provides a basis for budgeting cash flow;
- Highlights activities that are 'critical' and cannot be delayed;
- Highlights activities that can be compressed to meet a deadline;
- Help managers get and stay on plan.

Time elements of a project

Activity

- Is some action which requires time

Event

- It does not consume time.
- Is a point in time when an activity is started or completed.
- May also be known as a “milestone”

Project network approaches

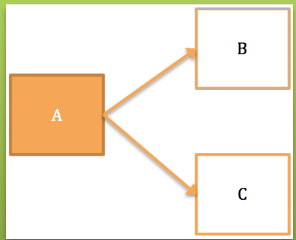
Activity-On-Node (AON)

- Uses a node to depict an activity

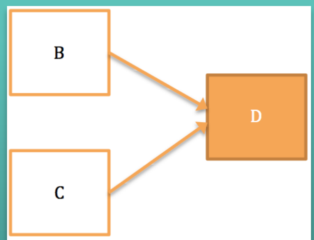
Activity-On-Arrow (AOA)

- Uses an arrow to depict an activity.

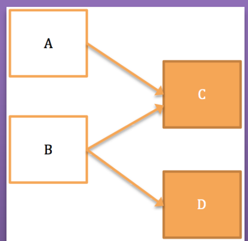
Types of activities



Burst - an activity that has more than one activity immediately following it



Merge - an activity that has two or more preceding activities on which it depends



Parallel - activities that can occur independently and, if desired, not at the same time.

Project network work flow

Path

– a sequence of connected, dependent activities.

Critical path

– the **longest path** through the activity network that allows for the completion of all activities;
– the **shortest expected time** in which the entire project can be completed.

Basic rules for developing a project network

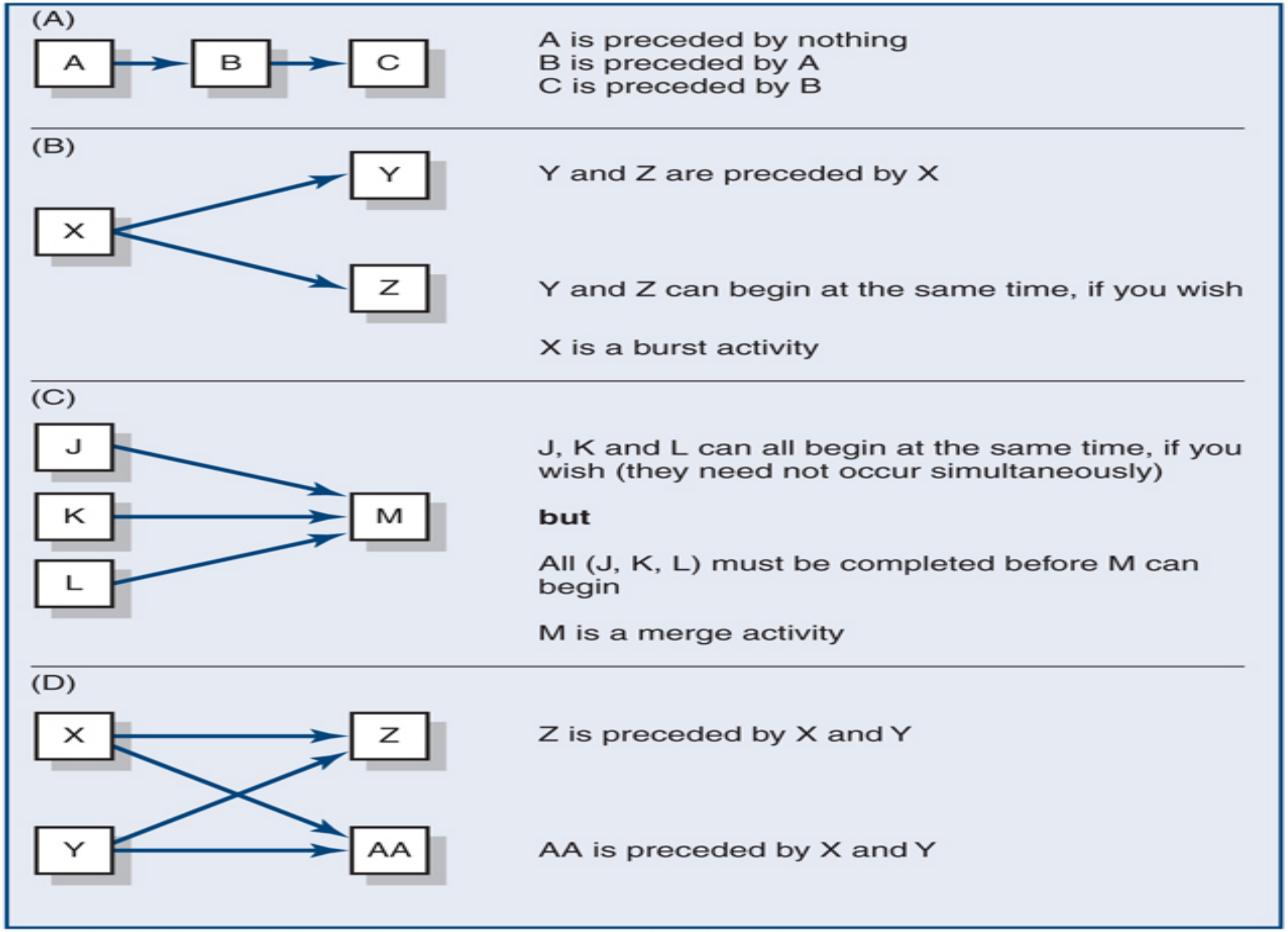
- Networks flow left to right
- An activity cannot begin until all preceding connected activities are complete
- Arrows on networks indicate precedence and flow
- Each activity should have an unique identification number
- An activity identification number must be larger than that of any preceding activities
- Looping is not allowed
- Conditional statements are not allowed
- Use common start and stop nodes

Activity-on-node fundamentals

- Activity-on-node (AON) or precedence diagram method.
- An activity is represented by a ***node*** (box).
- The dependencies are represented by ***arrows*** to indicate relationship and sequence.
- ***Predecessor*** activities are ones to be completed before.
- ***Successor*** activities are ones to be completed after.

Activity-on-node networks

Figure 6.2 ACTIVITY-ON-NODE NETWORK FUNDAMENTALS



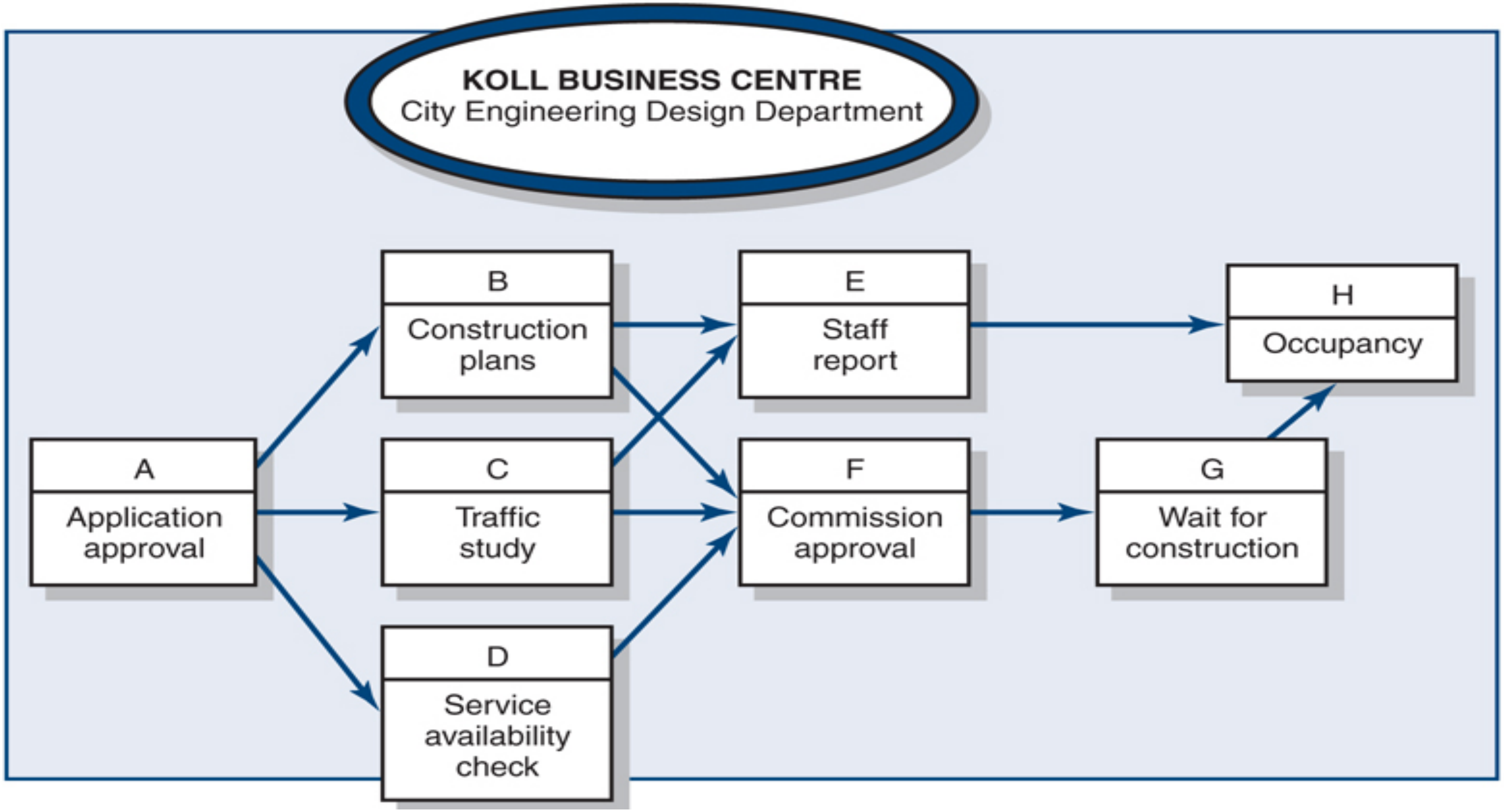
Exercise # 1 – Koll Business Centre

TABLE 6.1 **Network information**

Activity	Description	Preceding activity
A	Application approval	None
B	Construction plans	A
C	Traffic study	**A**
D	Service availability check	**A**
E	Staff report	B, C
F	Commission approval	B, C, D
G	Wait for construction	F
H	Occupancy	E, G

Exercise Part 2: Project network

Figure 6.4 KOLL BUSINESS CENTRE—COMPLETE NETWORK



Network computation process

Forward pass

- How soon can the activity start? (early start—ES)
- How soon can the activity finish? (early finish—EF)
- How soon can the project finish? (expected time—ET)

Backward pass

- How late can the activity start? (late start—LS)
- How late can the activity finish? (late finish—LF)

Key times of an activity

Term	Acronym	Description	Formula
Late finish	LF	The latest an activity can finish and not delay a following activity	LF = LS + DUR
Late start	LS	The latest an activity can start and not delay a following activity	LS = LF – DUR
Early finish	EF	The earliest an activity can finish if all preceding activities are finished by their early finish times	EF = ES + DUR
Early start	ES	The earliest an activity can start. It is the largest early finish of all its immediate predecessors	ES = EF – DUR

