

EECS 4314

Advanced Software Engineering



Topic 11:

Project Scheduling

Zhen Ming (Jack) Jiang

Project Management

- Project management is the application of knowledge, skills, tools and techniques to achieve **specific targets** within specified **budget** and **time constraints**
- Very important field
 - Has been studied in theory and practice for many years
- Before discussing project management, we need to understand what a project is

Project

- A project is
 - a temporary endeavor undertaken to create a "unique" product or service
- A project is composed of
 - a number of **related activities** that are directed to the accomplishment of a **desired objective**
- A project starts when
 - **at least one** of its activities is ready to start
- A project is completed when
 - **all of its activities** have been completed

Activity

- An activity
 - Must have a **clear start** and a clear **stop**
 - Must have a **duration** that can be forecasted
 - May require the **completion of other activities** before it begins
 - Should have some **deliverables** for ease of monitoring

Project Planning

- The goal of time activity and time planning is to:
 - **Define the activities** required to accomplish the project
 - Bring activities into an **appropriate sequence**
 - Determine the **resources and time needed** to perform an activity
 - **Create a schedule** based on an analysis of the activities and their relationships

Project Planning

- Managers should consider:
 - **Resource availability** - resources are there when needed
 - **Resource allocation** - there are no competing resources
 - **Staff responsibility** - which staff carry out each activity
 - **Cash flow forecasting** - a timed cash flow forecast
- Managers need to monitor and re-plan as the project progresses

Work Breakdown Structure (WBS)

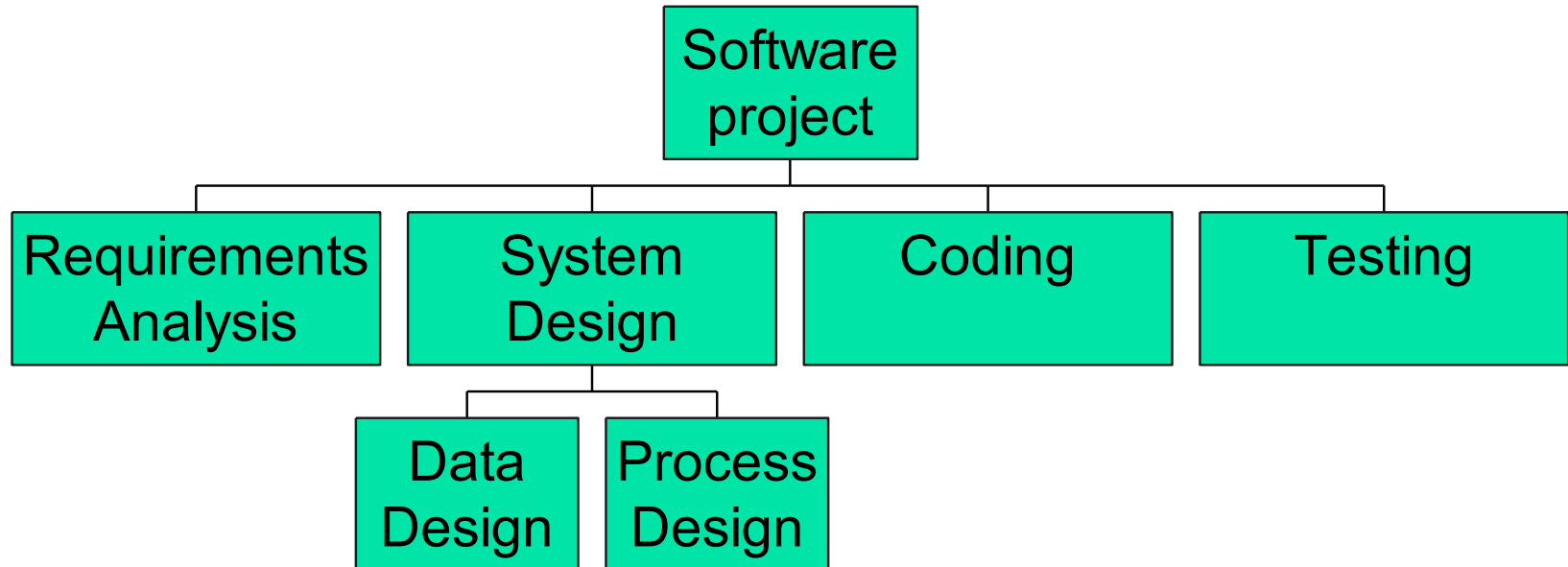
- Overall work has to be decomposed into manageable units
- Complex tasks are broken down into subtasks and further refined called Work Breakdown Structures (WBS)
- WBS contains a list of activities, derived from:
 - Previous experience
 - Expert brainstorming
- WBS helps in
 - identifying the main activities
 - break each main activity down into sub-activities which can further be broken down into lower level sub-activities

Creating WBS

- Phase based approach
- Product based approach
- Hybrid approach

Example of Phase-based Approach

Work Breakdown Structure (an extract)



Phase-based Approach

■ Advantage

- Activity list likely complete and non-overlapping
- WBS gives a structure that can be
 - refined as the project proceeds
 - used for determining dependencies among activities

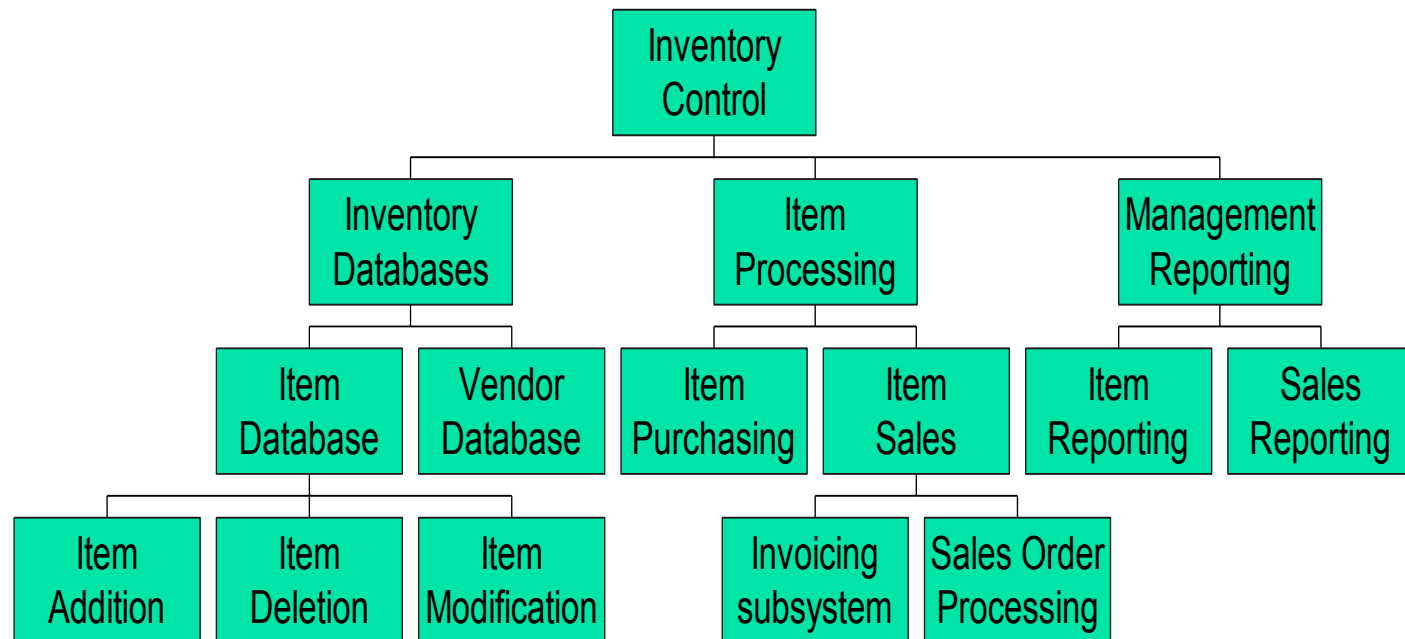
■ Disadvantage

- May miss some activities related to final product

Product based approach

- Product Breakdown Structure (PBS)
 - Shows how a system can be broken down into different products for development

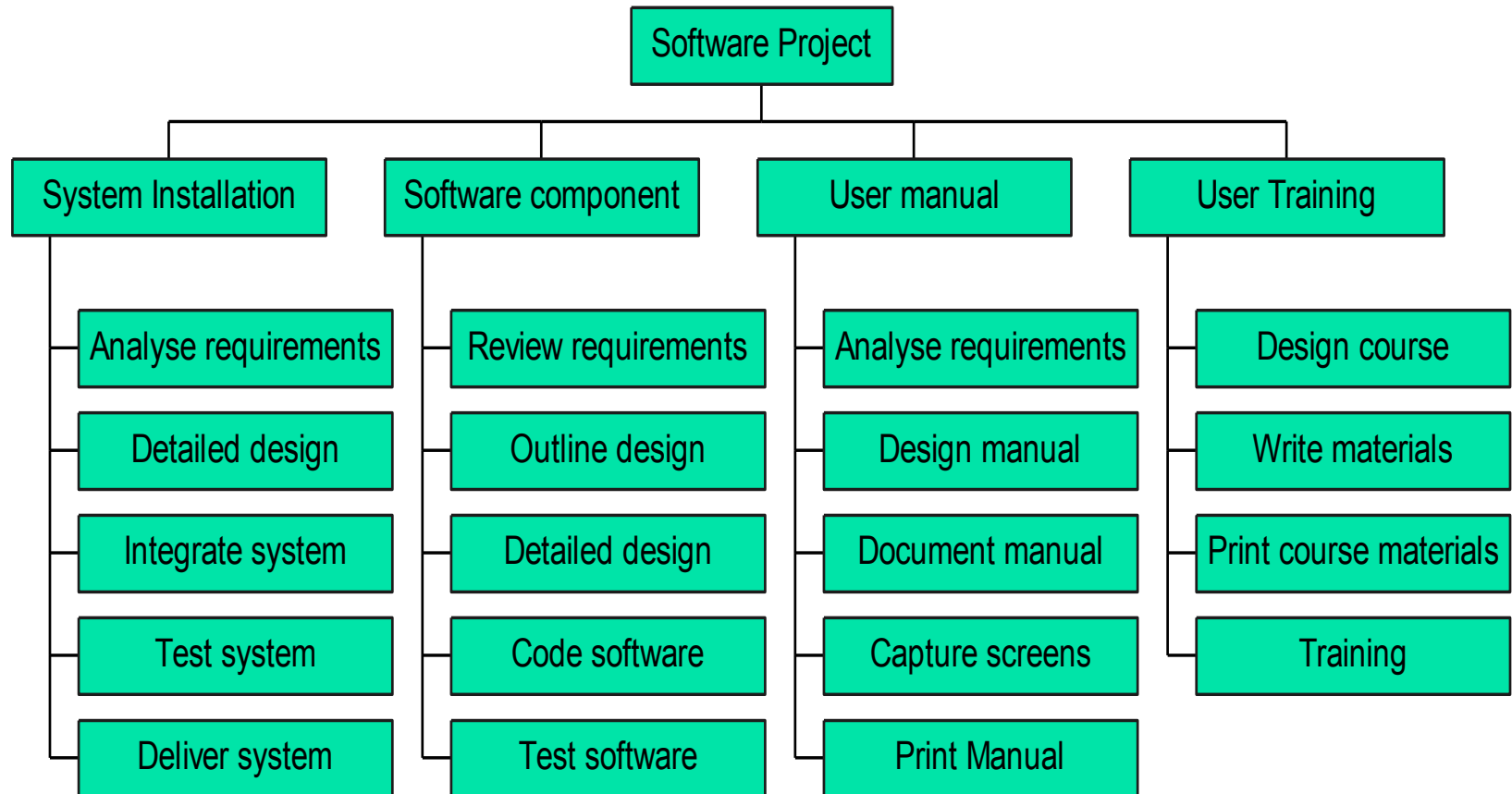
A Product Breakdown Structure (an extract)



