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Outline

- GLOBAL COMPANY PROFILE: BECHTEL GROUP
- THE IMPORTANCE OF PROJECT MANAGEMENT
- PROJECT PLANNING
  - The Project Manager
  - Work Breakdown Structure
- PROJECT SCHEDULING
- PROJECT CONTROLLING
Outline - Continued

- PROJECT MANAGEMENT TECHNIQUES: PERT AND CPM
  - The Framework of PERT and CPM
  - Network Diagrams and Approaches
  - Activity on Node Example
  - Determining the Project Schedule
    - Forward Pass
    - Backward Pass
    - Calculating Slack Time and Identifying the Critical Path(s)
Outline - Continued

- Variability in Activity Times
  - Three Time Estimates in PERT
  - Probability of Project Completion

- Cost-Time Tradeoffs and Project Crashing

- A Critique of PERT and CPM
Learning Objectives

When you complete this chapter, you should be able to:

*Identify or Define:*

- Work breakdown structure
- Critical path
- AOA and AON Networks
- Forward and Backward Passes
- Variability in Activity Times
When you complete this chapter, you should be able to:

Describe or Explain:

- The role of the project manager
- Program evaluation and review technique (PERT)
- Critical path method (CPM)
- Crashing a project
- The Use of MS Project
Bechtel

- Asked by Kuwait to begin rebuilding after Desert Storm
- 650 wells ablaze, others uncapped
- No water, electricity, food or facilities
- Land mines! Bombs! Grenades!
- Many fires inaccessible because of oil-covered roads
Bechtel

Project required:
- Storage, docking, and warehousing facilities at Dubai
- 125,000 tons of equipment and supplies
- 150 kilometers of pipeline capable of delivering 20,000,000 gallons of water per day to the fire site
- more than 200 lagoons with 1,000,000 gals of seawater
Bechtel
Other Projects

- Building 26 massive distribution centers in just two years for the internet company Webvan Group
- Constructing 30 high-security data centers worldwide for Equinix, Inc.
- Building and running a rail line between London and the Channel Tunnel ($4.6 billion)
- Developing an oil pipeline from the Caspian Sea region to Russia ($850 million)
- Expanding the Dubai Airport in the UAE ($600 million), and the Miami Airport in Florida ($2 billion)
Bechtel
Other Projects - Continued

- Building liquid natural gas plants in Yemen ($2 billion) and in Trinidad, West Indies ($1 billion)
- Building a new subway for Athens, Greece ($2.6 billion)
- Constructing a natural gas pipeline in Thailand ($700 million)
- Building a highway to link the north and south of Croatia ($303 million)
Strategic Importance of Project Management

- Bechtel Kuwait Project:
  - 8,000 workers
  - 1,000 construction professionals
  - 100 medical personnel
  - 2 helicopter evacuation teams
  - 6 full-service dining halls
  - 27,000 meals per day
  - 40 bed field hospital
Strategic Importance of Project Management - Continued

- **Microsoft Windows XP Project:**
  - hundreds of programmers
  - millions of lines of code
  - millions of dollars cost

- **Ford Redesign of Mustang Project:**
  - 450 member project team
  - Cost $700-million
  - 25% faster and 30% cheaper than comparable project at Ford
Project Characteristics

- Single unit
- Many related activities
- Difficult production planning and inventory control
- General purpose equipment
- High labor skills
An Example

◆ Building construction
An Example

- Research project
Management of Large Projects

- **Planning** - goal setting, project definition, team organization
- **Scheduling** - relating people, money, and supplies to specific activities and activities to one and other
- **Controlling** - monitoring resources, costs, quality, and budgets; revising plans and shifting resources to meet time and cost demands
Project Management Activities

**Planning**
- Objectives
- Resources
- Work breakdown schedule
- Organization

**Scheduling**
- Project activities
- Start & end times
- Network

**Controlling**
- Monitor, compare, revise, action
Project Organization
Works Best When

♦ Work can be defined with a specific goal and deadline
♦ The job is unique or somewhat unfamiliar to the existing organization
♦ The work contains complex interrelated tasks requiring specialized skills
♦ The project is temporary but critical to the organization
Project Planning, Scheduling, and Controlling