Project network activity legend

Early Start (ES)	Activity identifier	Early Finish (EF)
Start Slack (SL-Start)	Description	Finish Slack (SL-Finish)
Late Start (LS)	Duration	Late Finish (LF)

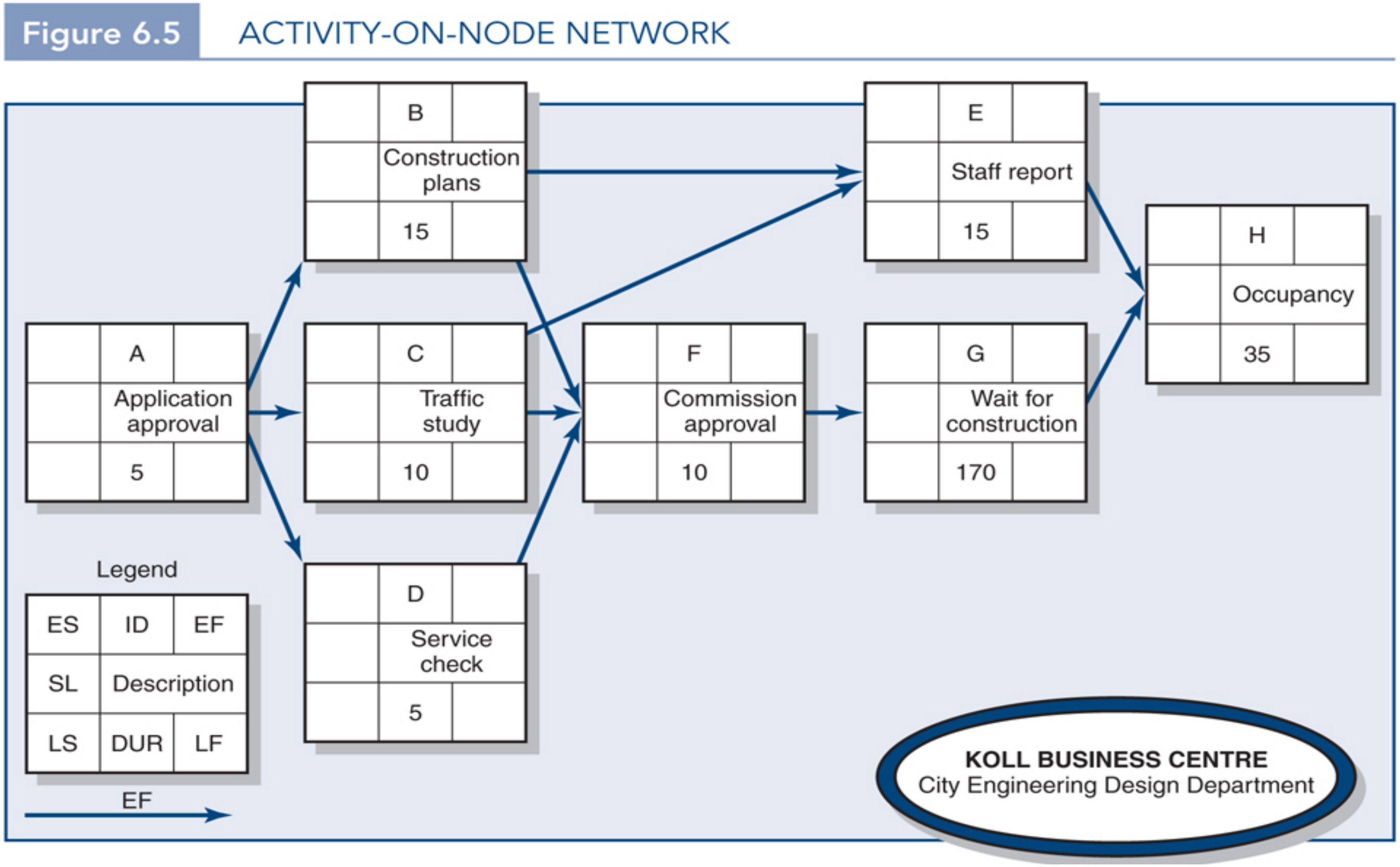
Exercise Part 3: Updated network information – duration/activity time

TABLE 6.2 Network information

KOLL BUSINESS CENTRE
City Engineering Design Department

Activity	Description	Preceding activity	Activity time
A	Application approval	None	5
B	Construction plans	A	15
C	Traffic study	**A**	10
D	Service availability check	**A**	5
E	Staff report	B, C	15
F	Commission approval	B, C, D	10
G	Wait for construction	F	170
H	Occupancy	E, G	35

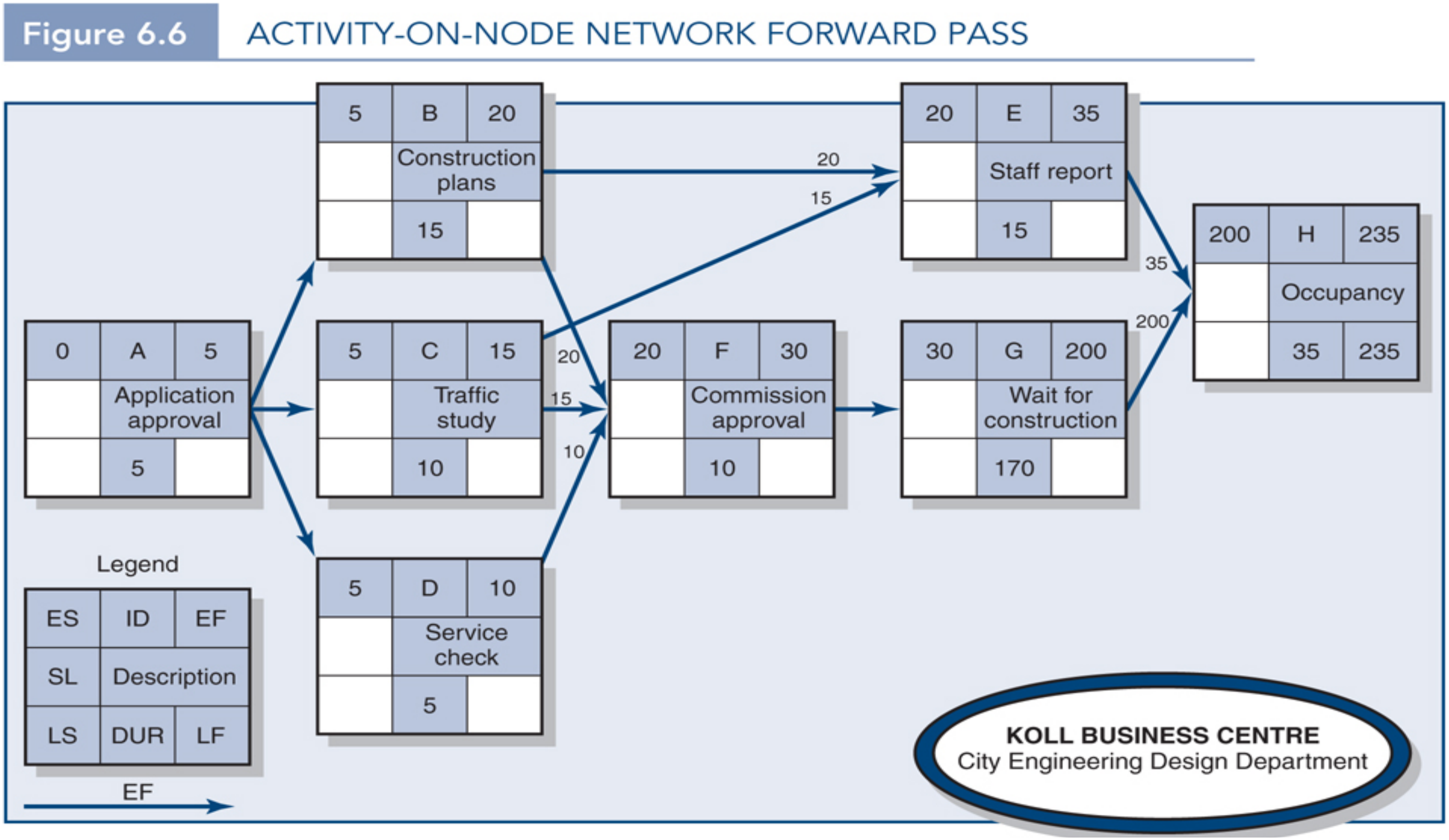
Exercise Part 4: Activity-on-node network



Forward pass computation process

1. Add activity times along each path in the network (ES + Duration = EF).
2. Carry the early finish (EF) to the next activity where it becomes its early start (ES) ……. ***unless***
3. the succeeding activity is a merge activity, in which case select the largest EF of all preceding activities

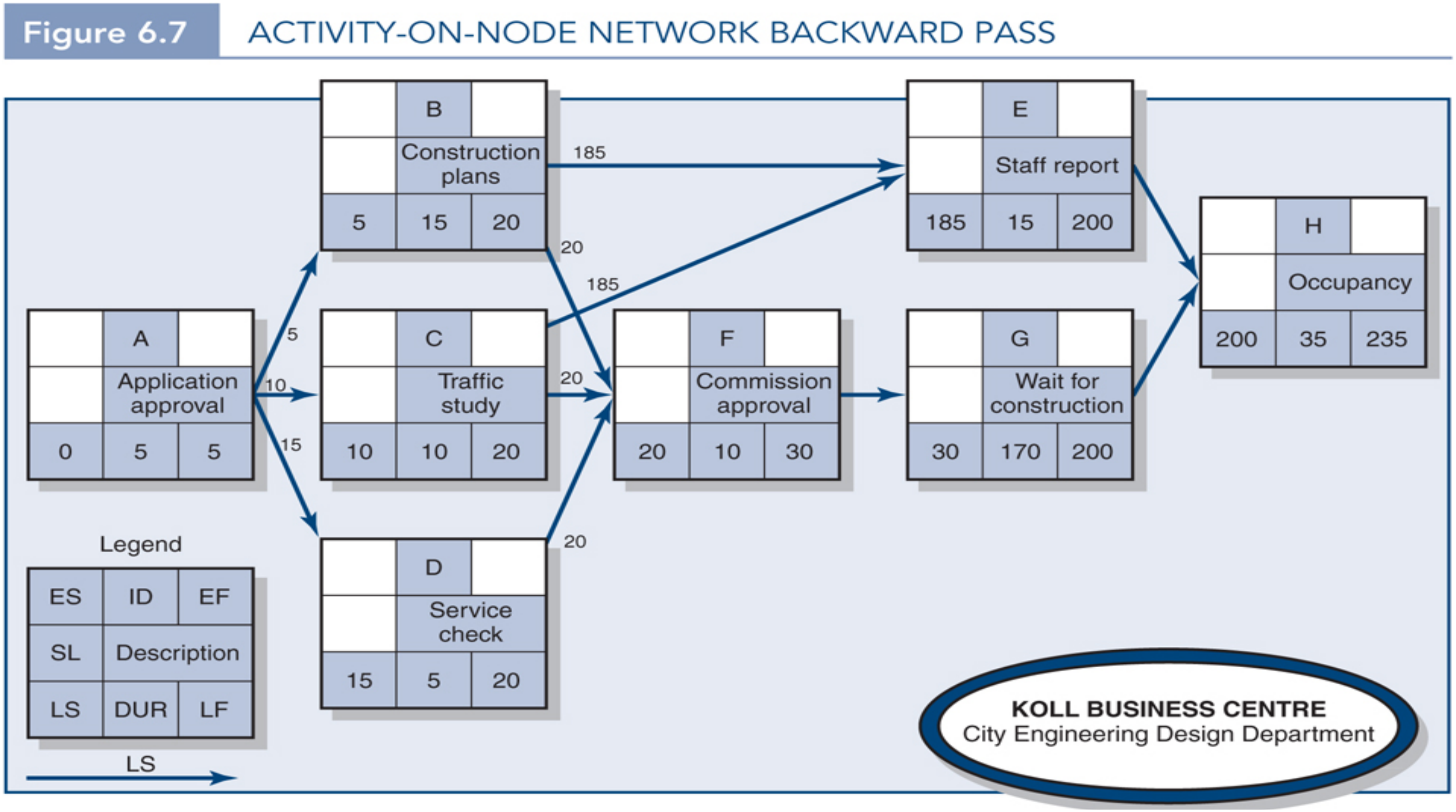
Exercise Part 5: Activity-on-node network forward pass