Hybrid Approach

- A mix of the phase-based and product-based approaches (most commonly used)
- The WBS consists of
 - a list of the products of the project; and
 - a list of phases for each product

Hybrid WBS



Schedule Development Methods

- Need to develop a schedule in which planned start and end dates are assigned to all activities
- Need to consider:
 - Activity precedence
 - Activity duration
 - Available resources

Project Scheduling

■ Steps

- Define activities
- Sequence activities
- Estimate time

■ Techniques

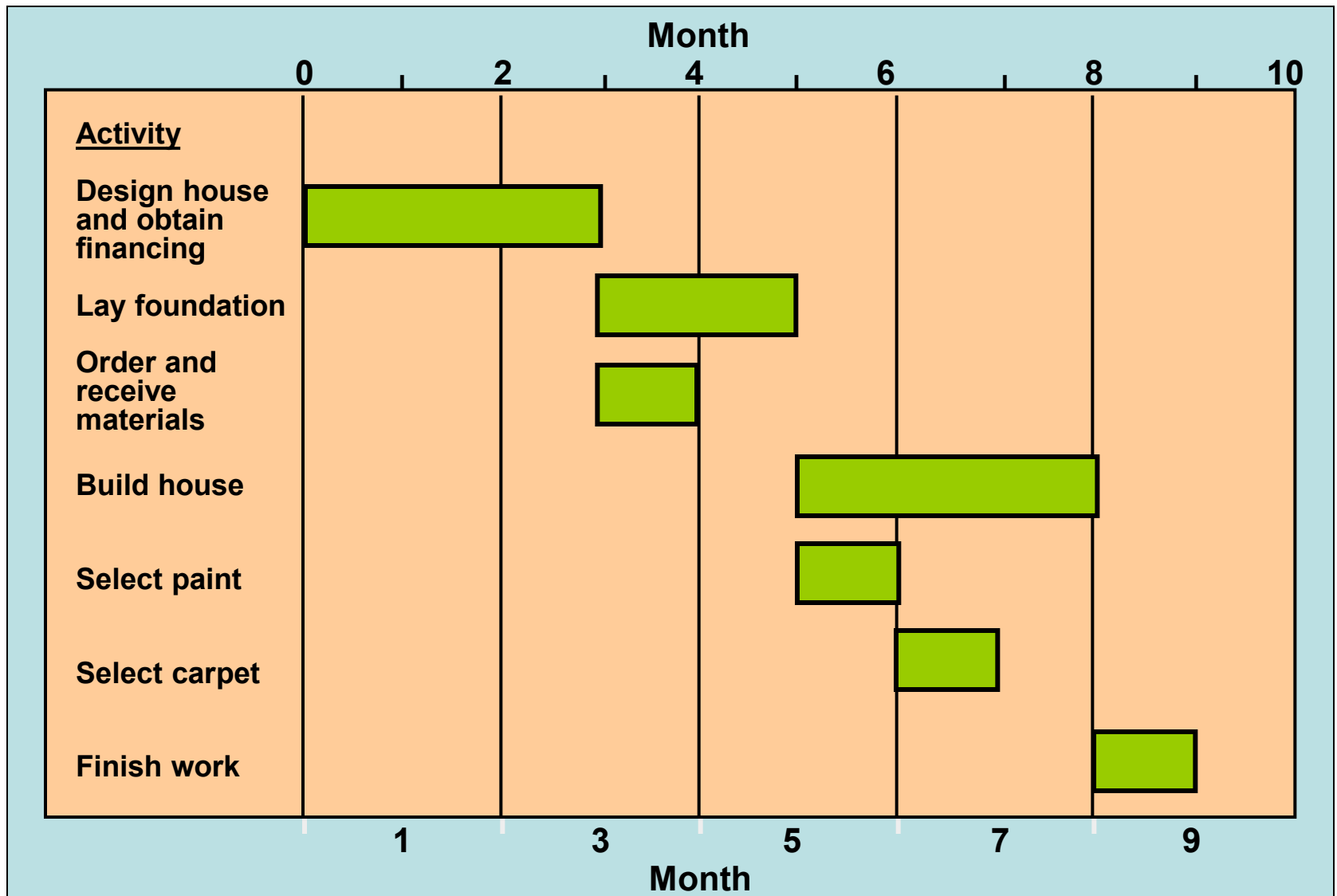
- Gantt chart
- CPM
- PERT

Gantt Chart

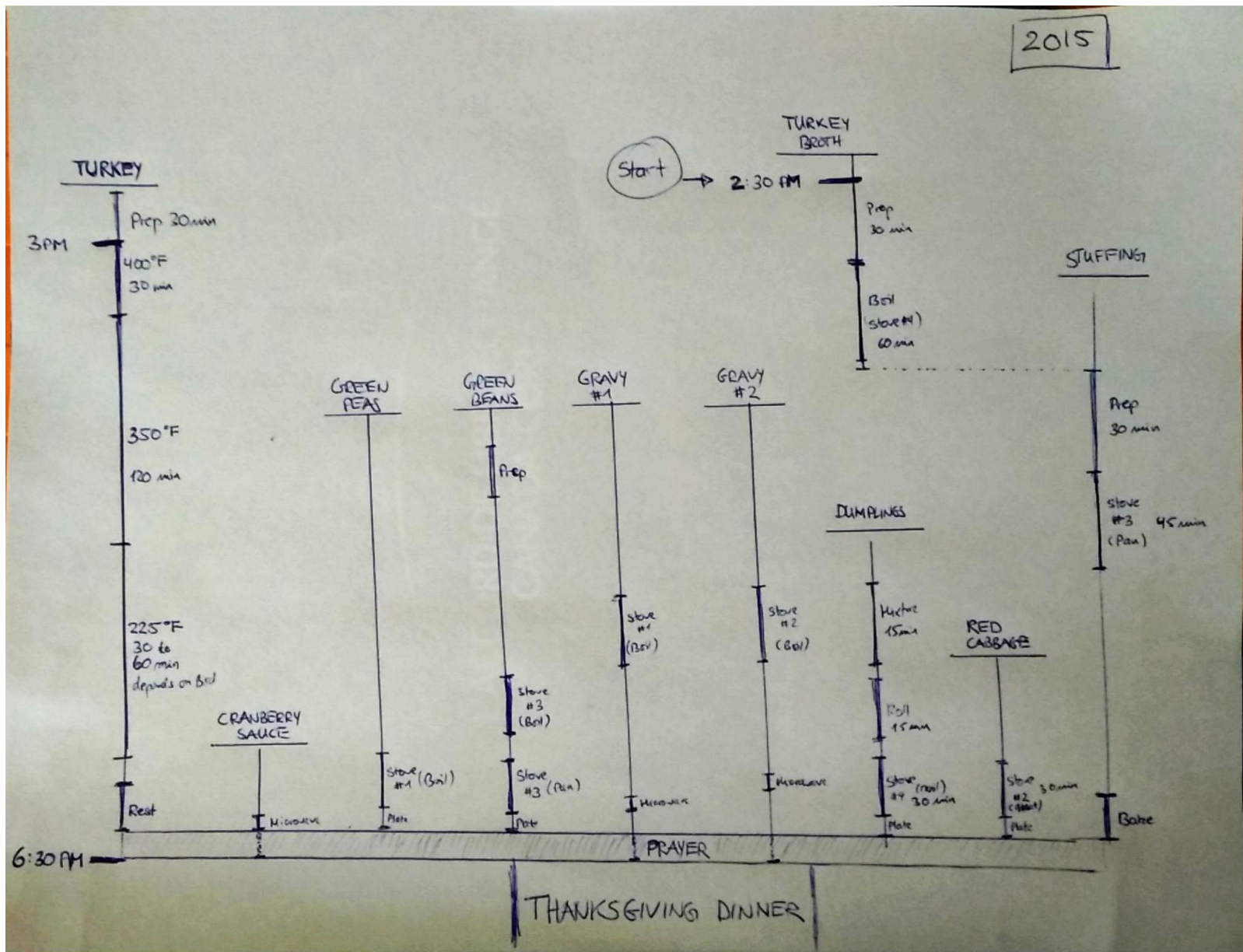
Gantt Chart

- Developed in 1918 by H.L. Gantt
- Graph or bar chart with a bar for each project activity that shows passage of time
- Provides visual display of project schedule
- Limitations
 - Does not clearly indicate details regarding the **progress of activities**
 - Does not give a clear indication of **interrelation between the activities**

Example of Gantt Chart



Gantt Chart for Thanksgiving



Critical Path Method (CPM)

Critical Path Method (CPM)

Overview

- Developed for industrial projects where activity times are generally known
- Process to determine and optimize critical path
- Should consult with functional expert
- Plan for the fastest completion of the project
- Identify activities whose delays is likely to affect the completion date for the whole project
- Very useful for repetitive activities with well known completion time

Critical Path Method (CPM)

- Primary objectives:
 - Plan for the fastest completion of the project
 - Identify activities whose delays is likely to affect the completion date for the whole project
 - Very useful for repetitive activities with well known completion time
- Developed by Du Pont Chemical Company and published in 1958
 - Can we decrease the completion time by spending more money?

Critical Path and Events

- Slack: the amount of time an activity can be delayed without delaying the project
- Critical event: an event that has zero slack
- Critical path: a path joining those critical events
 - Sequential activities upon which the project completion depends
 - Calculated as the longest path through a network (i.e., longest overall duration)
 - The shortest time possible to complete the project
- Benefits of Critical Path Analysis:
 - During planning stage
 - Shortening the critical path will reduce the overall project duration
 - During maintenance stage
 - Pay more attention to those activities which fall in the critical path

