CISC 322

Software Architecture

Project Scheduling (PERT/CPM)

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Project

- A project is
  - a temporary endeavour 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 plan

- A project plan is a schedule of activities indicating
  - The start and stop for each activity. The start and stop of each activity should be visible and easy to measure
  - When a resource is required
  - Amount of required project resources

Project Planning

- Managers should consider:
  - Resource availability
  - Resource allocation
  - Staff responsibility
  - Cash flow forecasting
- Mangers need to monitor and re-plan as the project progresses towards its pre-defined goal

Work Breakdown Structure (WBS)

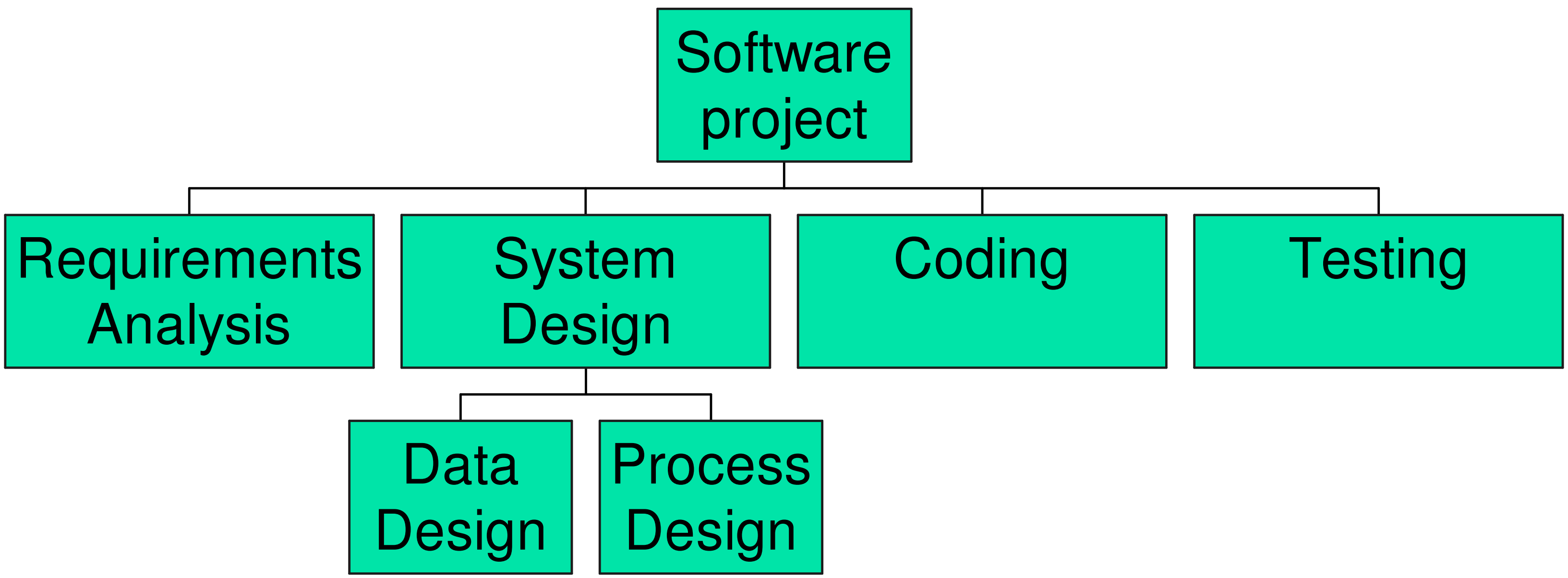
- Contains a list of activities for a project derived from
  - Previous experience
  - Expert brainstorming
- WBS helps in
  - identifying the main activities
  - break each main activity down into sub-activities which can further be broken down into lower level sub-activities
- WBS problems:
  - Too many levels
  - Too few levels

Creating WBS

- Phase based approach
- Product based approach
- Hybrid approach

Example of Phase-based Approach

Work Breakdown Structure (an extract)



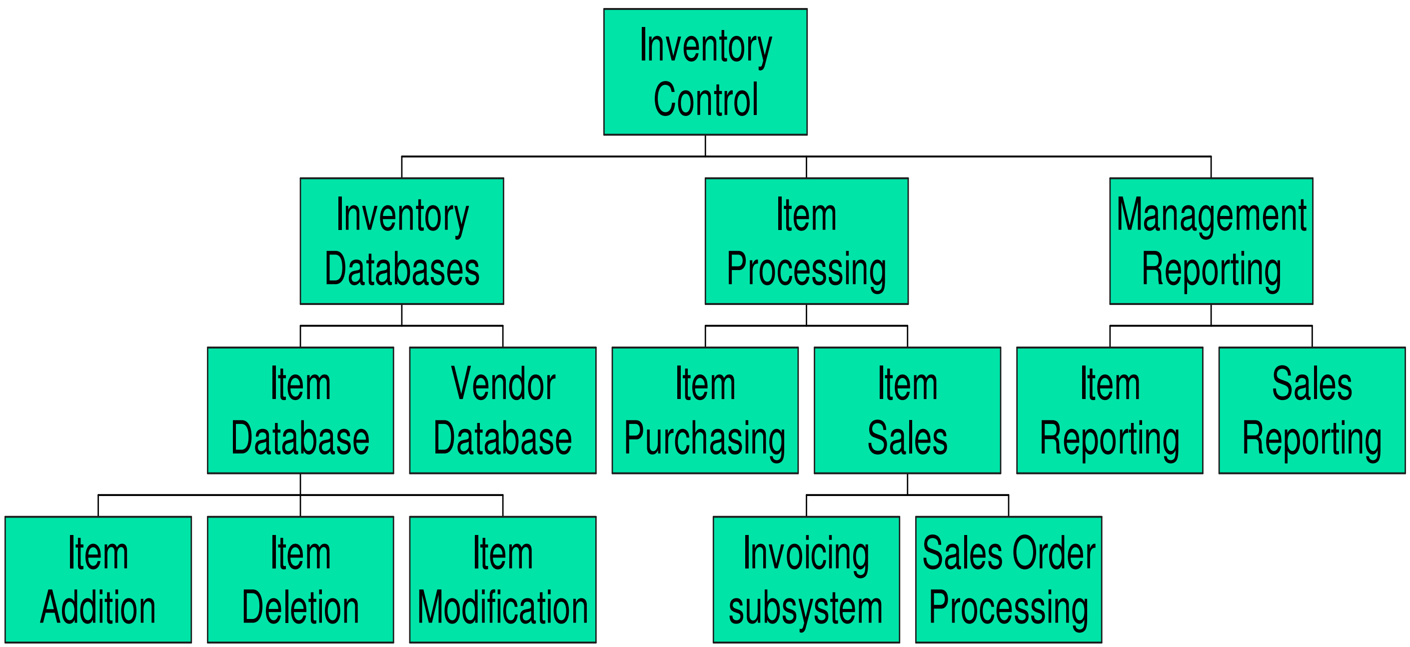
Phase-based Approach

- 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

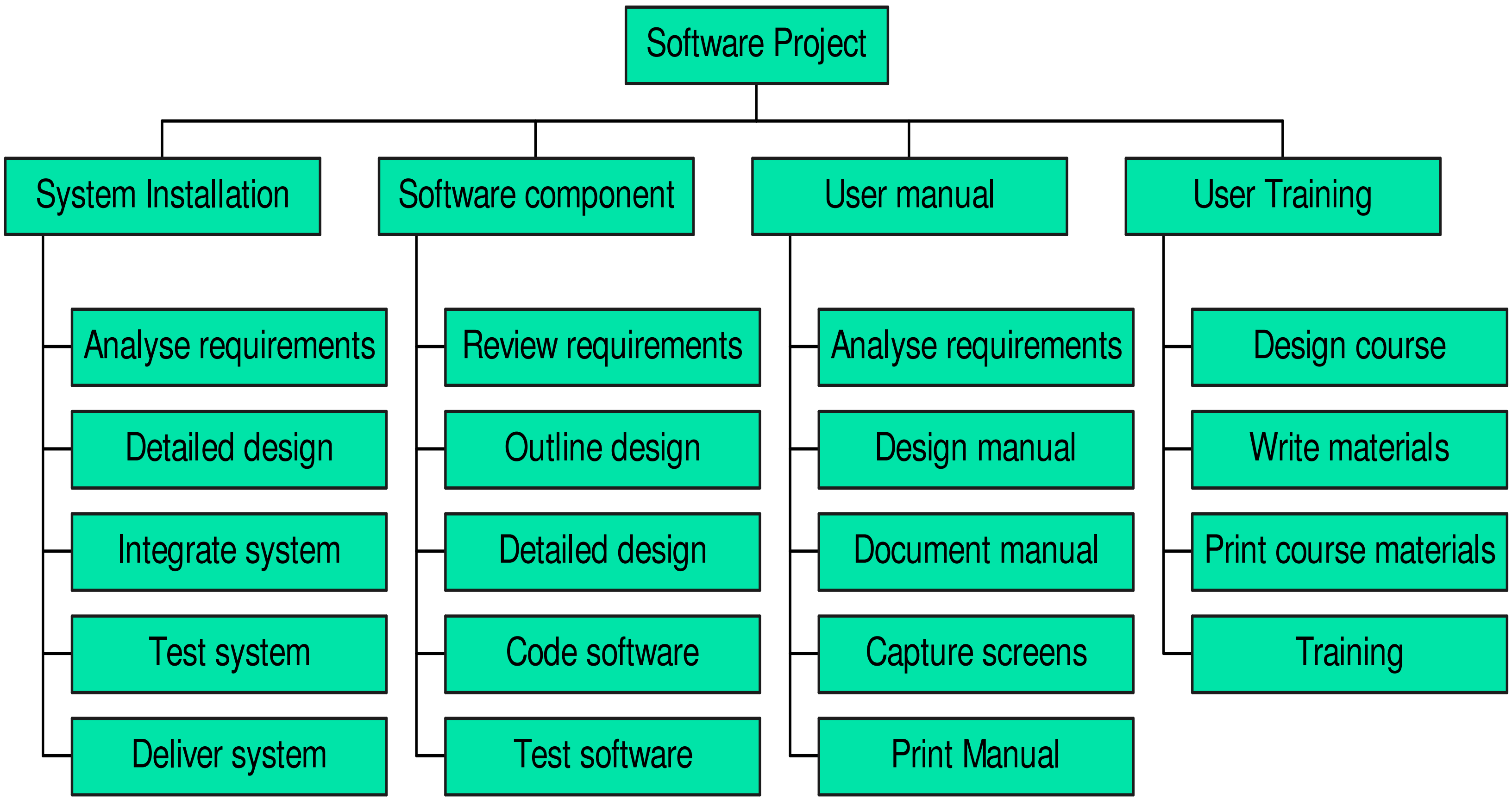
A Product Breakdown Structure (an extract)