Backward pass computation process

1. Subtract activity times along each path in the network (LF – Duration = LS).
2. Carry the late start (LS) to the next activity where it becomes its late finish (LF) ……. ***unless***
3. the succeeding activity is a burst activity, in which case select the smallest LF of all preceding activities.

Exercise Part 6: Activity-on-node network backward pass



Slack / Float

- Is the amount of time that a task in a project network can be delayed without causing a delay.
- Can be used to balance the schedule
- Allows flexibility in scheduling scarce resources.

Types of Slack

Total slack	Free slack
• Shared by activities along a path • Affects project completion date	• Owned by the activity • Affects subsequent tasks

Determining total slack (or float)

- The amount of time an activity can be delayed and not delay the overall project
- The amount of time an activity can exceed its early finish date without affecting the project end date or an imposed completion date

Total Start Slack = LS – ES, or

Total Finish Slack = LF – EF

- Total slack can change as the project progresses

Total Slack values

Total Slack value	Interpretation
TS > 0	Activity delay is possible without delaying the project completion
TS = 0	**Critical situation.** Any delay in zero float activities will cause the project completion date to slip. Identifies the critical path.
TS < 0	You are behind schedule. You can get negative slack if you put a constraint on your completion date

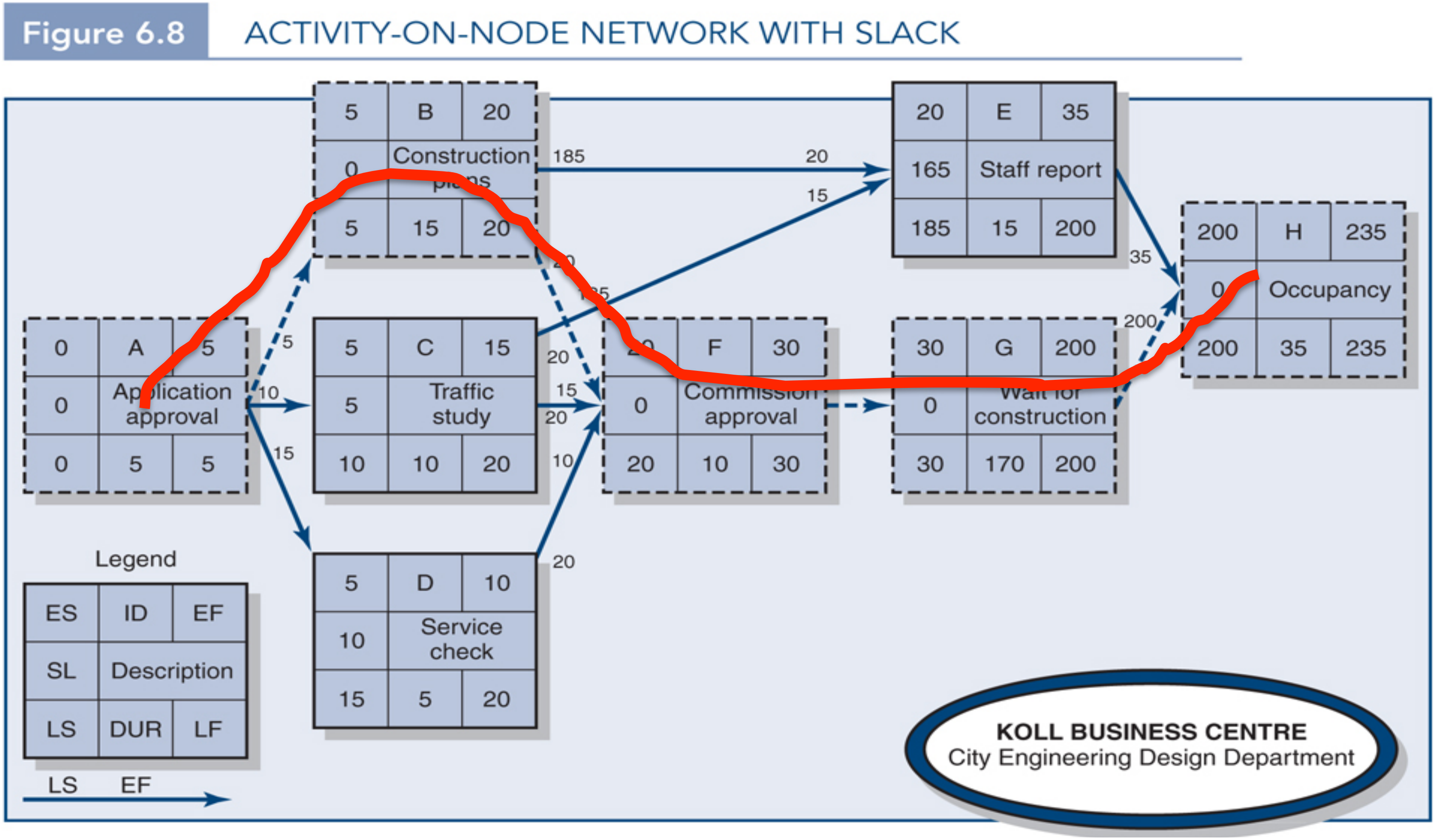
Ownership of total slack

Although total slack is calculated for each activity, it is NOT owned by that activity

Total slack is **shared by ALL** activities in a path

E.g. If the first activity in the path uses up the total slack, the total slack for the remaining activities becomes zero.

Exercise Part 7: Activity-on-node network with slack



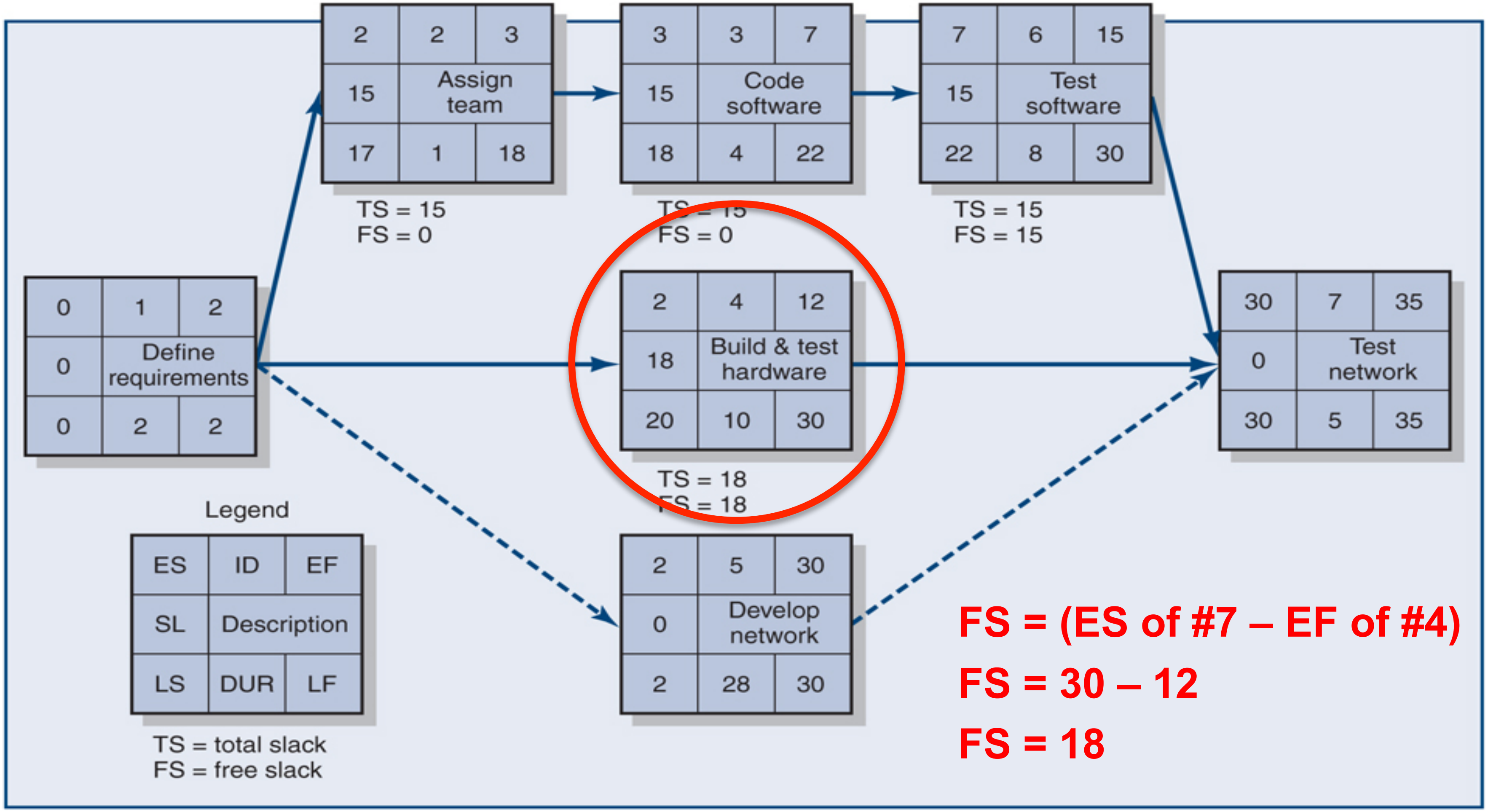
Determining Free slack (or float)

- Is owned by the activity
- Can never be negative
- Is the amount of time that an activity can be delayed without delaying the early start (ES) of any successive activities

$$\textbf{FS} = \textbf{ES}_{\textbf{(of successor activity)}} - \textbf{EF}_{\textbf{(of current activity)}}$$

Example: Free slack for an IT project

Figure 6.9 FREE SLACK EXAMPLE



FS = (ES of #7 – EF of #4)

FS = 30 – 12

FS = 18

Sensitivity

Is the likelihood the original critical path(s) will change once the project is initiated.