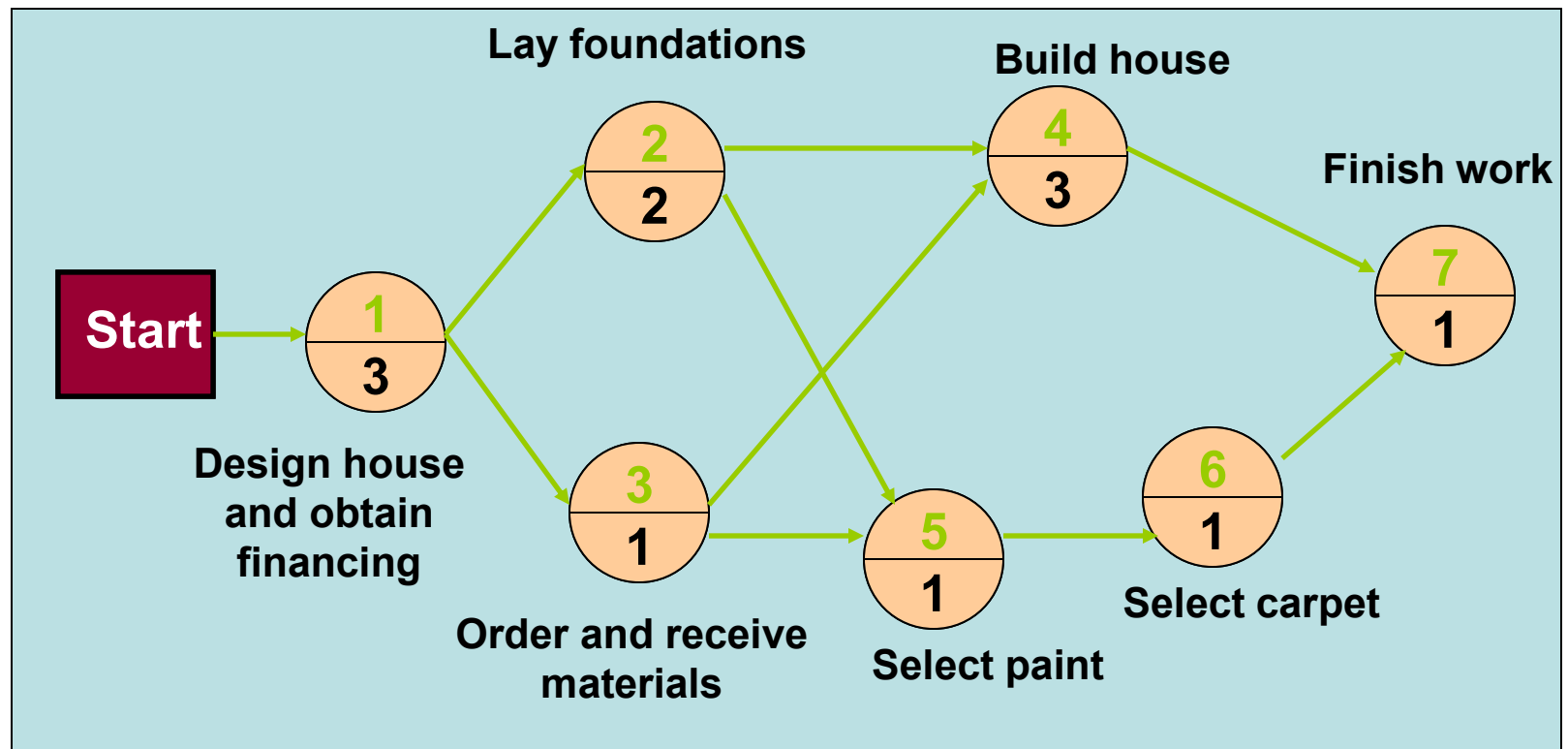
Critical Path Notes

- All projects have a critical path
- Any delay in activities on the critical path will impact the project completion time
- Shortening non-critical path tasks does not necessarily shorten the project schedule

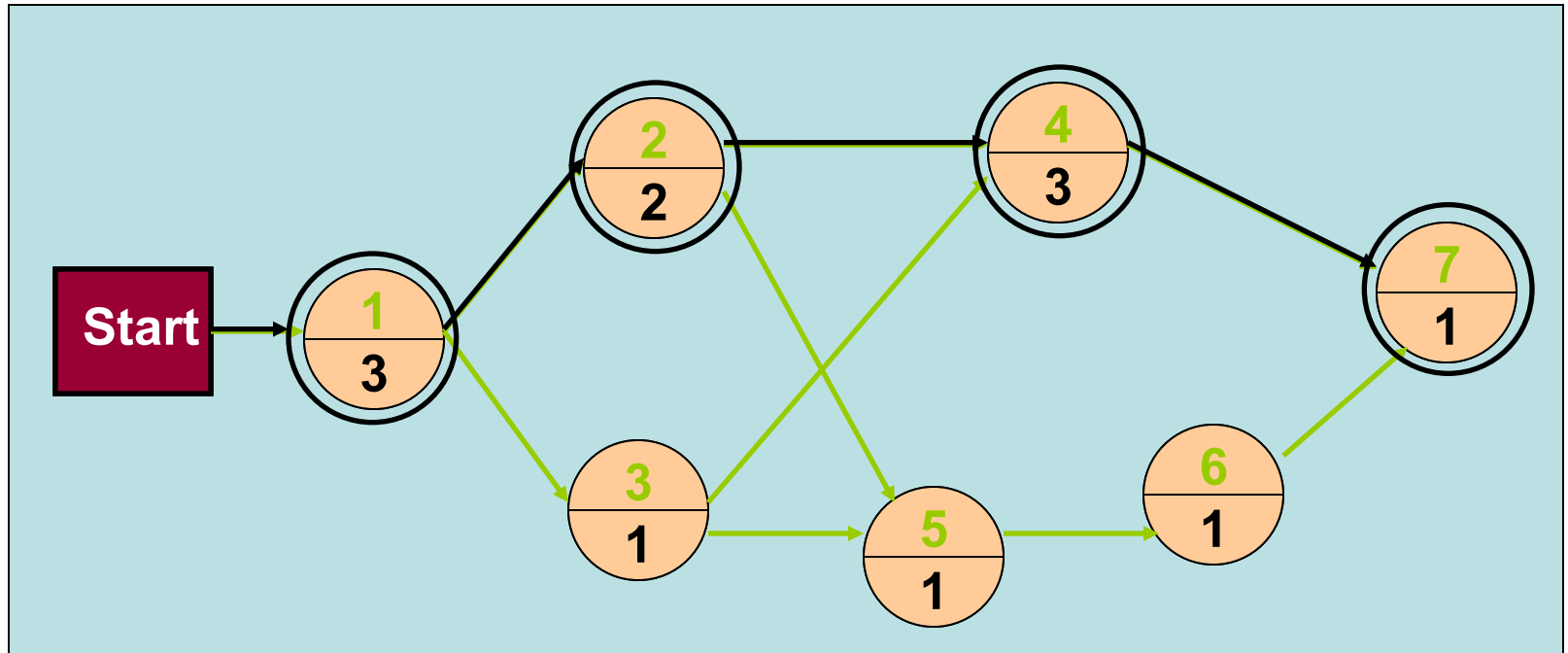
Activity Float

- Time allowed for an activity to delay
- 3 different types:
 - **Total float** (without affecting project completion) = latest start date – earliest start date
 - **Free float** (without affecting the next activity) = earliest start date of *next activity* – latest end date of *previous activity*
 - **Interfering float** = total float – free float

Scheduling Network for House Building Project



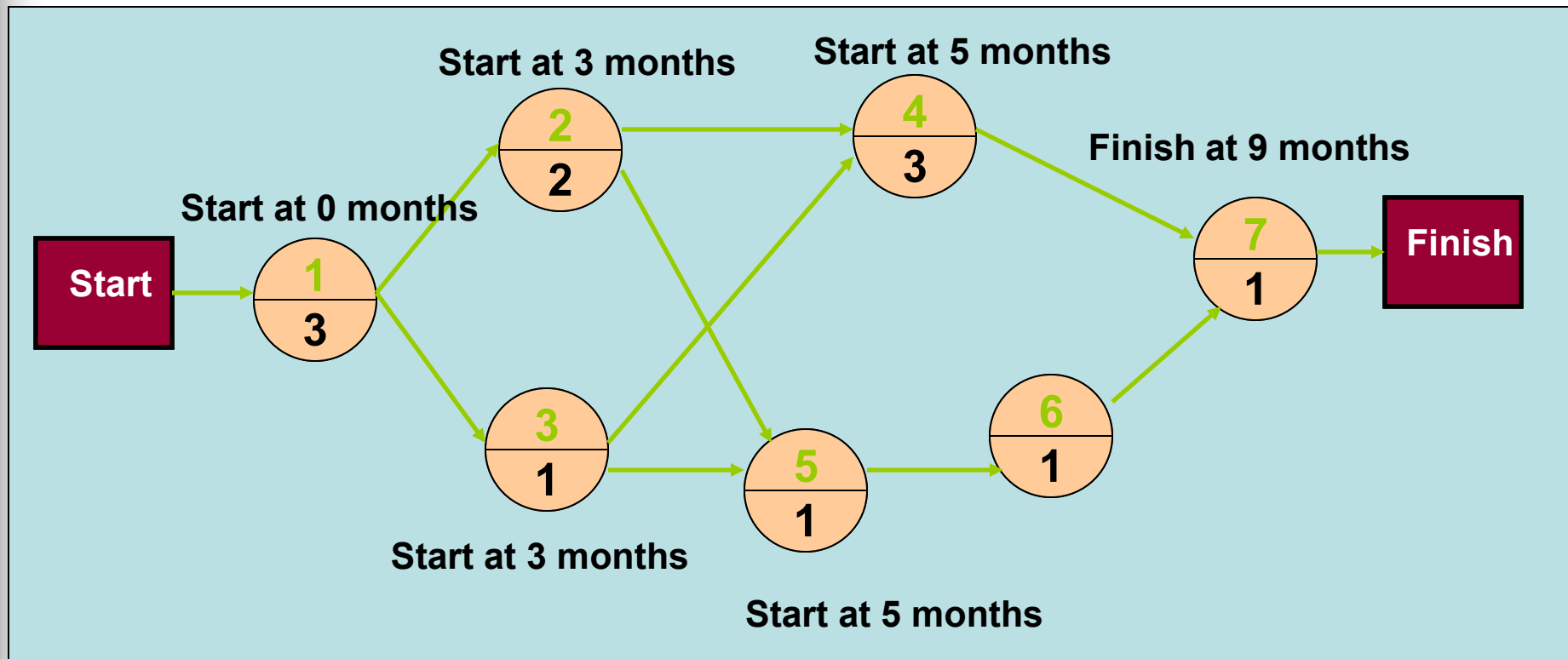
Critical Path



- A: 1-2-4-7
 $3 + 2 + 3 + 1 = 9$ months
- B: 1-2-5-6-7
 $3 + 2 + 1 + 1 + 1 = 8$ months
- C: 1-3-4-7
 $3 + 1 + 3 + 1 = 8$ months
- D: 1-3-5-6-7
 $3 + 1 + 1 + 1 + 1 = 7$ months

- Critical path
 - Longest path through a network
 - Minimum project completion time