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


Software Project
System Installation
Software component
User manual
User Training
Analyse requirements
Detailed design
Integrate system
Test system
Deliver system
Review requirements
Outline design
Detailed design
Code software
Test software
Analyse requirements
Design manual
Document manual
Capture screens
Print Manual
Design course
Write materials
Print course materials
Training

IBM MITP (Managing the Implementation of Total Project)

- IBM MITP is 5 levels:
  - Level 1: Project
  - Level 2: Deliverables (software, manuals etc)
  - Level 3: Components: key work items that lead to the production of the deliverables
  - Level 4: Work-packages: major work items or collection of related activities to produce a component (phases)
  - Level 5: Tasks/activities (individual responsibility)

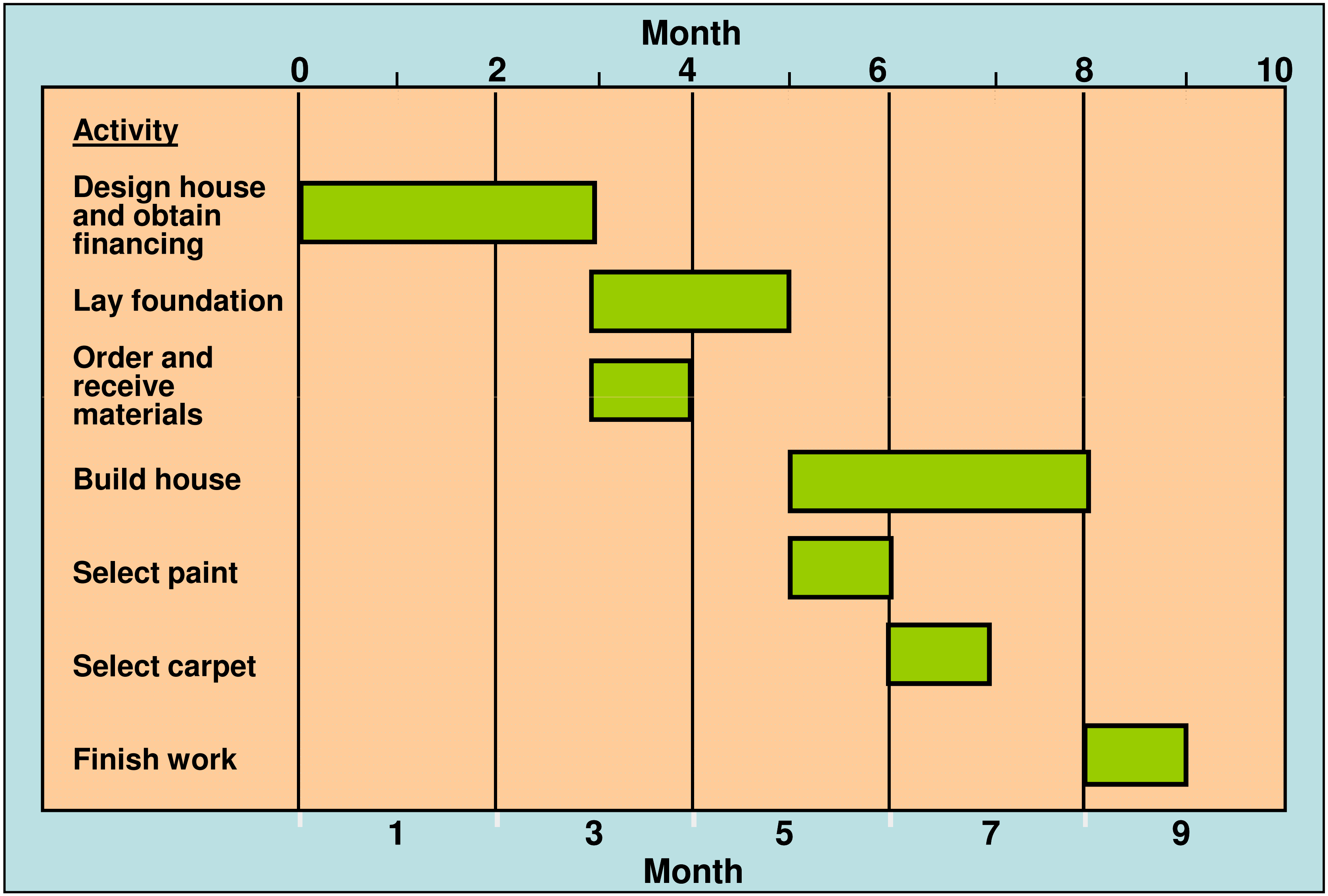
Project Scheduling

- **Steps**
  - Define activities
  - Sequence activities
  - Estimate time
  - Develop schedule
- **Techniques**
  - Gantt chart
  - CPM
  - PERT
  - Microsoft Project

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



PERT/CPM

- **PERT (Program Evaluation and Review Technique)**
  - Developed by U.S. Navy for Polaris missile project
  - Developed for R&D projects where activity times are generally uncertain
- **CPM (Critical Path Method)**
  - Developed by DuPont & Remington Rand
  - Developed for industrial projects where activity times are generally known

PERT/CPM

- CPM and PERT have been used to plan, schedule, and control a wide variety of projects:
  - R&D of new products and processes
  - Construction of buildings and highways
  - Maintenance of large and complex equipment
  - Design and installation of new systems

Program Evaluation and Review Technique (PERT)

- Primary objectives:
  - Shortest possible time
  - Coping with uncertain activity completion times, e.g.:
    - For a particular activity
    - 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

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

CPM Calculation

- 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

Critical Path and Events

- Critical event: an event that has zero *slack*
- Critical path: a path joining those critical events
- Benefit of Critical Path Analysis:
  - During planning stage
    - Shortening the critical path will reduce the overall project duration
  - During management stage
    - Pay more attention to those activities which fall in the critical path

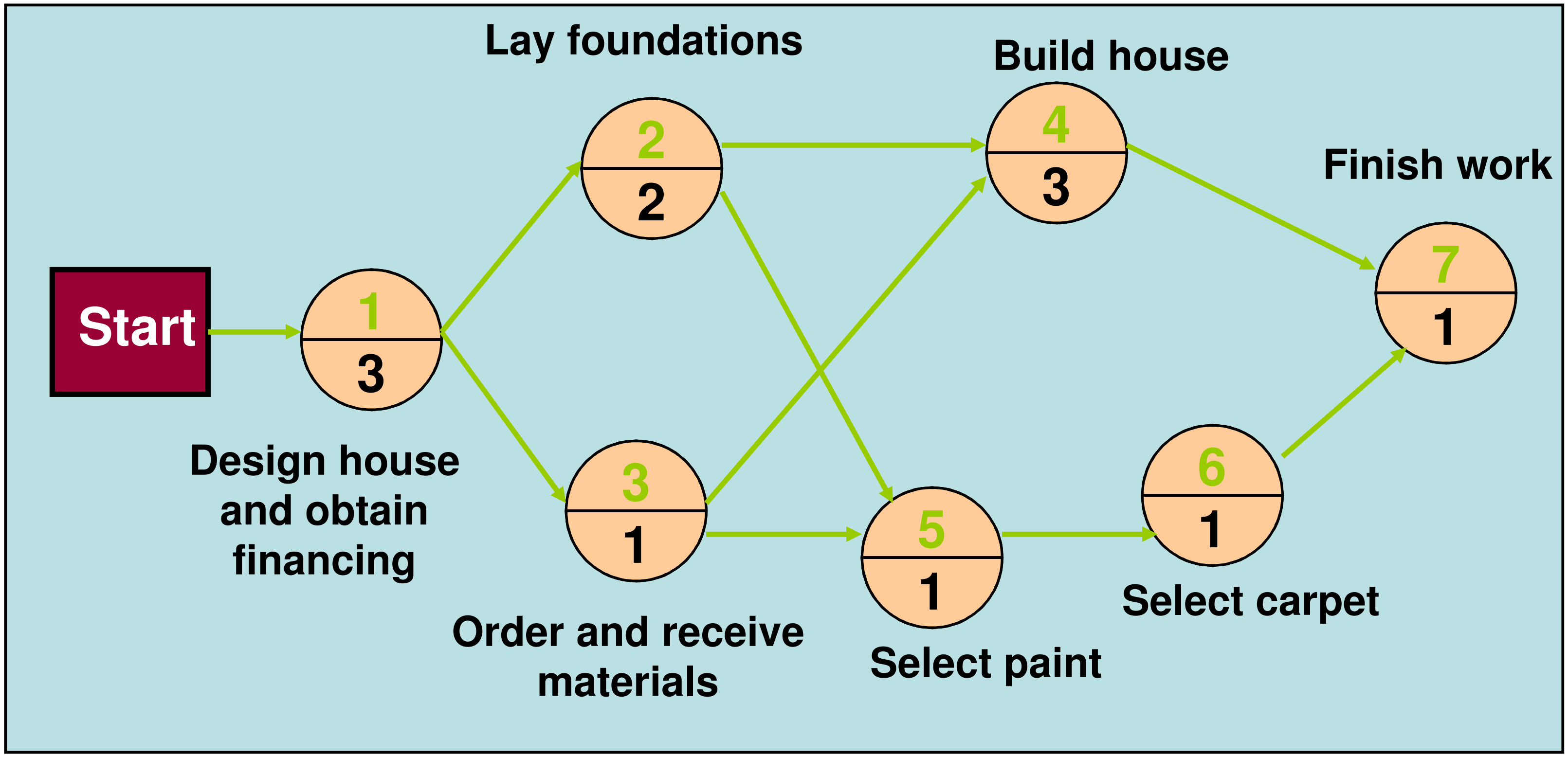
Activity Float

- Time allowed for an activity to delay
- 3 different types:
  - **Total float** (without affecting project completion)