Typical rules of thumb:

Very little slack and lots of critical paths

→ MORE sensitive

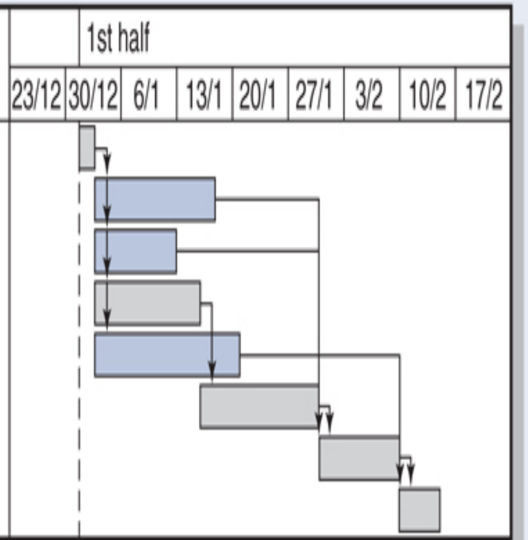
Lots of slack and only one critical path

→LESS sensitive

Example: Gantt Chart of an Air Control Project

Figure 6.12 AIR CONTROL PROJECT—GANTT CHART

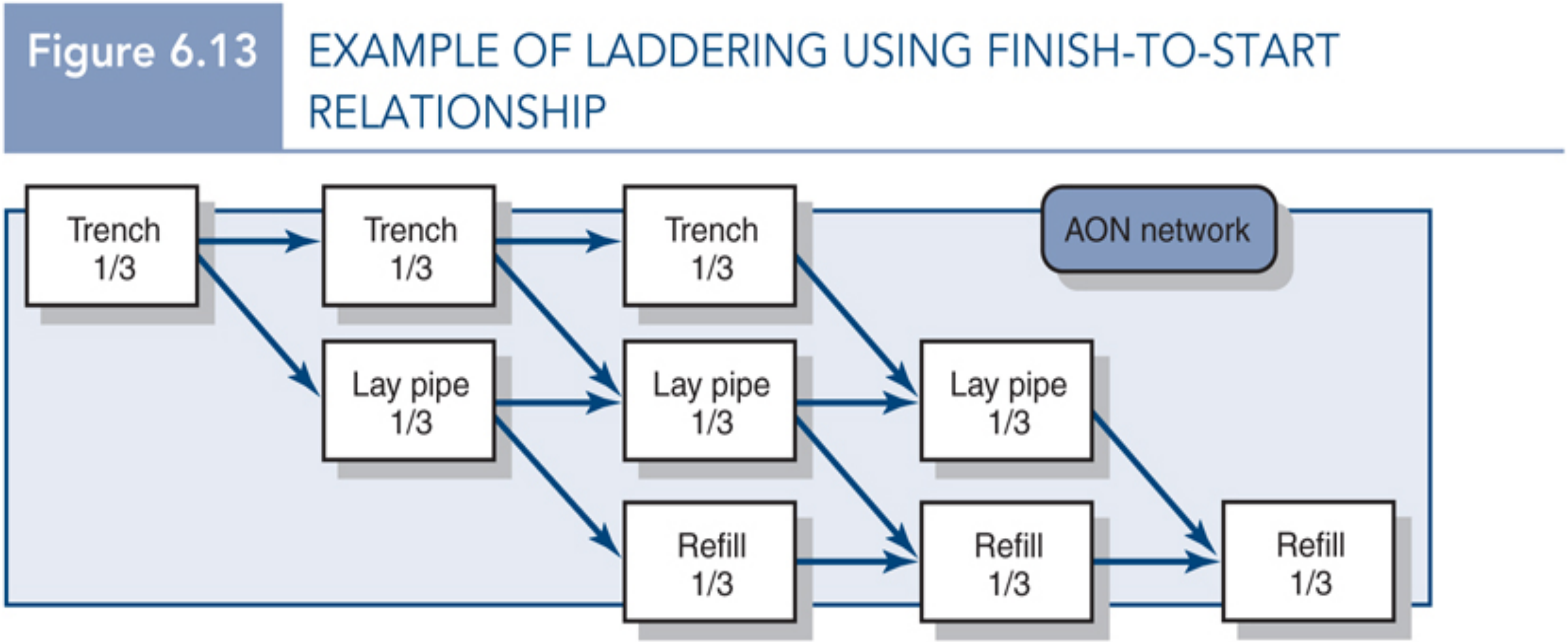
ID	Duration	Task name	Start	Finish	Late start	Late finish	Free slack	Total slack
1	2 days	Order review	Tue 1/1	Wed 2/1	Tue 1/1	Wed 2/1	0 days	0 days
2	15 days	Order vendor parts	Thu 3/1	Thu 17/1	Wed 16/1	Wed 30/1	13 days	13 days
3	10 days	Produce other standard parts	Thu 3/1	Sat 12/1	Mon 21/1	Wed 30/1	18 days	18 days
4	13 days	Design custom parts	Thu 3/1	Tue 15/1	Thu 3/1	Tue 15/1	0 days	0 days
5	18 days	Software development	Thu 3/1	Sun 20/1	Wed 23/1	Sat 9/2	20 days	20 days
6	15 days	Manufacture custom hardware	Wed 16/1	Wed 30/1	Wed 16/1	Wed 30/1	0 days	0 days
7	10 days	Assemble	Thu 31/1	Sat 9/2	Thu 31/1	Sat 9/2	0 days	0 days
8	5 days	Test	Sun 10/2	Thu 14/2	Sun 10/2	Thu 14/2	0 days	0 days



Extended network techniques
(a dose of reality)

- Laddering
- Lags
- Hammock / Summary

Example: Laddering using finish-to-start relationship



Lag

Is the minimum amount of time a dependent activity must be delayed to begin or end

The relationship between start and/or finish of a project activity and the start and/or finish of another activity

Most common lag relationships

- finish-to-start
- finish-to-finish
- start-to-start
- start-to-finish

Finish-to-start lag relationship

- Finish-to-start lags are often used when ordering materials. E.g. One day to place order and 19 days to receive the goods.

- Use of finish-to-start lags should be justified and approved to avoid unnecessary buffering

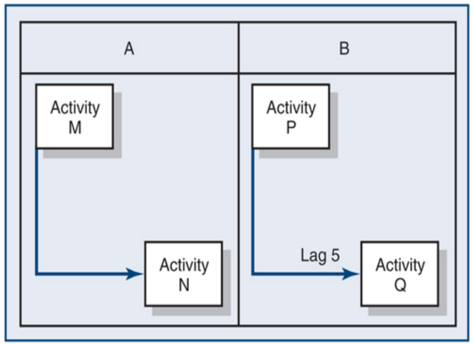
Example: Figure 6.14 FINISH-TO-START RELATIONSHIP

Start-to-start lag relationship

The start of an activity depends on the start of another activity.

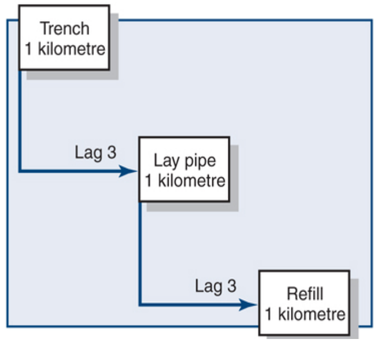
Examples:

Figure 6.15 START-TO-START RELATIONSHIP



Can reduce network detail and project delays

Figure 6.16 USE OF LAGS TO REDUCE DETAIL



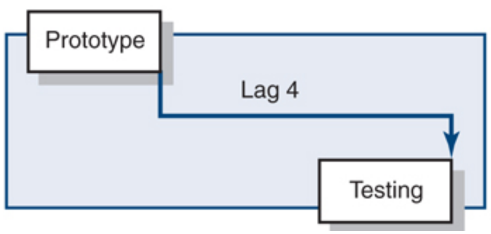
Often used in concurrent engineering

Finish-to-finish lag relationship

- The finish of one activity depends on the finish of another activity.

Example: Testing cannot be completed any earlier than four days after the prototype is complete. It cannot be finish-to-start because testing of subcomponents does not qualify as complete system testing.

Figure 6.18 FINISH-TO-FINISH RELATIONSHIP

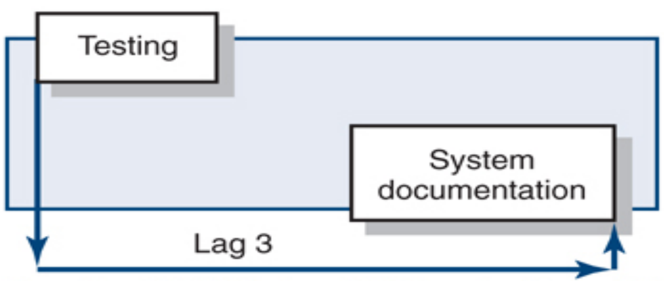


Start-to-finish lag relationship

- The finish of an activity depends on the start of another activity.