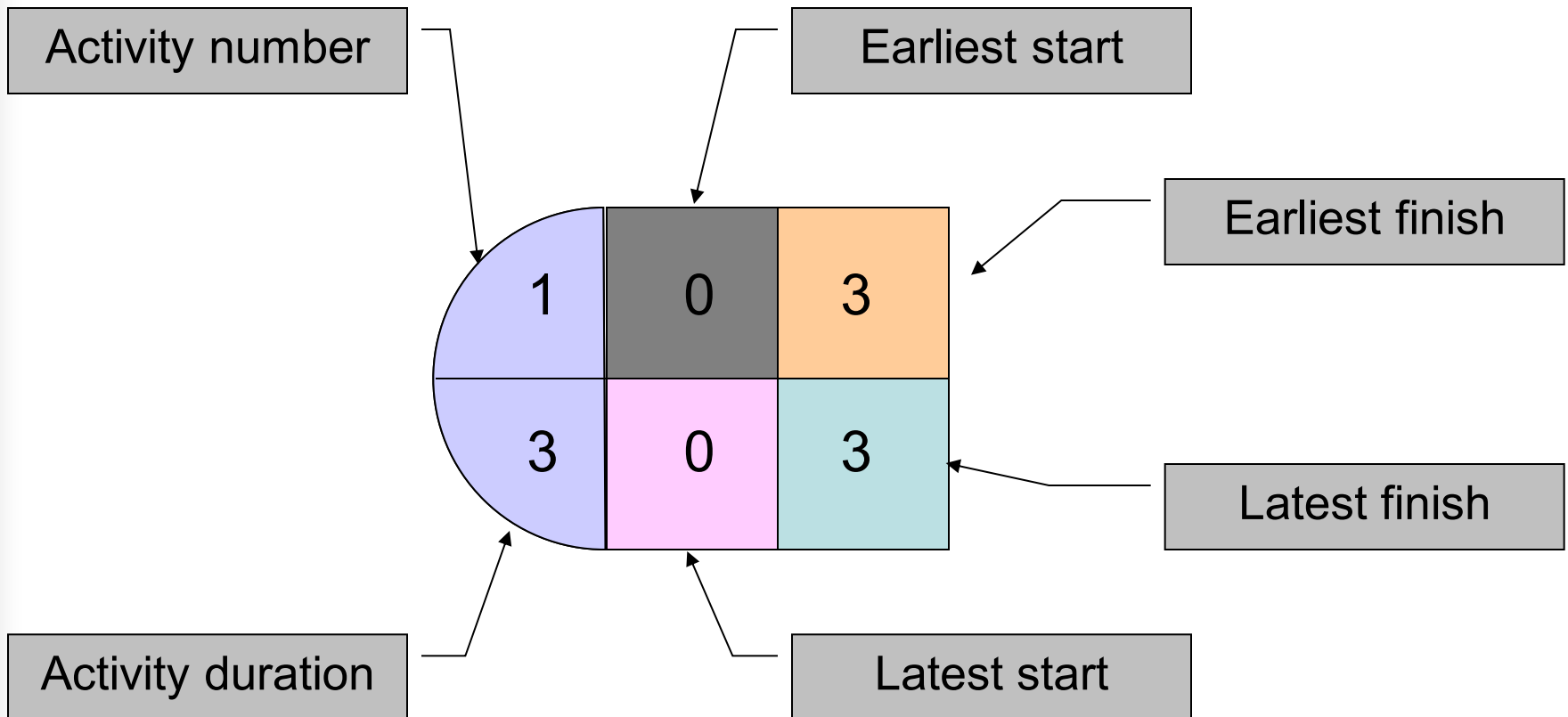
Activity Start Times



CPM Calculation Overview

- The forward pass
 - Calculate the **earliest** start dates of the activities
 - to calculate the project completion date
- The backward pass
 - Calculate the **latest** start dates for activities
 - to identify the critical path from the graph

Mode Configuration

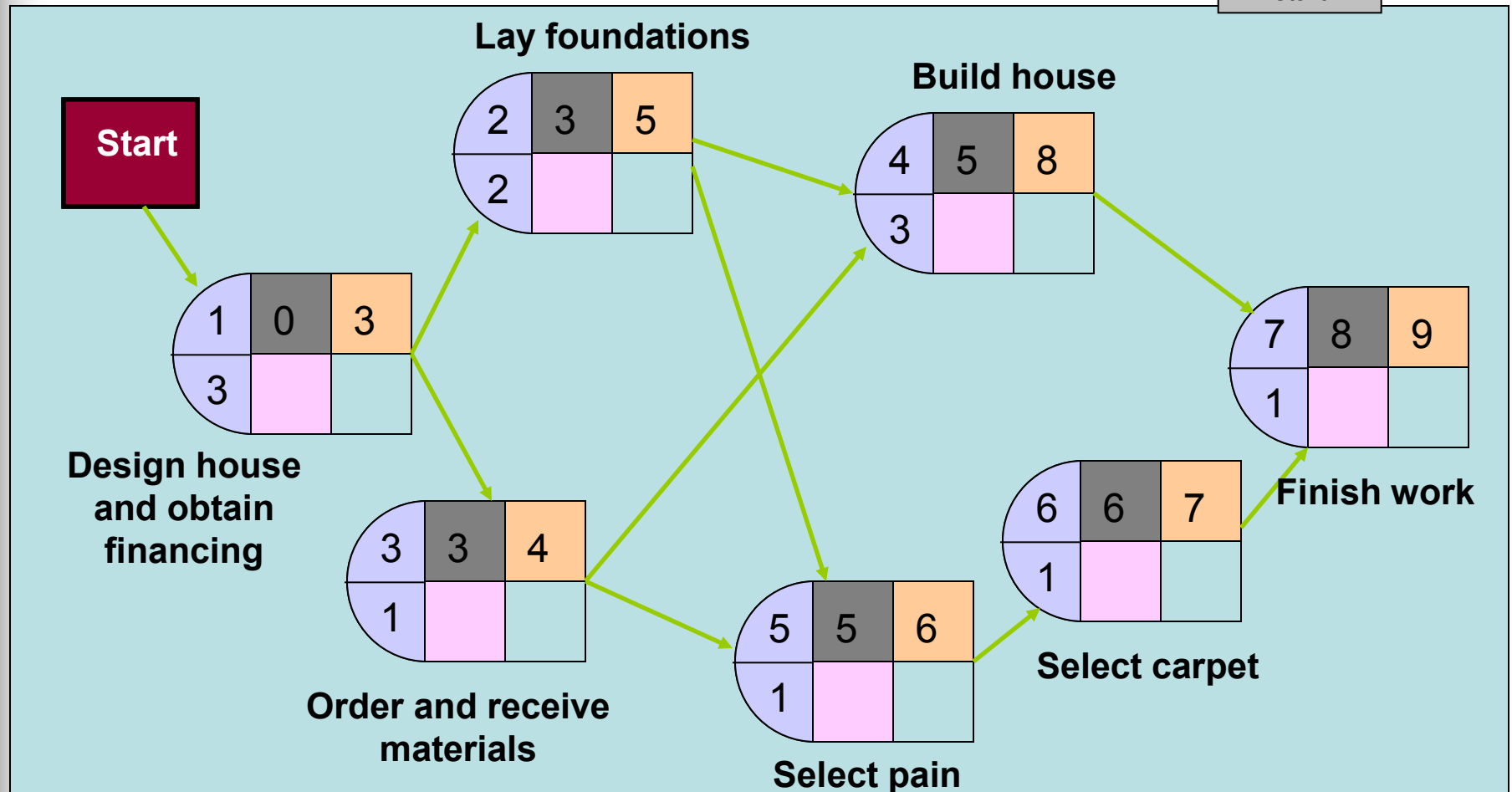
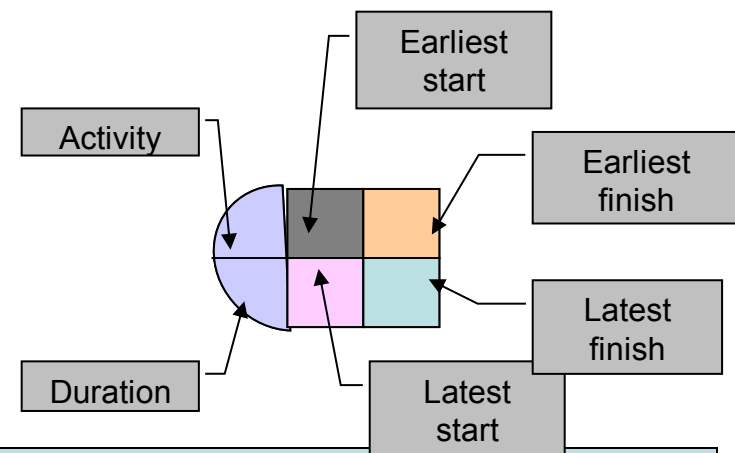


Forward Pass

- Start at the beginning of CPM/PERT network to determine the earliest activity times
- Always start from left (node) to right
- Earliest Start Time (ES)
 - earliest time an activity can start
 - $ES = \text{maximum } EF \text{ of immediate predecessors}$
- Earliest finish time (EF)
 - earliest time an activity can finish
 - earliest start time plus activity time

$$EF = ES + t$$

Earliest Activity Start and Finish Times



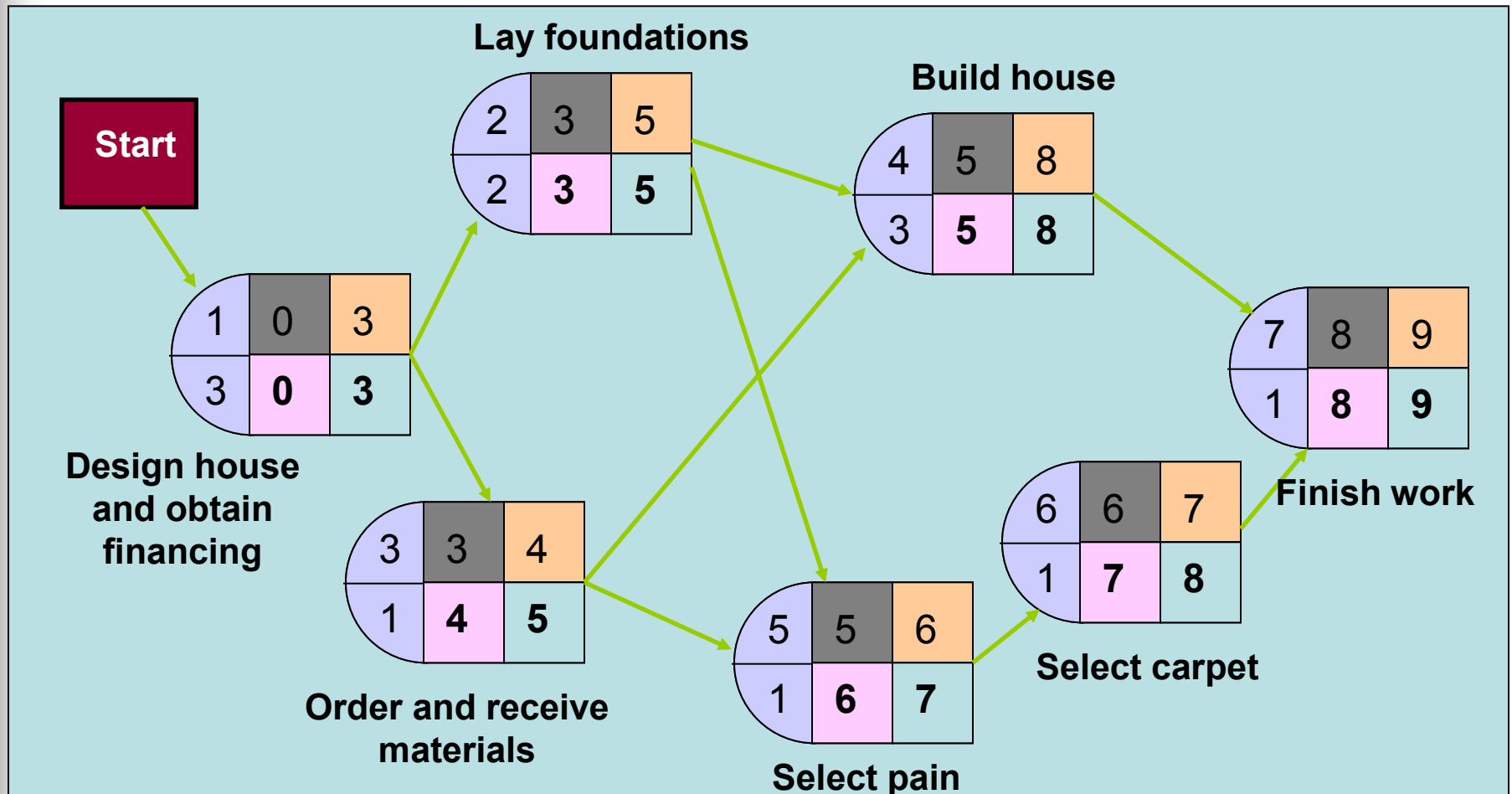
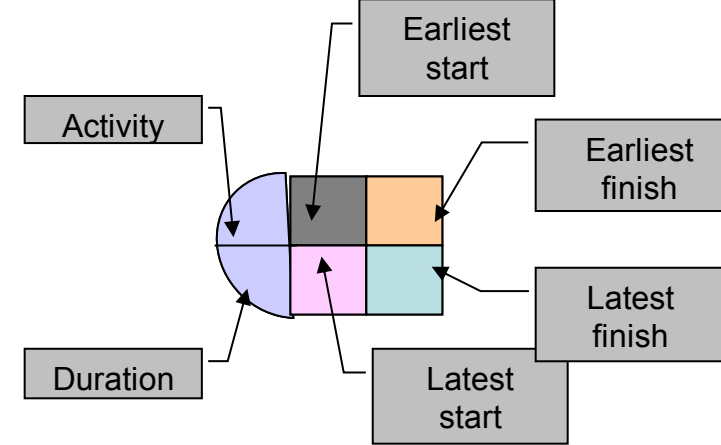
Backward Pass