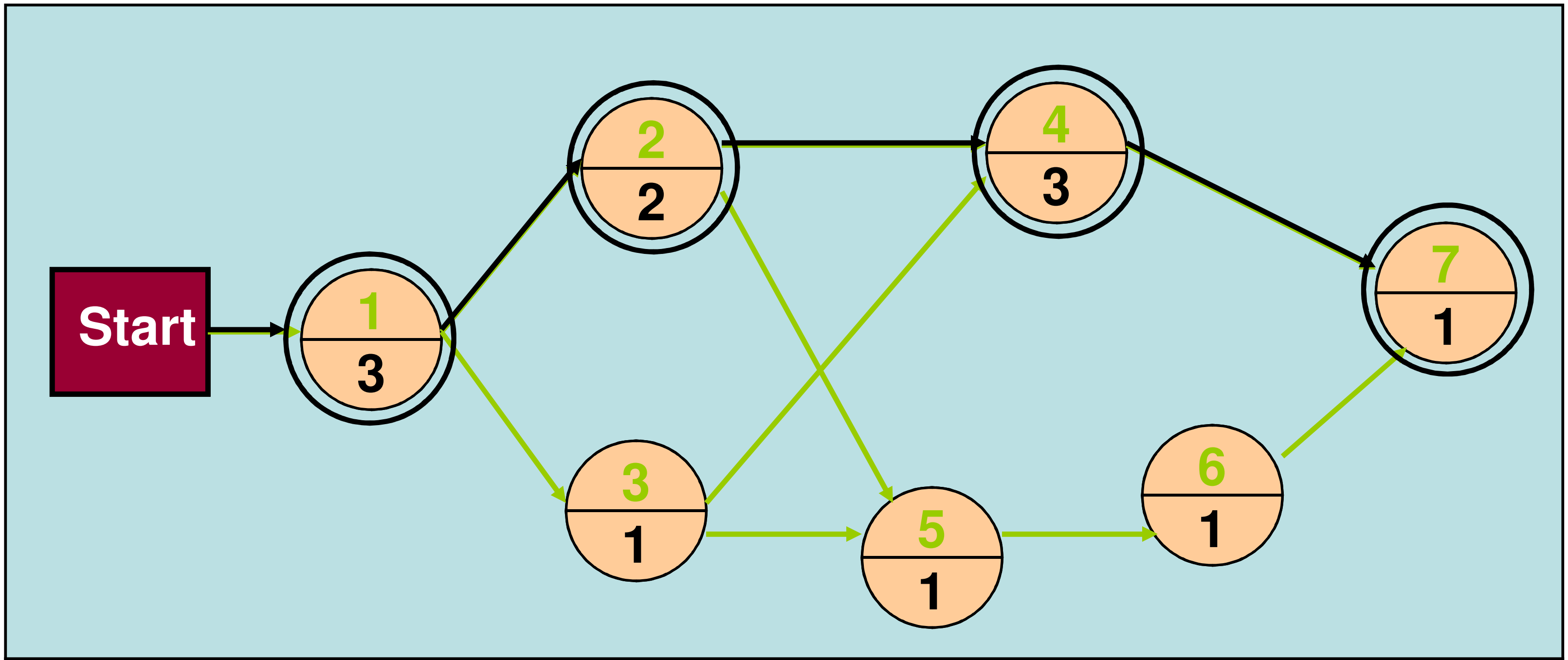
    = latest start date – earliest start date
  - **Free float** (without affecting the next activity)

    = 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 Pah



A: $\boxed{\begin{array}{l}\text{1-2-4-7} \\ 3 + 2 + 3 + 1 = 9 \text{ months}\end{array}}$

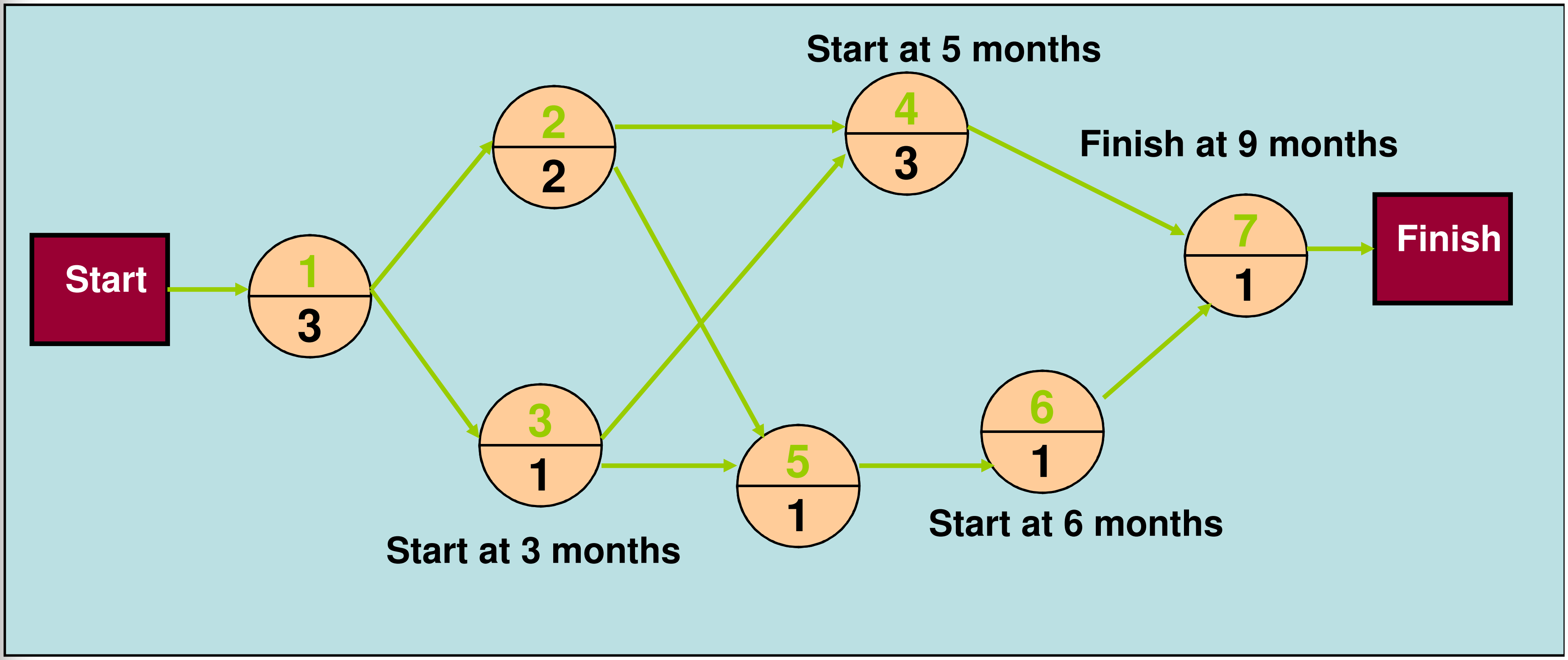
B: 1-2-5-6-7
3 + 2 + 1 + 1 + 1 = 8 months