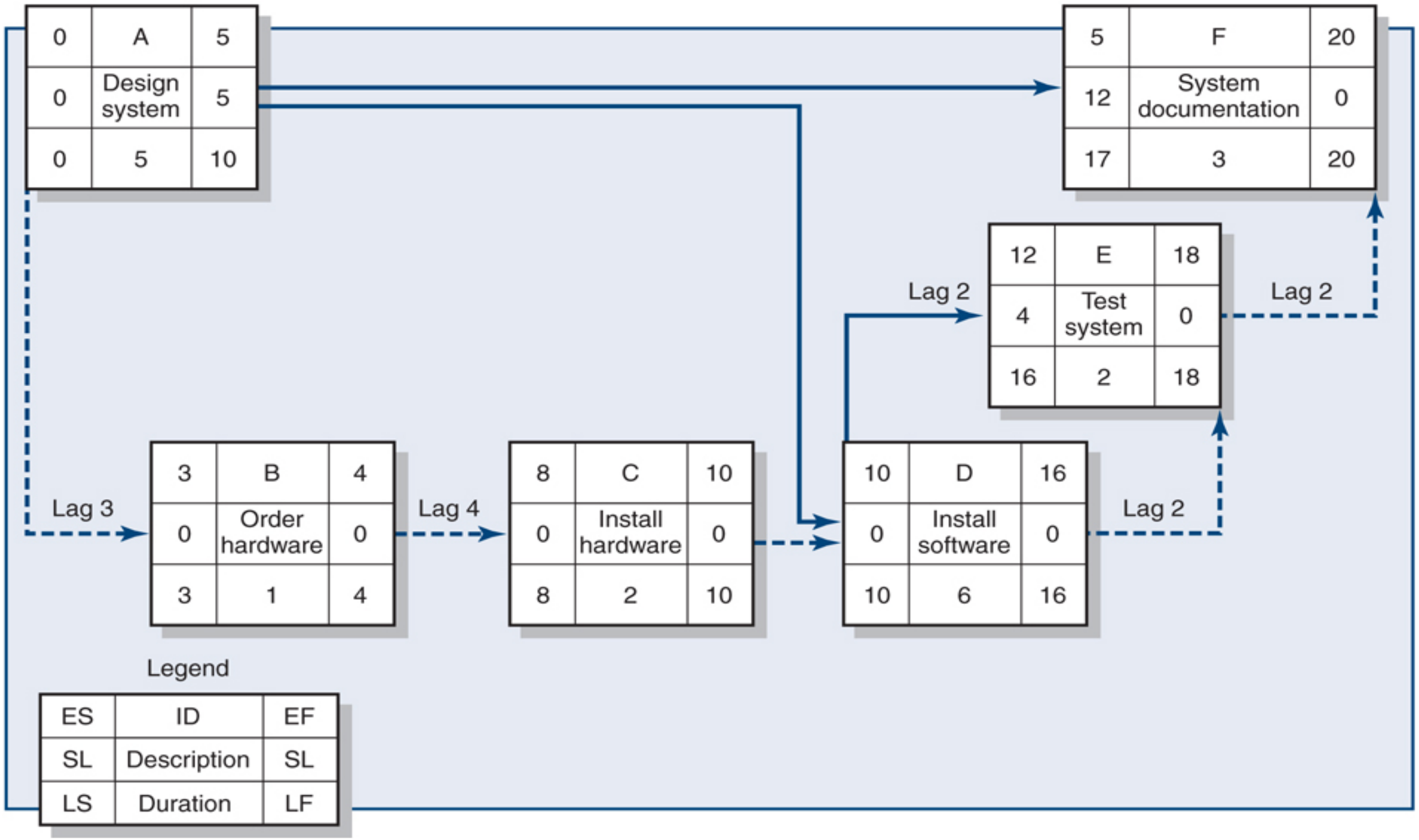
Example: The system documentation cannot end until three days after testing has started. Here all the relevant information is produced after three days of testing.

Figure 6.19 START-TO-FINISH RELATIONSHIP



Example: Network using lags

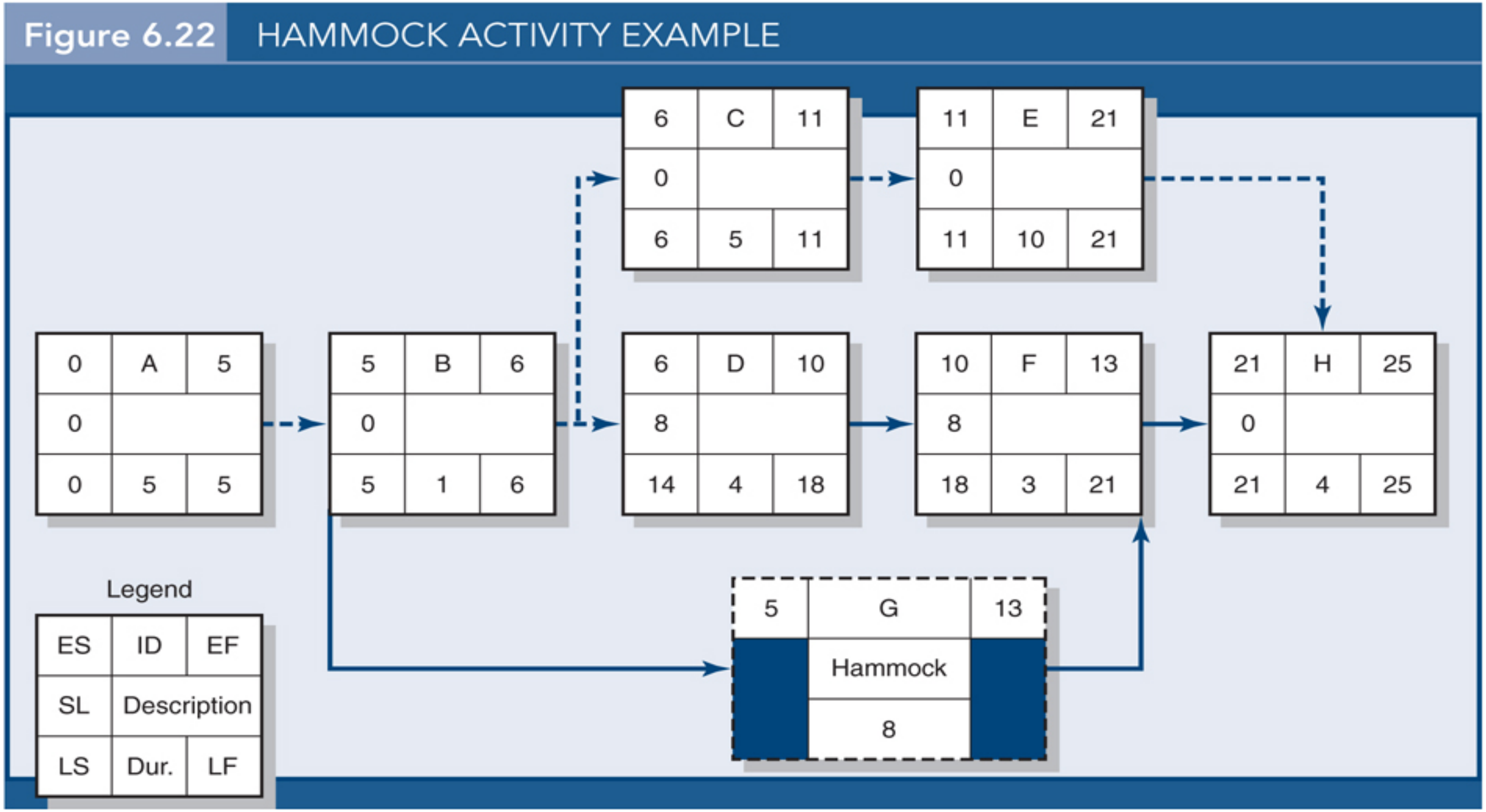
Figure 6.21 NETWORK USING LAGS



Hammock/Summary activities

- An activity that spans over a segment of a project.
- Duration of hammock activities is determined after the network plan is drawn.
- Hammock activities are used to aggregate sections of the project to facilitate getting the right amount of detail for specific sections of a project.

Example: Hammock activity




How confident are you in completing the project on time?

Applying statistics

PERT

- A project network gives a ‘*point estimate*’ on duration of each activity.
- PERT focus on the likelihood that the project will be completed on ‘time’ and ‘within budget’.
- PERT assumes a statistical distribution for each activity’s duration.
- Using a pre-defined distribution, the probability that the project will be completed in a certain time frame can be determined.

Program Evaluation and Review Technique (PERT)

Originally developed in 1958 for US Navy Polaris submarine project

Assumes that each activity duration has a range that follows a statistical distribution.

Each activity has duration can range from an optimistic time to a pessimistic time.

A weighted average for duration can be calculated

Two types of distributions are used:

- Beta distribution for activities (because usually work tends to stay behind once it gets behind)
- Normal distribution for projects

Is the sum of weighted average of the activities duration on the critical path.

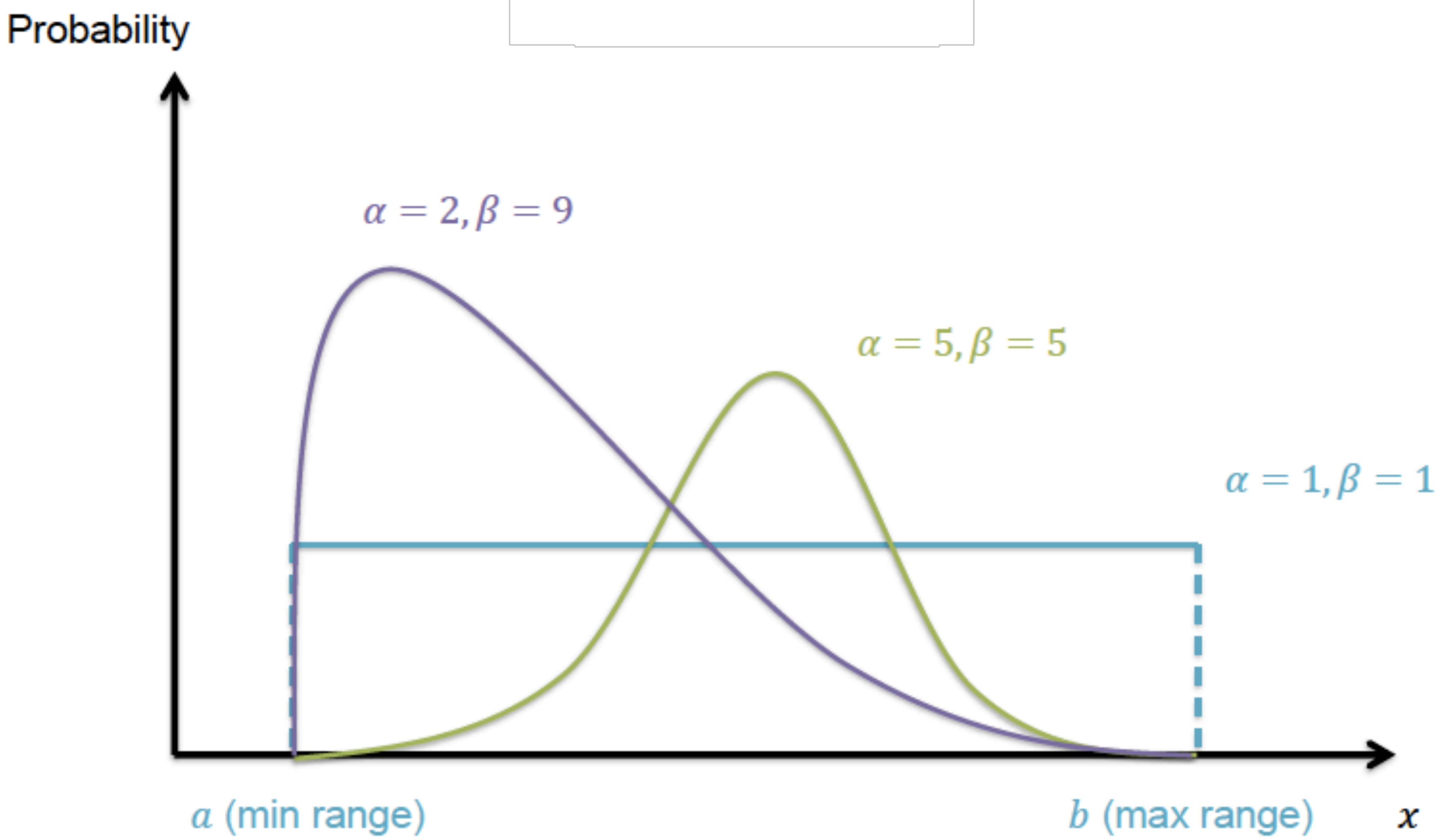
Properties of Beta Distribution

- PERT often uses the ‘beta PERT distribution’ as the statistical distribution for each activity’s duration.
- The beta distribution can take different shapes – symmetrical/asymmetrical.
- The beta distribution is bounded by a minimum range and maximum range, this makes it very useful to model the duration of activities in a project network.