- Determines latest activity times by starting at the end of CPM/PERT network and working forward
- Work from right (end node) to left
- Latest Start Time (LS)
 - Latest time an activity can start without delaying critical path time

$$LS = LF - t$$

- Latest finish time (LF)
 - latest time an activity can be completed without delaying critical path time
 - $LF = \text{minimum LS of immediate post-decessors}$

Latest Activity Start and Finish Times



Activity Slack

Activity	LS	ES	LF	EF	Slack S
*1	0	0	3	3	0
*2	3	3	5	5	0
3	4	3	5	4	1
*4	5	5	8	8	0
5	6	5	7	6	1
6	7	6	8	7	1
*7	8	8	9	9	0
* Critical Path					

Slack: amount of time an activity can be delayed without delaying the project

$$\text{activity slack} = LS - ES = LF - EF$$

Critical activities: have zero slack and lie on a critical path.

Program Evaluation and Review Technique (PERT)

Program Evaluation and Review Technique (PERT)

- Based on the idea that estimates are uncertain
- Uses ranges and probability and an expected value of the duration of a project
- E.g., The most likely completion time is 4 weeks but it could be anywhere between 3 weeks and 8 weeks
- Developed by the US Navy for the planning and control of the Polaris missile program

Probabilistic Time Estimates

- Beta distribution
 - a probability distribution traditionally used in CPM/PERT

Mean (expected time): $t = \frac{a + 4m + b}{6}$

Variance: $\sigma^2 = \left(\frac{b - a}{6} \right)^2$

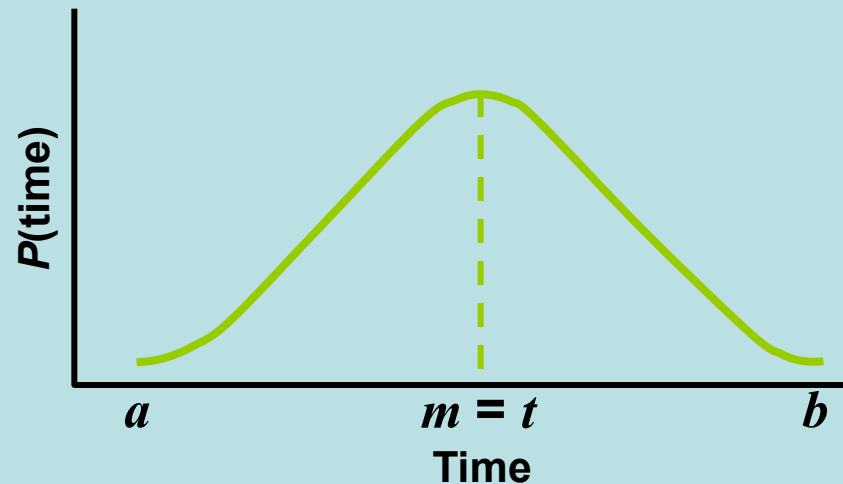
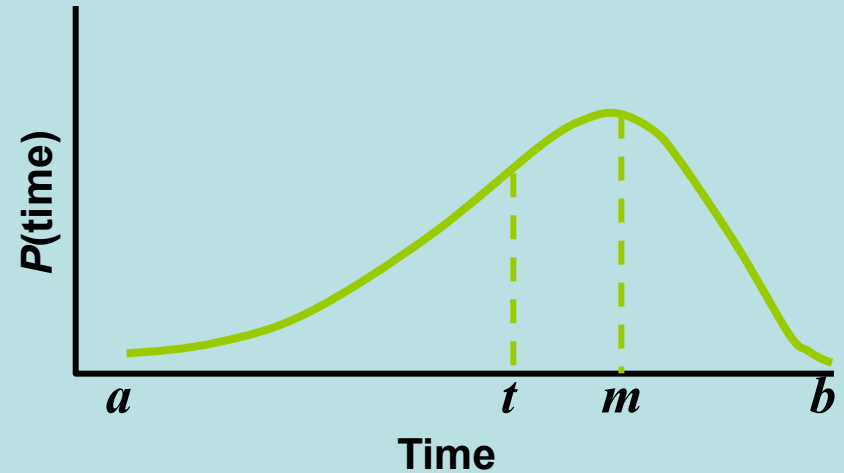
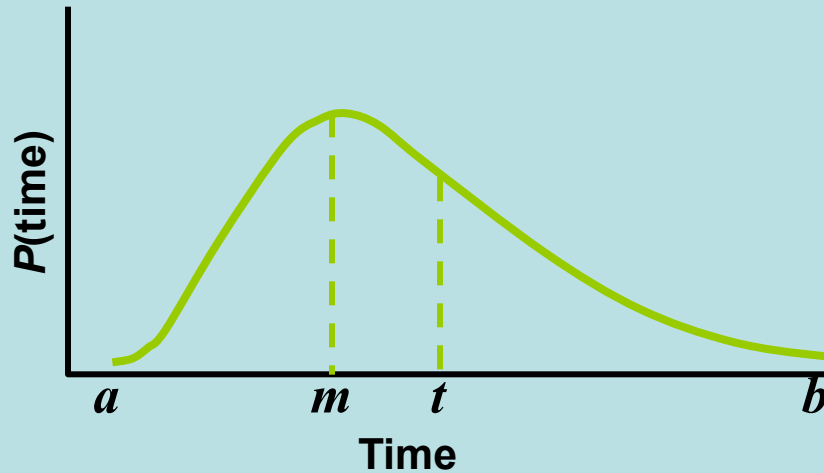
where

a = optimistic estimate

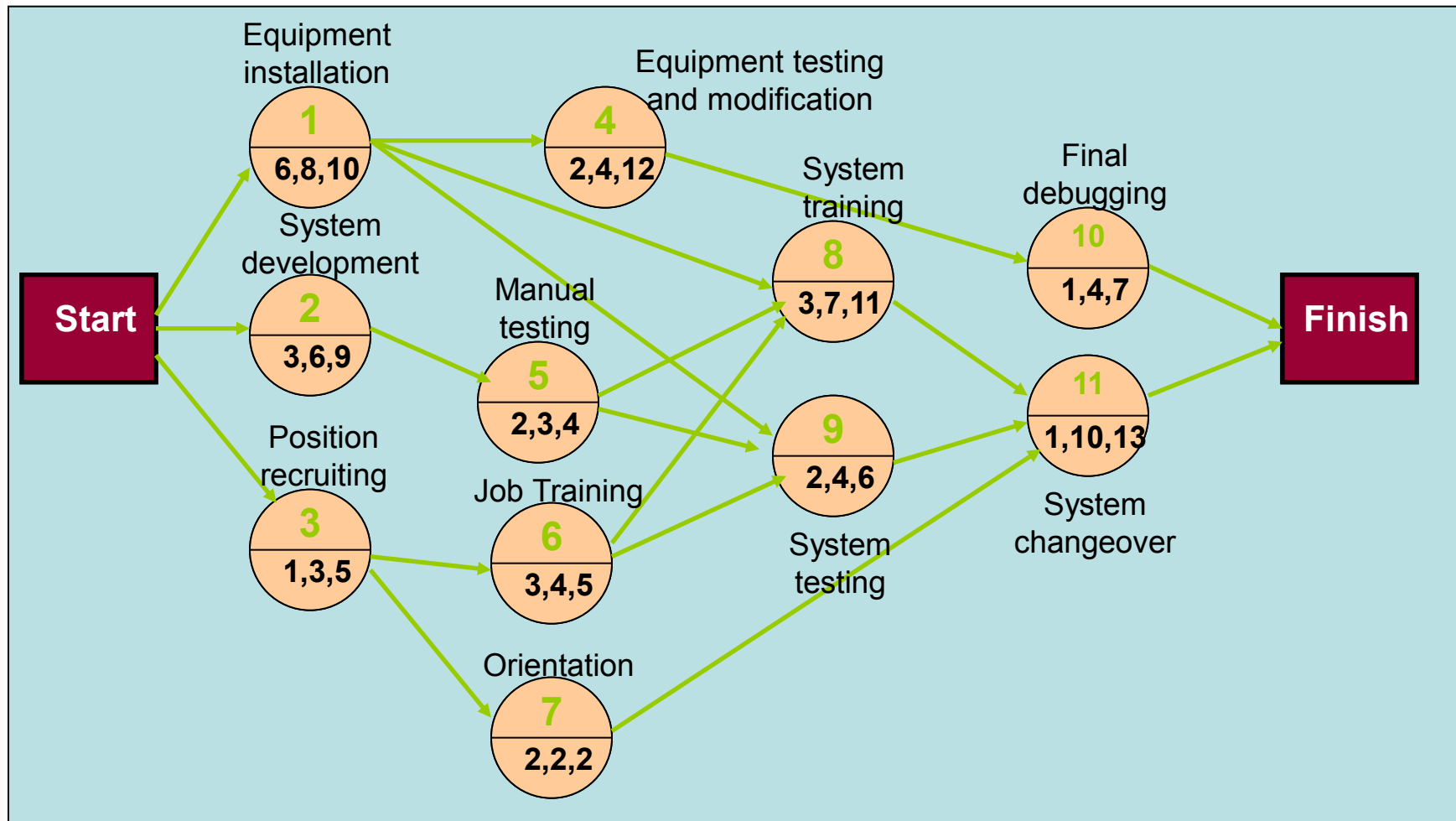
m = most likely time estimate

b = pessimistic time estimate

Examples of Beta Distributions



Project Network with Probabilistic Time Estimates: Example



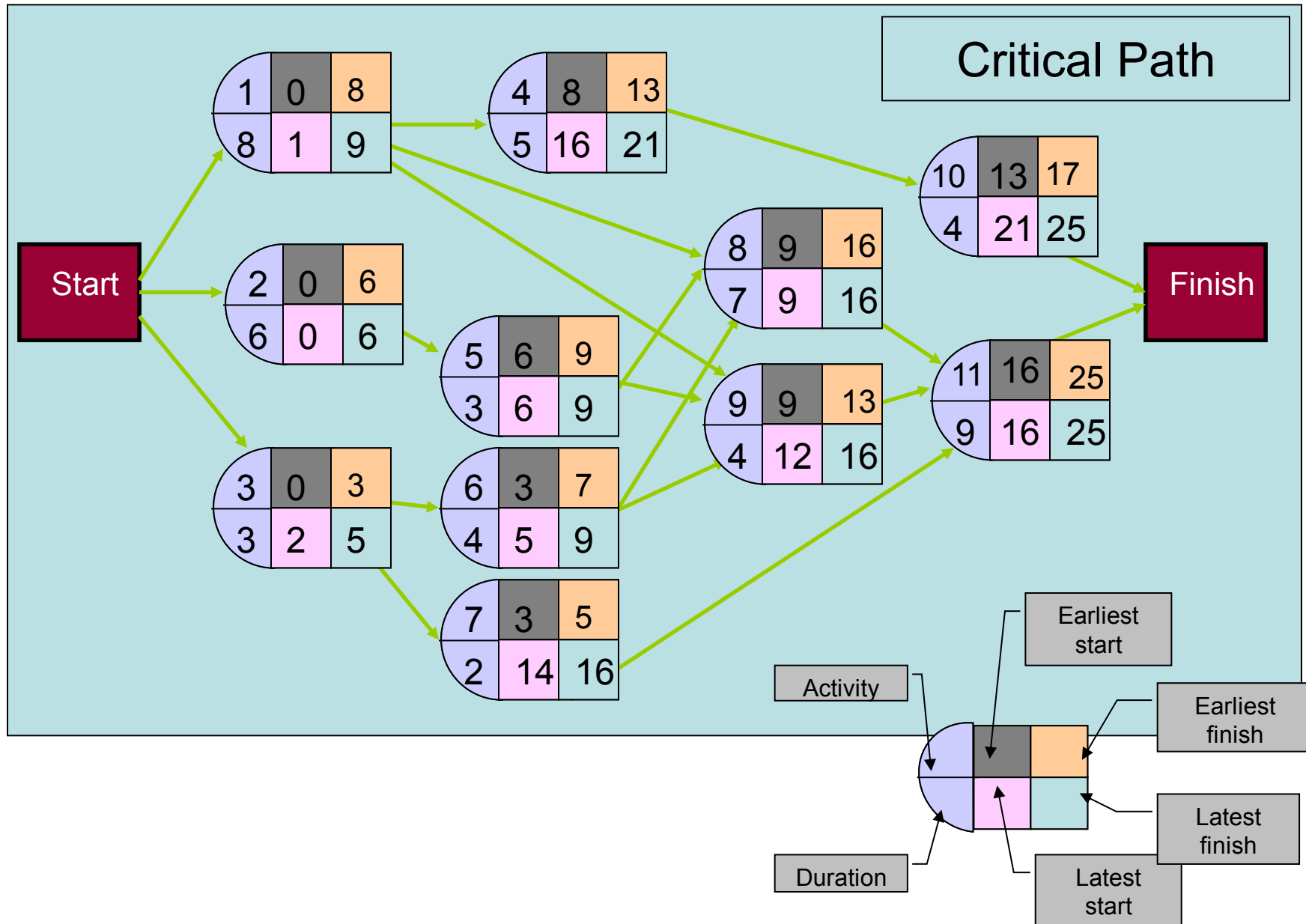
Activity Time Estimates

ACTIVITY	TIME ESTIMATES (WKS)			MEAN TIME	VARIANCE
	<i>a</i>	<i>m</i>	<i>b</i>	<i>t</i>	σ^2
1	6	8	10	8	0.44
2	3	6	9	6	1.00
3	1	3	5	3	0.44
4	2	4	12	5	2.78
5	2	3	4	3	0.11
6	3	4	5	4	0.11
7	2	2	2	2	0.00
8	3	7	11	7	1.78
9	2	4	6	4	0.44
10	1	4	7	4	1.00
11	1	10	13	9	4.00

Activity Early, Late Times, and Slack

ACTIVITY	t	σ^2	ES	EF	LS	LF	S
1	8	0.44	0	8	1	9	1
2	6	1.00	0	6	0	6	0
3	3	0.44	0	3	2	5	2
4	5	2.78	8	13	16	21	8
5	3	0.11	6	9	6	9	0
6	4	0.11	3	7	5	9	2
7	2	0.00	3	5	14	16	11
8	7	1.78	9	16	9	16	0
9	4	0.44	9	13	12	16	3
10	4	1.00	13	17	21	25	8
11	9	4.00	16	25	16	25	0

Earliest, Latest, and Slack



Total project variance

$$\sigma^2 = \sigma_2^2 + \sigma_5^2 + \sigma_8^2 + \sigma_{11}^2$$

$$\begin{aligned}\sigma &= 1.00 + 0.11 + 1.78 + 4.00 \\ &= 6.89 \text{ weeks}\end{aligned}$$

Probabilistic Network Analysis

Determine probability that project is completed within specified time

$$Z = \frac{x - \mu}{\sigma}$$

where

$\mu = t_p$ = project mean time

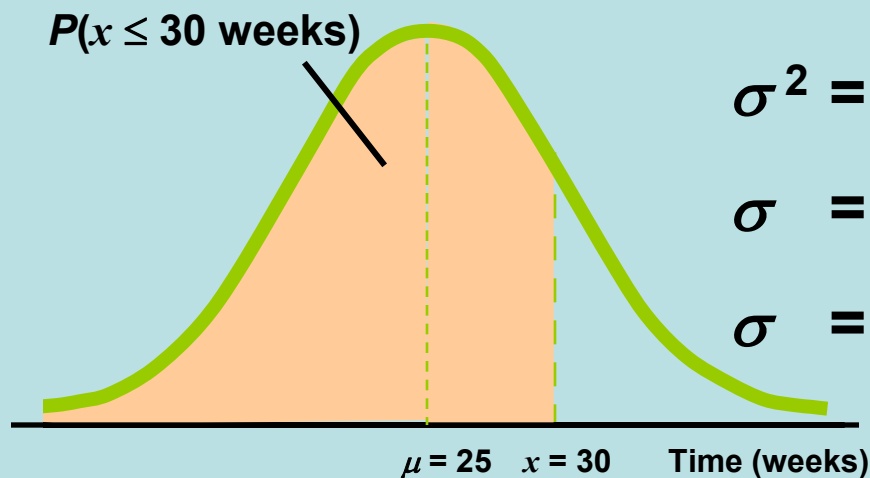
σ = project standard deviation

x = proposed project time

Z = number of standard deviations x is from mean

Probability of Completion Time

What is the probability that the project is completed within 30 weeks?



$$\sigma^2 = 6.89 \text{ weeks}$$

$$\sigma = \sqrt{6.89}$$

$$\sigma = 2.62 \text{ weeks}$$

$$\begin{aligned} Z &= \frac{x - \mu}{\sigma} \\ &= \frac{30 - 25}{2.62} \\ &= 1.91 \end{aligned}$$

From Z scores Table, a Z score of 1.91 corresponds to a probability 0.9719.

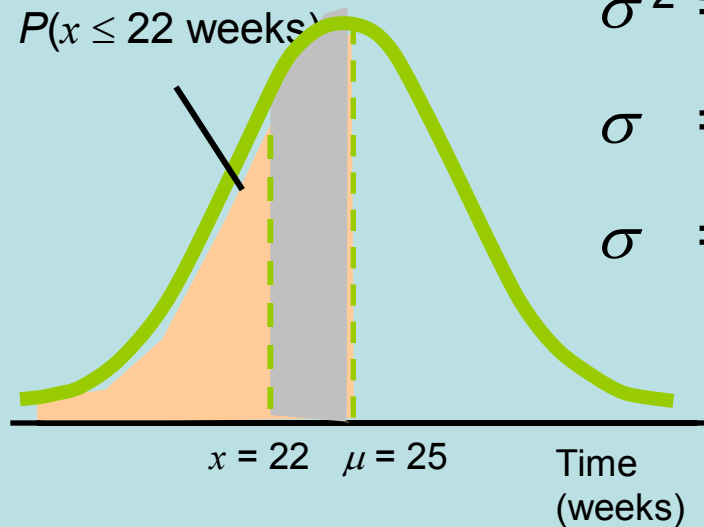
Z-values

Cumulative Normal Probability Tables (Z-Values)

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	0.53983	0.54380	0.54776	0.55172	0.55567	0.55962	0.56356	0.56749	0.57142	0.57535
0.2	0.57926	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
2.1	0.98214	0.98257	0.98300	0.98341	0.98382	0.98422	0.98461	0.98500	0.98537	0.98574
2.2	0.98610	0.98645	0.98679	0.98713	0.98745	0.98778	0.98809	0.98840	0.98870	0.98899
2.3	0.98928	0.98956	0.98983	0.99010	0.99036	0.99061	0.99086	0.99111	0.99134	0.99158
2.4	0.99180	0.99202	0.99224	0.99245	0.99266	0.99286	0.99305	0.99324	0.99343	0.99361
2.5	0.99379	0.99396	0.99413	0.99430	0.99446	0.99461	0.99477	0.99492	0.99506	0.99520
2.6	0.99534	0.99547	0.99560	0.99573	0.99585	0.99598	0.99609	0.99621	0.99632	0.99643
2.7	0.99653	0.99664	0.99674	0.99683	0.99693	0.99702	0.99711	0.99720	0.99728	0.99736
2.8	0.99744	0.99752	0.99760	0.99767	0.99774	0.99781	0.99788	0.99795	0.99801	0.99807
2.9	0.99813	0.99819	0.99825	0.99831	0.99836	0.99841	0.99846	0.99851	0.99856	0.99861
3.0	0.99865	0.99869	0.99874	0.99878	0.99882	0.99886	0.99889	0.99893	0.99896	0.99900
3.1	0.99903	0.99906	0.99910	0.99913	0.99916	0.99918	0.99921	0.99924	0.99926	0.99929
3.2	0.99931	0.99934	0.99936	0.99938	0.99940	0.99942	0.99944	0.99946	0.99948	0.99950
3.3	0.99952	0.99953	0.99955	0.99957	0.99958	0.99960	0.99961	0.99962	0.99964	0.99965
3.4	0.99966	0.99968	0.99969	0.99970	0.99971	0.99972	0.99973	0.99974	0.99975	0.99976
3.5	0.99977	0.99978	0.99978	0.99979	0.99980	0.99981	0.99981	0.99982	0.99983	0.99983
3.6	0.99984	0.99985	0.99985	0.99986	0.99986	0.99987	0.99987	0.99988	0.99988	0.99989
3.7	0.99989	0.99990	0.99990	0.99990	0.99991	0.99991	0.99992	0.99992	0.99992	0.99993

Probability of Completion Time

What is the probability that the project is completed within 22 weeks?



$$\sigma^2 = 6.89 \text{ weeks}$$

$$\sigma = \sqrt{6.89}$$

$$\sigma = 2.62 \text{ weeks}$$

$$\begin{aligned} Z &= \frac{x - \mu}{\sigma} \\ &= \frac{22 - 25}{2.62} \\ &= -1.14 \end{aligned}$$

From Z scores Table, a Z score of -1.14 corresponds to a probability of 0.1271

Z-values

Cumulative Normal Probability Tables (Z-Values)

Z	0.09	0.08	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0.00
-4.0	0.00002	0.00002	0.00002	0.00002	0.00003	0.00003	0.00003	0.00003	0.00003	0.00003
-3.9	0.00003	0.00003	0.00004	0.00004	0.00004	0.00004	0.00004	0.00004	0.00005	0.00005
-3.8	0.00005	0.00005	0.00005	0.00006	0.00006	0.00006	0.00006	0.00007	0.00007	0.00007
-3.7	0.00008	0.00008	0.00008	0.00008	0.00009	0.00009	0.00010	0.00010	0.00010	0.00011
-3.6	0.00011	0.00012	0.00012	0.00013	0.00013	0.00014	0.00014	0.00015	0.00015	0.00016
-3.5	0.00017	0.00017	0.00018	0.00019	0.00019	0.00020	0.00021	0.00022	0.00022	0.00023
-3.4	0.00024	0.00025	0.00026	0.00027	0.00028	0.00029	0.00030	0.00031	0.00032	0.00034
-3.3	0.00035	0.00036	0.00038	0.00039	0.00040	0.00042	0.00043	0.00045	0.00047	0.00048
-3.2	0.00050	0.00052	0.00054	0.00056	0.00058	0.00060	0.00062	0.00064	0.00066	0.00069
-3.1	0.00071	0.00074	0.00076	0.00079	0.00082	0.00084	0.00087	0.00090	0.00094	0.00097
-3.0	0.00100	0.00104	0.00107	0.00111	0.00114	0.00118	0.00122	0.00126	0.00131	0.00135
-2.9	0.00139	0.00144	0.00149	0.00154	0.00159	0.00164	0.00169	0.00175	0.00181	0.00187
-2.8	0.00193	0.00199	0.00205	0.00212	0.00219	0.00226	0.00233	0.00240	0.00248	0.00256
-2.7	0.00264	0.00272	0.00280	0.00289	0.00298	0.00307	0.00317	0.00326	0.00336	0.00347
-2.6	0.00357	0.00368	0.00379	0.00391	0.00402	0.00415	0.00427	0.00440	0.00453	0.00466
-2.5	0.00480	0.00494	0.00508	0.00523	0.00539	0.00554	0.00570	0.00587	0.00604	0.00621
-2.4	0.00639	0.00657	0.00676	0.00695	0.00714	0.00734	0.00755	0.00776	0.00798	0.00820
-2.3	0.00842	0.00866	0.00889	0.00914	0.00939	0.00964	0.00990	0.01017	0.01044	0.01072
-2.2	0.01101	0.01130	0.01160	0.01191	0.01222	0.01255	0.01287	0.01321	0.01355	0.01390
-2.1	0.01426	0.01463	0.01500	0.01539	0.01578	0.01618	0.01659	0.01700	0.01743	0.01786
-2.0	0.01831	0.01876	0.01923	0.01970	0.02018	0.02068	0.02118	0.02169	0.02222	0.02275
-1.9	0.02330	0.02385	0.02442	0.02500	0.02559	0.02619	0.02680	0.02743	0.02807	0.02872
-1.8	0.02938	0.03005	0.03074	0.03144	0.03216	0.03288	0.03362	0.03438	0.03515	0.03593
-1.7	0.03673	0.03754	0.03836	0.03920	0.04006	0.04093	0.04182	0.04272	0.04363	0.04457
-1.6	0.04551	0.04648	0.04746	0.04846	0.04947	0.05050	0.05155	0.05262	0.05370	0.05480
-1.5	0.05592	0.05705	0.05821	0.05938	0.06057	0.06178	0.06301	0.06426	0.06552	0.06681
-1.4	0.06811	0.06944	0.07078	0.07215	0.07353	0.07493	0.07636	0.07780	0.07927	0.08076
-1.3	0.08226	0.08379	0.08534	0.08692	0.08851	0.09012	0.09176	0.09342	0.09510	0.09680
-1.2	0.09853	0.10027	0.10204	0.10383	0.10565	0.10749	0.10935	0.11123	0.11314	0.11507
-1.1	0.11702	0.11900	0.12100	0.12302	0.12507	0.12714	0.12924	0.13136	0.13350	0.13567
-1.0	0.13786	0.14007	0.14231	0.14457	0.14686	0.14917	0.15151	0.15386	0.15625	0.15866
-0.9	0.16109	0.16354	0.16602	0.16853	0.17106	0.17361	0.17619	0.17879	0.18141	0.18406
-0.8	0.18673	0.18943	0.19215	0.19489	0.19766	0.20045	0.20327	0.20611	0.20897	0.21186
-0.7	0.21476	0.21770	0.22065	0.22363	0.22663	0.22965	0.23270	0.23576	0.23885	0.24196
-0.6	0.24510	0.24825	0.25143	0.25463	0.25785	0.26109	0.26435	0.26763	0.27093	0.27425
-0.5	0.27760	0.28096	0.28434	0.28774	0.29116	0.29460	0.29806	0.30153	0.30503	0.30854
-0.4	0.31207	0.31561	0.31918	0.32276	0.32636	0.32997	0.33360	0.33724	0.34090	0.34458
-0.3	0.34827	0.35197	0.35569	0.35942	0.36317	0.36693	0.37070	0.37448	0.37828	0.38209
-0.2	0.38591	0.38974	0.39358	0.39743	0.40129	0.40517	0.40905	0.41294	0.41683	0.42074

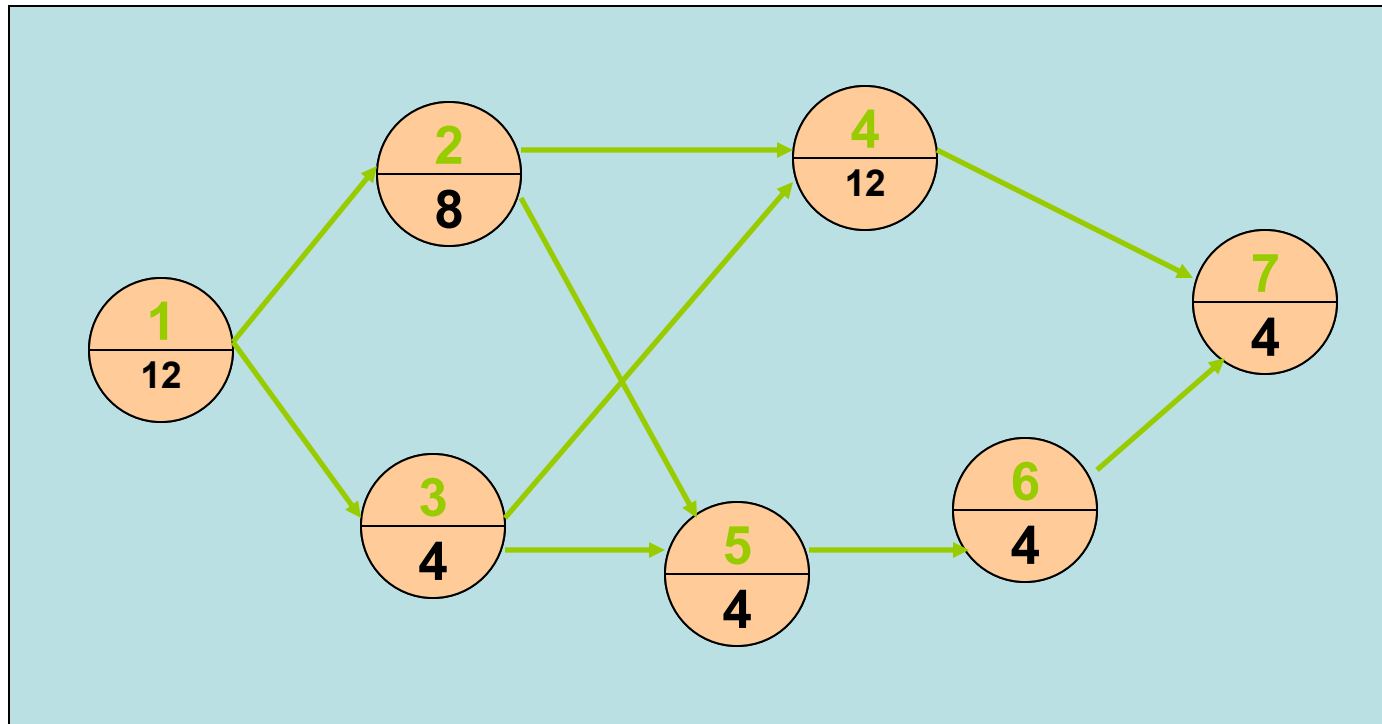
Limitations of PERT/CPM

- PERT/CPM assumes clearly defined, independent activities
- Specified precedence relationships
- Activity times (PERT) follow beta distribution
- Subjective time estimates
- Over-emphasis on critical path

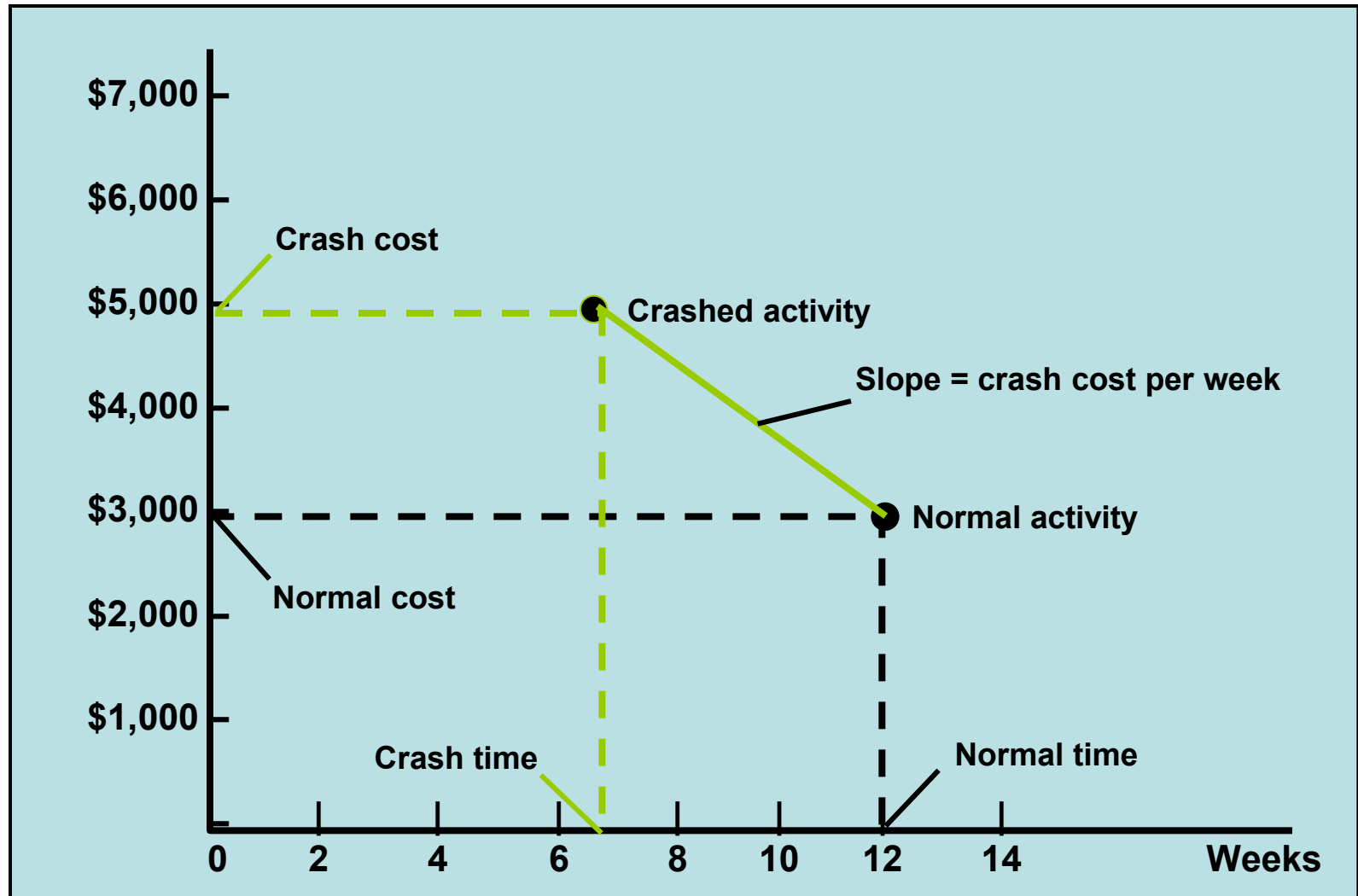
Project Crashing

- Crashing
 - reducing project time by expending additional resources
- Crash time
 - an amount of time an activity is reduced
- Crash cost
 - cost of reducing activity time
- Goal
 - reduce project duration at minimum cost

Project Crashing: Example

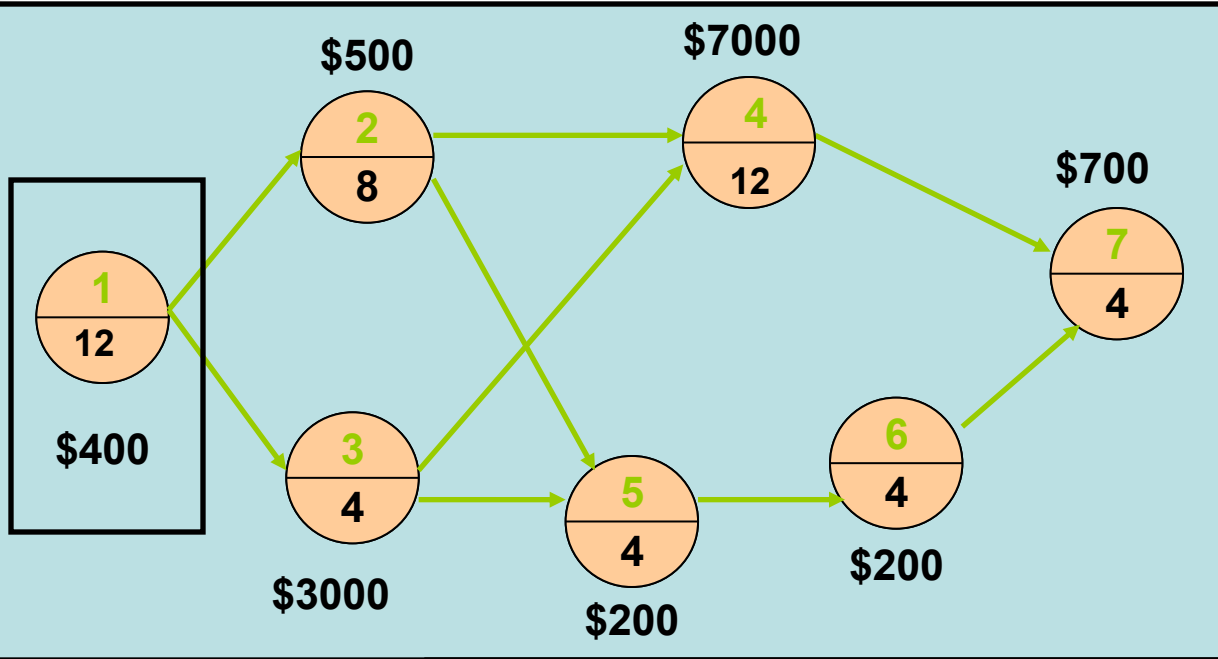


Project Crashing: Example



Normal Activity and Crash Data

ACTIVITY	NORMAL TIME (WEEKS)	CRASH TIME (WEEKS)	NORMAL COST	CRASH COST	TOTAL ALLOWABLE CRASH TIME (WEEKS)	CRASH COST PER WEEK
1	12	7	\$3,000	\$5,000	5	\$400
2	8	5	2,000	3,500	3	500
3	4	3	4,000	7,000	1	3,000
4	12	9	50,000	71,000	3	7,000
5	4	1	500	1,100	3	200
6	4	1	500	1,100	3	200
7	4	3	15,000	22,000	1	7,000
			<u>\$75,000</u>	<u>\$110,700</u>		

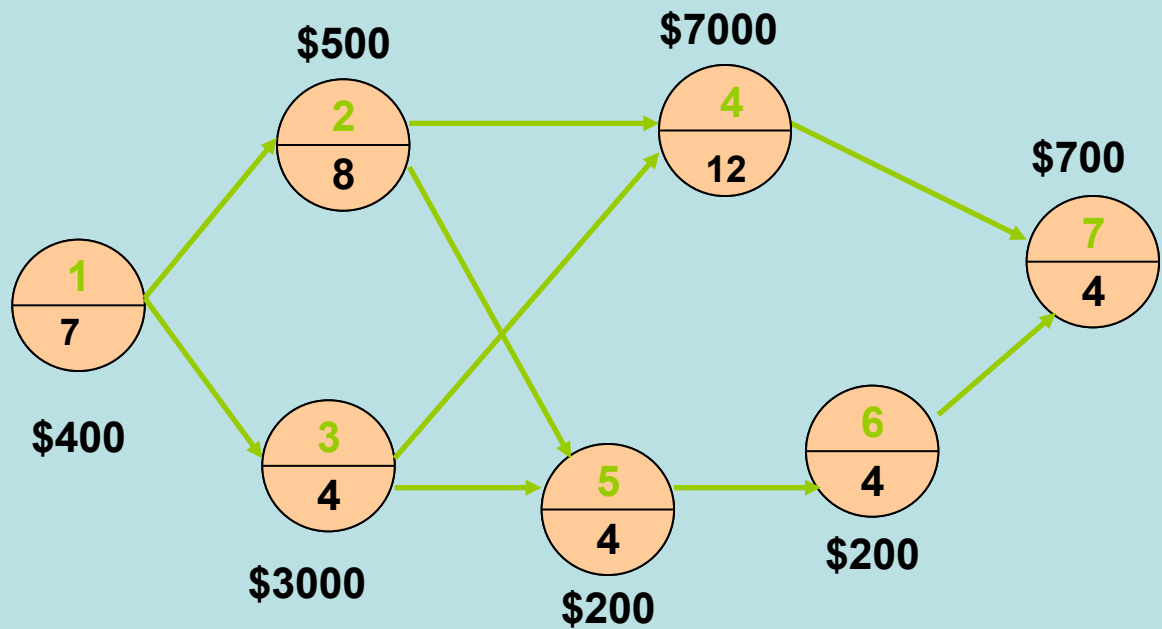


Project Duration:
36 weeks

FROM ...

TO...

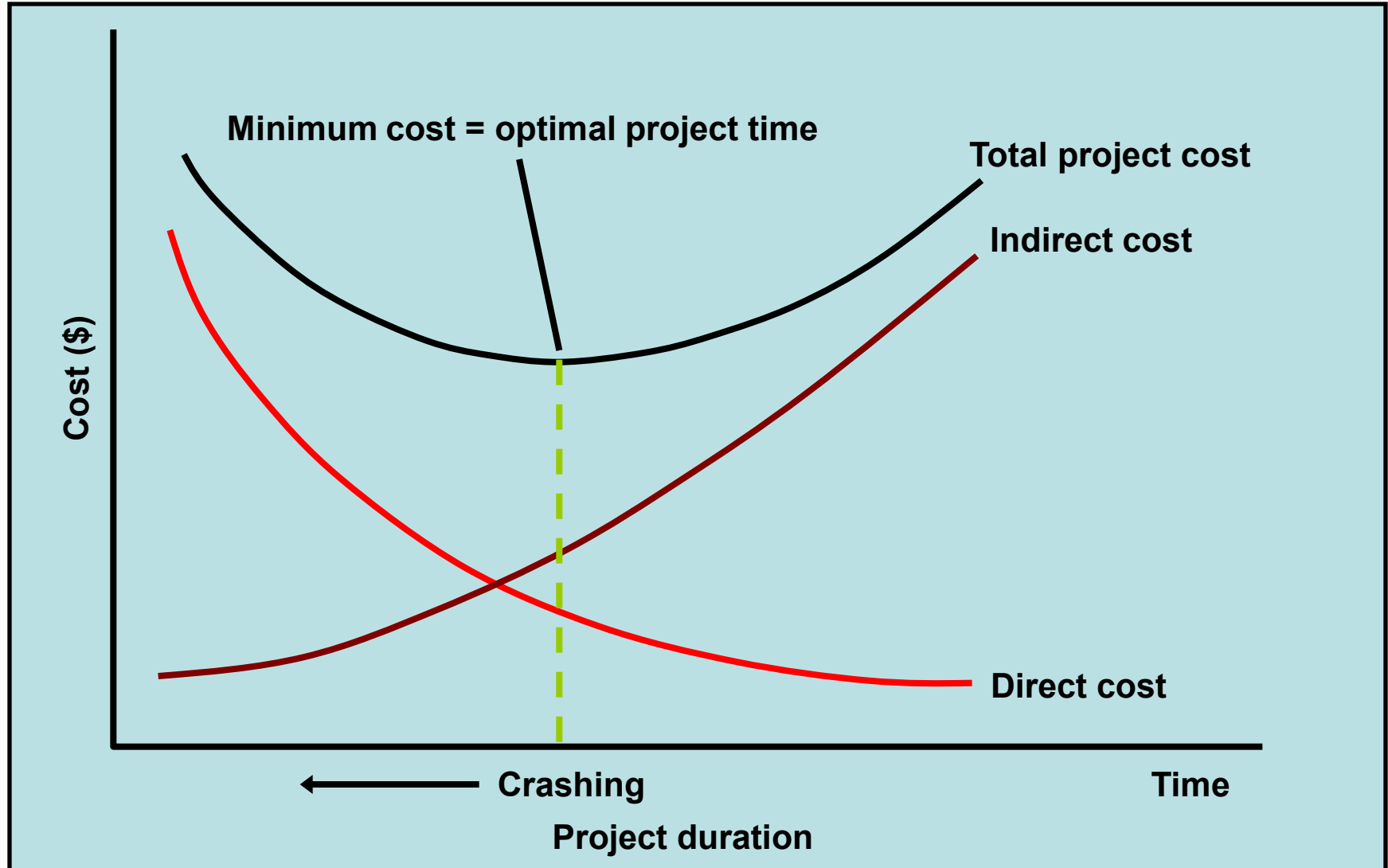
Project Duration:
31 weeks
Additional Cost:
\$2000



Time-Cost Relationship

- Crashing costs increase as project duration decreases
- Indirect costs increase as project duration increases
- Reduce project length as long as crashing costs are less than indirect costs

Time-Cost Tradeoff



References

- Hughes, B., and Cotterell, M. (1999) *Software Project Management*, 2nd edition, McGraw-Hill. (slides)
- Pfleeger, S.L. (1998) *Software Engineering: Theory and Practice*, Prentice Hall.
- Roberta Russell & Bernard W. Taylor, III (2006) *Operations Management - 5th Edition*, John Wiley & Sons (slides)
- http://miha.ef.uni-lj.si/_dokumenti3plus2/195166/norm-tables.pdf

Copyright 2006 John Wiley & Sons, Inc.

All rights reserved. Reproduction or translation of this work beyond that permitted in section 117 of the 1976 United States Copyright Act without express permission of the copyright owner is unlawful. Request for further information should be addressed to the Permission Department, John Wiley & Sons, Inc. The purchaser may make back-up copies for his/her own use only and not for distribution or resale. The Publisher assumes no responsibility for errors, omissions, or damages caused by the use of these programs or from the use of the information herein.