C: 1-3-4-7
3 + 1 + 3 + 1 = 8 months

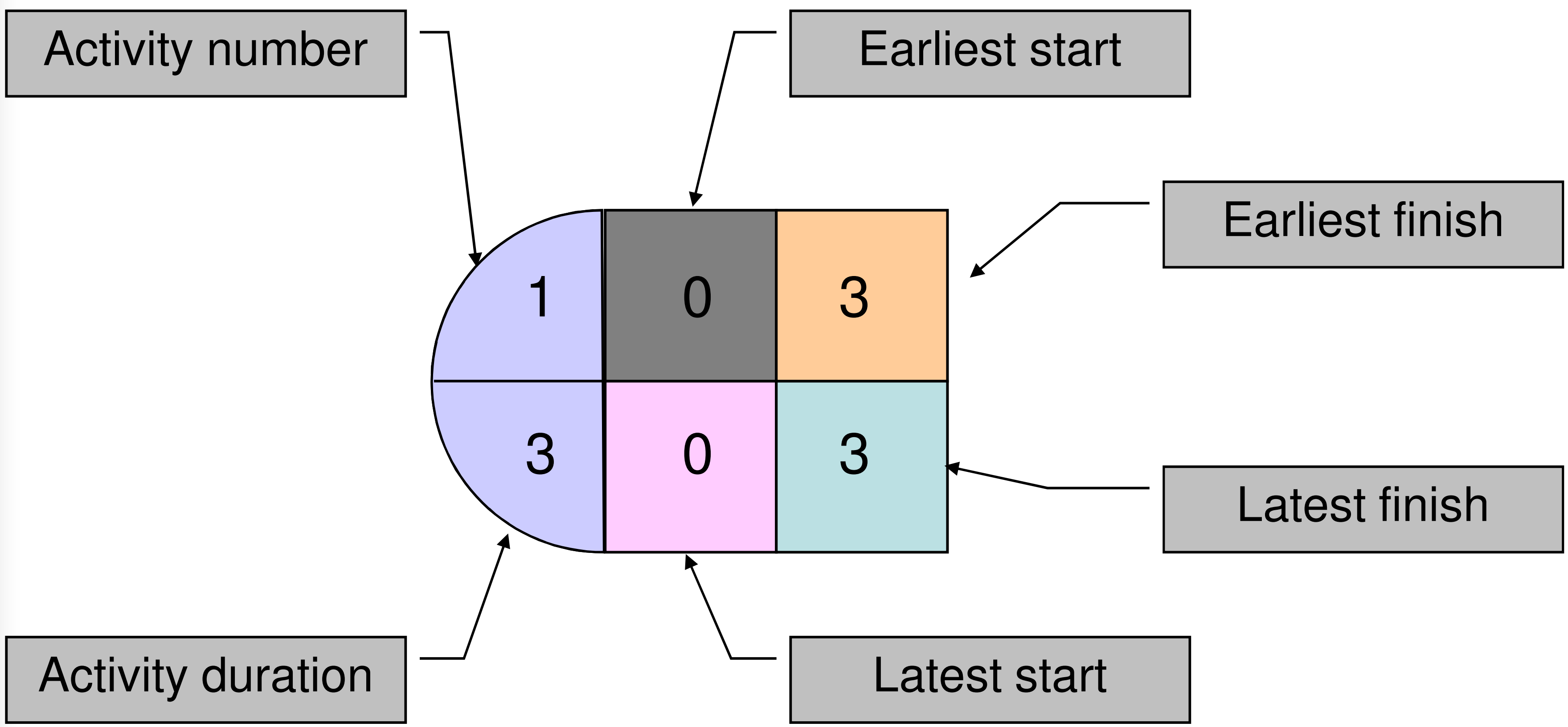
D: 1-3-5-6-7
3 + 1 + 1 + 1 + 1 = 7 months

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

Activity Start Times



Mode Configuration

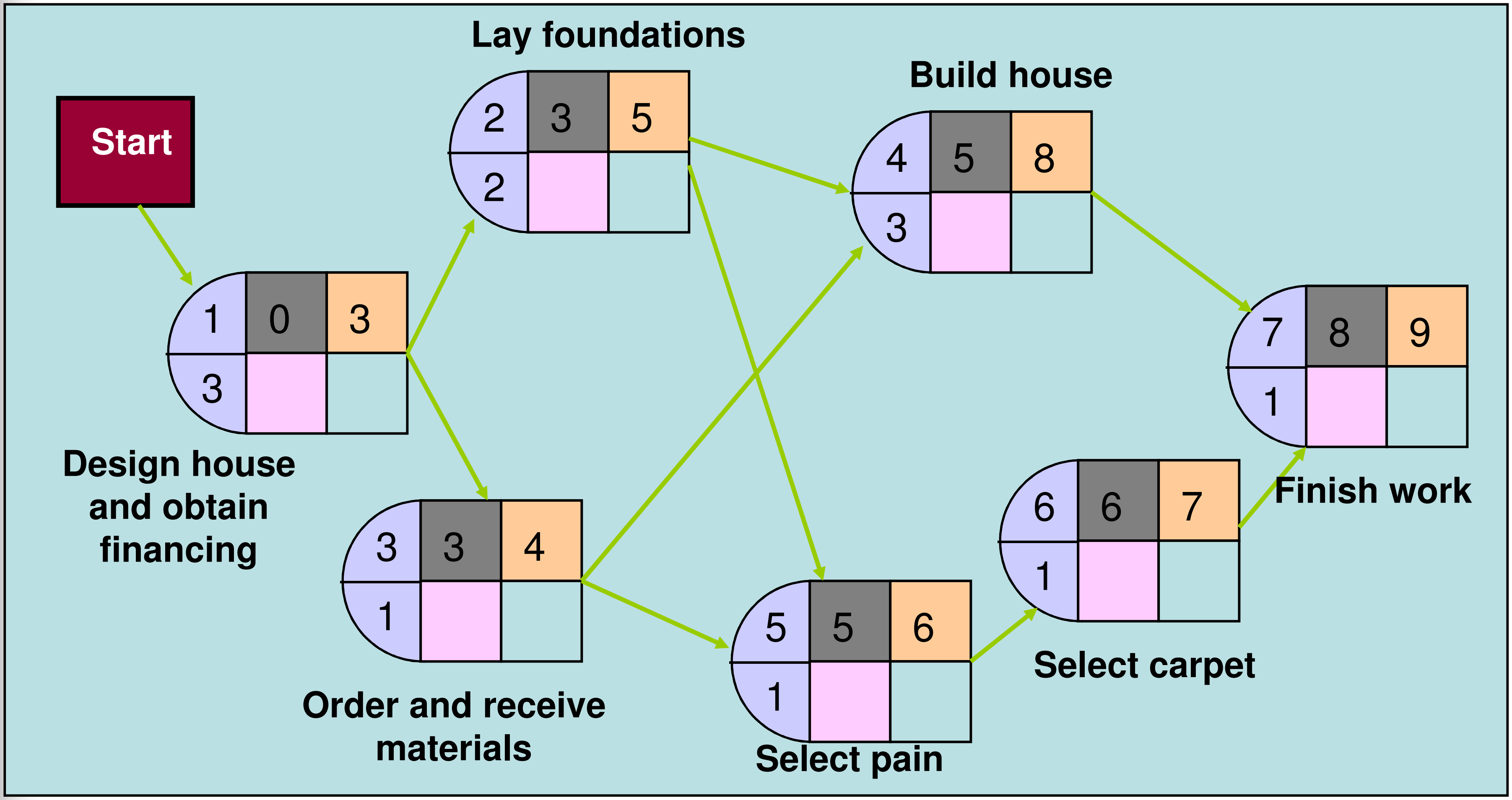


Forward Pass

- Start at the beginning of CPM/PERT network to determine the earliest activity times
- Earliest Start Time (ES)
  - earliest time an activity can start
  - ES = maximum EF 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



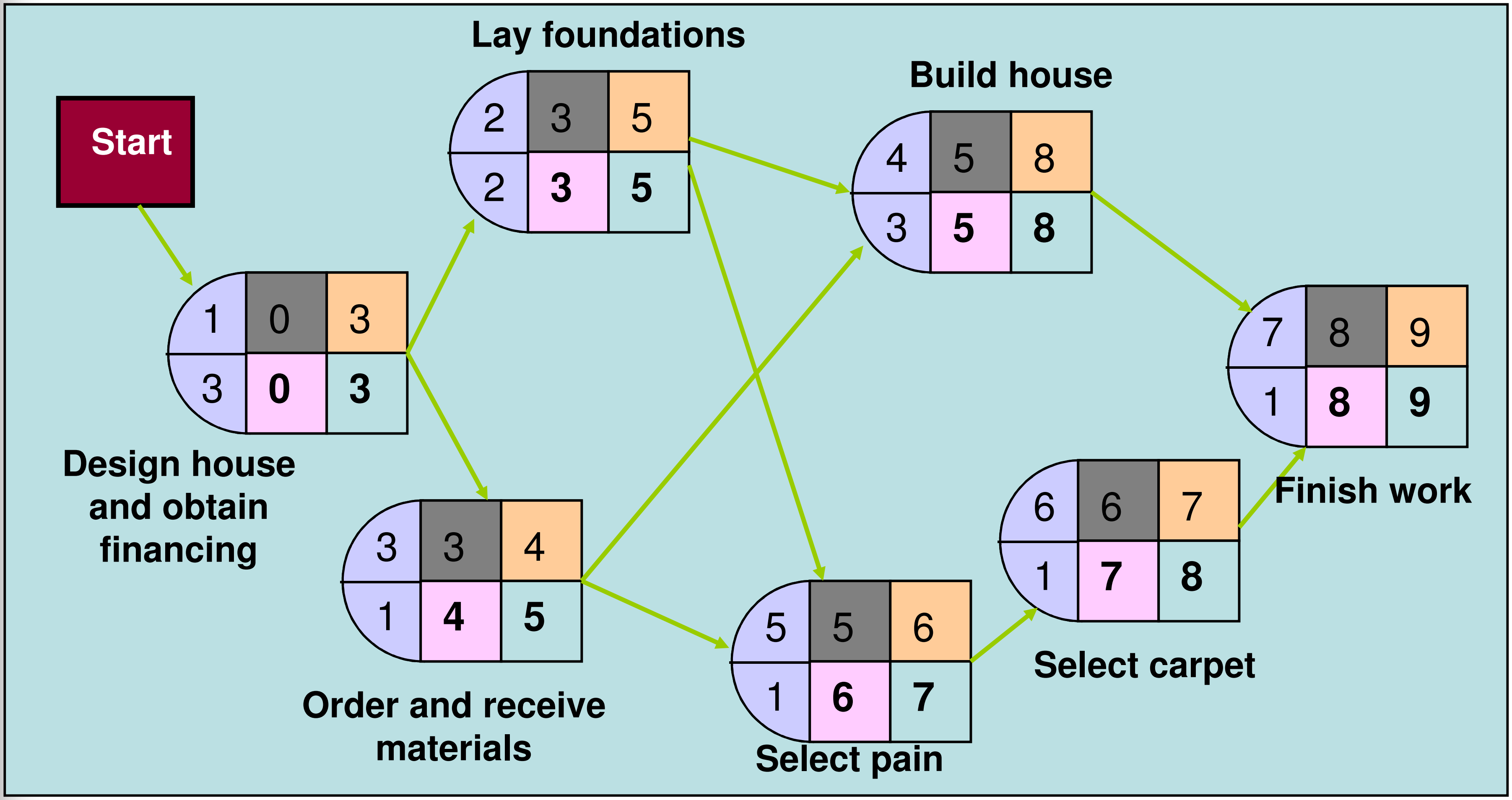
Backward Pass

- Determines latest activity times by starting at the end of CPM/PERT network and working forward
- 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
  - LS = minimum LS of immediate predecessors