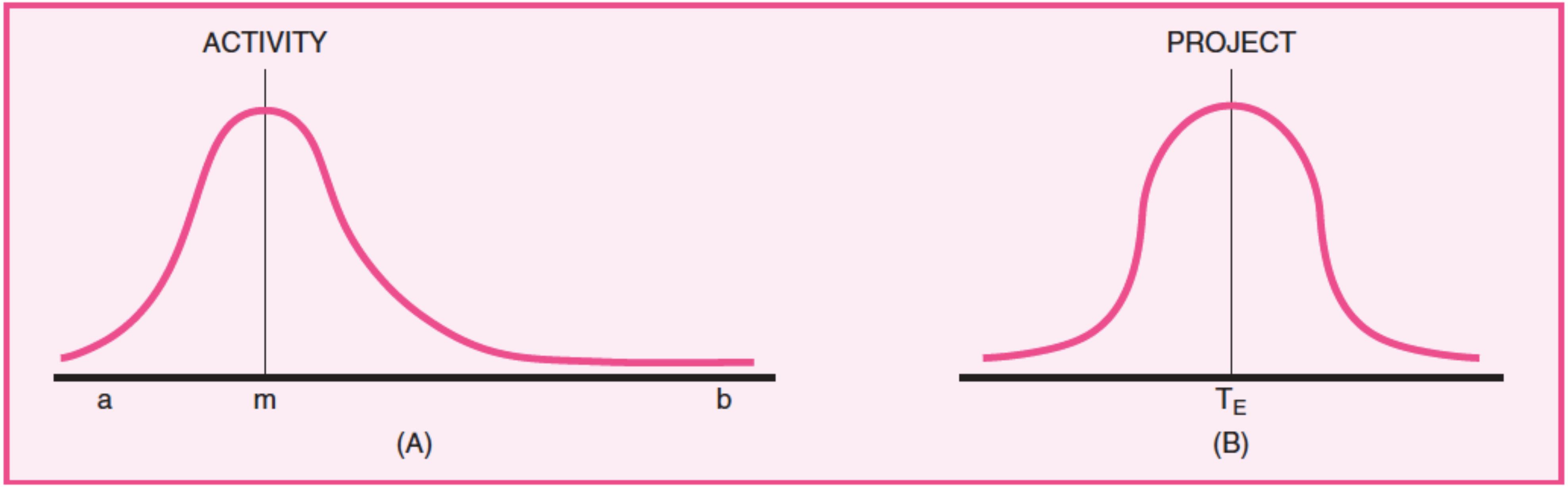
Normal Distribution Versus Beta Distribution

Distribution	Normal	Beta
Number of parameters	Two - μ (mean) and σ^2 (variance)	Four - α, β (shape parameters), a (min of range), b (max of range)
Symmetrical property	Always symmetrical about μ	Symmetrical if $\alpha = \beta$ Asymmetrical if $\alpha \neq \beta$
Mean	μ	$\mu = \frac{a + 4m + b}{6}$ m is the mode
Variance	σ^2	$\sigma^2 = \left(\frac{b-a}{6}\right)^2$

Beta Distribution Probability Density Function



Activity and Project frequency distributions

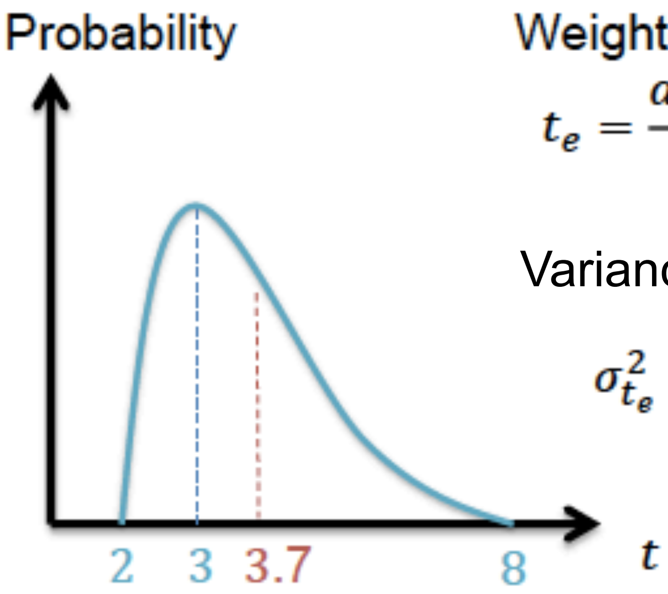


Integrating the beta distribution to a project network

Consider the following activity in a project network:

Activity ID	Description	Optimistic duration a	Most likely duration m	Pessimistic duration b
1.1	A	2	3	8

0	**1.1**	
	DES	
	3.7	



Weighted average duration

$$t_e = \frac{a + 4m + b}{6} = \frac{2 + 4(3) + 8}{6} = 3.7$$

Variance

$$\sigma_{t_e}^2 = \left(\frac{b - a}{6}\right)^2 = \left(\frac{8 - 2}{6}\right)^2 = 1.0$$

Integrating the beta distribution to a project network (cont'd)

Activity ID	Description	Optimistic duration a	Most likely duration m	Pessimistic duration b	t_e	σ_{t_e}
1-2	A	2	3	8	3.7	1.0
2-3	B	6	10	12	9.7	1.0
3-4	C	5	7	8	3.5	0.5

0	1.1	3.7
	DES	
	3.7	

→

3.7	1.2	13.4
	DES	
	9.7	

→

13.4	1.3	16.9
	DES	
	3.5	

Integrating the beta distribution to a project network (cont'd)

0	1.1	3.7
	DES	
	3.7	

→

3.7	1.2	13.4
	DES	
	9.7	

→

13.4	1.3	16.9
	DES	
	3.5	

Now you may determine the average project duration T_E:
T_E is the sum of all average duration times along the critical path

$$T_E = 3.7 + 9.7 + 3.5 = 16.9$$

You can also determine the standard deviation of the project duration σ_{T_E}:

$$\sigma_{T_E} = \sqrt{\sum \sigma_{t_e}^2} = \sqrt{1.0^2 + 1.0^2 + 0.5^2} = 1.5$$

Integrating the beta distribution to a project network (cont'd)

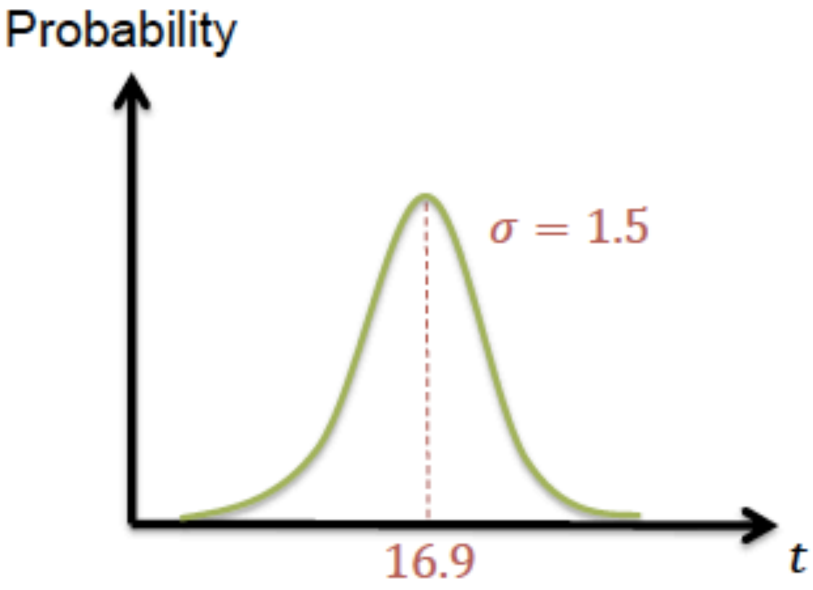
0	**1.1**	**3.7**
	DES	
	3.7	

→

3.7	**1.2**	**13.4**
	DES	
	9.7	

→

13.4	**1.3**	**16.9**
	DES	
	3.5	



Determine the probability of completing this project in less than 19 days.

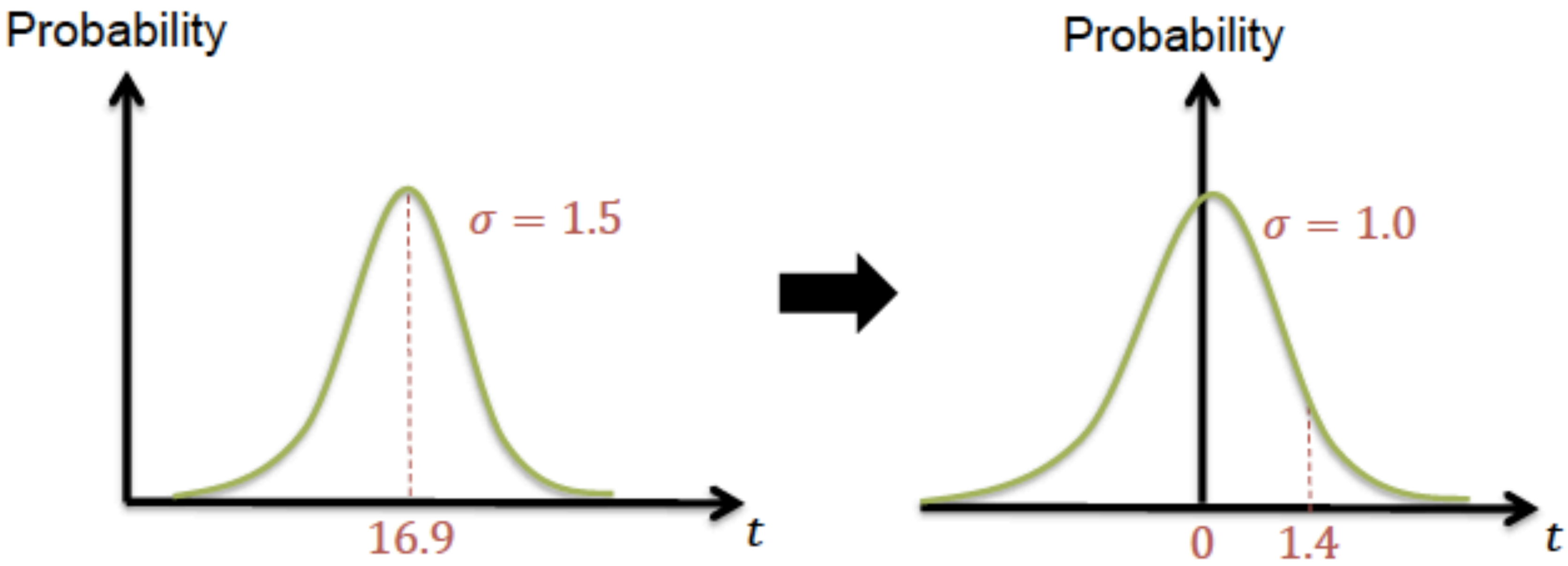
$$Z = \frac{T_S - T_E}{\sigma_{T_E}} = \frac{19 - 16.9}{1.5} = 1.4$$