Project Planning
1. Setting goals
2. Defining the project
3. Tying needs into timed project activities
4. Organizing the team

Project Scheduling
1. Tying resources to specific activities
2. Relating activities to each other
3. Updating and revising on a regular basis

Project Controlling
1. Monitoring resources, costs, quality, and budgets
2. Revising and changing plans
3. Shifting resources to meet demands

Before Project

During Project

Time/cost estimates
Budgets
Engineering diagrams
Cash flow charts
Material availability details

CPM/PERT
Gantt charts
Milestone charts
Cash flow schedules

Reports
• budgets
• delayed activities
• slack activities

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Project Planning, Scheduling, and Controlling

Planning the Project
- Time
  - Performance
    - Set the goals
- Cost
  - Define the project
- Develop work breakdown schedule
  - Identify team/resources

Scheduling the Project
- Sequence activities
- Assign people
  - Adams
  - Smith
  - Jones
- Schedule deliverables
- Schedule resources

Controlling the Project
- Revise and change plans
- Monitor resources, costs, quality
  - Adams
  - Smith
  - Jones
  - Shift resources

Timeline
- Before project
- Start of project
- During project
Project Planning

- Establishing objectives
- Defining project
- Creating work breakdown structure
- Determining resources
- Forming organization
Project Organization

- Often temporary structure
- Uses specialists from entire company
- Headed by project manager
  - Coordinates activities
  - Monitors schedule & costs
- Permanent structure called ‘matrix organization’
A Sample Project Organization

- President
  - Sales
  - Finance
  - Human Resources
    - Physiologist
    - Psychologist
  - Engineering
    - Propulsion Engineer
    - Structural Engineer
  - Quality Control
    - Test Engineer
    - Inspection Technician
  - Production
    - Technician
  - Project 1
    - Project Manager
    - Technician
  - Project 2
    - Project Manager
    - Technician
A Sample Project Organization

- President
  - Human Resources
  - Sales
  - Finance
  - Engineering
  - Quality Control
  - Production
    - Project 1
      - Project Manager
        - Propulsion Engineer
        - Structural Engineer
      - Technician
    - Project 2
      - Project Manager
        - Test Engineer
        - Inspection Technician
      - Technician
# Matrix Organization

<table>
<thead>
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<th>Mkt</th>
<th>Oper</th>
<th>Eng</th>
<th>Fin</th>
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<tbody>
<tr>
<td><strong>Project 1</strong></td>
<td><img src="image1" alt="Smiley Faces" /></td>
<td><img src="image2" alt="Smiley Faces" /></td>
<td><img src="image3" alt="Smiley Faces" /></td>
<td><img src="image4" alt="Smiley Faces" /></td>
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<td><strong>Project 2</strong></td>
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</table>
The Role of the Project Manager

- Project Plan and Schedule
- Revisions and Updates
- Project Manager
- Performance Reports
- Project Team
- Feedback Loop
- Top Management
- Resources

Information regarding times, costs, problems, delays
Work Breakdown Structure

1. Project
2. Major tasks in the project
3. Subtasks in the major tasks
4. Activities (or work packages) to be completed
Project Scheduling

- Identifying precedence relationships
- Sequencing activities
- Determining activity times & costs
- Estimating material & worker requirements
- Determining critical activities
Purposes of Project Scheduling

- Shows the relationship of each activity to others and to the whole project.
- Identifies the precedence relationships among activities.
- Encourages the setting of realistic time and cost estimates for each activity.
- Helps make better use of people, money, and material resources by identifying critical bottlenecks in the project.
Project Management Techniques

- Gantt chart
- Critical Path Method (CPM)
- Program Evaluation & Review Technique (PERT)
### Gantt Chart

<table>
<thead>
<tr>
<th>Activity</th>
<th>Time Period</th>
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<tbody>
<tr>
<td></td>
<td>J</td>
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<tr>
<td>Design</td>
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<tr>
<td>Build</td>
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<tr>
<td>Test</td>
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</tbody>
</table>
### Service Activities for A Delta Jet During a 60 Minute Layover