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

activity slack = *LS - ES = LF - EF*

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

Probabilistic Time Estimates

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

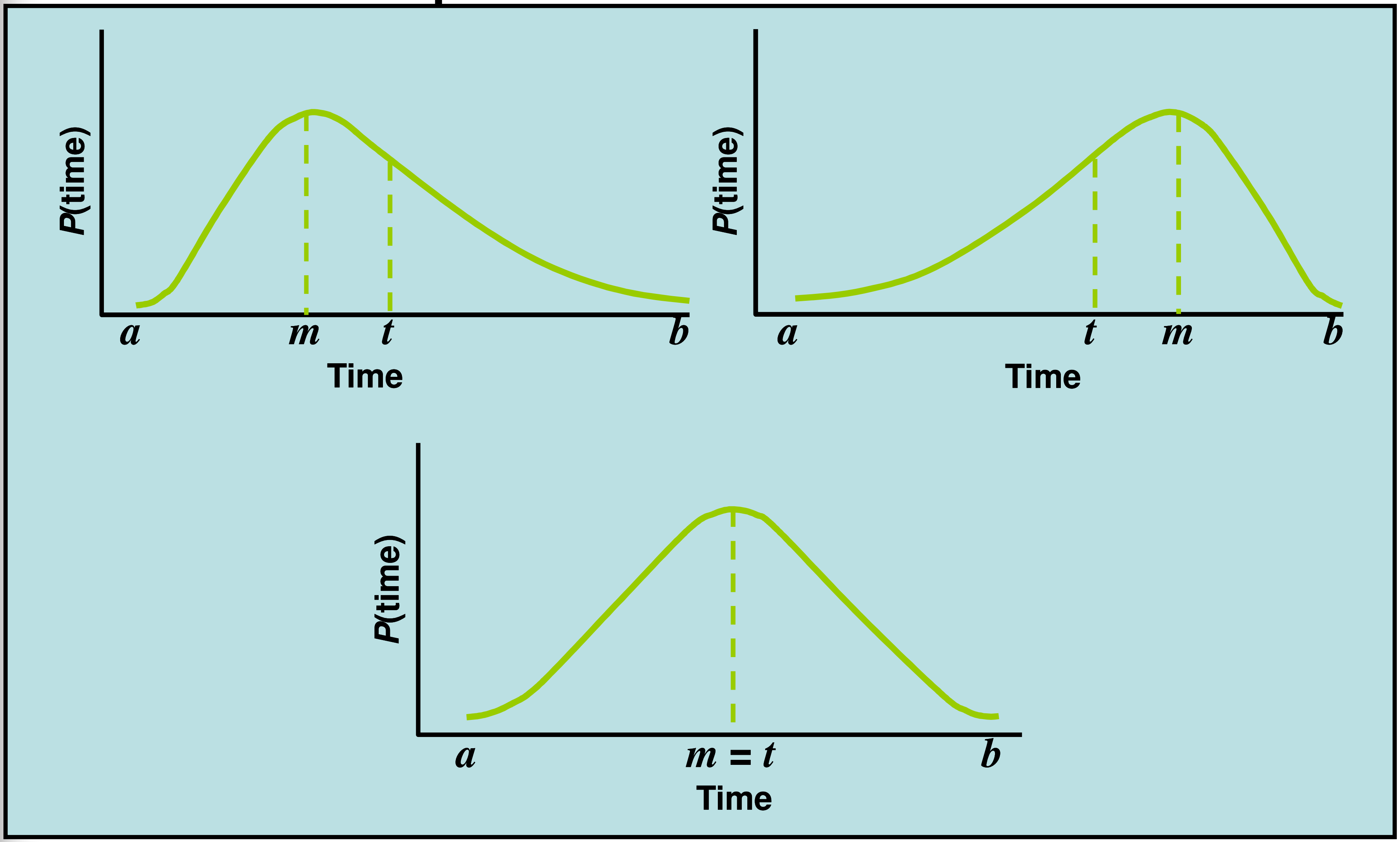
Mean (expected time): $$t = \frac{a + 4m + b}{6}$$

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

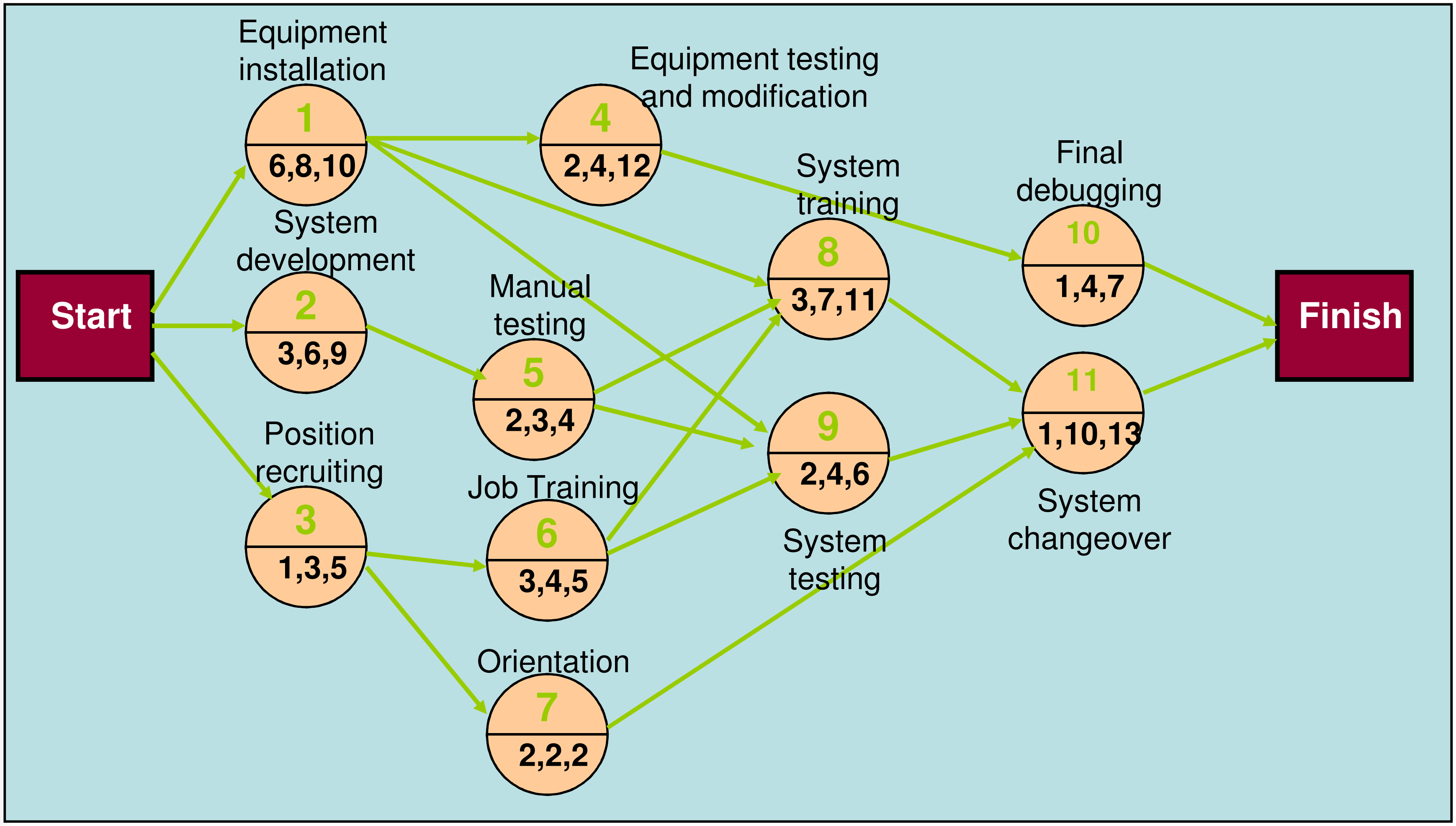
where

a = optimistic estimate
m = most likely time estimate
b = pessimistic time estimate

Examples of Beta Distributions



Project Network with Probabilistic Time Estimates: Example



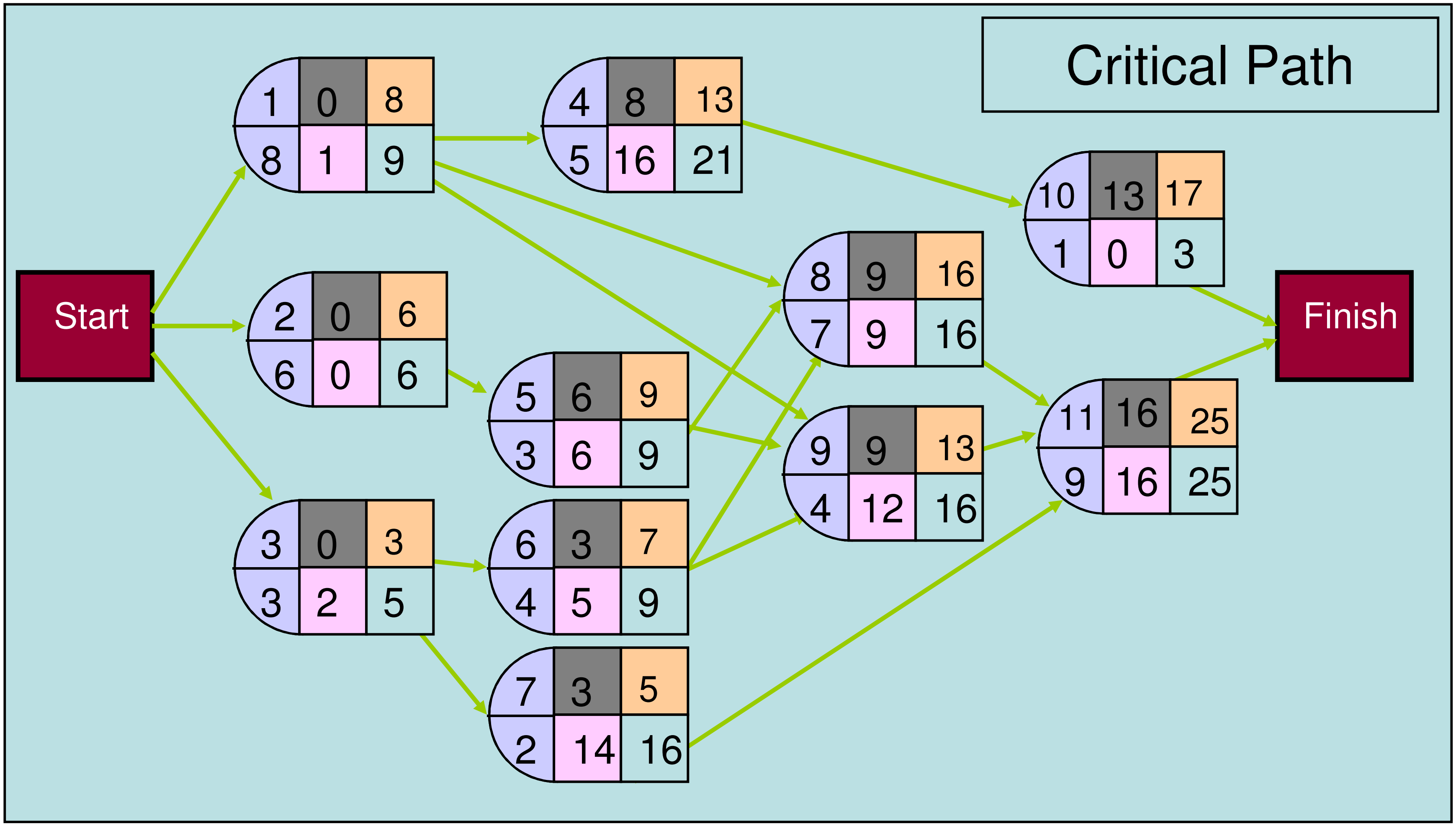
Activity Time Estimates

	TIME ESTIMATES (WKS)			MEAN TIME	VARIANCE
ACTIVITY	*a*	*m*	*b*	*t*	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

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

$\sigma = 1.00 + 0.11 + 1.78 + 4.00$

$= 6.89$ weeks

Probabilistic Network Analysis

Determine probability that project is completed within specified time

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

where

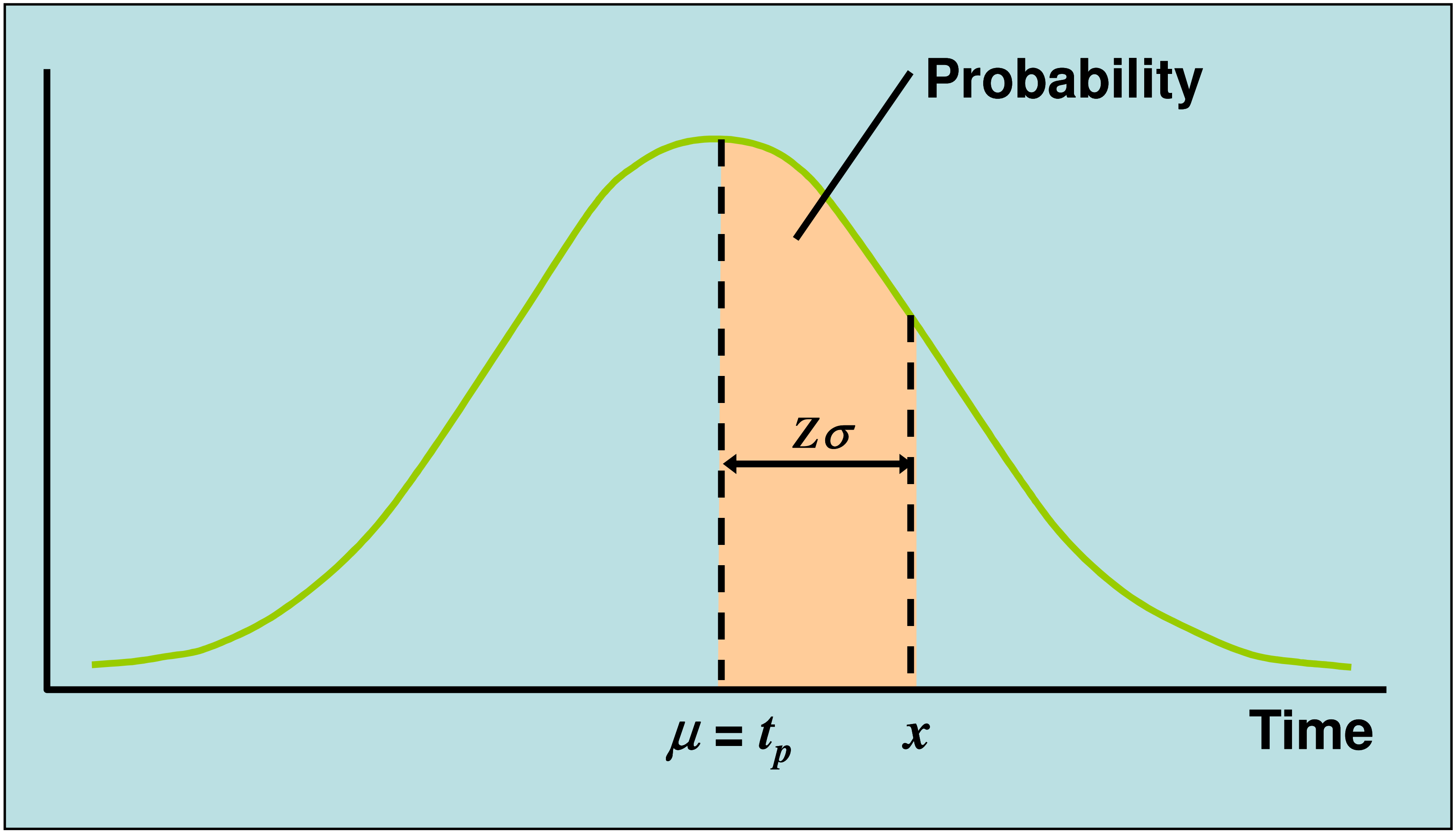
$\mu = t_p$ = ***project mean time***

σ = ***project standard deviation***

x = ***proposed project time***

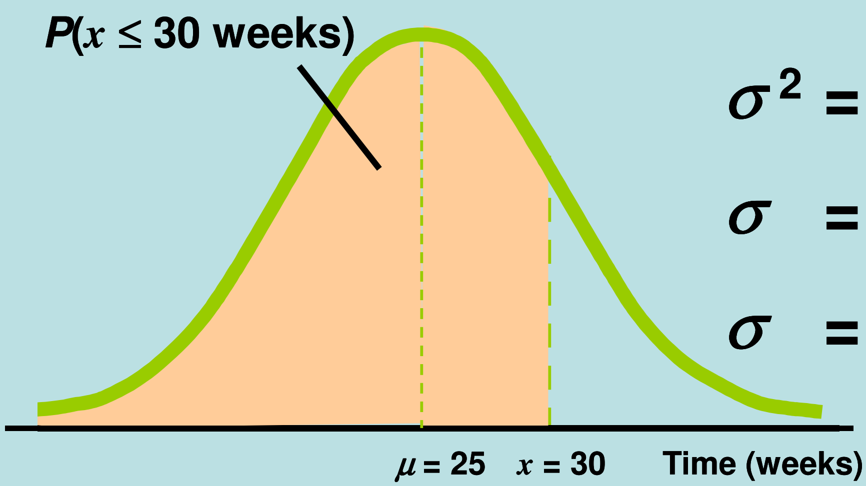
Z = ***number of standard deviations*** x ***is from mean***

Normal Distribution Of Project Time



Probability of Completion Time

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



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

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

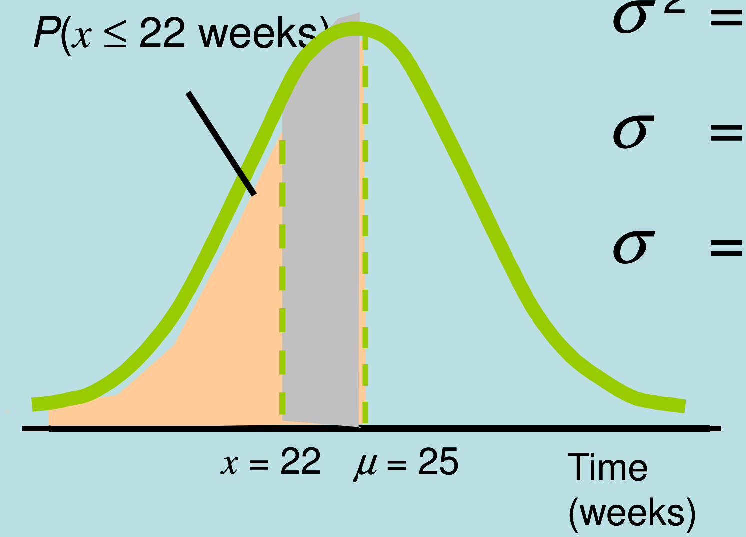
$$\sigma = 2.62 \text{ weeks}$$

$$Z = \frac{x - \mu}{\sigma} = \frac{30 - 25}{2.62} = 1.91$$

From Z scores Table, a Z score of 1.91 corresponds to a probability of 0.4719. Thus $P(30) = 0.4719 + 0.5000 = 0.9719$

Probability of Completion Time

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



$\sigma^2 = 6.89$ weeks

$\sigma = \sqrt{6.89}$

$\sigma = 2.62$ weeks

$$Z = \frac{x - \mu}{\sigma} = \frac{22 - 25}{2.62} = -1.14$$

From Z scores Table, a Z score of -1.14 corresponds to a probability of 0.3729. Thus $P(22) = 0.5000 - 0.3729 = 0.1271$

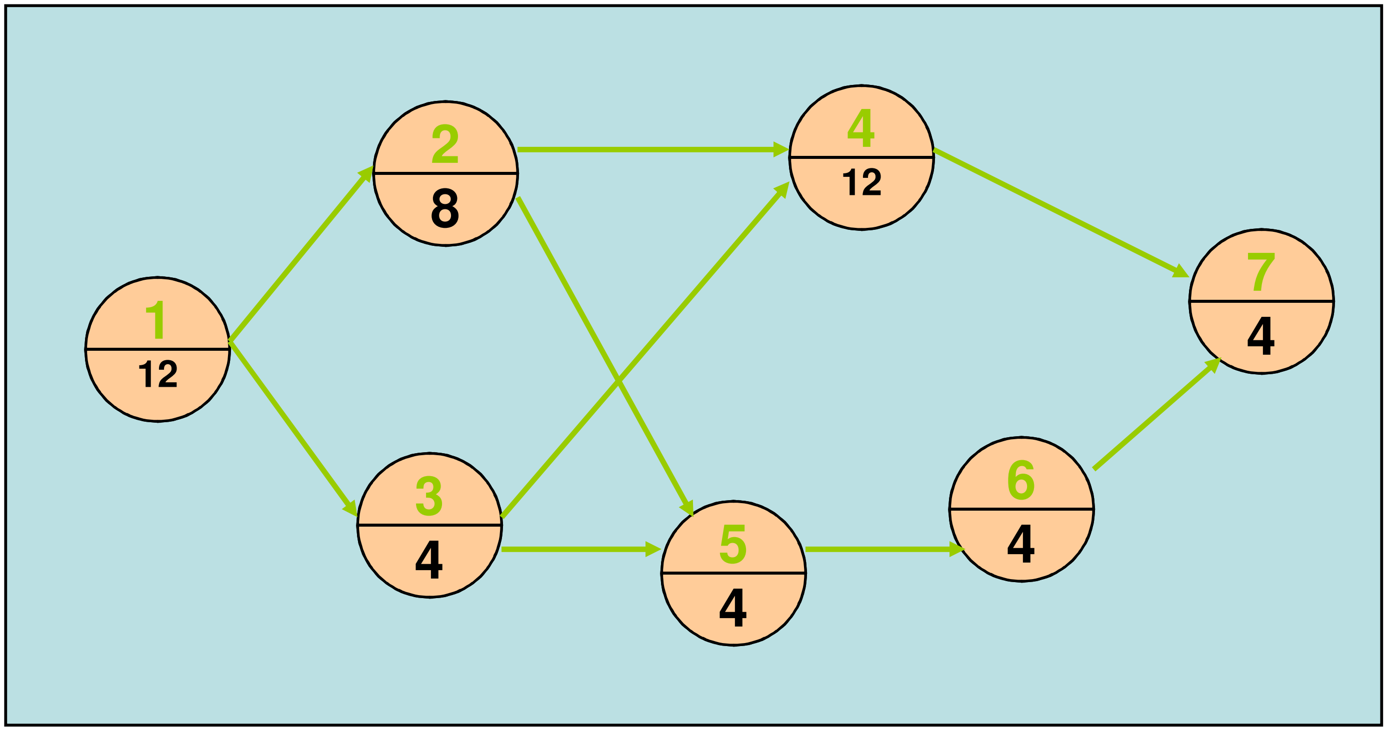
Limitations of PERT/CPM

- Assumes clearly defined, independent activities
- Specified precedence relationships
- Activity times (PERT) follow beta distribution
- Subjective time estimates
- Over-emphasis on critical path
  - Monte Carlo Simulations

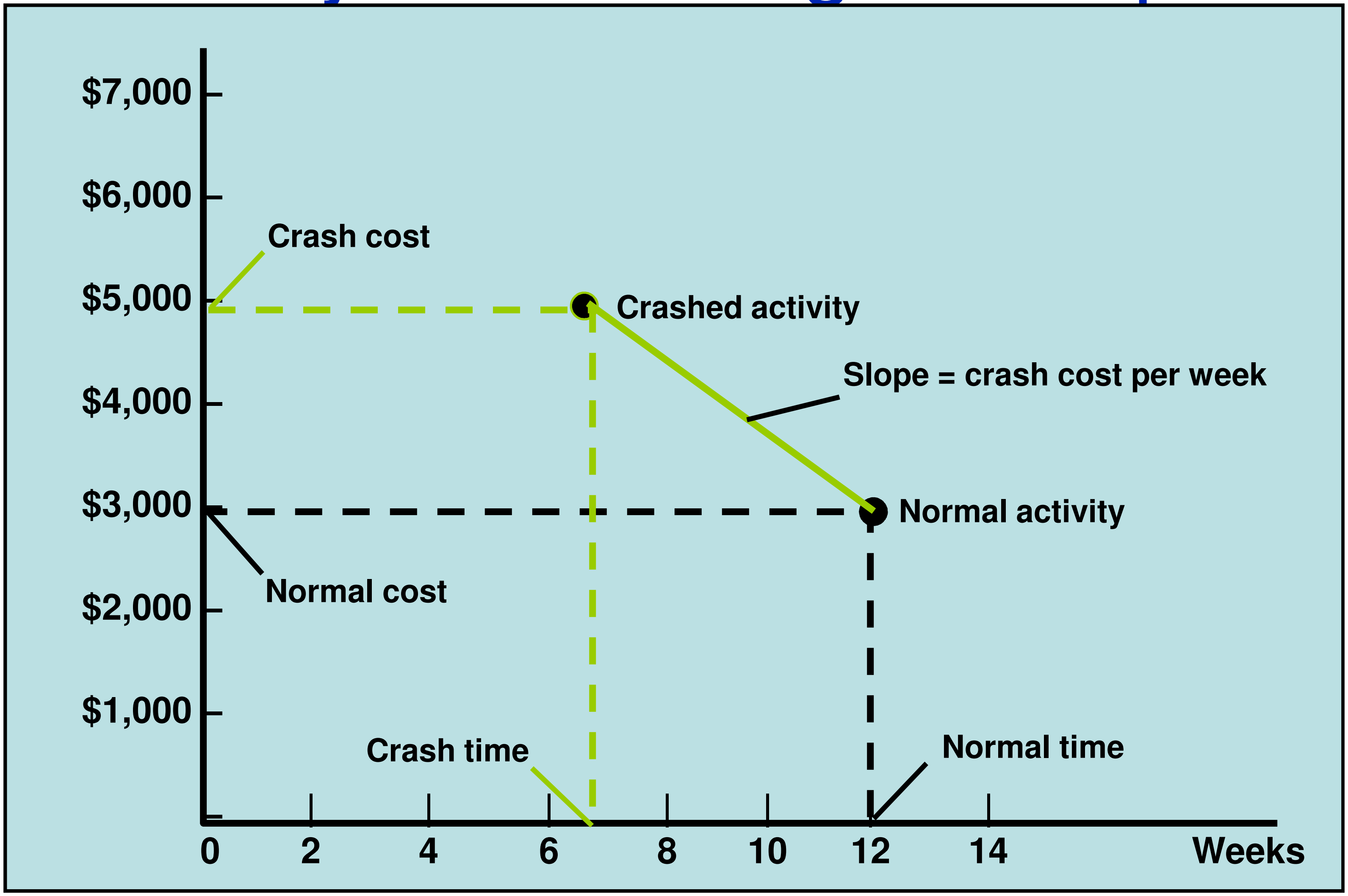
Project Crashing

- 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

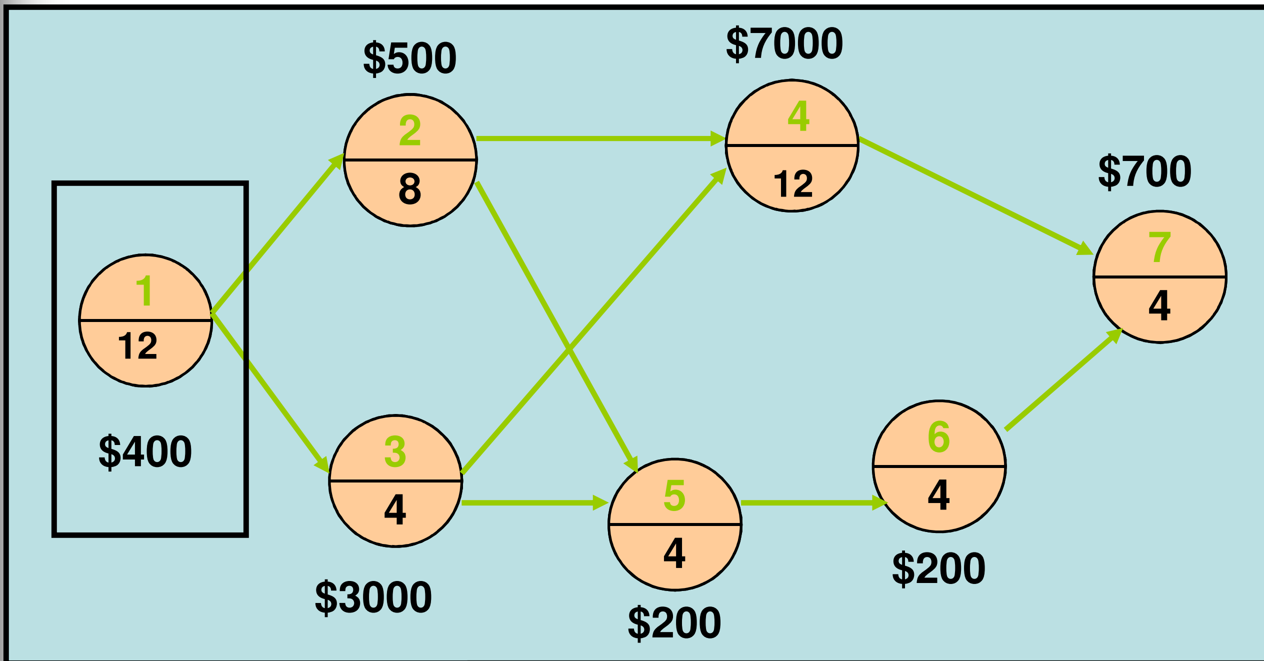


Normal Activity and Crash Data

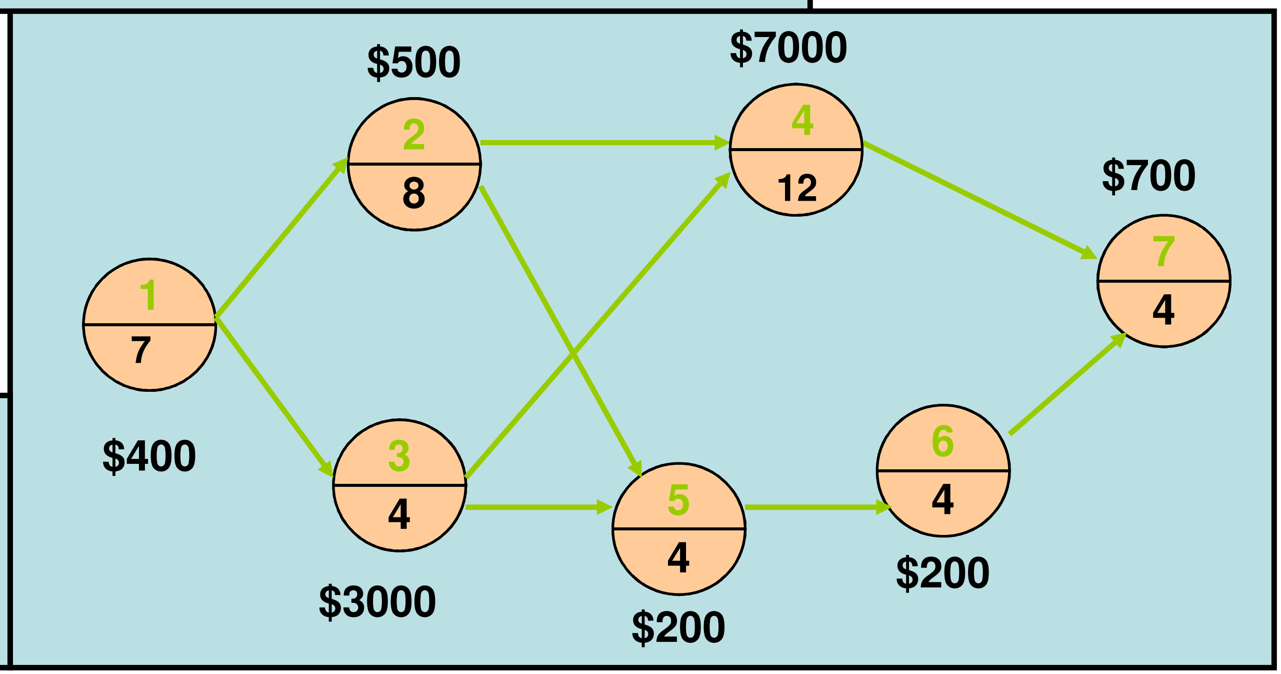
ACTIVITY	NORMAL TIME (WEEKS)	CRASH TIME (WEEKS)	NORMAL COST	CRASH COST	TOTAL ALLOWABLE CRASH TIME (WEEKS)	CRASH COST PER WEEK
1	12	7	$3,000	$5,000	5	$400
2	8	5	2,000	3,500	3	500
3	4	3	4,000	7,000	1	3,000
4	12	9	50,000	71,000	3	7,000
5	4	1	500	1,100	3	200
6	4	1	500	1,100	3	200
7	4	3	15,000	22,000	1	7,000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

Project Duration: 36 weeks

FROM …



TO…

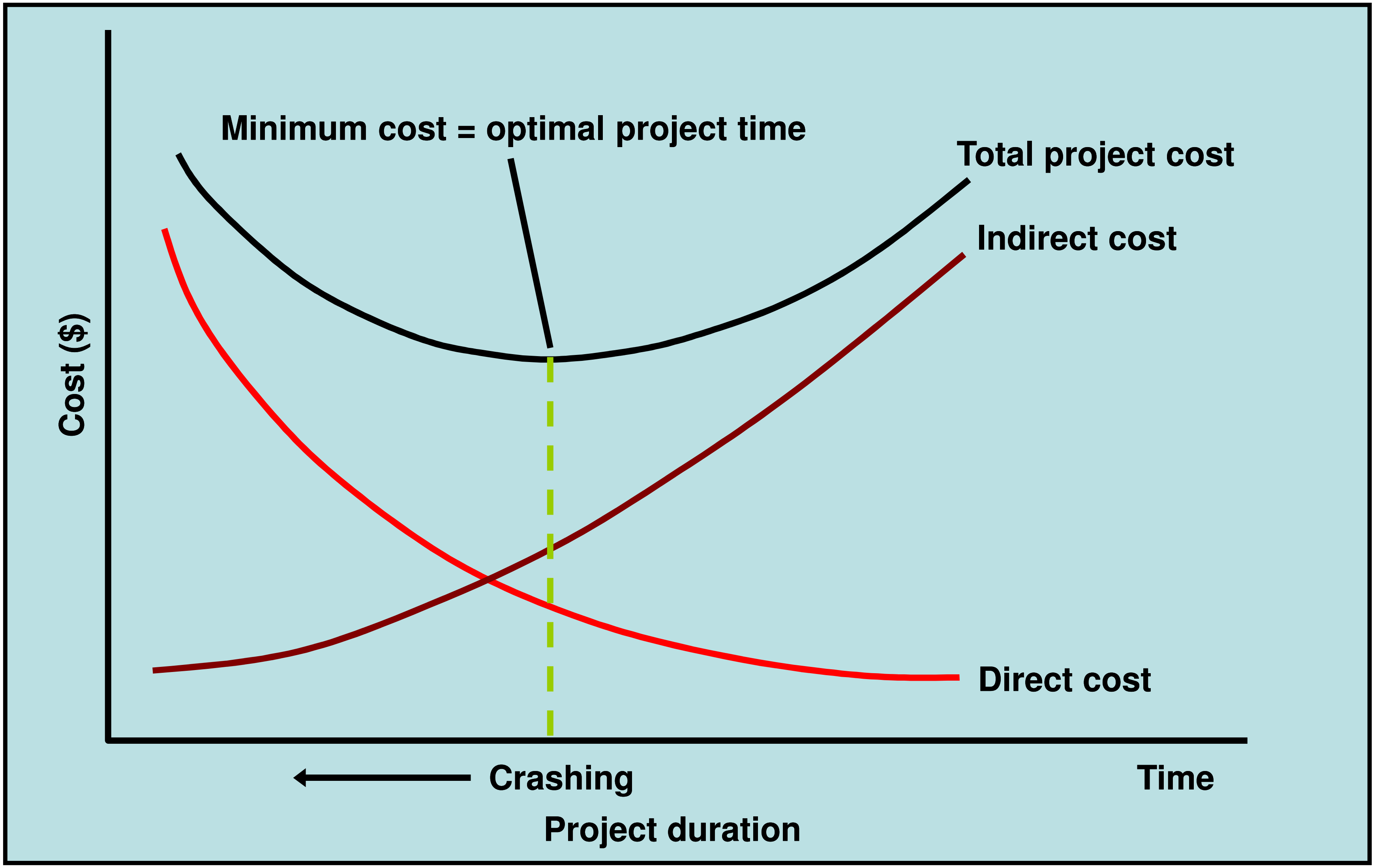


Project Duration: 31 weeks
Additional Cost: $2000

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



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- 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)