Cumulative [edit]

This table gives a probability that a statistic is less than Z (i.e. between negative infinity and Z).

z	+0.00	+0.01	+0.02	+0.03	+0.04	+0.05	+0.06	+0.07	+0.08	+0.09
0.0	0.50000	0.50399	0.50798	0.51197	0.51595	0.51994	0.52392	0.52790	0.53188	0.53586
0.1	0.53980	0.54380	0.54776	0.55172	0.55567	0.55966	0.56360	0.56749	0.57142	0.57535
0.2	0.57930	0.58317	0.58706	0.59095	0.59483	0.59871	0.60257	0.60642	0.61026	0.61409
0.3	0.61791	0.62172	0.62552	0.62930	0.63307	0.63683	0.64058	0.64431	0.64803	0.65173
0.4	0.65542	0.65910	0.66276	0.66640	0.67003	0.67364	0.67724	0.68082	0.68439	0.68793
0.5	0.69146	0.69497	0.69847	0.70194	0.70540	0.70884	0.71226	0.71566	0.71904	0.72240
0.6	0.72575	0.72907	0.73237	0.73565	0.73891	0.74215	0.74537	0.74857	0.75175	0.75490
0.7	0.75804	0.76115	0.76424	0.76730	0.77035	0.77337	0.77637	0.77935	0.78230	0.78524
0.8	0.78814	0.79103	0.79389	0.79673	0.79955	0.80234	0.80511	0.80785	0.81057	0.81327
0.9	0.81594	0.81859	0.82121	0.82381	0.82639	0.82894	0.83147	0.83398	0.83646	0.83891
1.0	0.84134	0.84375	0.84614	0.84849	0.85083	0.85314	0.85543	0.85769	0.85993	0.86214
1.1	0.86433	0.86650	0.86864	0.87076	0.87286	0.87493	0.87698	0.87900	0.88100	0.88298
1.2	0.88493	0.88686	0.88877	0.89065	0.89251	0.89435	0.89617	0.89796	0.89973	0.90147
1.3	0.90320	0.90490	0.90658	0.90824	0.90988	0.91149	0.91308	0.91466	0.91621	0.91774
1.4	0.91924	0.92073	0.92220	0.92364	0.92507	0.92647	0.92785	0.92922	0.93056	0.93189
1.5	0.93319	0.93448	0.93574	0.93699	0.93822	0.93943	0.94062	0.94179	0.94295	0.94408
1.6	0.94520	0.94630	0.94738	0.94845	0.94950	0.95053	0.95154	0.95254	0.95352	0.95449
1.7	0.95543	0.95637	0.95728	0.95818	0.95907	0.95994	0.96080	0.96164	0.96246	0.96327
1.8	0.96407	0.96485	0.96562	0.96638	0.96712	0.96784	0.96856	0.96926	0.96995	0.97062
1.9	0.97128	0.97193	0.97257	0.97320	0.97381	0.97441	0.97500	0.97558	0.97615	0.97670
2.0	0.97725	0.97778	0.97831	0.97882	0.97932	0.97982	0.98030	0.98077	0.98124	0.98169

Integrating the beta distribution to a project network (cont'd)



The probability of this project gets completed in less than 19 days is 0.9192 (91.92%)

Summary

Project Networks

- AON / AOA
- Burst, merge and parallel activities
- Network computation process
  - Backward and forward pass
- Total and Free slack
- Laddering, Lags and Hammocks
- PERT

Next class …

Scheduling Resources and Costs

BUT

Before this, an exercise time…..

Exercise 2, Appendix 7.1

The Global Tea and Organic Juice companies have merged. The following information has been collected for the "Consolidation Project":

1. Compute te for each activity
2. Compute the variance for each activity
3. Compute the expected project duration
4. What is the probability of completing project by day 112? Within 116 days?
5. What is the probability of completing "Negotiate with Unions", Activity 11, by day 90?

Table1.1

Activity	Opt. (a)	Ml. (m)	Pess. (b)
1	16	19	28
2	30	30	30
3	60	72	90
4	18	27	30
5	17	29	47
6	4	7	10
7	12	15	18
8	6	12	24
9	18	27	30
10	20	35	50
11	40	55	100
12	11	20	29
13	14	23	26
14	13	16	19
15	0	0	0

The weighted average activity time

The weighted average activity time is computed by the following formula:

$$t_e = \frac{a + 4m + b}{6} \qquad (7.1)$$

where t_e = weighted average activity time

a = optimistic activity time (1 chance in 100 of completing the activity earlier under *normal* conditions)

b = pessimistic activity time (1 chance in 100 of completing the activity later under *normal* conditions)

m = most likely activity time

Weighted average activity time calculated te Table 1.2

Activity	Opt. (a)	Ml. (m)	Pess. (b)	t_e
1	16	19	28	20
2	30	30	30	30
3	60	72	90	73
4	18	27	30	26
5	17	29	47	30
6	4	7	10	7
7	12	15	18	15
8	6	12	24	13
9	18	27	30	26
10	20	35	50	35
11	40	55	100	60
12	11	20	29	20
13	14	23	26	22
14	13	16	19	16
15	0	0	0	0

Variance and Standard Deviation

The variability in the activity time estimates is approximated by the following equations:

The standard deviation for the activity:

$$\sigma_{t_e} = \left(\frac{b-a}{6}\right) \tag{7.2}$$

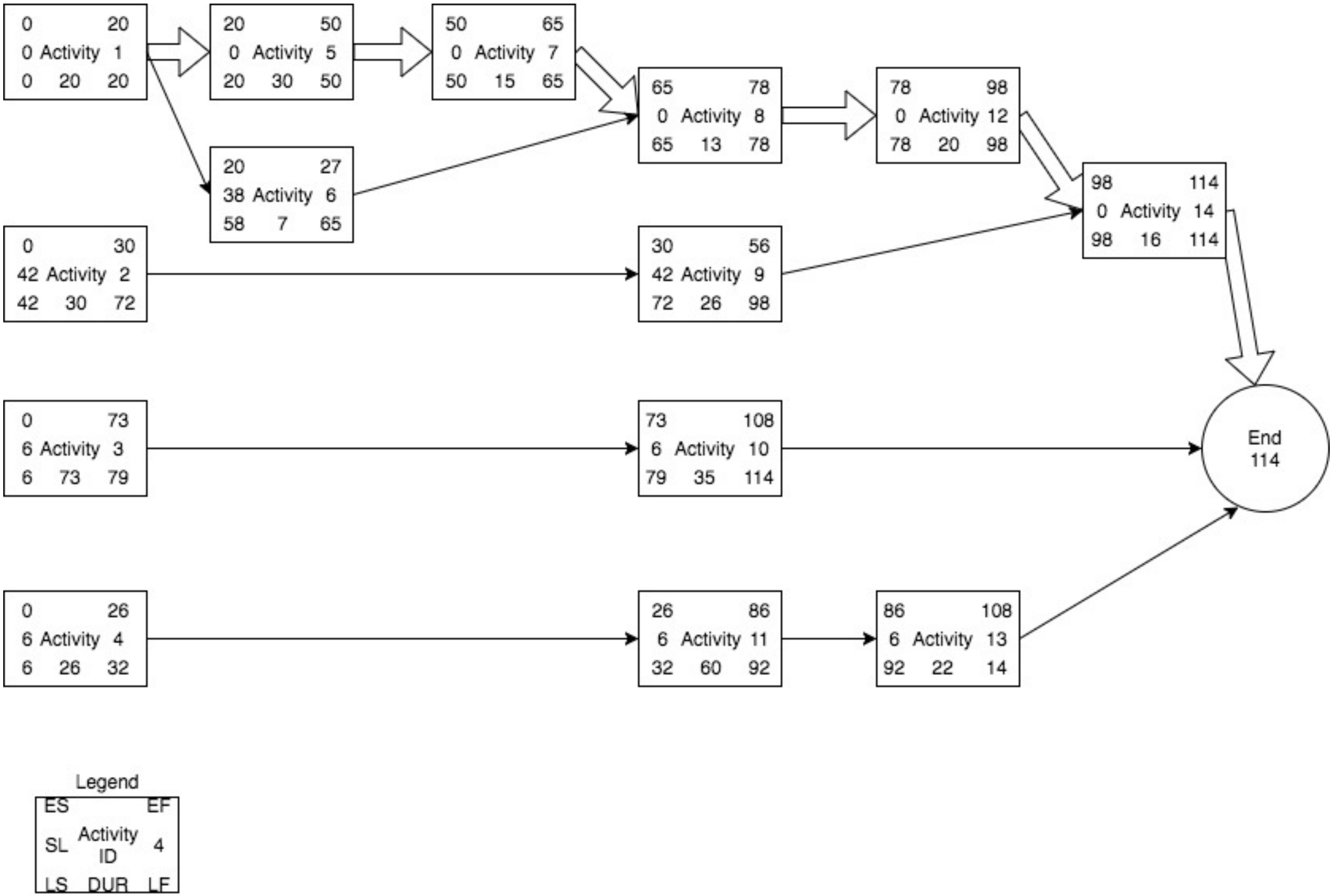
The standard deviation for the project:

$$\sigma_{T_E} = \sqrt{\Sigma\sigma_{t_e}^2} \tag{7.3}$$

Note the standard deviation of the activity is squared in this equation; this is also called variance. This sum includes only activities on the critical path(s) or path being reviewed.