<table>
<thead>
<tr>
<th>Activities</th>
<th>Time, minutes</th>
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<tbody>
<tr>
<td>Passengers</td>
<td></td>
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<tr>
<td>Deplaning</td>
<td></td>
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<tr>
<td>Baggage claim</td>
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<tr>
<td>Baggage</td>
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<tr>
<td>Container offload</td>
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<td>Fueling</td>
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<td>Pumping</td>
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<tr>
<td>Engine injection water</td>
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<tr>
<td>Cargo and mail</td>
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<tr>
<td>Container offload</td>
<td></td>
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<tr>
<td>Galley servicing</td>
<td></td>
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<tr>
<td>Main cabin door</td>
<td></td>
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<tr>
<td>Aft cabin door</td>
<td></td>
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<tr>
<td>Lavatory servicing</td>
<td></td>
</tr>
<tr>
<td>Aft, center, forward</td>
<td></td>
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<tr>
<td>Drinking water</td>
<td></td>
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<tr>
<td>Loading</td>
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<tr>
<td>Cabin cleaning</td>
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<td>First-class section</td>
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<td>Economy section</td>
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<tr>
<td>Cargo and mail</td>
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<td>Container/bulk loading</td>
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<td>Flight service</td>
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<tr>
<td>Galley/cabin check</td>
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<tr>
<td>Receive passengers</td>
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<td>Operating crew</td>
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<tr>
<td>Aircraft check</td>
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<td>Baggage</td>
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<tr>
<td>Loading</td>
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<tr>
<td>Passengers</td>
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<tr>
<td>Boarding</td>
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</tbody>
</table>

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Project Control Reports

- Detailed cost breakdowns for each task
- Total program labor curves
- Cost distribution tables
- Functional cost and hour summaries
- Raw materials and expenditure forecasts
- Variance reports
- Time analysis reports
- Work status reports
Network techniques

Developed in 1950’s

- CPM by DuPont for chemical plants (1957)
- PERT by Booz, Allen & Hamilton with the U.S. Navy, for Polaris missile (1958)

Consider precedence relationships and interdependencies

Each uses a different estimate of activity times
Questions Which May Be Addressed by PERT & CPM

- Is the project on schedule, ahead of schedule, or behind schedule?
- Is the project over or under cost budget?
- Are there enough resources available to finish the project on time?
- If the project must be finished in less than the scheduled amount of time, what is the way to accomplish this at least cost?
The Six Steps Common to PERT & CPM

1. Define the project and prepare the work breakdown structure,
2. Develop relationships among the activities. (Decide which activities must precede and which must follow others.)
3. Draw the network connecting all of the activities
4. Assign time and/or cost estimates to each activity
5. Compute the longest time path through the network. This is called the *critical path*
6. Use the network to help plan, schedule, monitor, and control the project
### A Comparison of AON and AOA Network Conventions

<table>
<thead>
<tr>
<th>Activity on Node (AON)</th>
<th>Activity Meaning</th>
<th>Activity on Arrow (AOA)</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="example.png" alt="AON Diagram" /></td>
<td>A comes before B, which comes before C.</td>
<td><img src="example.png" alt="AOA Diagram" /></td>
</tr>
<tr>
<td><img src="example.png" alt="AON Diagram" /></td>
<td>A and B must both be completed before C can start.</td>
<td><img src="example.png" alt="AOA Diagram" /></td>
</tr>
<tr>
<td><img src="example.png" alt="AON Diagram" /></td>
<td>B and C cannot begin until A is completed.</td>
<td><img src="example.png" alt="AOA Diagram" /></td>
</tr>
<tr>
<td><img src="example.png" alt="AON Diagram" /></td>
<td>C and D cannot begin until A and B have both been completed.</td>
<td><img src="example.png" alt="AOA Diagram" /></td>
</tr>
<tr>
<td><img src="example.png" alt="AON Diagram" /></td>
<td>C cannot begin until both A and B are completed; D cannot begin until B is completed. A dummy activity is introduced in AOA.</td>
<td><img src="example.png" alt="AOA Diagram" /></td>
</tr>
<tr>
<td><img src="example.png" alt="AON Diagram" /></td>
<td>B and C cannot begin until A is completed. D cannot begin until both B and C are completed. A dummy activity is again introduced in AOA.</td>
<td><img src="example.png" alt="AOA Diagram" /></td>
</tr>
</tbody>
</table>
### Milwaukee General Hospital’s Activities and Predecessors

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Immediate Predecessors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Build internal components</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>Modify roof and floor</td>
<td>-</td>
</tr>
<tr>
<td>C</td>
<td>Construct collection stack</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>Pour concrete and install frame</td>
<td>A, B</td>
</tr>
<tr>
<td>E</td>
<td>Build high-temperature burner</td>
<td>C</td>
</tr>
<tr>
<td>F</td>
<td>Install pollution control system</td>
<td>C</td>
</tr>
<tr>
<td>G</td>
<td>Install air pollution device</td>
<td>D, E</td>
</tr>
<tr>
<td>H</td>
<td>Inspect and test</td>
<td>F, G</td>
</tr>
</tbody>
</table>
AON Network for Milwaukee General Hospital

Start → A → C → F → H
Start → B → D → G → F

Arrows show precedence relationships
AOA Network (With Dummy Activities) for Milwaukee General

1. Build internal components
   - A

2. Build stack
   - C

3. Pour concrete/Install frame
   - D

4. Construct stack
   - 2

5. Build burner
   - E

6. Install controls
   - F

7. Inspect/Test
   - Install pollution control device
   - G

Dummy Activity
Critical Path Analysis

- Provides activity information
  - Earliest (ES) & latest (LS) start
  - Earliest (EF) & latest (LF) finish
  - Slack (S): Allowable delay

- Identifies critical path
  - Longest path in network
  - Shortest time project can be completed
  - Any delay on critical path activities delays project
  - Critical path activities have 0 slack
Earliest Start and Finish Steps

- Begin at starting event and work forward
- ES = 0 for starting activities
  - ES is earliest start
- EF = ES + Activity time
  - EF is earliest finish
- ES = Maximum EF of all predecessors for non-starting activities
Latest Start and Finish Steps

- Begin at ending event and work backward
- \( LF = \text{Maximum} \ EF \) for ending activities
  - \( LF \) is latest finish; \( EF \) is earliest finish
- \( LS = LF - \text{Activity time} \)
  - \( LS \) is latest start
- \( LF = \text{Minimum} \ LS \) of all successors for non-ending activities
Latest Start and Finish Steps

- **ES**: Earliest Start
- **LS**: Latest Start
- **EF**: Earliest Finish
- **LF**: Latest Finish
Critical Path for Milwaukee General Hospital

Start

- A
- B
- D
- C
- F
- G
- H

Arrows show precedence relationships
Gantt Chart
Earliest Start and Finish

**Milwaukee General Hospital**

<table>
<thead>
<tr>
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</table>

- A Build internal components
- B Modify roof and floor
- C Construct collection stack
- D Pour concrete and install frame
- E Build high-temperature burner
- F Install pollution control system
- G Install air pollution device
- H Inspect and test
<table>
<thead>
<tr>
<th>Task Description</th>
<th>Latest Start</th>
<th>Latest Finish</th>
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<tbody>
<tr>
<td>A Build internal components</td>
<td>1</td>
<td>2</td>
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<tr>
<td>B Modify roof and floor</td>
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<td>4</td>
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<tr>
<td>C Construct collection stack</td>
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<td>6</td>
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<tr>
<td>D Pour concrete and install frame</td>
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<tr>
<td>E Build high-temperature burner</td>
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<td>10</td>
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<tr>
<td>F Install pollution control system</td>
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<td>12</td>
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<tr>
<td>G Install air pollution device</td>
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<td>H Inspect and test</td>
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## Build House Project

### Activity Chart

<table>
<thead>
<tr>
<th>Activity</th>
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<th>2</th>
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<tbody>
<tr>
<td>1-2 Fdn &amp; frame</td>
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<td>1-3 Buy shrubs</td>
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<td>2-3 Roof</td>
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<td>2-4 Interior work</td>
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<td>3-4 Landscape</td>
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</tbody>
</table>
PERT Activity Times

- 3 time estimates
  - Optimistic times \((a)\)
  - Most-likely time \((m)\)
  - Pessimistic time \((b)\)
- Follow beta distribution
- Expected time: \( t = (a + 4m + b)/6 \)
- Variance of times: \( v = (b - a)^2/6 \)
Project Times

- **Expected project time** ($T$)
  - Sum of critical path activity times, $t$

- **Project variance** ($V$)
  - Sum of critical path activity variances, $v$

*Used to obtain probability of project completion!*
PERT Probability Example

You’re a project planner for General Dynamics. A submarine project has an expected completion time of 40 weeks, with a standard deviation of 5 weeks. What is the probability of finishing the sub in 50 weeks or less?
Converting to Standardized Variable

\[ Z = \frac{X - T}{s} = \frac{50 - 40}{5} = 2.0 \]

Normal Distribution

\( s = 5 \)

\( T = 40 \quad 50 \quad X \)

Standardized Normal Distribution

\( s_Z = 1 \)

\( m_Z = 0 \quad 2.0 \quad Z \)
Obtaining the Probability

Standardized Normal Probability Table (Portion)

<table>
<thead>
<tr>
<th>Z</th>
<th>0.00</th>
<th>0.01</th>
<th>0.02</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.50000</td>
<td>0.50399</td>
<td>0.50798</td>
</tr>
<tr>
<td>2.0</td>
<td>0.97725</td>
<td>0.97784</td>
<td>0.97831</td>
</tr>
<tr>
<td>2.1</td>
<td>0.98214</td>
<td>0.98257</td>
<td>0.98300</td>
</tr>
</tbody>
</table>

Probabilities in body

$S_z = 1$

$z = 0$

$Z = 2.0$

$Z = 2.1$

$P(Z < 2.1) = 0.98214$
Variability of Completion Time for Noncritical Paths

- Variability of times for activities on noncritical paths must be considered when finding the probability of finishing in a specified time.
- Variation in noncritical activity may cause change in critical path.
Factors to Consider when Crashing

- The amount by which an activity is crashed is, in fact, permissible.
- Taken together, the shortened activity durations will enable one to finish the project by the due date.
- The total cost of crashing is as small as possible.
Steps in Project Crashing

- Compute the crash cost per time period. For crash costs assumed linear over time:

\[
\text{Crash cost per period} = \frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal time} - \text{Crash time}}
\]

- Using current activity times, find the critical path.

- If there is only one critical path, then select the activity on this critical path that (a) can still be crashed, and (b) has the smallest crash cost per period. Note that a single activity may be common to more than one critical path.

- Update all activity times.
Crash and Normal Times and Costs for Activity B

Crash Cost/Week = \frac{\text{Crash Cost} - \text{Normal Cost}}{\text{Normal Time} - \text{Crash Time}}

= \frac{\$34,000 - \$30,000}{3 - 1}
= \frac{\$4,000}{2 \text{ Weeks}} = \$2,000/\text{Week}
Cost-Time Curves Used in Crashing Analysis

Activity 5–6
(t = 9)

Activity 2–4
(t = 16)

Cost

$600

$500

$400

$300

6
7
8
Time (weeks)

$3,000

$2,000

$1,000

12
14
Time (weeks)
Advantages of PERT/CPM

- Especially useful when scheduling and controlling large projects.
- Straightforward concept and not mathematically complex.
- Graphical networks aid perception of relationships among project activities.
- Critical path & slack time analyses help pinpoint activities that need to be closely watched.
- Project documentation and graphics point out who is responsible for various activities.
- Applicable to a wide variety of projects.
- Useful in monitoring schedules and costs.
Limitations of PERT/CPM

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