3.Compute the expected project duration

Activity	Description	Predecessor	Opt. (a)	Ml. (m)	Pess. (b)	t_e	Variance $[(b - a)/6]^2$	Critical?
1	Codify Accounts	None	16	19	28	20	4	x
2	File articles of unifications	None	30	30	30	30	0	
3	Unify Price and Credit policy	None	60	72	90	73	25	
4	Unify Personnel policies	None	18	27	30	26	4	
5	Unify Data Processing	1	17	29	47	30	25	x
6	Train accounting staff	1	4	7	10	7	1	
7	Pilot run data processing	5	12	15	18	15	1	x
8	Calculate P&L and balance sheet	6,7	6	12	24	13	9	x
9	Transfer real property	2	18	27	30	26	4	
10	Train salesforce	3	20	35	50	35	25	
11	Negotiate with Unions	4	40	55	100	60	100	
12	Determine capital needs	8	11	20	29	20	9	x
13	Explain personnel policies	11	14	23	26	22	4	
14	Secure line of credit	9,12	13	16	19	16	1	x
15	END	10,13, 14	0	0	0	0	0	


0 20 0 Activity 1 0 20 20
20 50 0 Activity 5 20 30 50
50 65 0 Activity 7 50 15 65
65 78 0 Activity 8 65 13 78
78 98 0 Activity 12 78 20 98
20 27 38 Activity 6 58 7 65
98 114 0 Activity 14 98 16 114
0 30 42 Activity 2 42 30 72
30 56 42 Activity 9 72 26 98
0 73 6 Activity 3 6 73 79
73 108 6 Activity 10 79 35 114
End 114
0 26 6 Activity 4 6 26 32
26 86 6 Activity 11 32 60 92
86 108 6 Activity 13 92 22 14
Legend
ES EF
SL Activity ID 4
LS DUR LF

4. What is the probability of completing the project by day 112?

The equation below is used to compute the 'Z' value found in statistical tables (Z = number of standard deviations from the mean), which in turn tells the probability of completing the project in the time specified.

$$Z = \frac{T_S - T_E}{\sqrt{\Sigma \sigma_{t_e}^2}} \tag{7.4}$$

where T_E = critical path duration

T_S = scheduled project duration

Z = probability (of meeting scheduled duration)

Solution

$$\frac{T_S - T_E}{\sqrt{\sum \sigma_{t_e}^2}} = \frac{116 - 114}{\sqrt{4 + 25 + 1 + 9 + 9 + 1}} = \frac{+2}{\sqrt{49}} = \frac{+2}{7} = +.28$$

$$\frac{T_S - T_E}{\sqrt{\sum \sigma_{t_e}^2}} = \frac{112 - 114}{\sqrt{4 + 25 + 1 + 9 + 9 + 1}} = \frac{-2}{\sqrt{49}} = \frac{-2}{7} = -.28$$

Within 112 days? P = .39 =NORMSDIST(0.28)

Within 116 days? P ≈ .61 =NORMSDIST(-0.28)

Standard Normal Probabilities

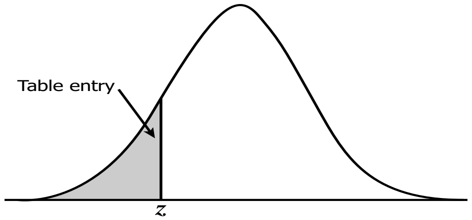


Table entry for z is the area under the standard normal curve to the left of z.

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
−3.4	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0003	.0002
−3.3	.0005	.0005	.0005	.0004	.0004	.0004	.0004	.0004	.0004	.0003
−3.2	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0005	.0005	.0005
−3.1	.0010	.0009	.0009	.0009	.0008	.0008	.0008	.0008	.0007	.0007
−3.0	.0013	.0013	.0013	.0012	.0012	.0011	.0011	.0011	.0010	.0010
−2.9	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015	.0014	.0014
−2.8	.0026	.0025	.0024	.0023	.0023	.0022	.0021	.0021	.0020	.0019
−2.7	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028	.0027	.0026
−2.6	.0047	.0045	.0044	.0043	.0041	.0040	.0039	.0038	.0037	.0036
−2.5	.0062	.0060	.0059	.0057	.0055	.0054	.0052	.0051	.0049	.0048
−2.4	.0082	.0080	.0078	.0075	.0073	.0071	.0069	.0068	.0066	.0064
−2.3	.0107	.0104	.0102	.0099	.0096	.0094	.0091	.0089	.0087	.0084
−2.2	.0139	.0136	.0132	.0129	.0125	.0122	.0119	.0116	.0113	.0110
−2.1	.0179	.0174	.0170	.0166	.0162	.0158	.0154	.0150	.0146	.0143
−2.0	.0228	.0222	.0217	.0212	.0207	.0202	.0197	.0192	.0188	.0183
−1.9	.0287	.0281	.0274	.0268	.0262	.0256	.0250	.0244	.0239	.0233
−1.8	.0359	.0351	.0344	.0336	.0329	.0322	.0314	.0307	.0301	.0294
−1.7	.0446	.0436	.0427	.0418	.0409	.0401	.0392	.0384	.0375	.0367
−1.6	.0548	.0537	.0526	.0516	.0505	.0495	.0485	.0475	.0465	.0455
−1.5	.0668	.0655	.0643	.0630	.0618	.0606	.0594	.0582	.0571	.0559
−1.4	.0808	.0793	.0778	.0764	.0749	.0735	.0721	.0708	.0694	.0681
−1.3	.0968	.0951	.0934	.0918	.0901	.0885	.0869	.0853	.0838	.0823
−1.2	.1151	.1131	.1112	.1093	.1075	.1056	.1038	.1020	.1003	.0985
−1.1	.1357	.1335	.1314	.1292	.1271	.1251	.1230	.1210	.1190	.1170
−1.0	.1587	.1562	.1539	.1515	.1492	.1469	.1446	.1423	.1401	.1379
−0.9	.1841	.1814	.1788	.1762	.1736	.1711	.1685	.1660	.1635	.1611
−0.8	.2119	.2090	.2061	.2033	.2005	.1977	.1949	.1922	.1894	.1867
−0.7	.2420	.2389	.2358	.2327	.2296	.2266	.2236	.2206	.2177	.2148
−0.6	.2743	.2709	.2676	.2643	.2611	.2578	.2546	.2514	.2483	.2451
−0.5	.3085	.3050	.3015	.2981	.2946	.2912	.2877	.2843	.2810	.2776
−0.4	.3446	.3409	.3372	.3336	.3300	.3264	.3228	.3192	.3156	.3121
−0.3	.3821	.3783	.3745	.3707	.3669	.3632	.3594	.3557	.3520	.3483
−0.2	.4207	.4168	.4129	.4090	.4052	.4013	.3974	.3936	.3897	.3859
−0.1	.4602	.4562	.4522	.4483	.4443	.4404	.4364	.4325	.4286	.4247
−0.0	.5000	.4960	.4920	.4880	.4840	.4801	.4761	.4721	.4681	.4641

Standard Normal Probabilities

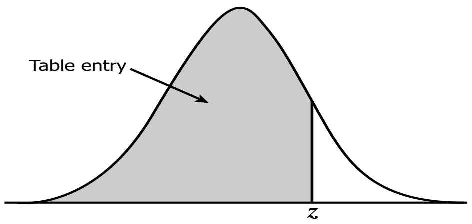
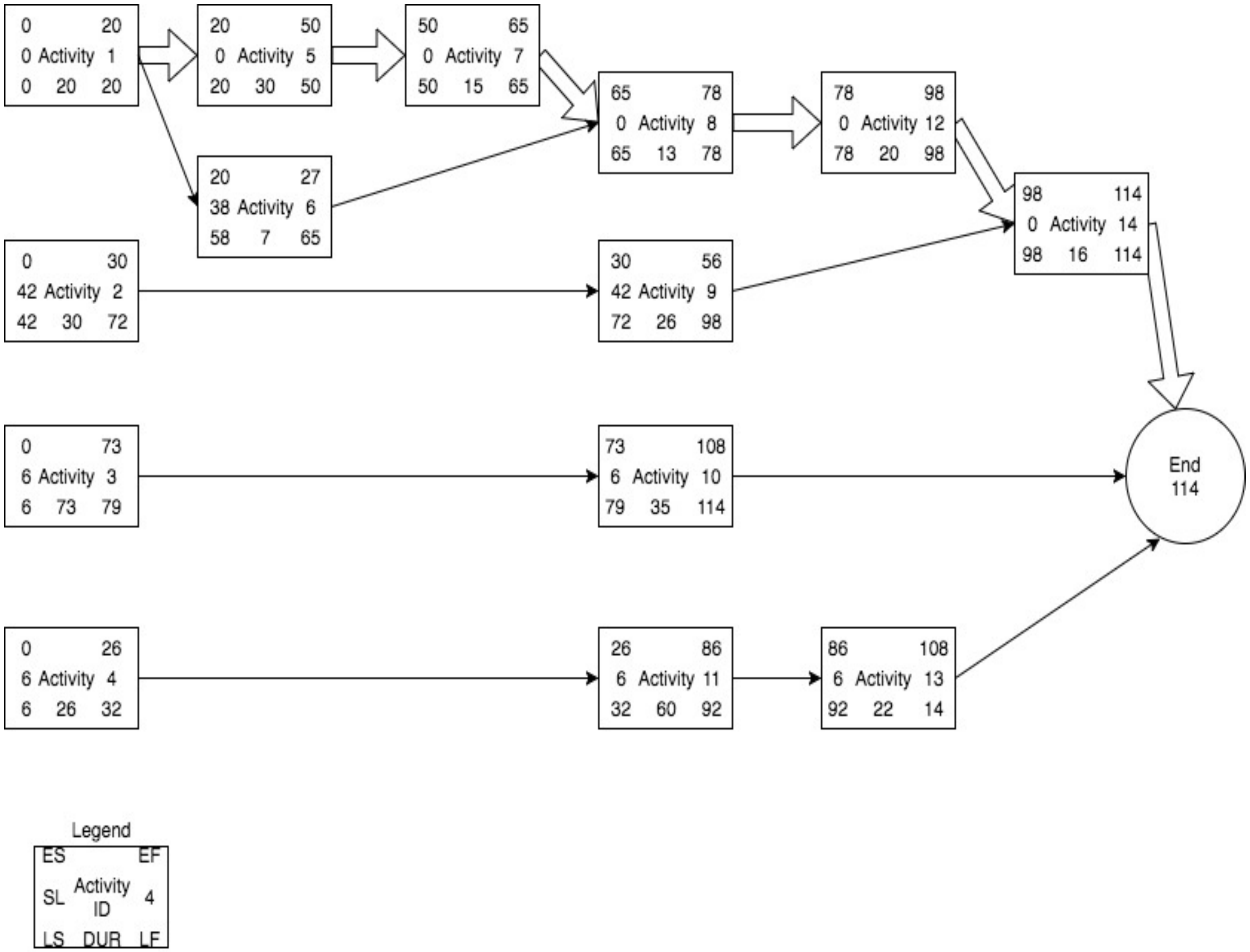


Table entry for z is the area under the standard normal curve to the left of z.

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

5. What is the probability of completing 'Negotiate with Unions' by day 90?

Activity	Description	Predecessor	Estimated time
1	Codify accounts	None	20
2	File articles of unification	None	30
3	Unify price	None	73
4	Unify personnel policies	None	26
5	Unify data processing	1	30
6	Train account staff	1	7
7	Pilot run data processing	5	15
8	Calculate P&L and balance sheet	6,7	13
9	Transfer real property	2	26
10	Train salesforce	3	35
11	Negotiate with union	4	60


0 20
0 Activity 1
0 20 20
20 50
0 Activity 5
20 30 50
50 65
0 Activity 7
50 15 65
65 78
0 Activity 8
65 13 78
78 98
0 Activity 12
78 20 98
20 27
38 Activity 6
58 7 65
98 114
0 Activity 14
98 16 114
0 30
42 Activity 2
42 30 72
30 56
42 Activity 9
72 26 98
0 73
6 Activity 3
6 73 79
73 108
6 Activity 10
79 35 114
End
114
0 26
6 Activity 4
6 26 32
26 86
6 Activity 11
32 60 92
86 108
6 Activity 13
92 22 14
Legend
ES EF
SL Activity ID 4
LS DUR LF

Solution

Te = 86 days

$$\frac{T_{S} - T_{E}}{\sqrt{\sum \sigma_{t_e}^2}} = \frac{90 - 86}{\sqrt{4 + 100}} = \frac{+4}{\sqrt{104}} = \frac{+4}{10} = +.40$$

Probability of within 90 days ≈ .65

But even after all calculations you might end up with this: