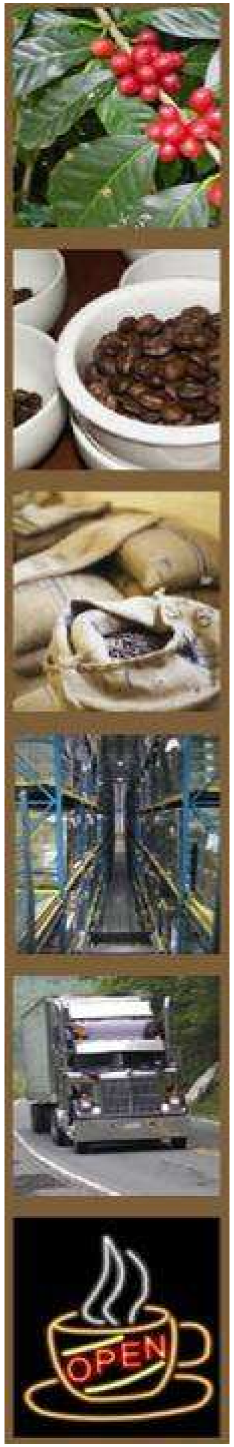
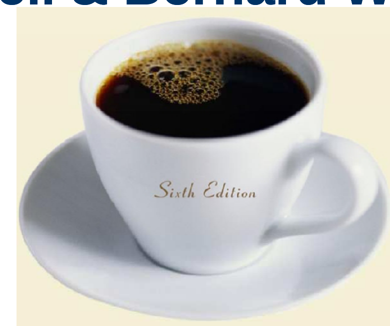


# Chapter 1-17

## *Operations Management*

**Roberta Russell & Bernard W. Taylor, III**



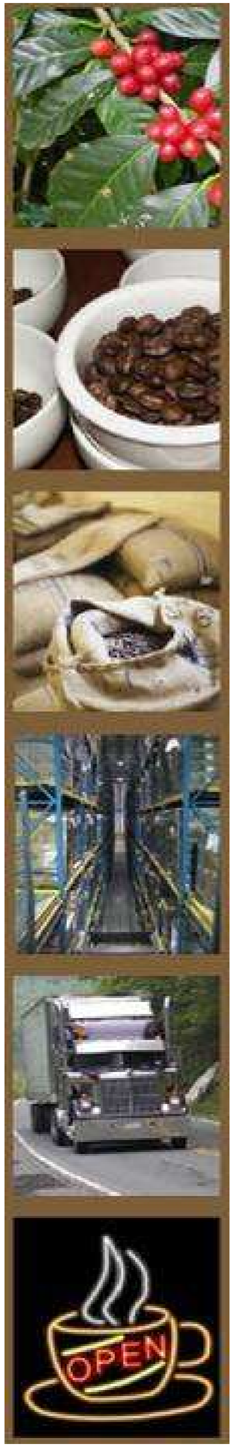
# Organization of This Text: Part I – Operations Management

# Organization of This Text: Part II – Supply Chain Management

| | |
|---|---|
| ◆ Supply Chain Strategy and Design: | Chapter 10 (Slide 507) |
| ◆ Global Supply Chain Procurement and Distribution: | Chapter 11 (Slide 534) |
| ◆ Forecasting: | Chapter 12 (Slide 575) |
| ◆ Inventory Management: | Chapter 13 (Slide 641) |
| ◆ Sales and Operations Planning: | Chapter 14 (Slide 703) |
| ◆ Resource Planning: | Chapter 15 (Slide 767) |
| ◆ Lean Systems: | Chapter 16 (Slide 827) |
| ◆ Scheduling: | Chapter 17 (Slide 878) |

# Learning Objectives of this Course

- Gain an appreciation of strategic importance of operations and supply chain management in a global business environment
- Understand how operations relates to other business functions
- Develop a working knowledge of concepts and methods related to designing and managing operations and supply chains
- Develop a skill set for quality and process improvement

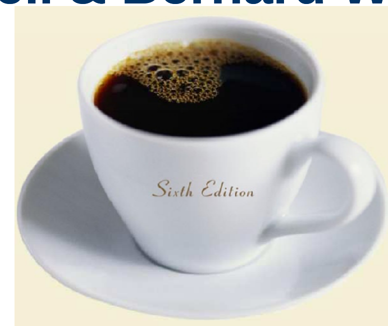


# Chapter 1

## *Introduction to Operations and Supply Chain Management*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**



# Lecture Outline

- What Operations and Supply Chain Managers Do
- Operations Function
- Evolution of Operations and Supply Chain Management
- Globalization and Competitiveness
- Operations
- Strategy and Organization of the Text
- Learning Objectives for This Course

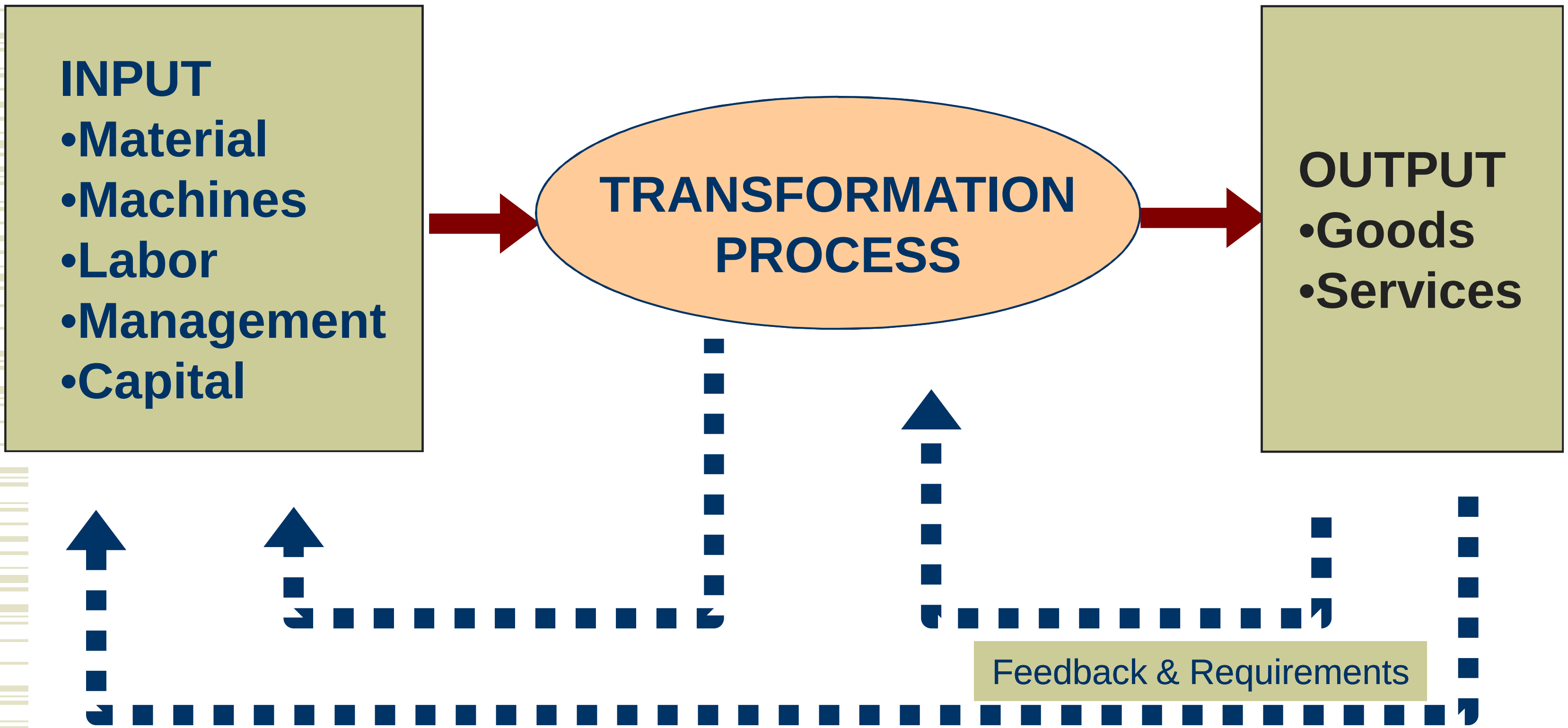
# What Operations and Supply Chain Managers Do

- What is Operations Management?
  - design, operation, and improvement of productive systems
- What is Operations?
  - a function or system that transforms inputs into outputs of greater value
- What is a Transformation Process?
  - a series of activities along a *value chain* extending from supplier to customer
  - activities that do not add value are superfluous and should be eliminated

# Transformation Process

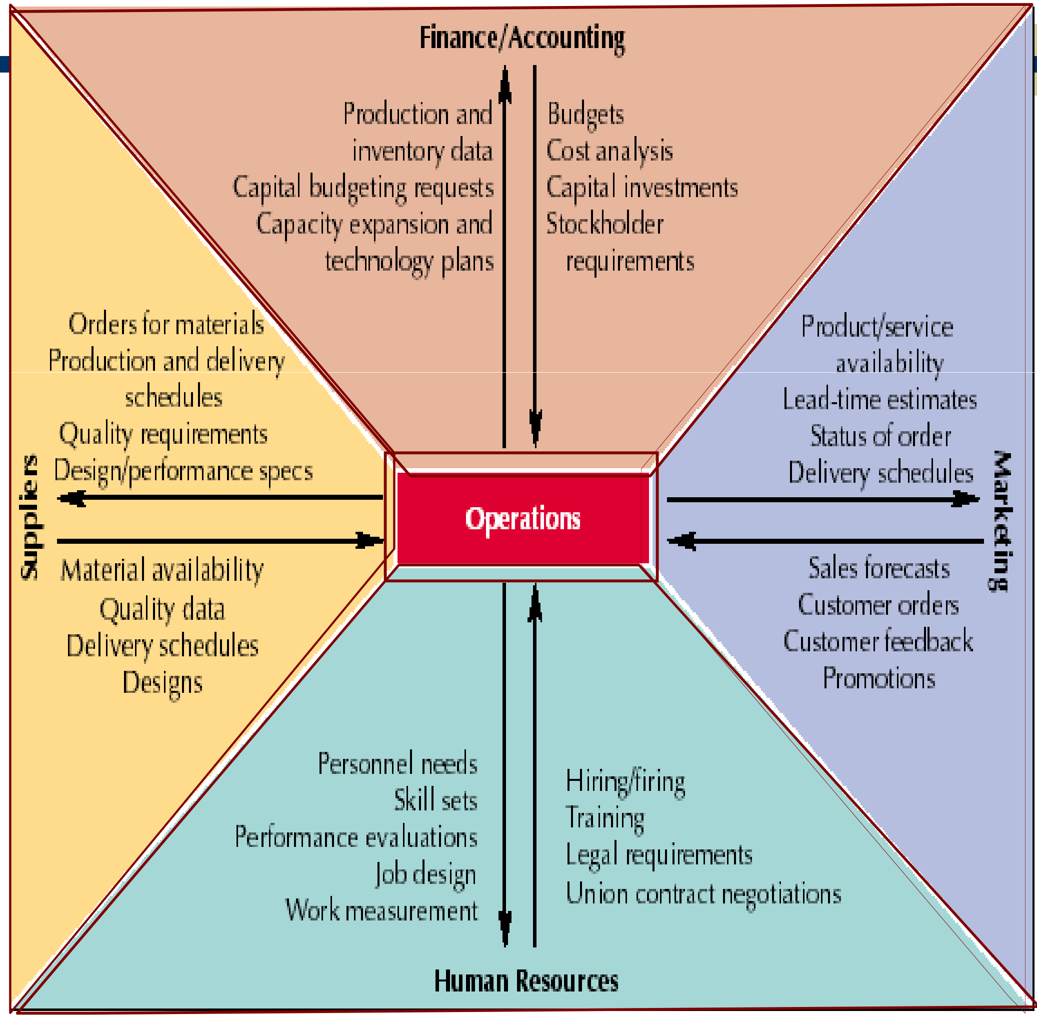
- *Physical:* as in manufacturing operations
- *Locational:* as in transportation or warehouse operations
- *Exchange:* as in retail operations
- *Physiological:* as in health care
- *Psychological:* as in entertainment
- *Informational:* as in communication

# Operations as a Transformation Process



# Operations Function

- Operations
- Marketing
- Finance and Accounting
- Human Resources
- Outside Suppliers



# How is Operations Relevant to my Major?

- **Accounting**
- **Information Technology**
- **Management**

- "As an auditor you must understand the fundamentals of operations management."
- "IT is a tool, and there's no better place to apply it than in operations."
- "We use so many things you learn in an operations class—scheduling, lean production, theory of constraints, and tons of quality tools."

# How is Operations Relevant to my Major? (cont.)

- **Economics**
- **Marketing**
- **Finance**

- "It's all about processes. I live by flowcharts and Pareto analysis."
- "How can you do a good job marketing a product if you're unsure of its quality or delivery status?"
- "Most of our capital budgeting requests are from operations, and most of our cost savings, too."

# Evolution of Operations and Supply Chain Management

- **Craft production**
  - process of handcrafting products or services for individual customers
- **Division of labor**
  - dividing a job into a series of small tasks each performed by a different worker
- **Interchangeable parts**
  - standardization of parts initially as replacement parts; enabled mass production

# Evolution of Operations and Supply Chain Management (cont.)

- **Scientific management**
  - systematic analysis of work methods
- **Mass production**
  - high-volume production of a standardized product for a mass market
- **Lean production**
  - adaptation of mass production that prizes quality and flexibility

# Historical Events in Operations Management

| Era | Events/Concepts | Dates | Originator |
| --- | --- | --- | --- |
| Industrial Revolution | Steam engine | 1769 | James Watt |
| | Division of labor | 1776 | Adam Smith |
| | Interchangeable parts | 1790 | Eli Whitney |
| Scientific Management | Principles of scientific management | 1911 | Frederick W. Taylor |
| | Time and motion studies | 1911 | Frank and Lillian Gilbreth |
| | Activity scheduling chart | 1912 | Henry Gantt |
| | Moving assembly line | 1913 | Henry Ford |

# Historical Events in Operations Management (cont.)

| Era | Events/Concepts | Dates | Originator |
|---|---|---|---|
| **Human Relations** | Hawthorne studies | 1930 | Elton Mayo |
| | Motivation theories | 1940s | Abraham Maslow |
| | | 1950s | Frederick Herzberg |
| | | 1960s | Douglas McGregor |
| **Operations Research** | Linear programming | 1947 | George Dantzig |
| | Digital computer | 1951 | Remington Rand |
| | Simulation, waiting line theory, decision theory, PERT/CPM | 1950s | Operations research groups |
| | MRP, EDI, EFT, CIM | 1960s, 1970s | Joseph Orlicky, IBM and others |

# Historical Events in Operations Management (cont.)

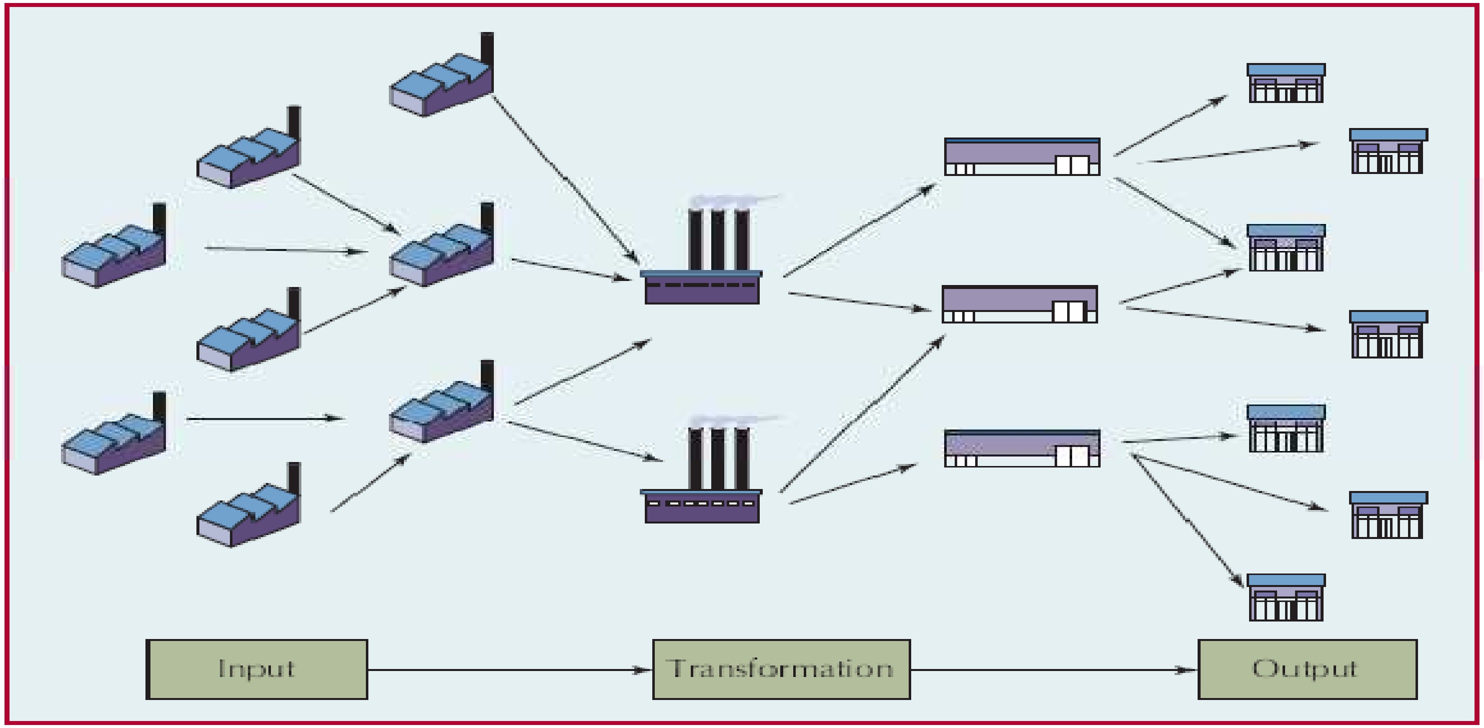
| Era | Events/Concepts | Dates | Originator |
|---|---|---|---|
| **Quality Revolution** | JIT (just-in-time) | 1970s | Taiichi Ohno (Toyota) |
| | TQM (total quality management) | 1980s | W. Edwards Deming, Joseph Juran |
| | Strategy and operations | 1980s | Wickham Skinner, Robert Hayes |
| | Business process reengineering | 1990s | Michael Hammer, James Champy |
| | Six Sigma | 1990s | GE, Motorola |

# Historical Events in Operations Management (cont.)

| Era | Events/Concepts | Dates | Originator |
|---|---|---|---|
| **Internet Revolution** | Internet, WWW, ERP, supply chain management | 1990s | ARPANET, Tim Berners-Lee SAP, i2 Technologies, ORACLE |
| | E-commerce | 2000s | Amazon, Yahoo, eBay, Google, and others |
| **Globalization** | WTO, European Union, and other trade agreements, global supply chains, outsourcing, BPO, Services Science | 1990s 2000s | Numerous countries and companies |

# Evolution of Operations and Supply Chain Management (cont.)

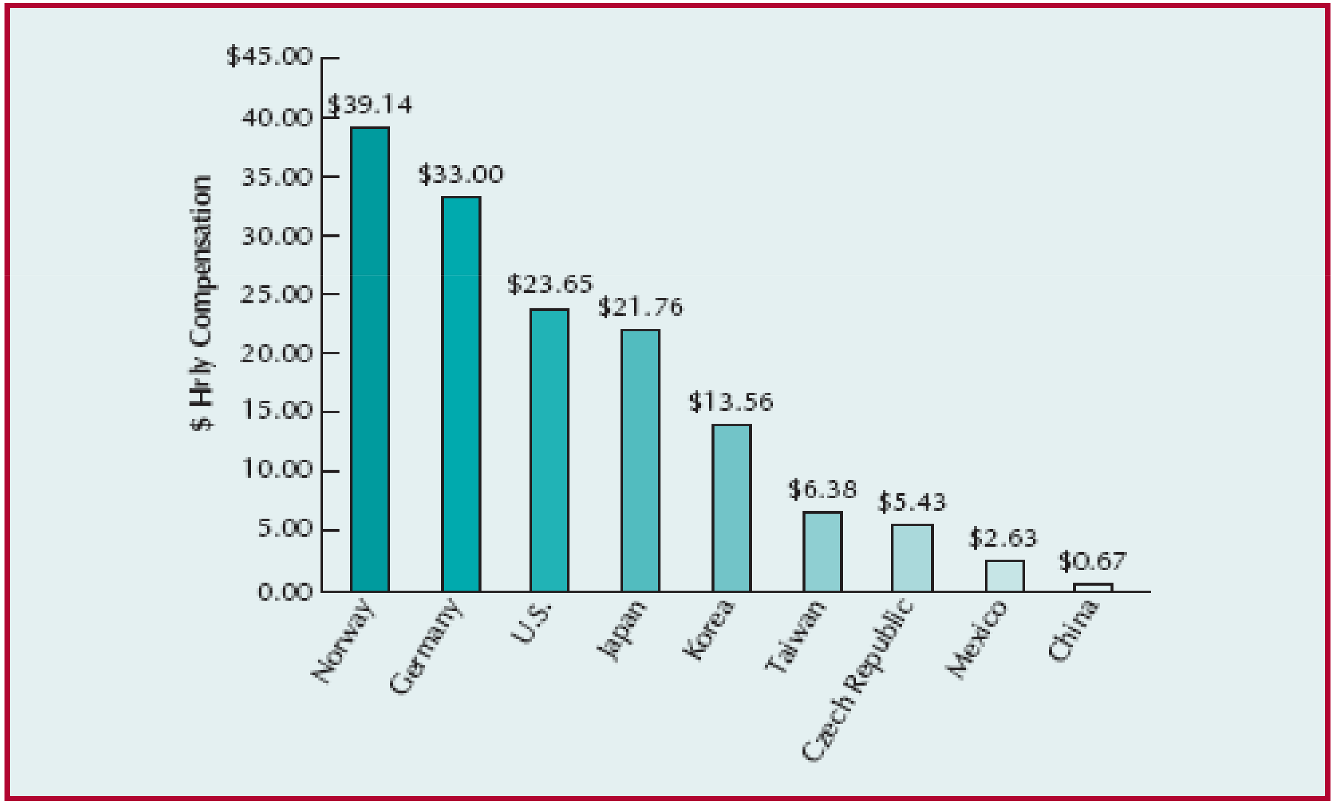
- **Supply chain management**
  - **management of the flow of information, products, and services across a network of customers, enterprises, and supply chain partners**



# Globalization and Competitiveness

- Why "go global"?
  - favorable cost
  - access to international markets
  - response to changes in demand
  - reliable sources of supply
  - latest trends and technologies
- Increased globalization
  - results from the Internet and falling trade barriers

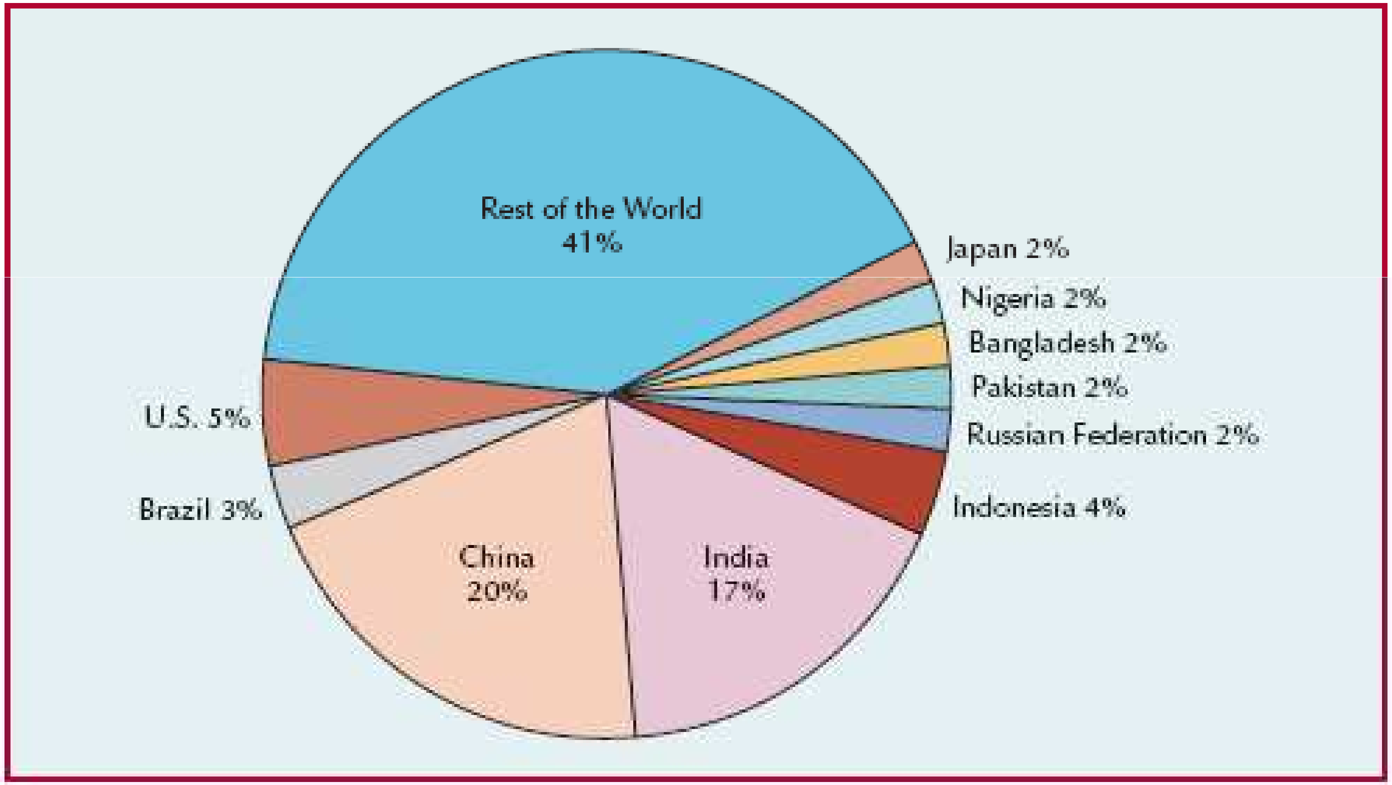
# Globalization and Competitiveness (cont.)




**Hourly Compensation Costs for Production Workers**

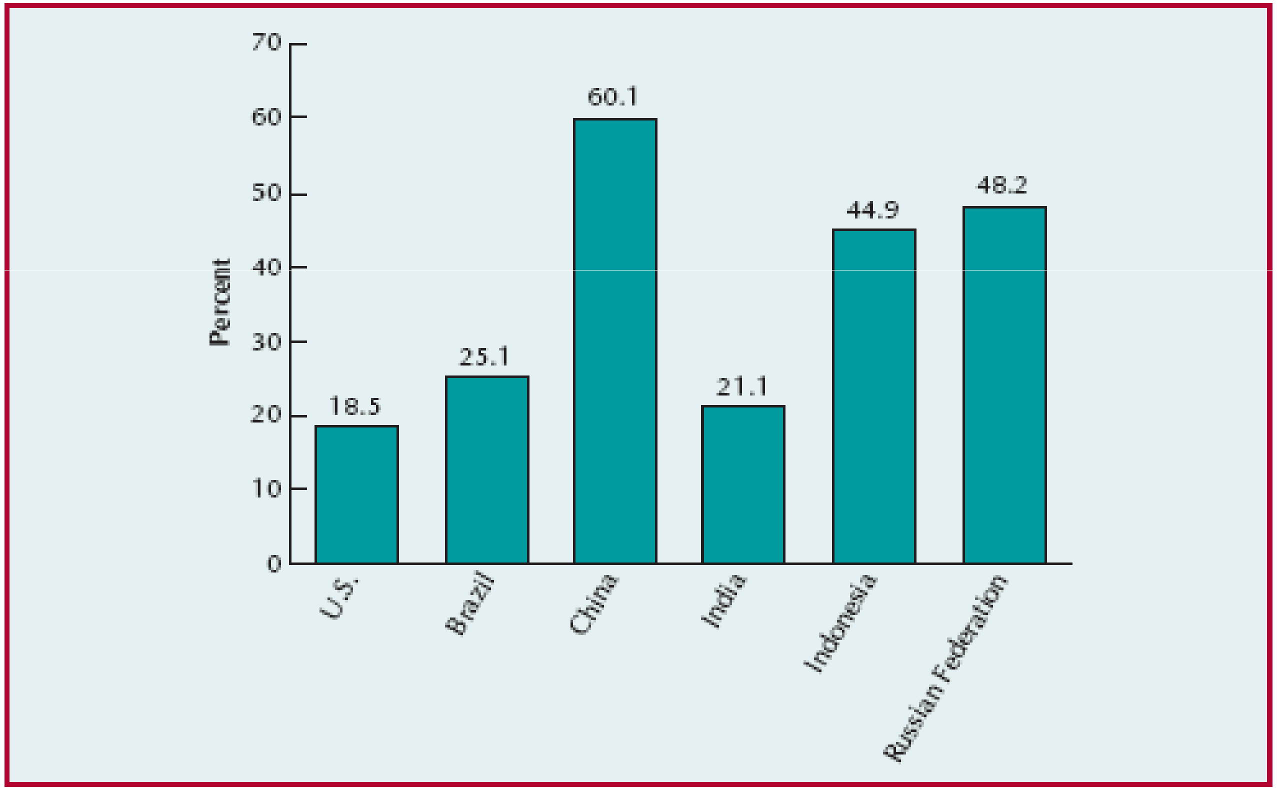
*Source:* U.S. Bureau of Labor Statistics, 2005.

# Globalization and Competitiveness (cont.)




**World Population Distribution**
*Source:* U.S. Census Bureau, 2006.

# Globalization and Competitiveness (cont.)




**Trade in Goods as % of GDP**

(sum of merchandise exports and imports divided by GDP, valued in U.S. dollars)

# Productivity and Competitiveness

- **Competitiveness**
  - degree to which a nation can produce goods and services that meet the test of international markets
- **Productivity**
  - ratio of output to input
- **Output**
  - sales made, products produced, customers served, meals delivered, or calls answered
- **Input**
  - labor hours, investment in equipment, material usage, or square footage

# Productivity and Competitiveness (cont.)

***Single Factor-Productivity***

$$\frac{\text{Output}}{\text{Labor}} \qquad \frac{\text{Output}}{\text{Materials}} \qquad \frac{\text{Output}}{\text{Capital}}$$

***Multifactor Productivity***

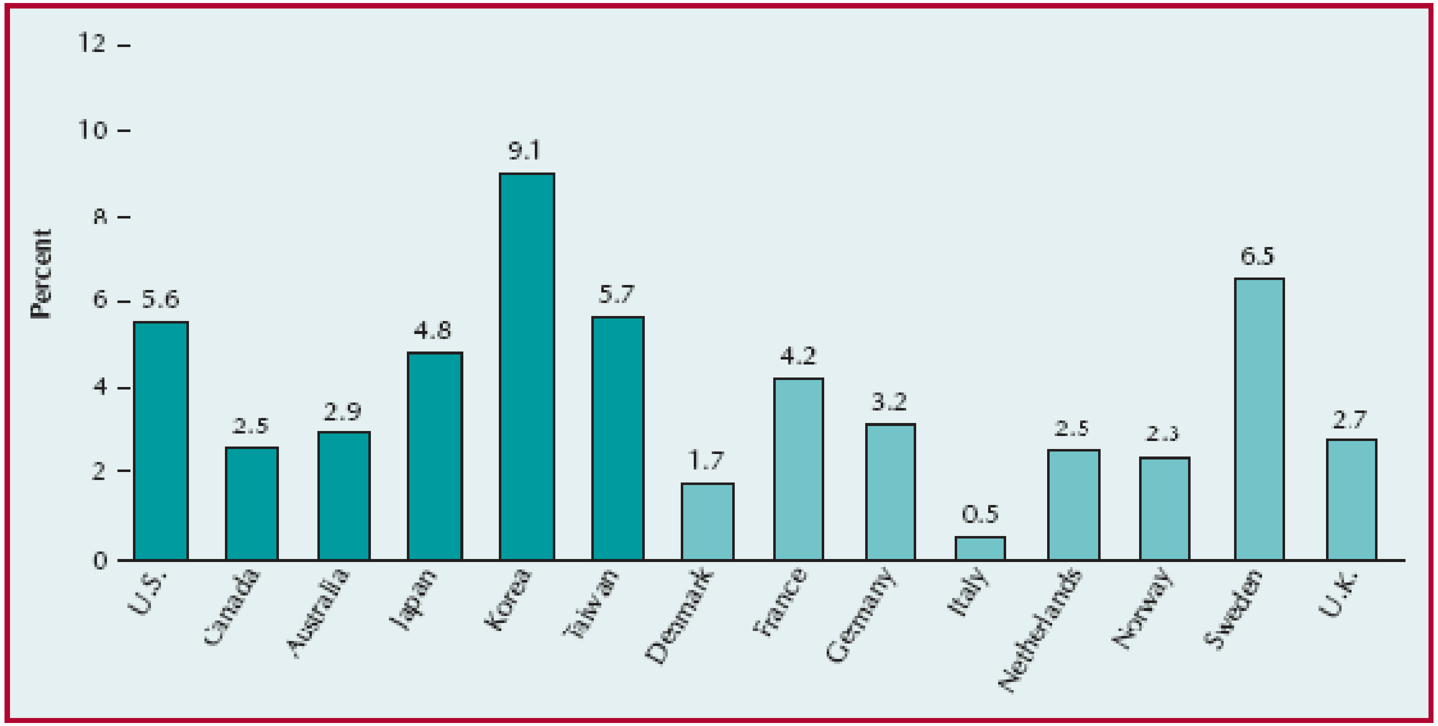
$$\frac{\text{Output}}{\text{Labor + Materials + Overhead}} \qquad \frac{\text{Output}}{\text{Labor + Energy + Capital}}$$

***Total Factor Productivity***

$$\frac{\text{Goods and services produced}}{\text{All inputs used to produce them}}$$

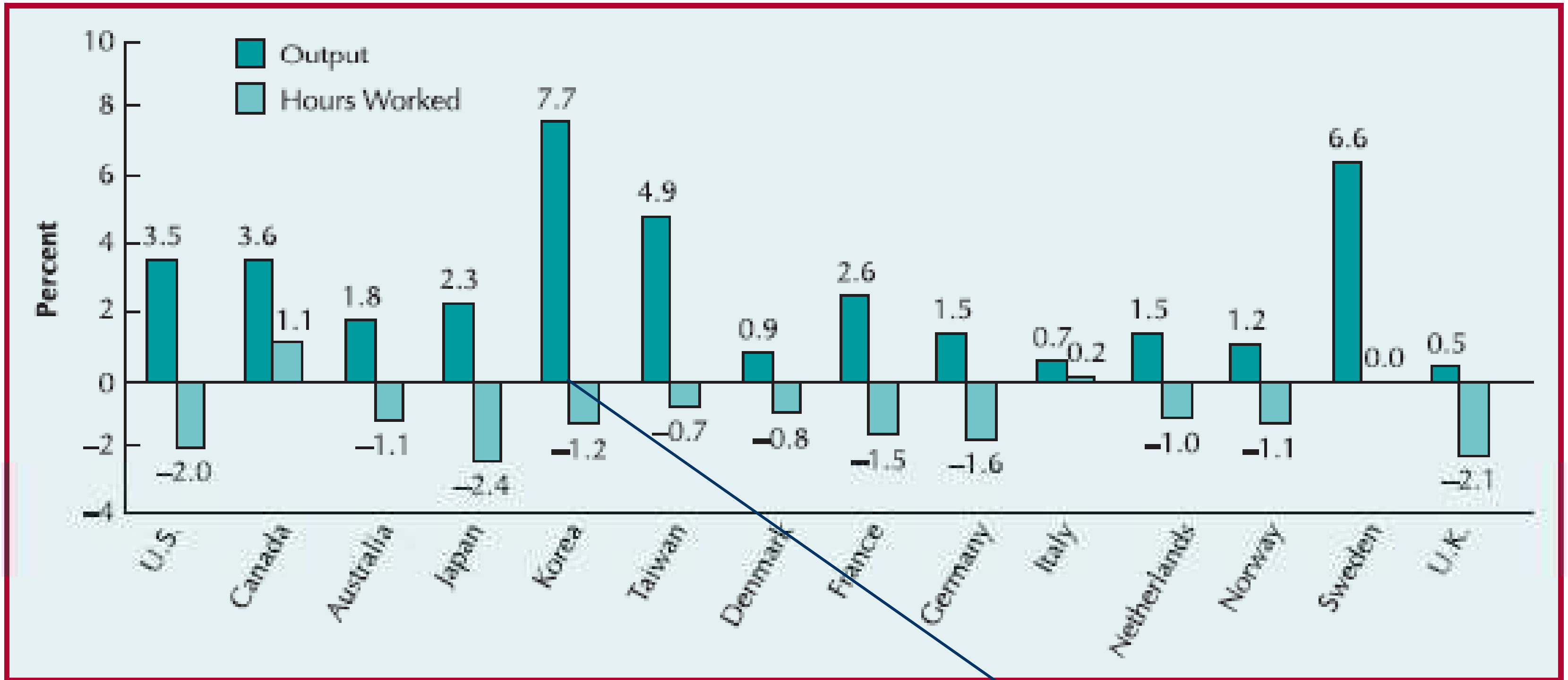
**Measures of Productivity**

# Productivity and Competitiveness (cont.)




**Average Annual Growth Rates in Productivity, 1995-2005.**
*Source:* Bureau of Labor Statistics. A Chartbook of International Labor Comparisons. January 2007, p. 28.

# Productivity and Competitiveness (cont.)




**Average Annual Growth Rates in Output and Input, 1995-2005**

*Source:* Bureau of Labor Statistics. A Chartbook of International Labor Comparisons, January 2007, p. 26.

Dramatic Increase in Output w/ Decrease in Labor Hours

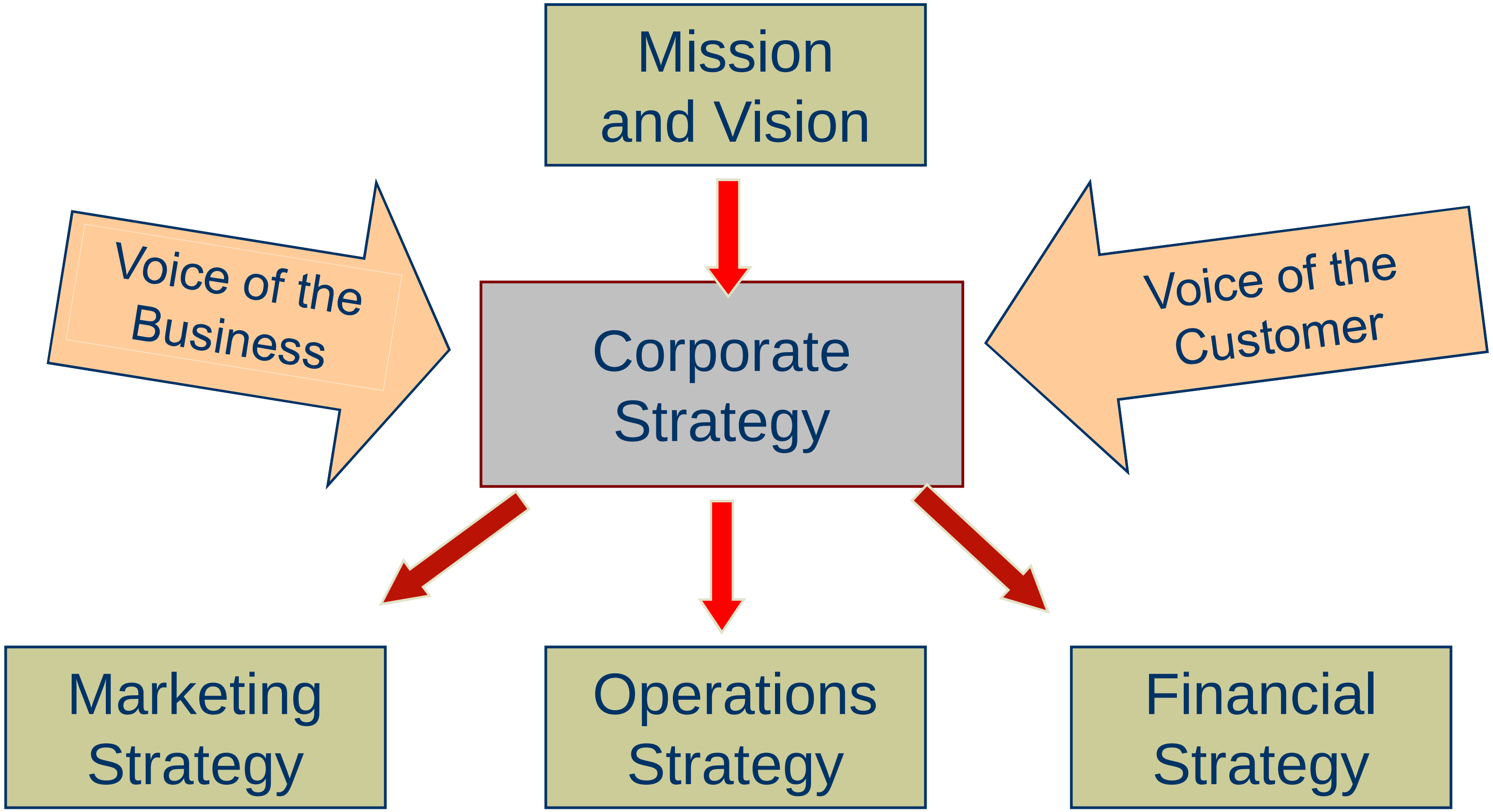
# Productivity and Competitiveness (cont.)

- Retrenching
  - productivity is increasing, but both output and input decrease with input decreasing at a faster rate
- Assumption that more input would cause output to increase at the same rate
  - certain limits to the amount of output may not be considered
  - *output produced* is emphasized, not *output sold*; increased inventories

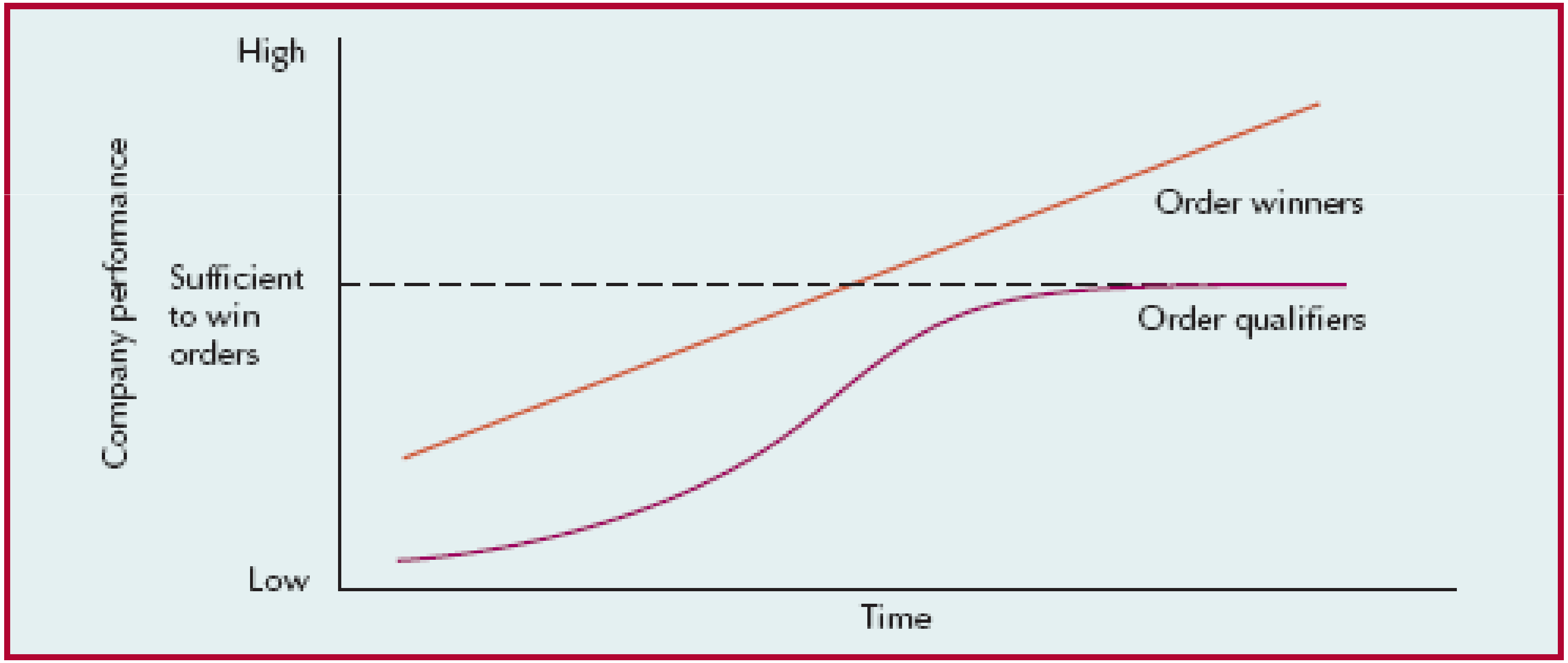
# Strategy and Operations

- Strategy
  - Provides direction for achieving a mission
- Five Steps for Strategy Formulation
  - Defining a primary task
    - What is the firm in the business of doing?
  - Assessing core competencies
    - What does the firm do better than anyone else?
  - Determining order winners and order qualifiers
    - What qualifies an item to be considered for purchase?
    - What wins the order?
  - Positioning the firm
    - How will the firm compete?
  - Deploying the strategy

# Strategic Planning



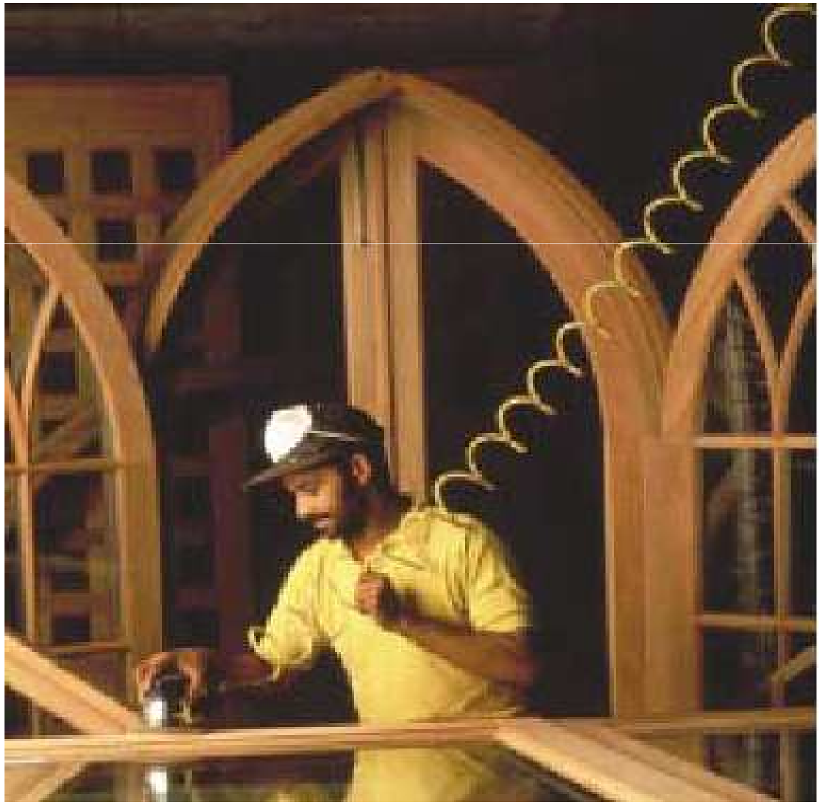
# Order Winners and Order Qualifiers




*Source:* Adapted from Nigel Slack, Stuart Chambers, Robert Johnston, and Alan Betts, *Operations and Process Management*, Prentice Hall, 2006, p. 47

# Positioning the Firm

- Cost
- Speed
- Quality
- Flexibility



# Positioning the Firm: Cost

- Waste elimination
  - relentlessly pursuing the removal of all waste
- Examination of cost structure
  - looking at the entire cost structure for reduction potential
- Lean production
  - providing low costs through disciplined operations

# Positioning the Firm: Speed

- fast moves, fast adaptations, tight linkages
- Internet
  - conditioned customers to expect immediate responses
- Service organizations
  - always competed on speed (McDonald's, LensCrafters, and Federal Express)
- Manufacturers
  - time-based competition:  build-to-order production and efficient supply chains
- Fashion industry
  - two-week design-to-rack lead time of Spanish retailer, Zara

# Positioning the Firm: Quality

- Minimizing defect rates or conforming to design specifications; please the customer
- Ritz-Carlton - one customer at a time
  - Service system is designed to “move heaven and earth” to satisfy customer
  - Every employee is empowered to satisfy a guest’s wish
  - Teams at all levels set objectives and devise quality action plans
  - Each hotel has a quality leader

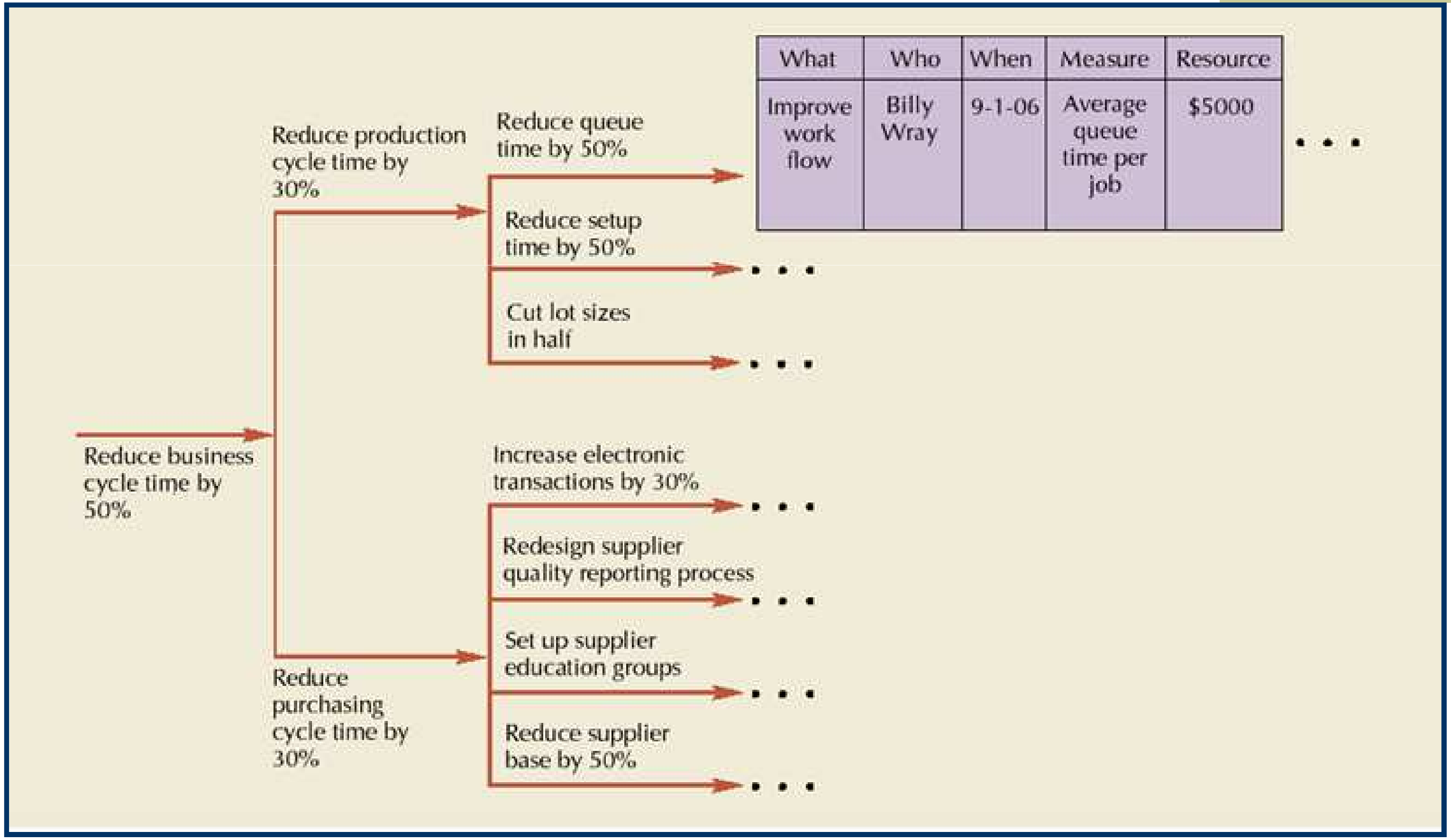
# Positioning the Firm: Flexibility

- ability to adjust to changes in product mix, production volume, or design
- National Bicycle Industrial Company
  - offers 11,231,862 variations
  - delivers within two weeks at costs only 10% above standard models
  - *mass customization*: the mass production of customized parts

# Policy Deployment

- Policy deployment
  - translates corporate strategy into measurable objectives
- Hoshins
  - action plans generated from the policy deployment process

# Policy Deployment




**Derivation of an Action Plan Using Policy Deployment**

# Balanced Scorecard

- Balanced scorecard
  - measuring more than financial performance
    - finances
    - customers
    - processes
    - learning and growing
- Key performance indicators
  - a set of measures that help managers evaluate performance in critical areas

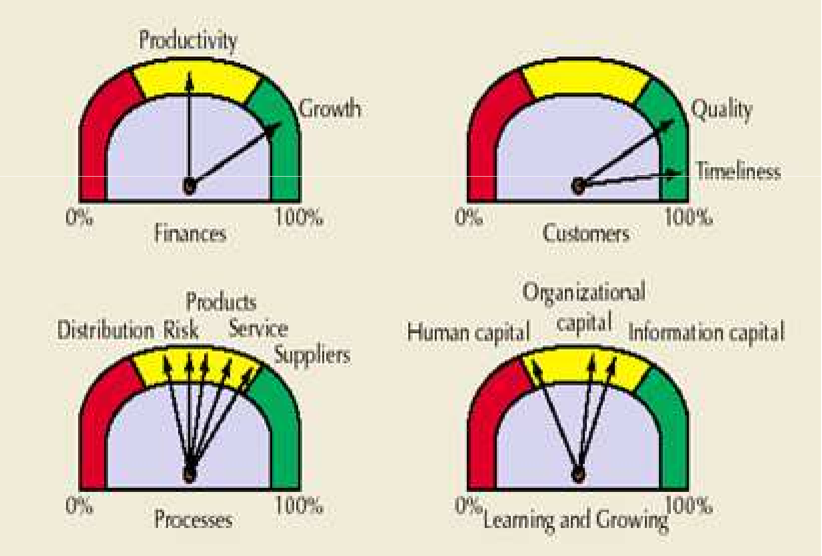
# Balanced Scorecard

## Balanced Scorecard Worksheet

| Dimension | | Objectives | Key Performance Indicator | Goal for 2008 | KPI Results to Date | Score | Mean Performance |
|---|---|---|---|---|---|---|---|
| Finances | Productivity | Become industry cost leader | % reduction in cost per unit | 20% | 10% | 50% | 65% |
| | Growth | Increase market share | Market share | 50% | 40% | 80% | |
| Customers | Quality | Zero defects | % good quality first pass | 100% | 80% | 80% | 87% |
| | Timeliness | On-time delivery | % of on-time deliveries | 95% | 90% | 95% | |
| Processes | Suppliers | Integrate into production | % orders delivered to assembly | 50% | 40% | 80% | 73% |
| | | Reduce inspections | % suppliers ISO 9000 certified | 90% | 60% | 67% | |
| | Products | Reduce time to produce | Cycle time | 10 mins. | 12 mins. | 83% | 52% |
| | | Improve quality | # warranty claims | 200 | 1000 | 20% | |
| | Distribution | Reduce transportation costs | % FTL shipments | 75% | 30% | 40% | 40% |
| | Post-sales Service | Improve response to customer inquiries | % queries satisfied on first pass | 90% | 60% | 67% | 67% |
| | Risk | Reduce Inventory obsolescence | Inventory turnover | 12 | 6 | 50% | 50% |
| | | Reduce customer backlog | % order backlogged | 10% | 20% | 50% | |
| Learning & Growing | Human capital | Develop quality improvement skills | # of six sigma Black Belts | 25 | 2 | 8% | 35% |
| | | | % trained in SPC | 80% | 50% | 63% | |
| | Information capital | Provide technology to improve processes | % customers who can track orders | 100% | 60% | 60% | 61% |
| | | | % suppliers who use EDI | 80% | 50% | 63% | |
| | Organizational capital | Create innovative culture | # of employee suggestions | 100 | 60 | 60% | 55% |
| | | | % of products new this year | 20% | 10% | 50% | |

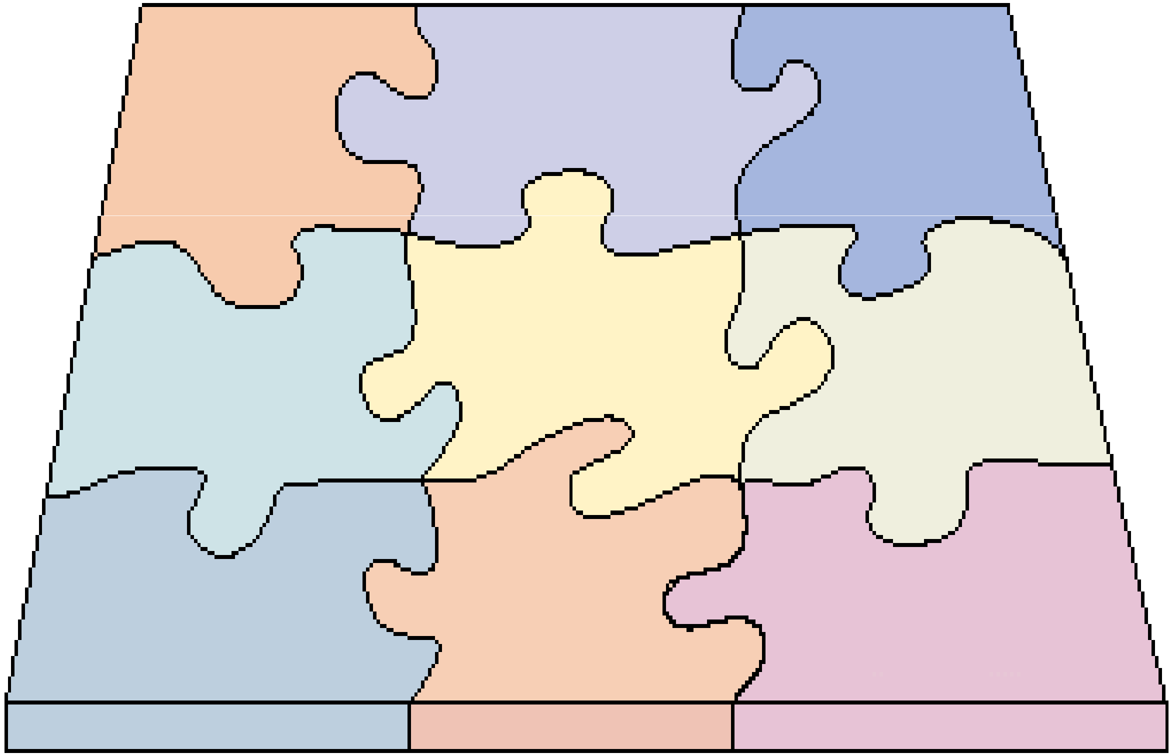
# Balanced Scorecard

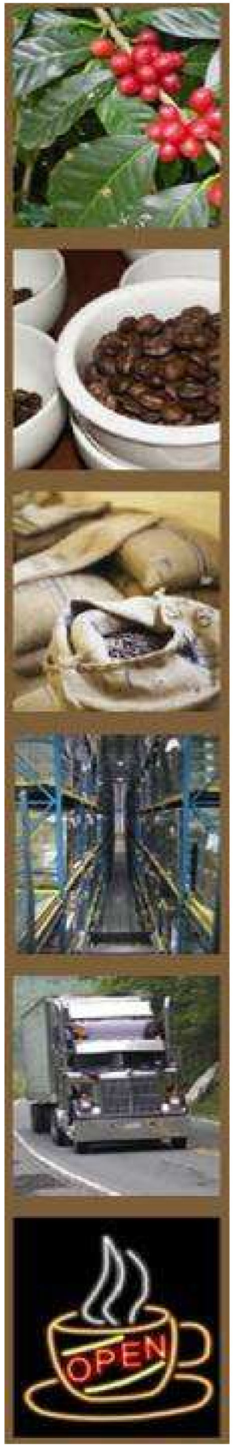

Radar Chart




Dashboard

# Operations Strategy





# Chapter 1 Supplement

## *Decision Analysis*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Decision Analysis
- Decision Making without Probabilities
- Decision Analysis with Excel
- Decision Analysis with OM Tools
- Decision Making with Probabilities
- Expected Value of Perfect Information
- Sequential Decision Tree

# Decision Analysis

- Quantitative methods
  - a set of tools for operations manager
- Decision analysis
  - a set of quantitative decision-making techniques for decision situations in which uncertainty exists
  - Example of an uncertain situation
    - demand for a product may vary between 0 and 200 units, depending on the state of market

# Decision Making Without Probabilities

- *States of nature*
  - Events that may occur in the future
  - Examples of states of nature:
    - high or low demand for a product
    - good or bad economic conditions
- *Decision making under risk*
  - probabilities can be assigned to the occurrence of states of nature in the future
- *Decision making under uncertainty*
  - probabilities can NOT be assigned to the occurrence of states of nature in the future

# Payoff Table

- Payoff table
  - method for organizing and illustrating payoffs from different decisions given various states of nature
- Payoff
  - outcome of a decision

| Decision | States Of Nature a | b |
|---|---|---|
| 1 | Payoff 1a | Payoff 1b |
| 2 | Payoff 2a | Payoff 2b |

# Decision Making Criteria Under Uncertainty

- Maximax
  - choose decision with the maximum of the maximum payoffs
- Maximin
  - choose decision with the maximum of the minimum payoffs
- Minimax regret
  - choose decision with the minimum of the maximum regrets for each alternative

# Decision Making Criteria Under Uncertainty (cont.)

- Hurwicz
  - choose decision in which decision payoffs are weighted by a coefficient of optimism, alpha
  - coefficient of optimism is a measure of a decision maker's optimism, from *0* (completely pessimistic) to *1* (completely optimistic)
- Equal likelihood (La Place)
  - choose decision in which each state of nature is weighted equally

# Southern Textile Company

| | STATES OF NATURE | |
|---|---|---|
| **DECISION** | ***Good Foreign Competitive Conditions*** | ***Poor Foreign Competitive Conditions*** |
| **Expand** | **$ 800,000** | **$ 500,000** |
| **Maintain status quo** | **1,300,000** | **-150,000** |
| **Sell now** | **320,000** | **320,000** |

# Maximax Solution

| DECISION | STATES OF NATURE: *Good Foreign Competitive Conditions* | *Poor Foreign Competitive Conditions* |
|---|---|---|
| Expand | $ 800,000 | $ 500,000 |
| Maintain status quo | 1,300,000 | -150,000 |
| Sell now | 320,000 | 320,000 |

| | | |
|---|---|---|
| *Expand:* | $800,000 | |
| *Status quo:* | 1,300,000 | ← *Maximum* |
| *Sell:* | 320,000 | |

***Decision: Maintain status quo***

# Maximin Solution

| | STATES OF NATURE | |
|---|---|---|
| DECISION | *Good Foreign Competitive Conditions* | *Poor Foreign Competitive Conditions* |
| **Expand** | **$ 800,000** | **$ 500,000** |
| **Maintain status quo** | **1,300,000** | **-150,000** |
| **Sell now** | **320,000** | **320,000** |

| | | |
|---|---|---|
| ***Expand:*** | **$500,000** | ← ***Maximum*** |
| ***Status quo:*** | **-150,000** | |
| ***Sell:*** | **320,000** | |

***Decision: Expand***

# Minimax Regret Solution

| Good Foreign Competitive Conditions | Poor Foreign Competitive Conditions |
|---|---|
| **$1,300,000 - 800,000 = 500,000** | **$500,000 - 500,000 = 0** |
| **1,300,000 - 1,300,000 = 0** | **500,000 - (-150,000)= 650,000** |
| **1,300,000 - 320,000 = 980,000** | **500,000 - 320,000= 180,000** |

| | | |
|---|---|---|
| ***Expand:*** | **$500,000** | ← ***Minimum*** |
| ***Status quo:*** | **650,000** | |
| ***Sell:*** | **980,000** | |

***Decision: Expand***

# Hurwicz Criteria

| | STATES OF NATURE | |
|---|---|---|
| **DECISION** | *Good Foreign Competitive Conditions* | *Poor Foreign Competitive Conditions* |
| Expand | $ 800,000 | $ 500,000 |
| Maintain status quo | 1,300,000 | -150,000 |
| Sell now | 320,000 | 320,000 |

$\alpha = 0.3$ $\quad$ $1 - \alpha = 0.7$

***Expand:*** **$800,000(0.3) + 500,000(0.7) = $590,000** ← ***Maximum***

***Status quo:*** **1,300,000(0.3) -150,000(0.7) = 285,000**

***Sell:*** **320,000(0.3) + 320,000(0.7) = 320,000**

***Decision: Expand***

# Equal Likelihood Criteria

| DECISION | STATES OF NATURE: *Good Foreign Competitive Conditions* | STATES OF NATURE: *Poor Foreign Competitive Conditions* |
|---|---|---|
| Expand | $ 800,000 | $ 500,000 |
| Maintain status quo | 1,300,000 | -150,000 |
| Sell now | 320,000 | 320,000 |

**Two states of nature each weighted 0.50**

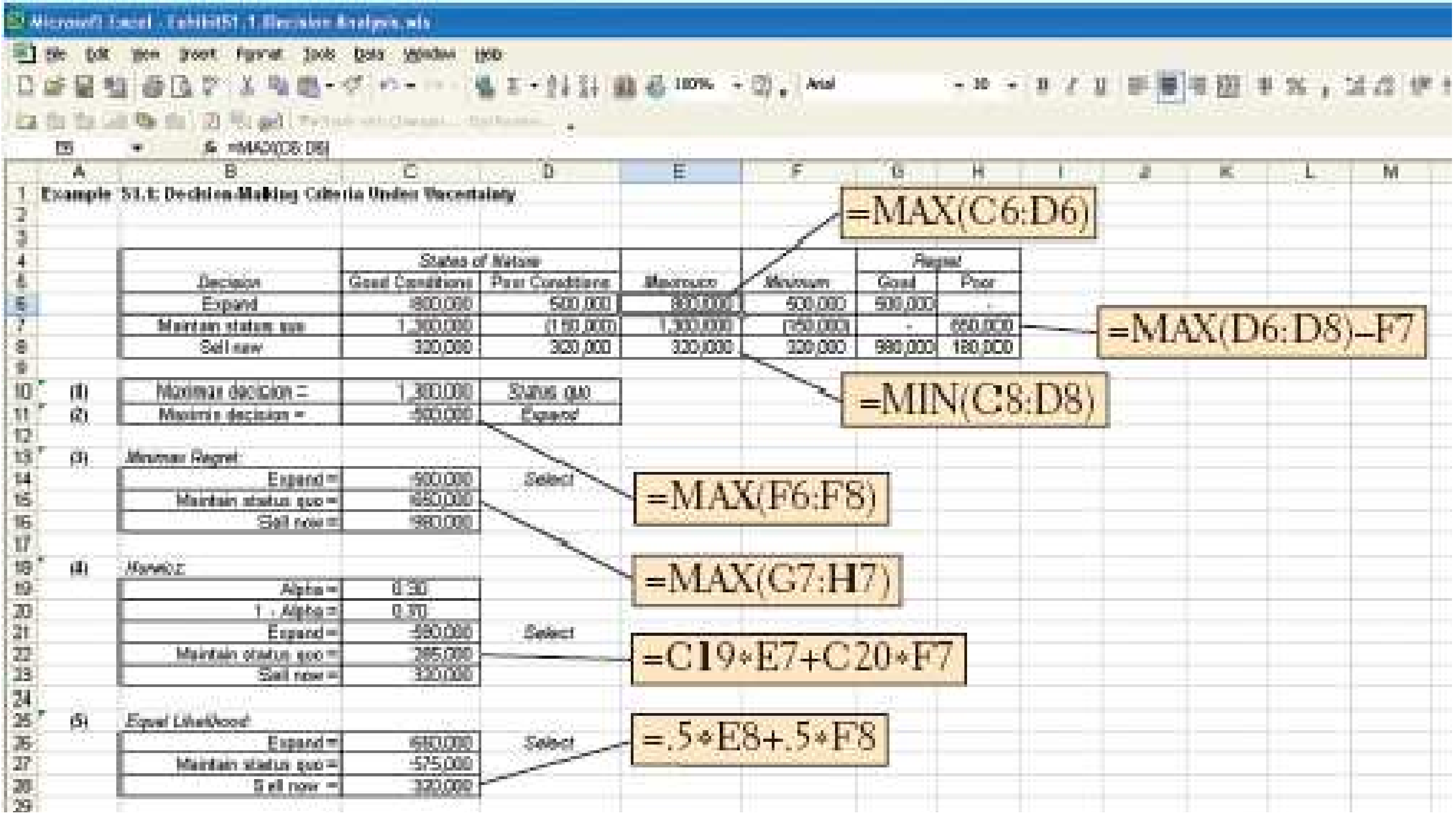
***Expand:*** **$800,000(0.5) + 500,000(0.5) = $650,000** ← ***Maximum***

***Status quo:*** **1,300,000(0.5) -150,000(0.5) = 575,000**

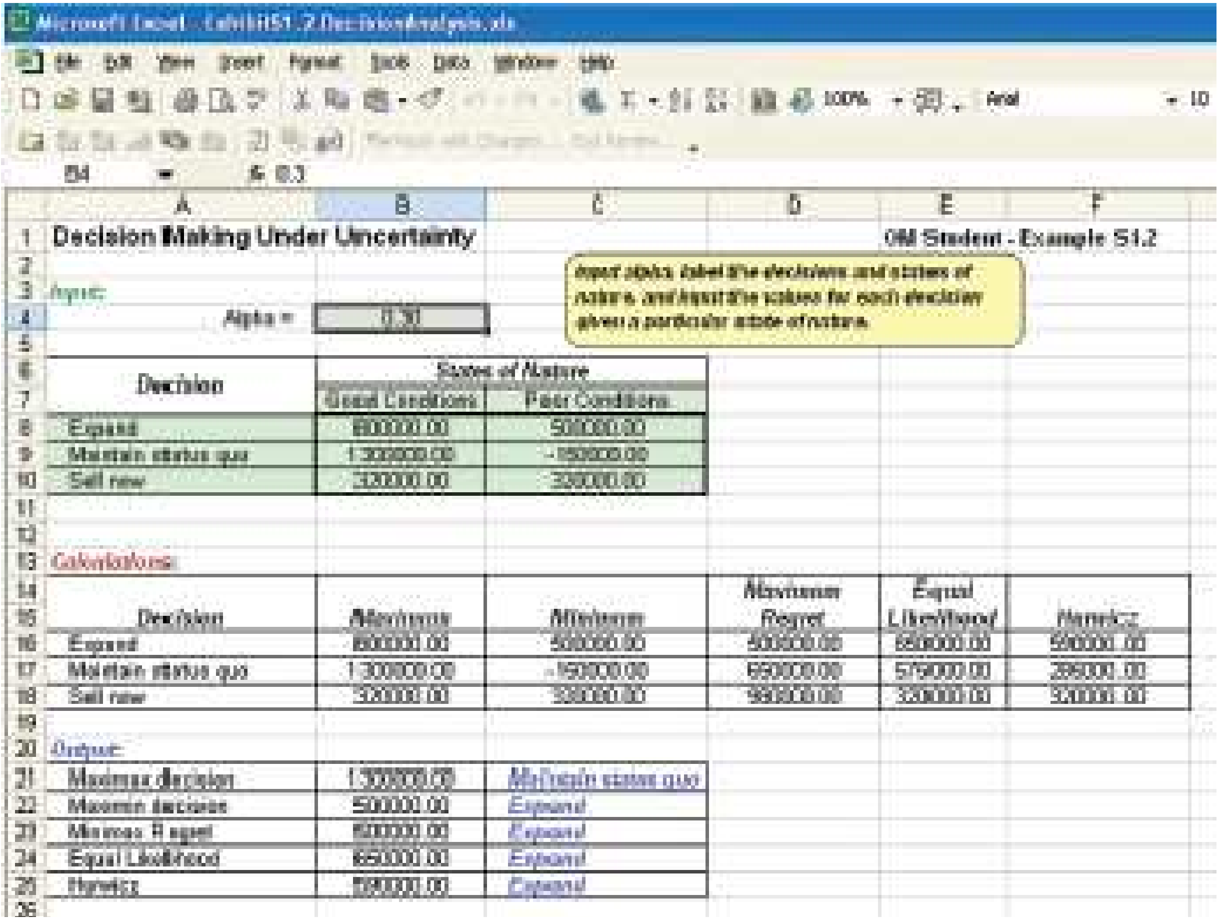
***Sell:*** **320,000(0.5) + 320,000(0.5) = 320,000**

***Decision: Expand***

# Decision Analysis with Excel



# Decision Analysis with OM Tools



Decision Making Under Uncertainty — OM Student - Example S1.2

Input alpha, label the decisions and states of nature, and input the values for each decision given a particular state of nature.

Input:

Alpha = 0.30

| Decision | States of Nature: Good Conditions | States of Nature: Poor Conditions |
|---|---|---|
| Expand | 800000.00 | 500000.00 |
| Maintain status quo | 1300000.00 | -150000.00 |
| Sell now | 320000.00 | 320000.00 |

Calculations:

| Decision | Maximum | Minimum | Maximum Regret | Equal Likelihood | Hurwicz |
|---|---|---|---|---|---|
| Expand | 800000.00 | 500000.00 | 500000.00 | 650000.00 | 590000.00 |
| Maintain status quo | 1300000.00 | -150000.00 | 650000.00 | 575000.00 | 285000.00 |
| Sell now | 320000.00 | 320000.00 | 980000.00 | 320000.00 | 320000.00 |

Output:

| | | |
|---|---|---|
| Maximax decision | 1300000.00 | Maintain status quo |
| Maximin decision | 500000.00 | Expand |
| Minimax Regret | 500000.00 | Expand |
| Equal Likelihood | 650000.00 | Expand |
| Hurwicz | 590000.00 | Expand |

# Decision Making with Probabilities

- Risk involves assigning probabilities to states of nature
- Expected value
  - a weighted average of decision outcomes in which each future state of nature is assigned a probability of occurrence

# Expected value

$$EV(x) = \sum_{i=1}^{n} p(x_i)x_i$$

*where*

$x_i$ = outcome *i*

$p(x_i)$ = probability of outcome *i*

# Decision Making with Probabilities: Example

| DECISION | STATES OF NATURE<br>*Good Foreign Competitive Conditions* | <br>*Poor Foreign Competitive Conditions* |
|---|---|---|
| Expand | $ 800,000 | $ 500,000 |
| Maintain status quo | 1,300,000 | -150,000 |
| Sell now | 320,000 | 320,000 |

p(good) = 0.70 p(poor) = 0.30

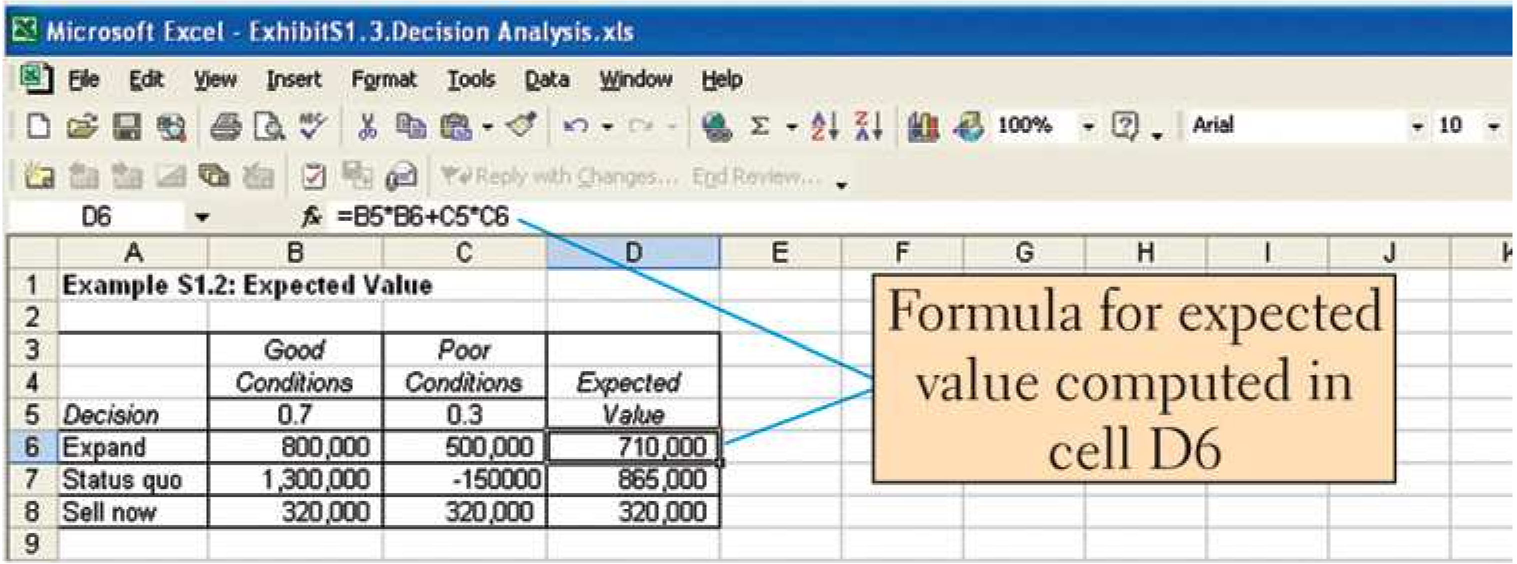
EV(expand): $800,000(0.7) + 500,000(0.3) = $710,000

EV(status quo): 1,300,000(0.7) -150,000(0.3) = 865,000 ← Maximum

EV(sell): 320,000(0.7) + 320,000(0.3) = 320,000

**Decision: Status quo**

# Decision Making with Probabilities: Excel




| | A | B | C | D |
|---|---|---|---|---|
| 1 | **Example S1.2: Expected Value** | | | |
| 2 | | | | |
| 3 | | *Good* | *Poor* | |
| 4 | | *Conditions* | *Conditions* | *Expected* |
| 5 | *Decision* | 0.7 | 0.3 | *Value* |
| 6 | Expand | 800,000 | 500,000 | 710,000 |
| 7 | Status quo | 1,300,000 | -150000 | 865,000 |
| 8 | Sell now | 320,000 | 320,000 | 320,000 |
| 9 | | | | |

# Expected Value of Perfect Information

- **EVPI**
  - maximum value of perfect information to the decision maker
  - maximum amount that would be paid to gain information that would result in a decision better than the one made without perfect information

# EVPI Example

- Good conditions will exist *70%* of the time
  - choose maintain status quo with payoff of *$1,300,000*
- Poor conditions will exist *30%* of the time
  - choose expand with payoff of *$500,000*
- Expected value given perfect information

  = *$1,300,000 (0.70) + 500,000 (0.30)*

  = *$1,060,000*
- Recall that expected value without perfect information was $865,000 (maintain status quo)
- EVPI= *$1,060,000 - 865,000 = $195,000*

# Sequential Decision Trees

- A graphical method for analyzing decision situations that require a sequence of decisions over time
- Decision tree consists of
  - Square nodes - indicating decision points
  - Circles nodes - indicating states of nature
  - Arcs - connecting nodes

# Evaluations at Nodes

Compute EV at nodes 6 & 7

EV(node 6)= *0.80($3,000,000)* + *0.20($700,000)* = *$2,540,000*

EV(node 7)= *0.30($2,300,000)* + *0.70($1,000,000)*= *$1,390,000*

Decision at node 4 is between

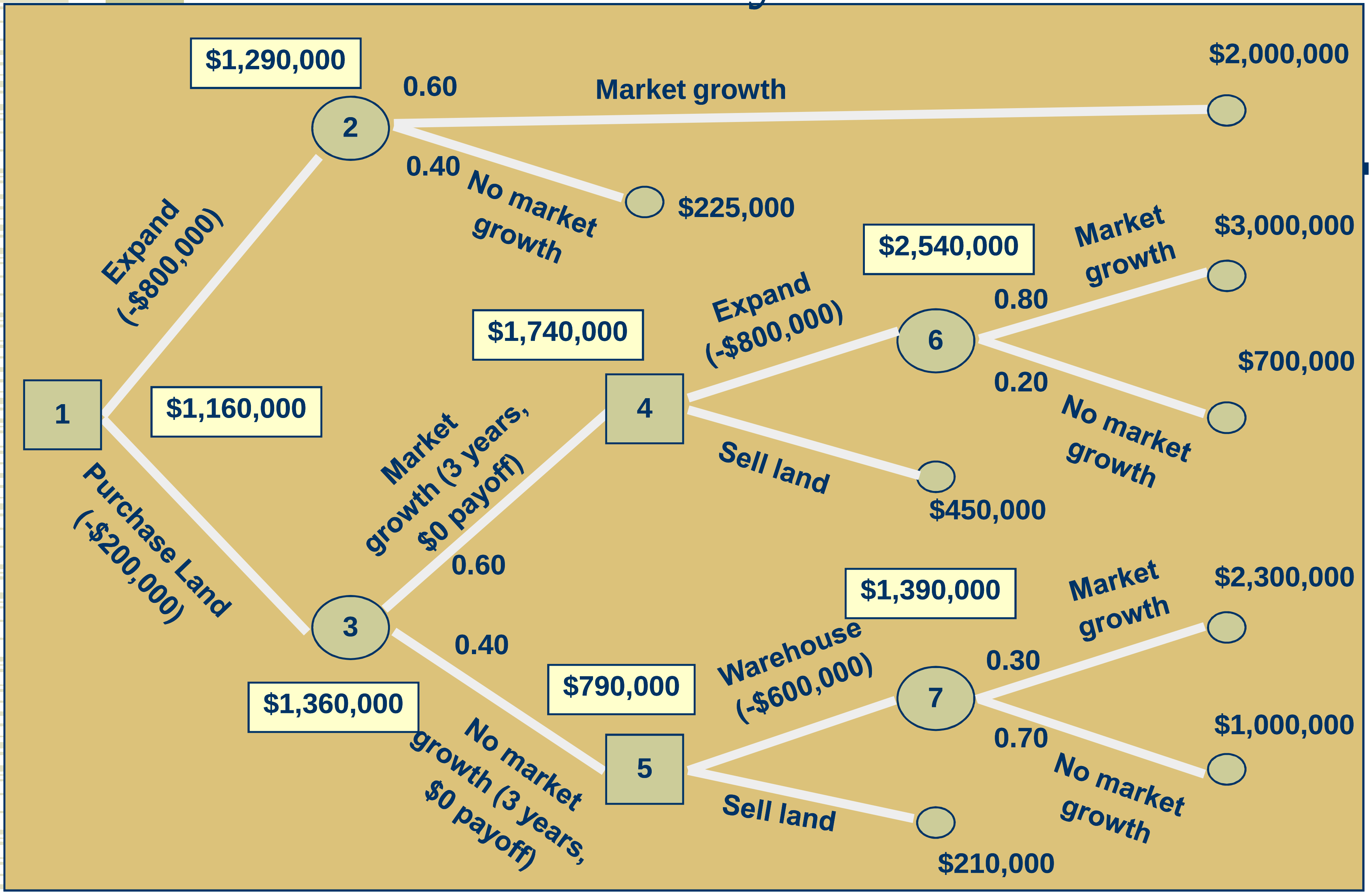
*$2,540,000* for Expand and

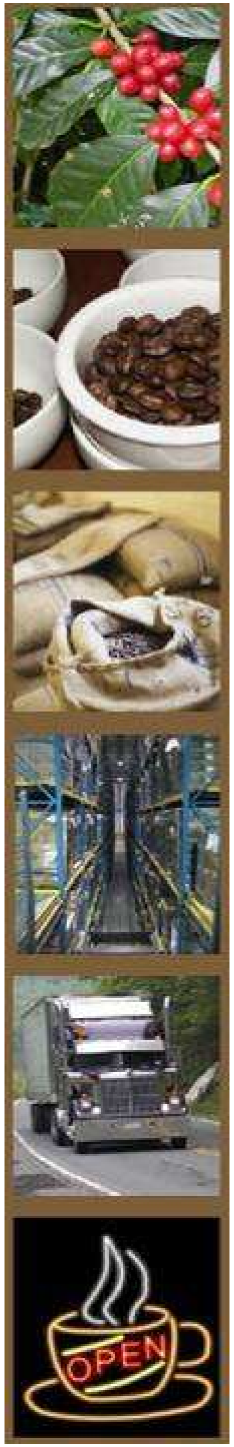
*$450,000* for Sell land

Choose Expand

Repeat expected value calculations and decisions at remaining nodes

# Decision Tree Analysis





# Chapter 2

## *Quality Management*

*Operations Management*

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- What Is Quality?
- Evolution of Quality Management
- Quality Tools
- TQM and QMS
- Focus of Quality Management—Customers
- Role of Employees in Quality Improvement
- Quality in Service Companies
- Six Sigma
- Cost of Quality
- Effect of Quality Management on Productivity
- Quality Awards
- ISO 9000

# What Is Quality?

- *Oxford American Dictionary*
  - a degree or level of excellence
- American Society for Quality
  - totality of features and characteristics that satisfy needs without deficiencies
- Consumer’s and producer’s perspective

# What Is Quality: Customer's Perspective

- **Fitness for use**
  - how well product or service does what it is supposed to
- **Quality of design**
  - designing quality characteristics into a product or service
- A Mercedes and a Ford are equally "fit for use," but with different design dimensions.

# Dimensions of Quality: Manufactured Products

- Performance
  - basic operating characteristics of a product; how well a car handles or its gas mileage
- Features
  - “extra” items added to basic features, such as a stereo CD or a leather interior in a car
- Reliability
  - probability that a product will operate properly within an expected time frame; that is, a TV will work without repair for about seven years

# Dimensions of Quality: Manufactured Products (cont.)

- Conformance
  - degree to which a product meets pre–established standards
- Durability
  - how long product lasts before replacement; with care, L.L.Bean boots may last a lifetime
- Serviceability
  - ease of getting repairs, speed of repairs, courtesy and competence of repair person

# Dimensions of Quality: Manufactured Products (cont.)

- Aesthetics
  - how a product looks, feels, sounds, smells, or tastes
- Safety
  - assurance that customer will not suffer injury or harm from a product; an especially important consideration for automobiles
- Perceptions
  - subjective perceptions based on brand name, advertising, and like

# Dimensions of Quality: Services

- Time and timeliness
  - how long must a customer wait for service, and is it completed on time?
  - is an overnight package delivered overnight?
- Completeness:
  - is everything customer asked for provided?
  - is a mail order from a catalogue company complete when delivered?

# Dimensions of Quality: Service (cont.)

- Courtesy:
  - how are customers treated by employees?
  - are catalogue phone operators nice and are their voices pleasant?
- Consistency
  - is same level of service provided to each customer each time?
  - is your newspaper delivered on time every morning?

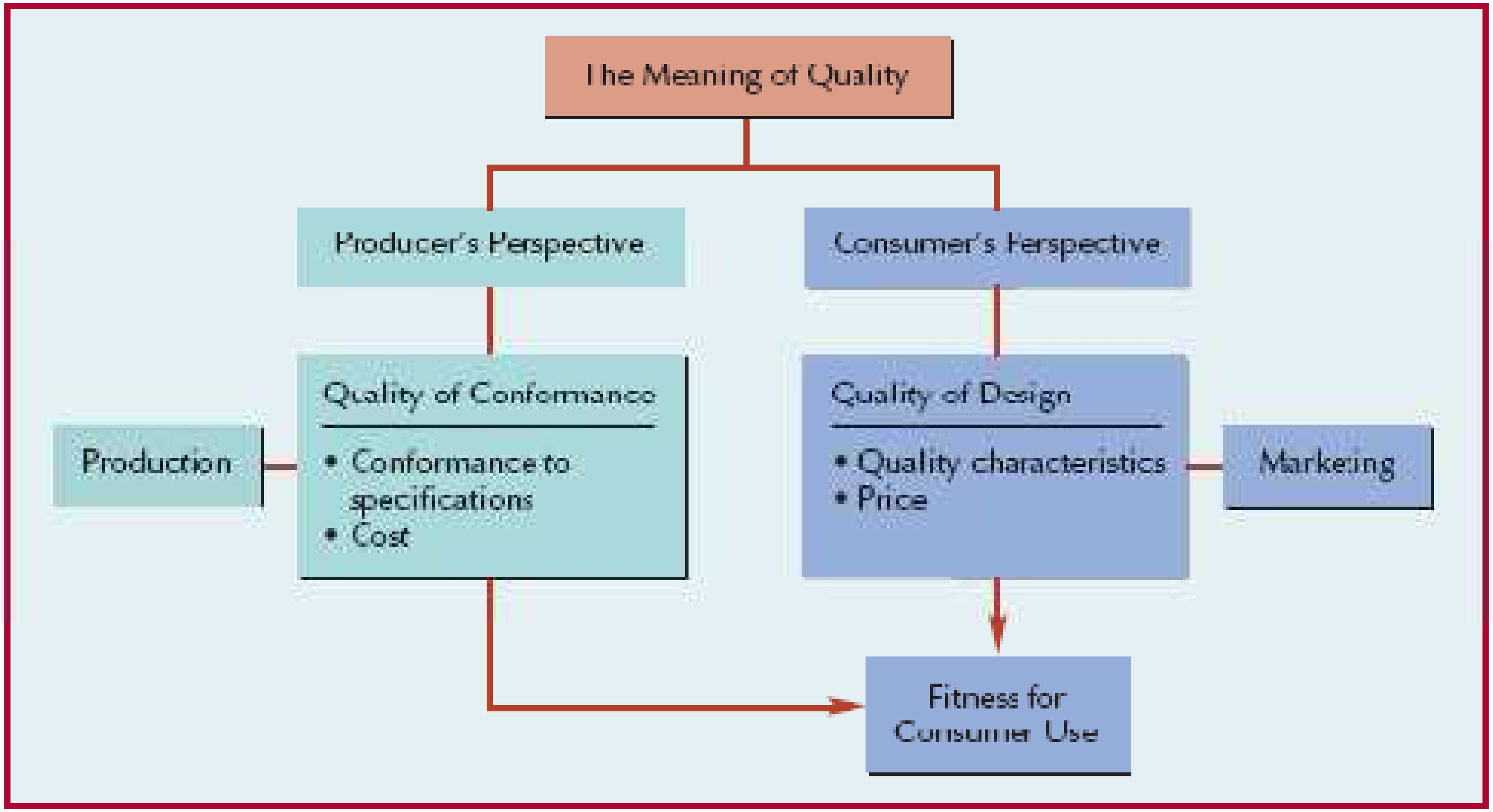
# Dimensions of Quality: Service (cont.)

- Accessibility and convenience
  - how easy is it to obtain service?
  - does service representative answer you calls quickly?
- Accuracy
  - is service performed right every time?
  - is your bank or credit card statement correct every month?
- Responsiveness
  - how well does company react to unusual situations?
  - how well is a telephone operator able to respond to a customer’s questions?

# What Is Quality: Producer's Perspective

- Quality of conformance
  - making sure product or service is produced according to design
    - if new tires do not conform to specifications, they wobble
    - if a hotel room is not clean when a guest checks in, hotel is not functioning according to specifications of its design

# Meaning of Quality



# What Is Quality: A Final Perspective

- Customer's and producer's perspectives depend on each other
- Producer's perspective:
  - production process and COST
- Customer's perspective:
  - fitness for use and PRICE
- Customer's view must dominate

# Evolution of Quality Management: Quality Gurus

- Walter Shewart
  - In 1920s, developed control charts
  - Introduced term "*quality assurance*"
- W. Edwards Deming
  - Developed courses during World War II to teach statistical quality-control techniques to engineers and executives of companies that were military suppliers
  - After war, began teaching statistical quality control to Japanese companies
- Joseph M. Juran
  - Followed Deming to Japan in 1954
  - Focused on strategic quality planning
  - Quality improvement achieved by focusing on projects to solve problems and securing breakthrough solutions

# Evolution of Quality Management: Quality Gurus (cont.)

- Armand V. Feigenbaum
  - In 1951, introduced concepts of total quality control and continuous quality improvement
- Philip Crosby
  - In 1979, emphasized that costs of poor quality far outweigh cost of preventing poor quality
  - In 1984, defined absolutes of quality management—conformance to requirements, prevention, and “zero defects”
- Kaoru Ishikawa
  - Promoted use of quality circles
  - Developed “fishbone” diagram
  - Emphasized importance of internal customer

# Deming's 14 Points

1. ***Create constancy of purpose***
2. ***Adopt philosophy of prevention***
3. ***Cease mass inspection***
4. ***Select a few suppliers based on quality***
5. ***Constantly improve system and workers***

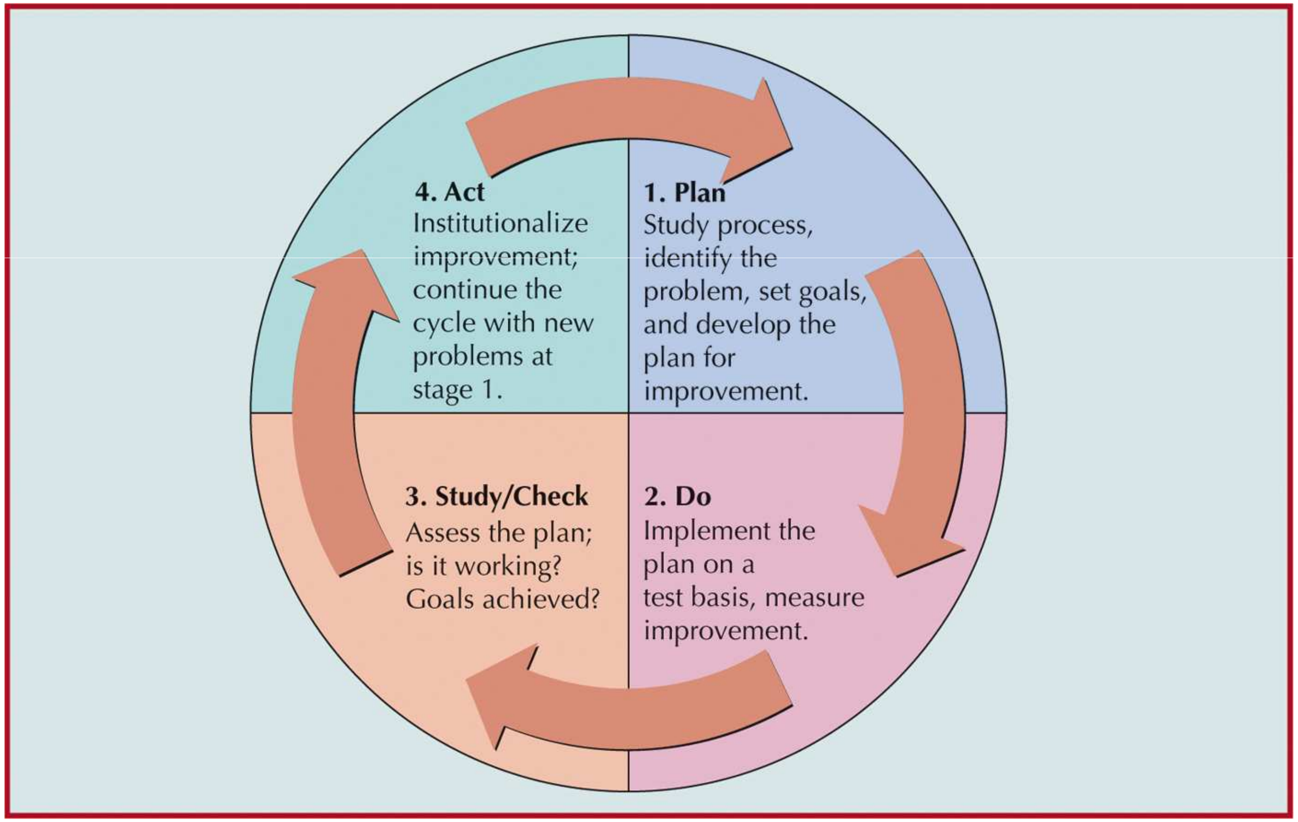
# Deming's 14 Points (cont.)

6. ***Institute worker training***
7. ***Instill leadership among supervisors***
8. ***Eliminate fear among employees***
9. ***Eliminate barriers between departments***
10. ***Eliminate slogans***

# Deming’s 14 Points (cont.)

11. ***Remove numerical quotas***
12. ***Enhance worker pride***
13. ***Institute vigorous training and education programs***
14. ***Develop a commitment from top management to implement above 13 points***

# Deming Wheel: PDCA Cycle

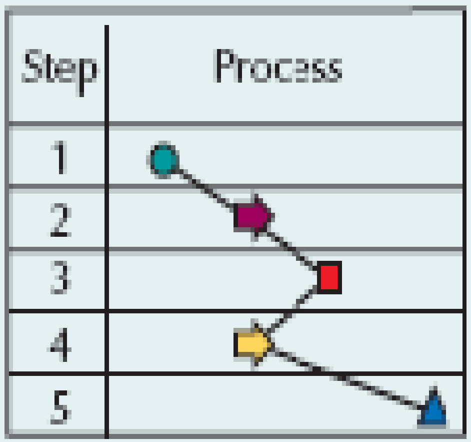


# Quality Tools

- Process Flow Chart
- Cause-and-Effect Diagram
- Check Sheet
- Pareto Analysis
- Histogram
- Scatter Diagram
- Statistical Process Control Chart

# Flow Chart

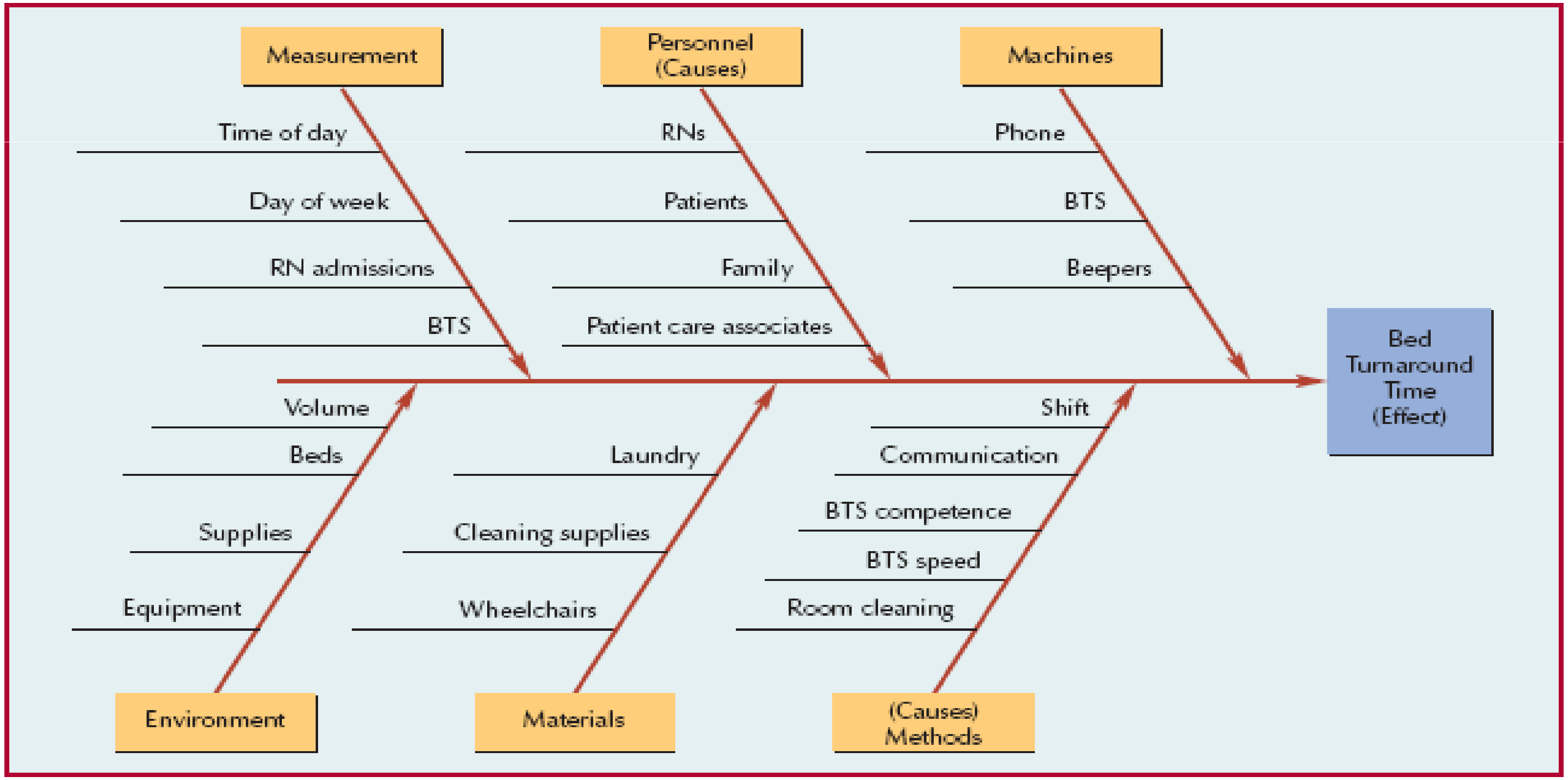
**Process Flowchart**




A diagram of the steps in a process; helps focus on where in a process a quality problem might exist.

# Cause-and-Effect Diagram

- Cause-and-effect diagram ("fishbone" diagram)
  - chart showing different categories of problem causes



# Cause-and-Effect Matrix

- Cause-and-effect matrix
  - grid used to prioritize causes of quality problems

| | Key Input (X) Variables | Customer rank / Weight | Key Output (Y) Variables (CTQC's) | | | | | | Score | Rank of X Variables/ Importance to Customer |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 Turnaround time | 2 Patient flow | 3 Physician time | 4 Emergency dept. | 5 Patient time | 6 Operating room | | |
| | | Customer rank | 1 | 3 | 2 | 5 | 6 | 4 | | |
| | | Weight | *10* | *9* | *9* | *7* | *7* | *8* | | |
| 1 | BTS | | 9 | 8 | 10 | 8 | | 5 | 348 | 3 |
| 2 | Beepers | | 7 | 5 | 8 | | 5 | | 222 | 7 |
| 3 | Volume | | 7 | 10 | 6 | 7 | 5 | 5 | 338 | 4 |
| 4 | Beds | | 4 | | 9 | | | | 121 | 10 |
| 5 | Time of day | | 3 | 4 | 5 | 4 | 10 | | 239 | 8 |
| 6 | Day of week | | 9 | 10 | 6 | | | 6 | 232 | 5 |
| 7 | Communication | | 9 | 8 | 10 | 8 | 7 | 9 | 429 | 1 |
| 8 | BTS competence | | 10 | 9 | 7 | | 7 | 7 | 349 | 2 |
| 9 | Room cleaning | | 7 | 5 | 3 | | 8 | 4 | 230 | 6 |
| 10 | Supplies | | 8 | 9 | | | | | 161 | 9 |

$(8)(10) + (9)(9) - 161$

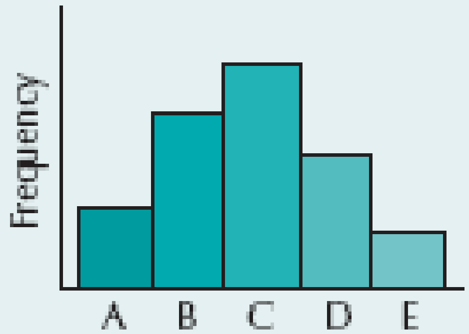
# Check Sheets and Histograms

**Check Sheet**

| Items | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| Dirt | ✓✓ | | | ✓✓ |
| Old | | ✓ | | ✓ |
| Temp. | ✓ | ✓✓ | ✓✓ | |
| Fault | ✓✓✓ | | ✓✓ | |

A fact-finding tool for tallying the number of defects for a list of previously identified problem causes.

**Histogram**



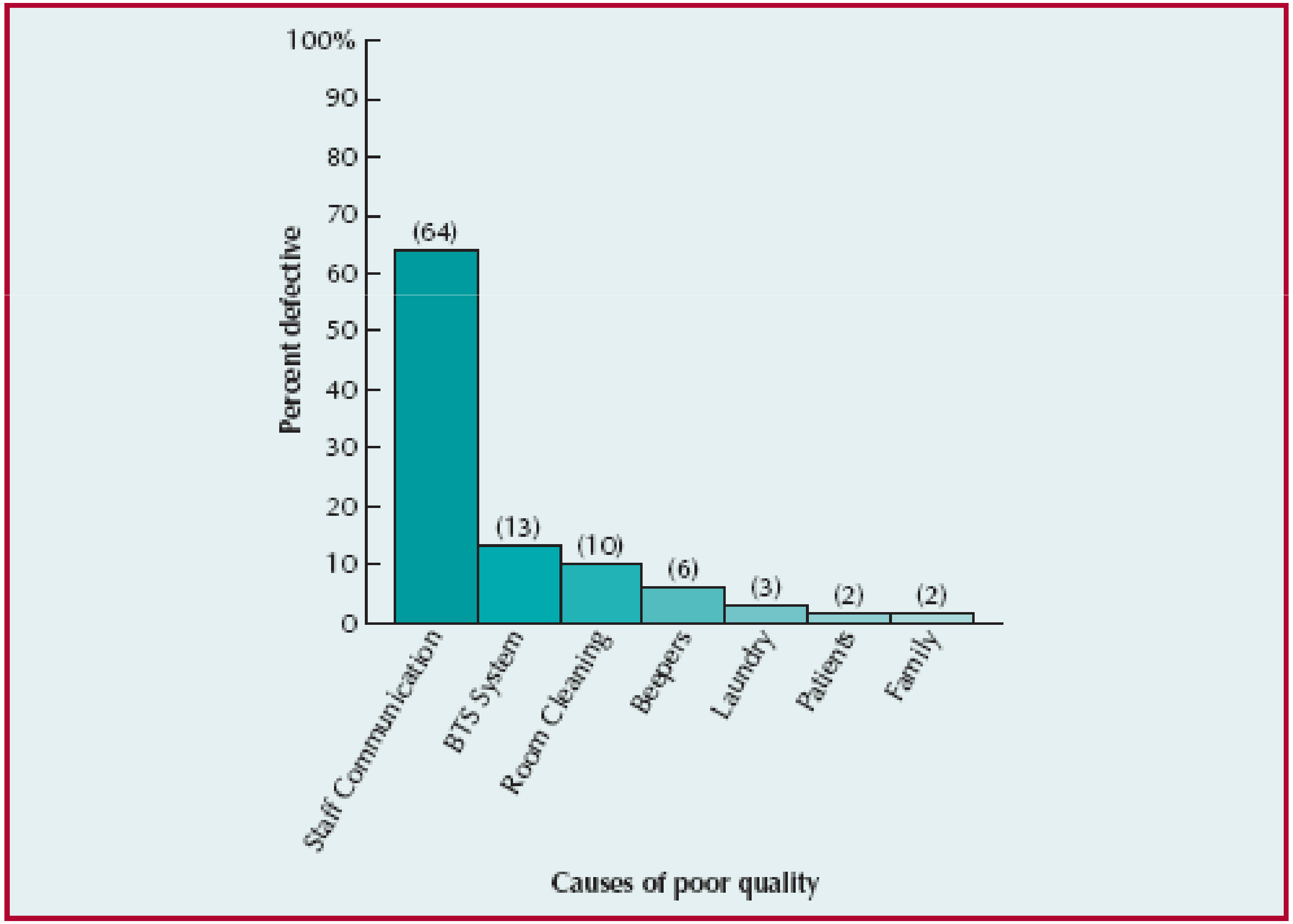

A diagram showing the frequency of data related to a quality problem.

# Pareto Analysis

- Pareto analysis
  - most quality problems result from a few causes

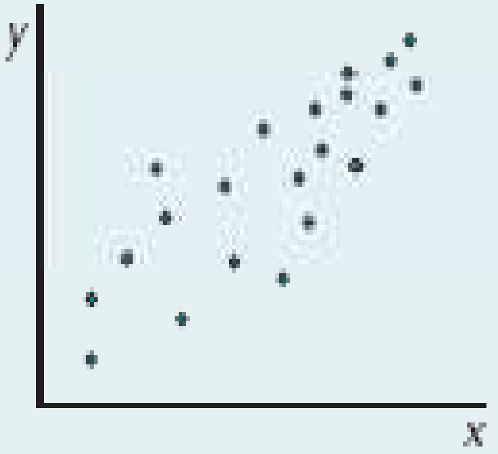
| *Cause* | *Number of Defects* | *Percentage* |
|---|---|---|
| Staff communication | 83 | 64% |
| BTS system | 17 | 13 |
| Room cleaning | 13 | 10 |
| Beepers | 7 | 6 |
| Laundry | 4 | 3 |
| Patients | 3 | 2 |
| Family | 3 | 2 |
| | 130 | 100% |

# Pareto Chart



# Scatter Diagram

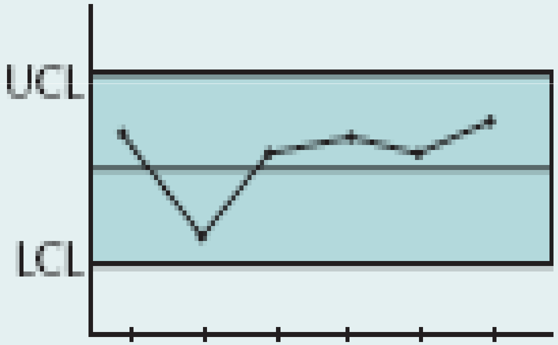
Scatter Diagram




A graph showing the relationship between two variables in a process; identifies a pattern that may cause a quality problem.

# Control Chart

**Statistical Process Control Chart**




A chart with statistical upper and lower limits; if the process stays between these limits over time, it is in control and a problem does not exist.

# TQM and QMS

- **Total Quality Management (TQM)**
  - **customer-oriented, leadership, strategic planning, employee responsibility, continuous improvement, cooperation, statistical methods, and training and education**
- **Quality Management System (QMS)**
  - **system to achieve customer satisfaction that complements other company systems**

# Focus of Quality Management—Customers

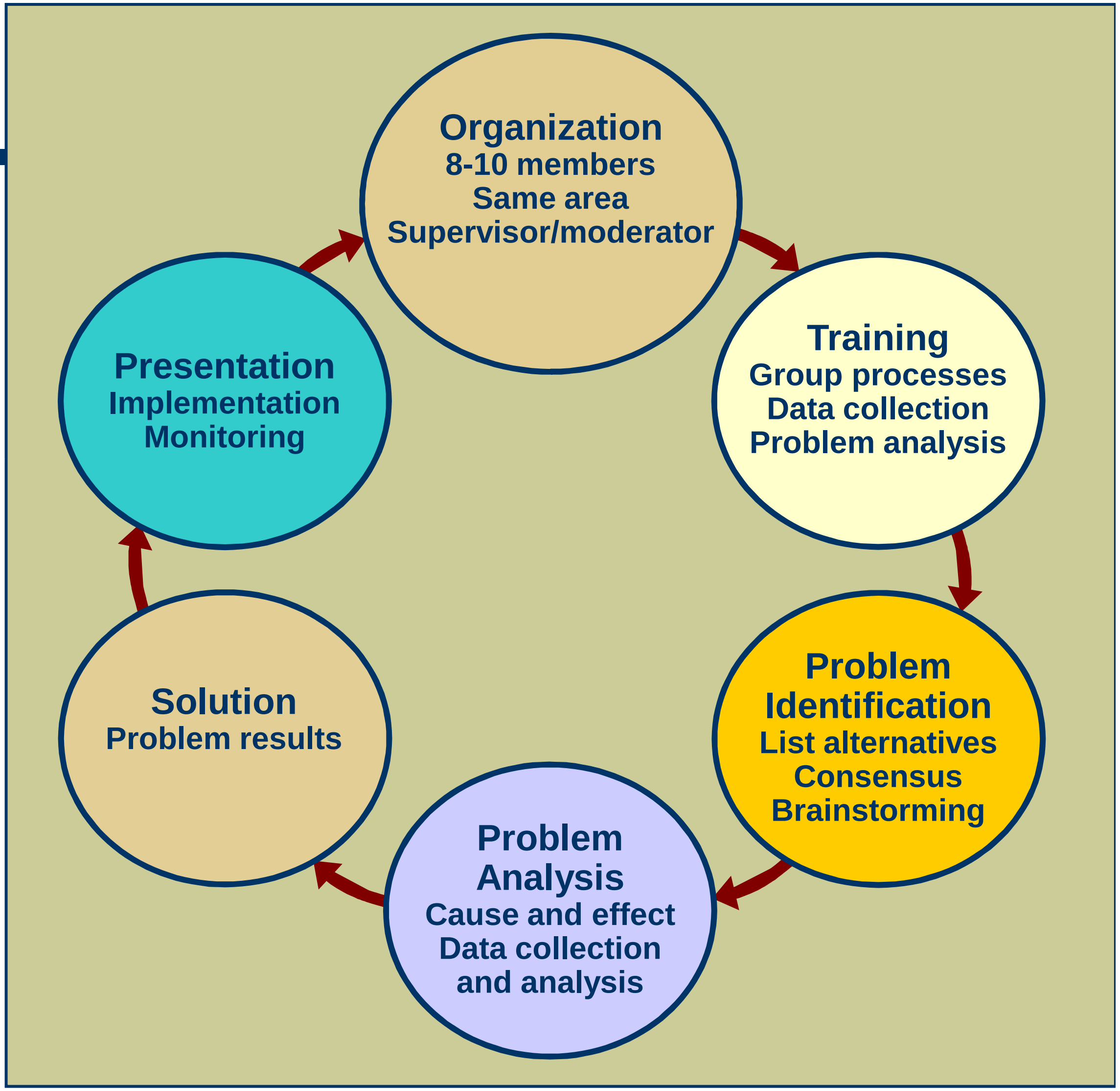
- **TQM and QMSs**
  - **serve to achieve customer satisfaction**
- **Partnering**
  - **a relationship between a company and its supplier based on mutual quality standards**
- **Measuring customer satisfaction**
  - **important component of any QMS**
  - **customer surveys, telephone interviews**

# Role of Employees in Quality Improvement

- **Participative problem solving**
  - employees involved in quality-management
  - every employee has undergone extensive training to provide quality service to Disney's guests
- **Kaizen**
  - involves everyone in process of continuous improvement

# Quality Circles and QITs

- Quality circle
  - group of workers and supervisors from same area who address quality problems
- Process/Quality improvement teams (QITs)
  - focus attention on business processes rather than separate company functions



# Quality in Services

- Service defects are not always easy to measure because service output is not usually a tangible item
- Services tend to be labor intensive
- Services and manufacturing companies have similar inputs but different processes and outputs

# Quality Attributes in Services

- Principles of TQM apply equally well to services and manufacturing
- Timeliness
  - how quickly a service is provided?
- Benchmark
  - "best" level of quality achievement in one company that other companies seek to achieve

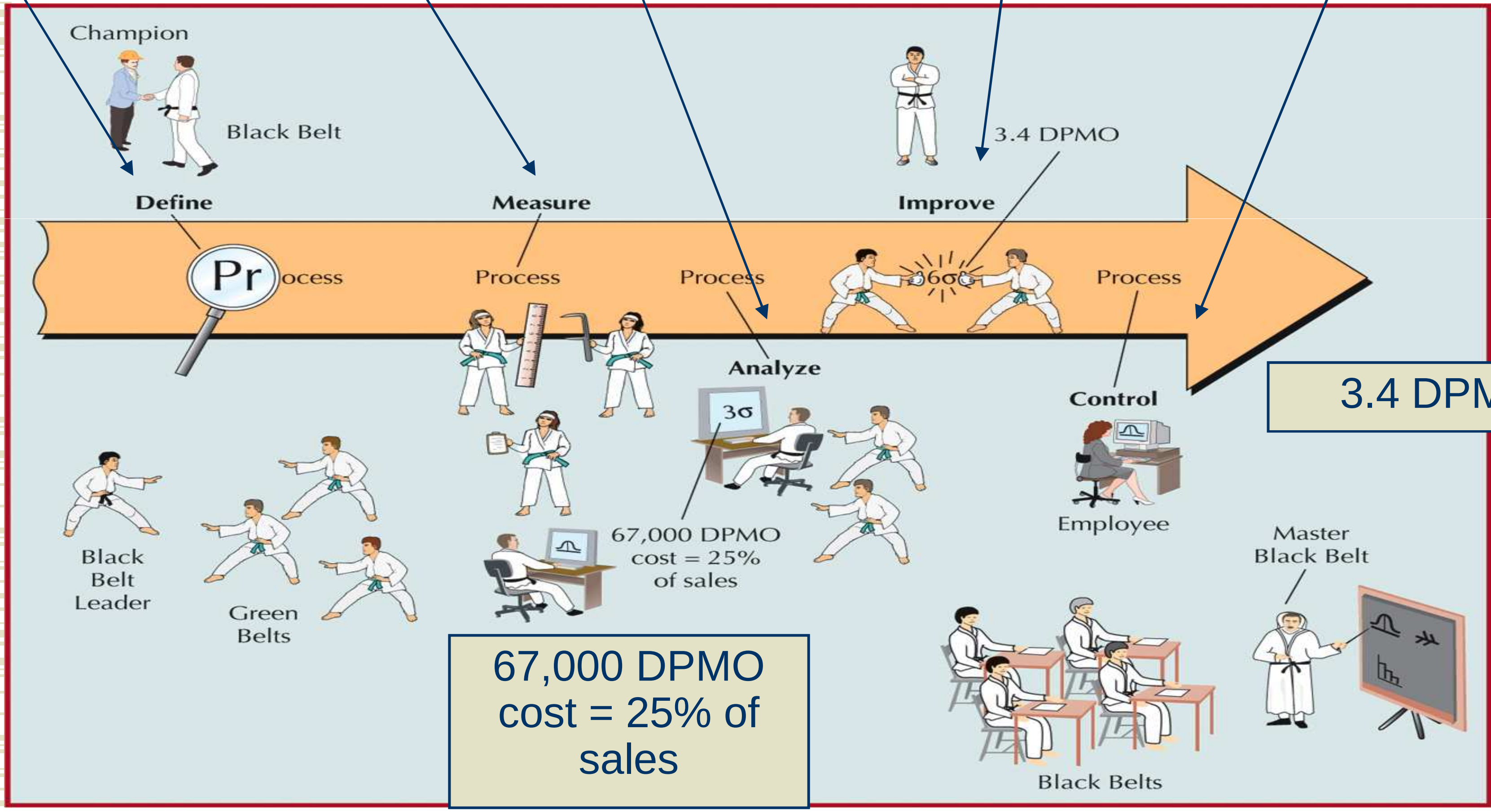
*"quickest, friendliest, most accurate service available."*

# Six Sigma

- A process for developing and delivering virtually perfect products and services
- Measure of how much a process deviates from perfection
- 3.4 defects per million opportunities
- Six Sigma Process
  - four basic steps of Six Sigma—align, mobilize, accelerate, and govern
- Champion
  - an executive responsible for project success

# Six Sigma:
# Breakthrough Strategy—DMAIC

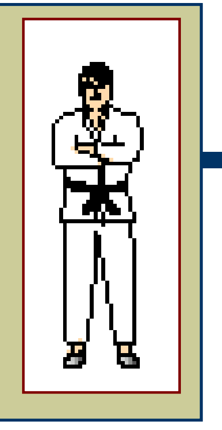
DEFINE
MEASURE
ANALYZE
IMPROVE
CONTROL



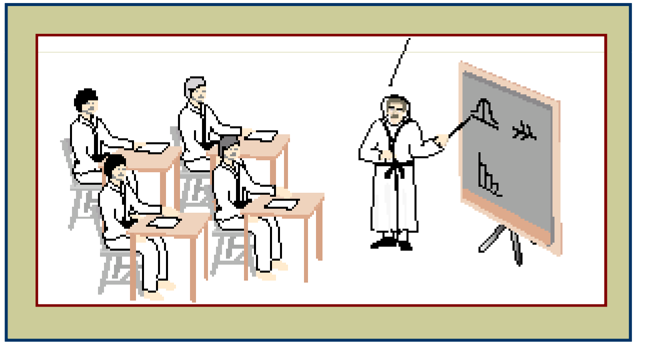

3.4 DPMO

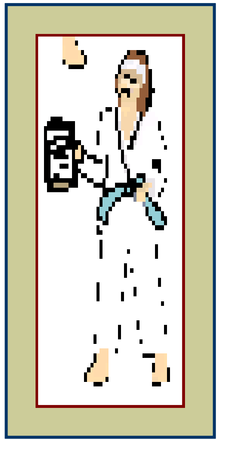
67,000 DPMO cost = 25% of sales

# Six Sigma:
## Black Belts and Green Belts



- **Black Belt**
  - project leader
- **Master Black Belt**
  - a teacher and mentor for Black Belts
- **Green Belts**
  - project team members





# Six Sigma

- Design for Six Sigma (DFSS)
  - a systematic approach to designing products and processes that will achieve Six Sigma
- Profitability
  - typical criterion for selection Six Sigma project
  - one of the factors distinguishing Six Sigma from TQM
  - "Quality is not only free, it is an honest-to-everything profit maker."

# Cost of Quality

- Cost of Achieving Good Quality
  - Prevention costs
    - costs incurred during product design
  - Appraisal costs
    - costs of measuring, testing, and analyzing
- Cost of Poor Quality
  - Internal failure costs
    - include scrap, rework, process failure, downtime, and price reductions
  - External failure costs
    - include complaints, returns, warranty claims, liability, and lost sales

# Prevention Costs

- Quality planning costs
  - costs of developing and implementing quality management program
- Product-design costs
  - costs of designing products with quality characteristics
- Process costs
  - costs expended to make sure productive process conforms to quality specifications
- Training costs
  - costs of developing and putting on quality training programs for employees and management
- Information costs
  - costs of acquiring and maintaining data related to quality, and development and analysis of reports on quality performance

# Appraisal Costs

- Inspection and testing
  - costs of testing and inspecting materials, parts, and product at various stages and at end of process
- Test equipment costs
  - costs of maintaining equipment used in testing quality characteristics of products
- Operator costs
  - costs of time spent by operators to gather data for testing product quality, to make equipment adjustments to maintain quality, and to stop work to assess quality

# Internal Failure Costs

- Scrap costs
  - costs of poor-quality products that must be discarded, including labor, material, and indirect costs
- Rework costs
  - costs of fixing defective products to conform to quality specifications
- Process failure costs
  - costs of determining why production process is producing poor-quality products
- Process downtime costs
  - costs of shutting down productive process to fix problem
- Price-downgrading costs
  - costs of discounting poor-quality products—that is, selling products as "seconds"

# External Failure Costs

- Customer complaint costs
  - costs of investigating and satisfactorily responding to a customer complaint resulting from a poor-quality product
- Product return costs
  - costs of handling and replacing poor-quality products returned by customer
- Warranty claims costs
  - costs of complying with product warranties
- Product liability costs
  - litigation costs resulting from product liability and customer injury
- Lost sales costs
  - costs incurred because customers are dissatisfied with poor-quality products and do not make additional purchases

# Measuring and Reporting Quality Costs

- **Index numbers**
  - ratios that measure quality costs against a base value
  - **labor index**
    - ratio of quality cost to labor hours
  - **cost index**
    - ratio of quality cost to manufacturing cost
  - **sales index**
    - ratio of quality cost to sales
  - **production index**
    - ratio of quality cost to units of final product

# Quality–Cost Relationship

- **Cost of quality**
  - difference between price of nonconformance and conformance
  - cost of doing things wrong
    - 20 to 35% of revenues
  - cost of doing things right
    - 3 to 4% of revenues

# Effect of Quality Management on Productivity

- **Productivity**
  - ratio of output to input
- **Quality impact on productivity**
  - fewer defects increase output, and quality improvement reduces inputs
- **Yield**
  - a measure of productivity

**Yield=(total input)(% good units) + (total input)(1-%good units)(% reworked)**

**or**

***Y=(I)(%G)+(I)(1-%G)(%R)***

# Computing Product Cost per Unit

$$\text{Product Cost} = \frac{(K_d)(I) + (K_r)(R)}{Y}$$

*where:*

$K_d$ = direct manufacturing cost per unit

$I$ = input

$K_r$ = rework cost per unit

$R$ = reworked units

$Y$ = yield

# Computing Product Yield for Multistage Processes

$$Y = (I)(\%g_1)(\%g_2)\ \ldots\ (\%g_n)$$

where:

$I$ = input of items to the production process that will result in finished products

$g_i$ = good-quality, work-in-process products at stage $i$

# Quality–Productivity Ratio

QPR

- productivity index that includes productivity and quality costs

$$QPR = \frac{(\text{good-quality units})}{(\text{input})\,(\text{processing cost}) + (\text{reworked units})\,(\text{rework cost})}\,(100)$$

# Malcolm Baldrige Award

- Created in 1987 to stimulate growth of quality management in United States
- Categories
  - Leadership
  - Information and analysis
  - Strategic planning
  - Human resource focus
  - Process management
  - Business results
  - Customer and market focus

# Other Awards for Quality

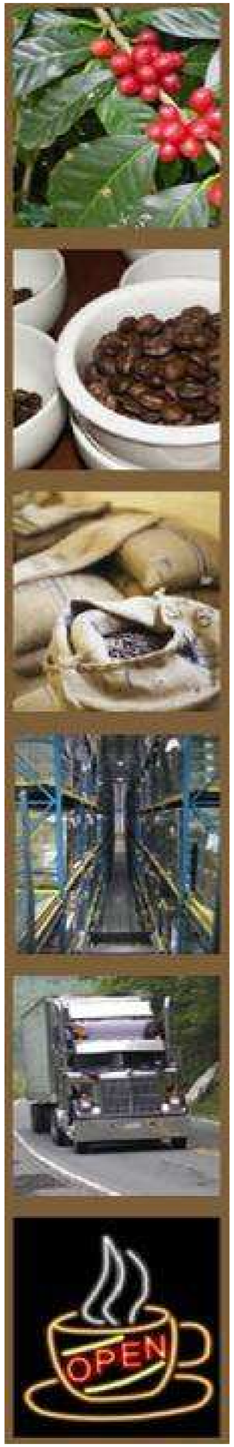
- National individual awards
  - Armand V. Feigenbaum Medal
  - Deming Medal
  - E. Jack Lancaster Medal
  - Edwards Medal
  - Shewart Medal
  - Ishikawa Medal
- International awards
  - European Quality Award
  - Canadian Quality Award
  - Australian Business Excellence Award
  - Deming Prize from Japan

# ISO 9000

- A set of procedures and policies for international quality certification of suppliers
- Standards
  - ISO 9000:2000
    - *Quality Management Systems—Fundamentals and Vocabulary*
    - defines fundamental terms and definitions used in ISO 9000 family
- ISO 9001:2000
  - *Quality Management Systems—Requirements*
  - standard to assess ability to achieve customer satisfaction
- ISO 9004:2000
  - *Quality Management Systems—Guidelines for Performance Improvements*
  - guidance to a company for continual improvement of its quality-management system

# ISO 9000 Certification, Implications, and Registrars

- ISO 9001:2000—only standard that carries third-party *certification*
- Many overseas companies will not do business with a supplier unless it has ISO 9000 certification
- ISO 9000 accreditation
- ISO registrars



# Chapter 3

## *Statistical Process Control*

***Operations Management***

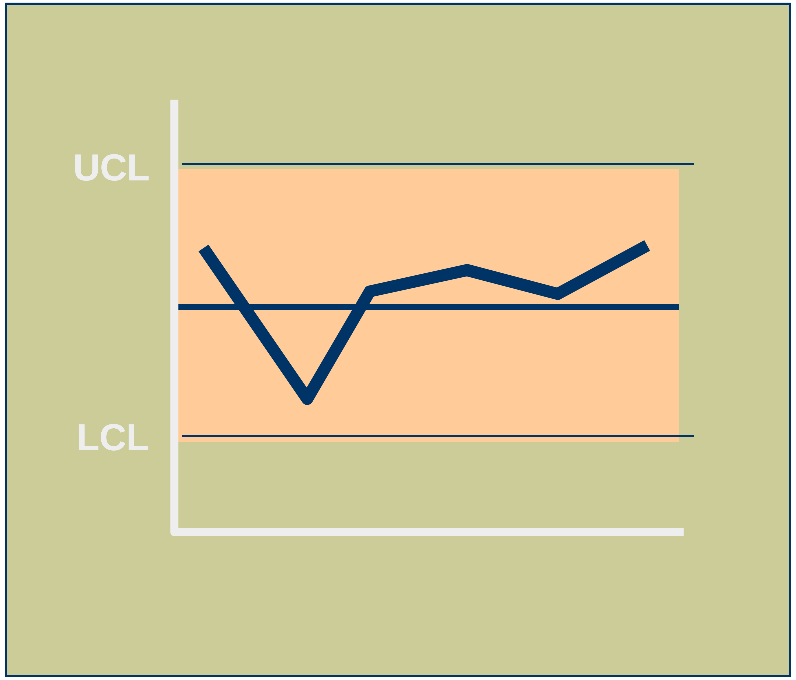
**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Basics of Statistical Process Control
- Control Charts
- Control Charts for Attributes
- Control Charts for Variables
- Control Chart Patterns
- SPC with Excel and OM Tools
- Process Capability

# Basics of Statistical Process Control

- Statistical Process Control (SPC)
  - monitoring production process to detect and prevent poor quality
- Sample
  - subset of items produced to use for inspection
- Control Charts
  - process is within statistical control limits



# Basics of Statistical Process Control (cont.)

- Random
  - inherent in a process
  - depends on equipment and machinery, engineering, operator, and system of measurement
  - natural occurrences
- Non-Random
  - special causes
  - identifiable and correctable
  - include equipment out of adjustment, defective materials, changes in parts or materials, broken machinery or equipment, operator fatigue or poor work methods, or errors due to lack of training

# SPC in Quality Management

- SPC
  - tool for identifying problems in order to make improvements
  - contributes to the TQM goal of continuous improvements

# Quality Measures: Attributes and Variables

- **Attribute**
  - a product characteristic that can be evaluated with a discrete response
  - good – bad; yes - no
- **Variable measure**
  - a product characteristic that is continuous and can be measured
  - weight - length

# SPC Applied to Services

- Nature of defect is different in services
- Service defect is a failure to meet customer requirements
- Monitor time and customer satisfaction

# SPC Applied to Services (cont.)

- Hospitals
  - timeliness and quickness of care, staff responses to requests, accuracy of lab tests, cleanliness, courtesy, accuracy of paperwork, speed of admittance and checkouts
- Grocery stores
  - waiting time to check out, frequency of out-of-stock items, quality of food items, cleanliness, customer complaints, checkout register errors
- Airlines
  - flight delays, lost luggage and luggage handling, waiting time at ticket counters and check-in, agent and flight attendant courtesy, accurate flight information, passenger cabin cleanliness and maintenance

# SPC Applied to Services (cont.)

- Fast-food restaurants
  - waiting time for service, customer complaints, cleanliness, food quality, order accuracy, employee courtesy
- Catalogue-order companies
  - order accuracy, operator knowledge and courtesy, packaging, delivery time, phone order waiting time
- Insurance companies
  - billing accuracy, timeliness of claims processing, agent availability and response time

# Where to Use Control Charts

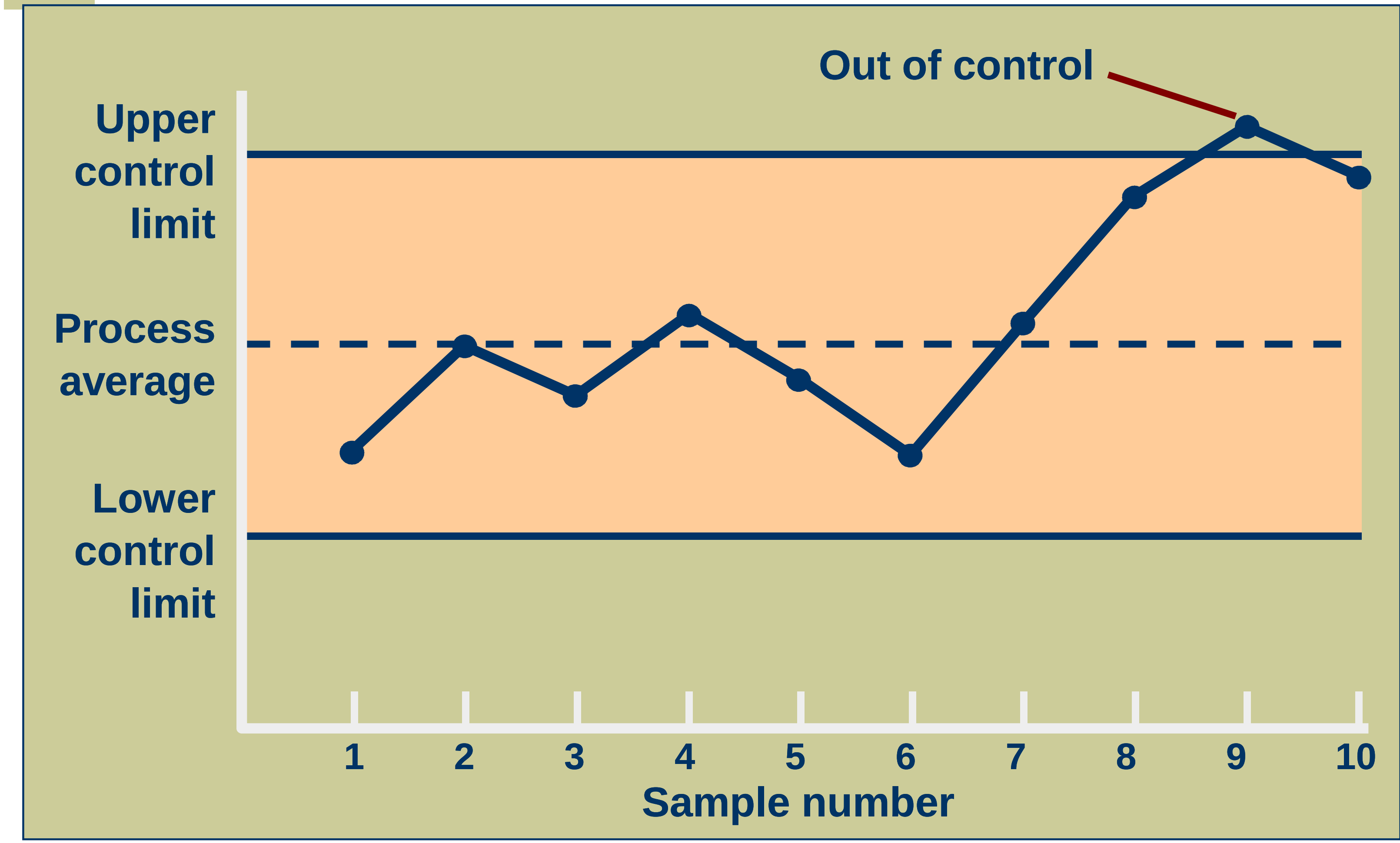
- Process has a tendency to go out of control
- Process is particularly harmful and costly if it goes out of control
- Examples
  - at the beginning of a process because it is a waste of time and money to begin production process with bad supplies
  - before a costly or irreversible point, after which product is difficult to rework or correct
  - before and after assembly or painting operations that might cover defects
  - before the outgoing final product or service is delivered

# Control Charts

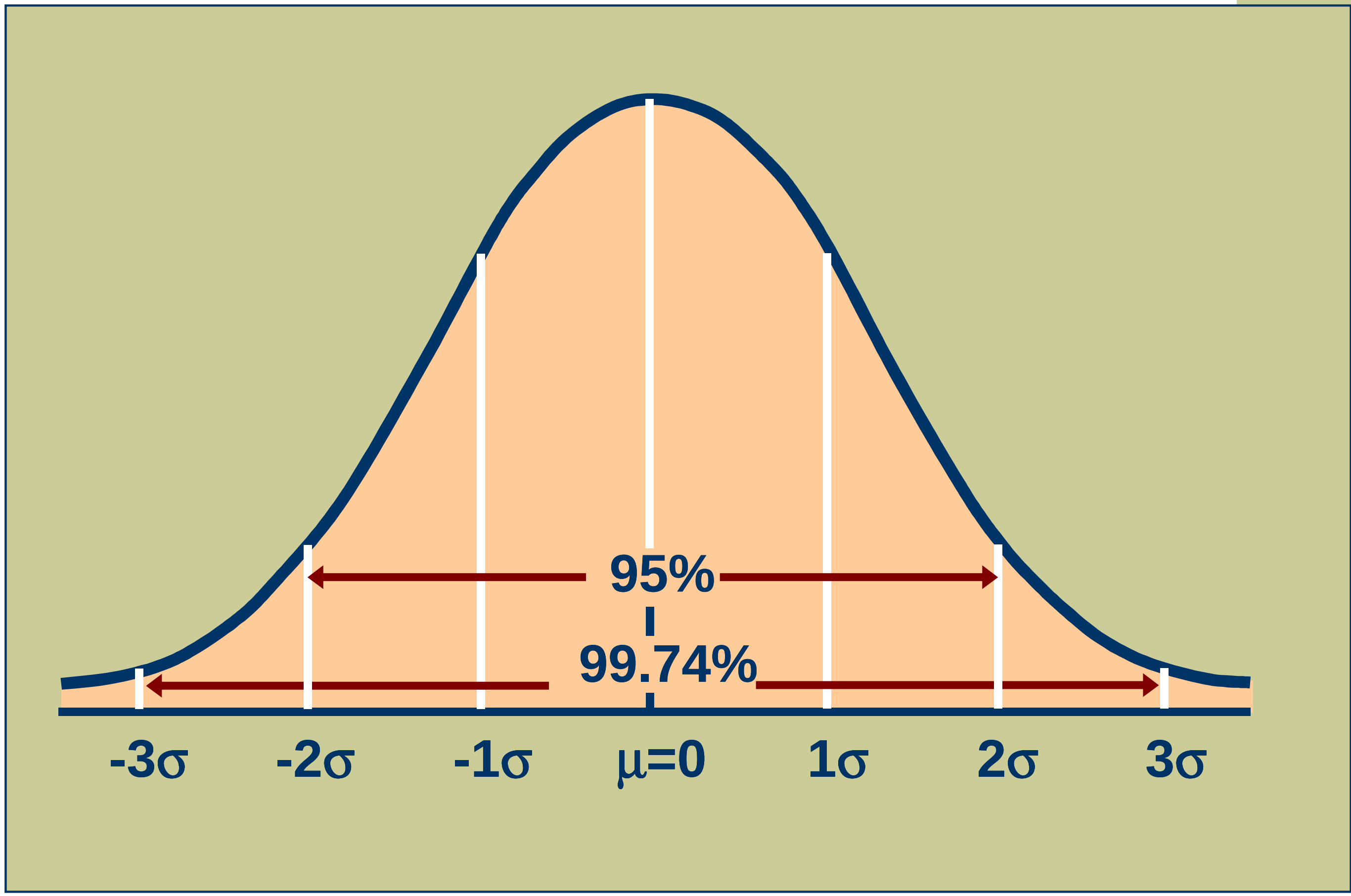
- A graph that establishes control limits of a process
- Control limits
  - upper and lower bands of a control chart

- Types of charts
  - Attributes
    - p-chart
    - c-chart
  - Variables
    - mean (x bar – chart)
    - range (R-chart)

# Process Control Chart



# Normal Distribution



# A Process Is in Control If …

1. … no sample points outside limits
2. … most points near process average
3. … about equal number of points above and below centerline
4. … points appear randomly distributed

# Control Charts for Attributes

- p-chart
  - uses portion defective in a sample
- c-chart
  - uses number of defective items in a sample

# p-Chart

$$UCL = \bar{p} + z\sigma_p$$

$$LCL = \bar{p} - z\sigma_p$$

$z$ = number of standard deviations from process average

$\bar{p}$ = sample proportion defective; an estimate of process average

$\sigma_p$ = standard deviation of sample proportion

$$\sigma_p = \sqrt{\frac{\bar{p}(1 - \bar{p})}{n}}$$

# Construction of p-Chart

| SAMPLE | NUMBER OF DEFECTIVES | PROPORTION DEFECTIVE |
|---|---|---|
| 1 | 6 | .06 |
| 2 | 0 | .00 |
| 3 | 4 | .04 |
| : | : | : |
| : | : | : |
| 20 | 18 | .18 |
| | 200 | |

20 samples of 100 pairs of jeans

# Construction of p-Chart (cont.)

$$\bar{p} = \frac{\text{total defectives}}{\text{total sample observations}} = 200 / 20(100) = 0.10$$

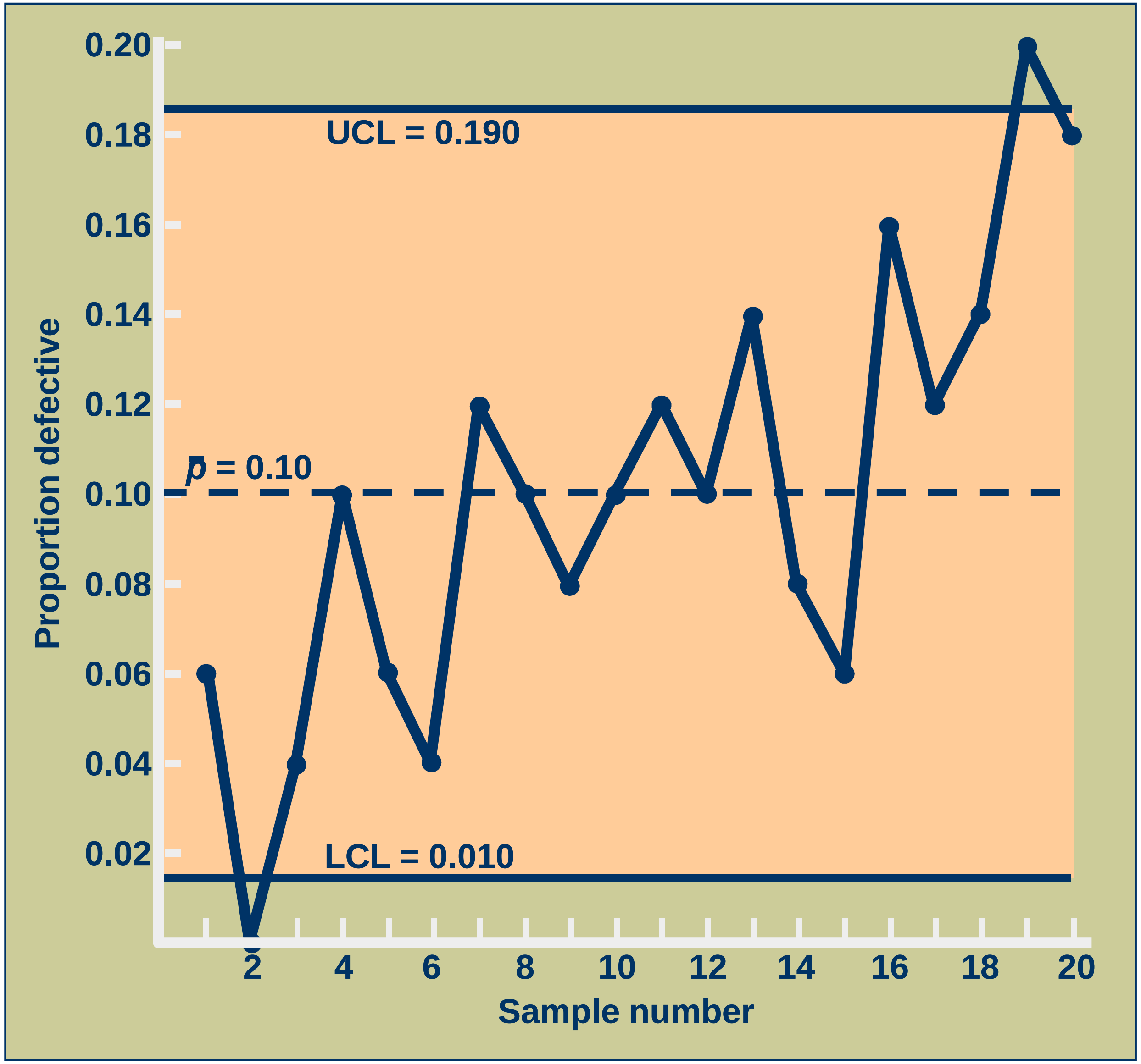
$$UCL = \bar{p} + z\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}} = 0.10 + 3\sqrt{\frac{0.10(1 - 0.10)}{100}}$$

UCL = 0.190

$$LCL = \bar{p} - z\sqrt{\frac{\bar{p}(1 - \bar{p})}{n}} = 0.10 - 3\sqrt{\frac{0.10(1 - 0.10)}{100}}$$

LCL = 0.010

# Construction of p-Chart (cont.)



# c-Chart

$$UCL = \bar{c} + z\sigma_c$$

$$LCL = \bar{c} - z\sigma_c$$

$$\sigma_c = \sqrt{\bar{c}}$$

where

*c* = number of defects per sample

# c-Chart (cont.)

**Number of defects in 15 sample rooms**

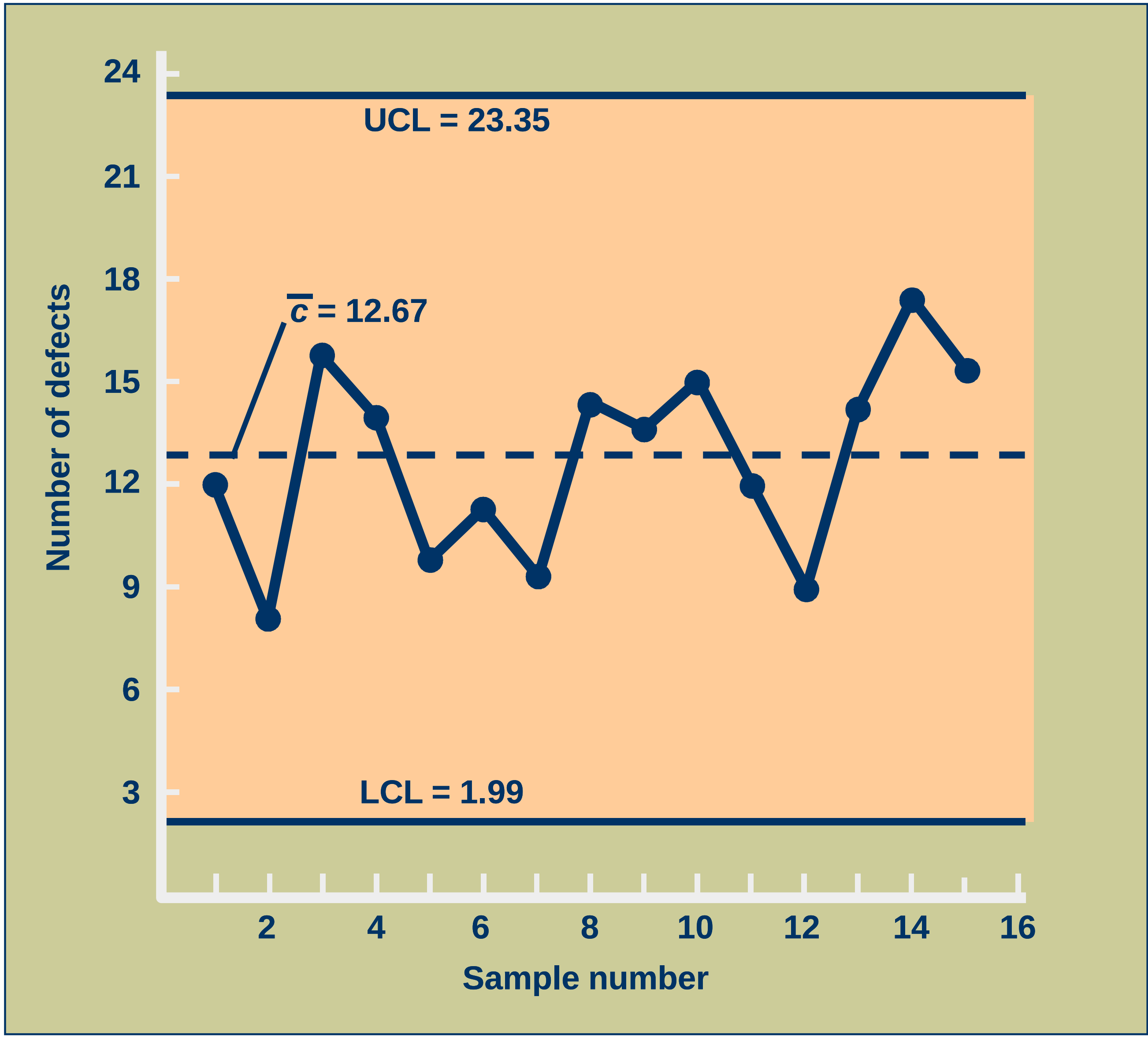
| SAMPLE | NUMBER OF DEFECTS |
|---|---|
| 1 | 12 |
| 2 | 8 |
| 3 | 16 |
| : | : |
| : | : |
| 15 | 15 |
| | 190 |

$$\bar{c} = \frac{190}{15} = 12.67$$

$$\begin{aligned} UCL &= \bar{c} + z\sigma_c \\ &= 12.67 + 3\sqrt{12.67} \\ &= 23.35 \end{aligned}$$

$$\begin{aligned} LCL &= \bar{c} - z\sigma_c \\ &= 12.67 - 3\sqrt{12.67} \\ &= 1.99 \end{aligned}$$

# c-Chart (cont.)



UCL = 23.35
c̄ = 12.67
LCL = 1.99
Number of defects
24
21
18
15
12
9
6
3
2
4
6
8
10
12
14
16
Sample number

# Control Charts for Variables

- Range chart ( $\bar{R}$-Chart )
  - uses amount of dispersion in a sample
- Mean chart ( x -Chart )
  - uses process average of a sample

# x-bar Chart: Standard Deviation Known

$$UCL = \bar{\bar{x}} + z\sigma_x \qquad LCL = \bar{\bar{x}} - z\sigma_x$$

$$\bar{\bar{x}} = \frac{x_1 + x_2 + \ldots x_n}{n}$$

where

$\bar{\bar{x}}$ = average of sample means

# x-bar Chart Example: Standard Deviation Known (cont.)

| | Observations (Slip-Ring Diameter, cm) | | | | | |
|---|---|---|---|---|---|---|
| Sample *k* | *1* | *2* | *3* | *4* | *5* | $\bar{x}$ |
| 1 | 5.02 | 5.01 | 4.94 | 4.99 | 4.96 | 4.98 |
| 2 | 5.01 | 5.03 | 5.07 | 4.95 | 4.96 | 5.00 |
| 3 | 4.99 | 5.00 | 4.93 | 4.92 | 4.99 | 4.97 |
| 4 | 5.03 | 4.91 | 5.01 | 4.98 | 4.89 | 4.96 |
| 5 | 4.95 | 4.92 | 5.03 | 5.05 | 5.01 | 4.99 |
| 6 | 4.97 | 5.06 | 5.06 | 4.96 | 5.03 | 5.01 |
| 7 | 5.05 | 5.01 | 5.10 | 4.96 | 4.99 | 5.02 |
| 8 | 5.09 | 5.10 | 5.00 | 4.99 | 5.08 | 5.05 |
| 9 | 5.14 | 5.10 | 4.99 | 5.08 | 5.09 | 5.08 |
| 10 | 5.01 | 4.98 | 5.08 | 5.07 | 4.99 | 5.03 |
| | | | | | | 50.09 |

# x-bar Chart Example: Standard Deviation Known (cont.)

$$\bar{\bar{x}} = \frac{50.09}{10} = 5.01$$

$$\begin{aligned}
\text{UCL} &= \bar{\bar{x}} + z\sigma_{\bar{x}} \\
&= 5.01 + 3(.08/\sqrt{10}) \\
&= 5.09 \\
\text{LCL} &= \bar{\bar{x}} - z\sigma_{\bar{x}} \\
&= 5.01 - 3\left(.08/\sqrt{10}\right) \\
&= 4.93
\end{aligned}$$

# x-bar Chart Example: Standard Deviation Unknown

$$UCL = \bar{\bar{x}} + A_2\bar{R} \qquad LCL = \bar{\bar{x}} - A_2\bar{R}$$

where

$x$ = average of sample means

# Control Limits

| Sample Size $n$ | Factor for $\bar{x}$-Chart $A_2$ | Factors for R-Chart $D_3$ | $D_4$ |
|---|---|---|---|
| 2 | 1.88 | 0 | 3.27 |
| 3 | 1.02 | 0 | 2.57 |
| 4 | 0.73 | 0 | 2.28 |
| 5 | 0.58 | 0 | 2.11 |
| 6 | 0.48 | 0 | 2.00 |
| 7 | 0.42 | 0.08 | 1.92 |
| 8 | 0.37 | 0.14 | 1.86 |
| 9 | 0.34 | 0.18 | 1.82 |
| 10 | 0.31 | 0.22 | 1.78 |
| 11 | 0.29 | 0.26 | 1.74 |
| 12 | 0.27 | 0.28 | 1.72 |
| 13 | 0.25 | 0.31 | 1.69 |
| 14 | 0.24 | 0.33 | 1.67 |
| 15 | 0.22 | 0.35 | 1.65 |
| 16 | 0.21 | 0.36 | 1.64 |
| 17 | 0.20 | 0.38 | 1.62 |
| 18 | 0.19 | 0.39 | 1.61 |
| 19 | 0.19 | 0.40 | 1.60 |
| 20 | 0.18 | 0.41 | 1.59 |
| 21 | 0.17 | 0.43 | 1.58 |
| 22 | 0.17 | 0.43 | 1.57 |
| 23 | 0.16 | 0.44 | 1.56 |
| 24 | 0.16 | 0.45 | 1.55 |
| 25 | 0.15 | 0.46 | 1.54 |

# x-bar Chart Example: Standard Deviation Unknown

| | OBSERVATIONS (SLIP- RING DIAMETER, CM) | | | | | | |
|---|---|---|---|---|---|---|---|
| SAMPLE *k* | *1* | *2* | *3* | *4* | *5* | $\bar{x}$ | *R* |
| 1 | 5.02 | 5.01 | 4.94 | 4.99 | 4.96 | 4.98 | 0.08 |
| 2 | 5.01 | 5.03 | 5.07 | 4.95 | 4.96 | 5.00 | 0.12 |
| 3 | 4.99 | 5.00 | 4.93 | 4.92 | 4.99 | 4.97 | 0.08 |
| 4 | 5.03 | 4.91 | 5.01 | 4.98 | 4.89 | 4.96 | 0.14 |
| 5 | 4.95 | 4.92 | 5.03 | 5.05 | 5.01 | 4.99 | 0.13 |
| 6 | 4.97 | 5.06 | 5.06 | 4.96 | 5.03 | 5.01 | 0.10 |
| 7 | 5.05 | 5.01 | 5.10 | 4.96 | 4.99 | 5.02 | 0.14 |
| 8 | 5.09 | 5.10 | 5.00 | 4.99 | 5.08 | 5.05 | 0.11 |
| 9 | 5.14 | 5.10 | 4.99 | 5.08 | 5.09 | 5.08 | 0.15 |
| 10 | 5.01 | 4.98 | 5.08 | 5.07 | 4.99 | 5.03 | 0.10 |
| | | | | | | 50.09 | 1.15 |

Example 15.4

# x-bar Chart Example: Standard Deviation Unknown (cont.)

$$\bar{R} = \frac{\sum R}{k} = \frac{1.15}{10} = 0.115$$

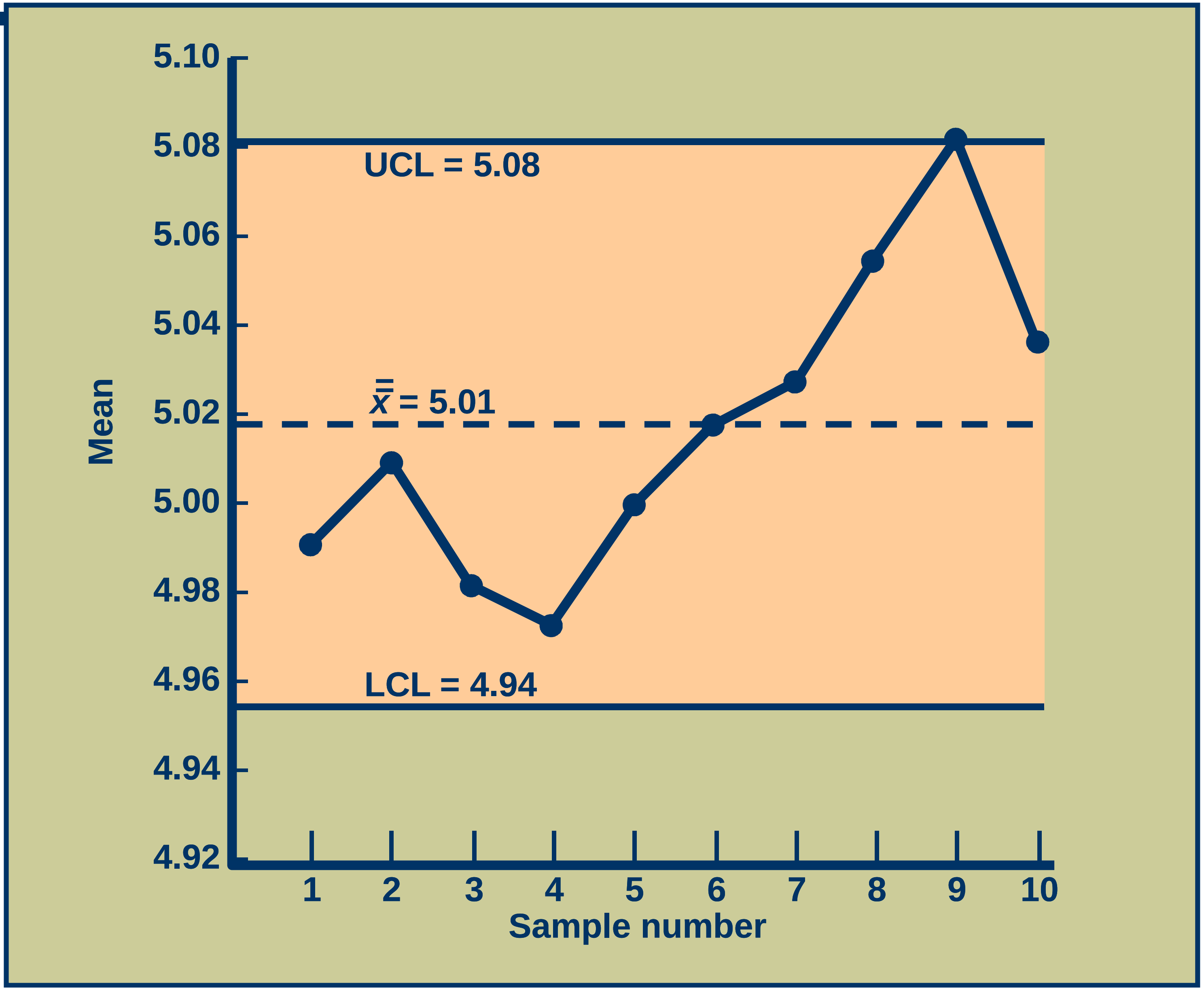
$$\bar{\bar{x}} = \frac{\sum \bar{x}}{k} = \frac{50.09}{10} = 5.01 \text{ cm}$$

$$UCL = \bar{\bar{x}} + A_2\bar{R} = 5.01 + (0.58)(0.115) = 5.08$$

$$LCL = \bar{\bar{x}} - A_2\bar{R} = 5.01 - (0.58)(0.115) = 4.94$$

Retrieve Factor Value $A_2$

# x- bar Chart Example (cont.)



# R- Chart

$$UCL = D_4\bar{R} \qquad LCL = D_3\bar{R}$$

$$\bar{R} = \frac{\sum R}{k}$$

where

$R$ = range of each sample

$k$ = number of samples

# R-Chart Example

| | OBSERVATIONS (SLIP-RING DIAMETER, CM) | | | | | | |
|---|---|---|---|---|---|---|---|
| SAMPLE *k* | *1* | *2* | *3* | *4* | *5* | $\bar{x}$ | *R* |
| 1 | 5.02 | 5.01 | 4.94 | 4.99 | 4.96 | 4.98 | 0.08 |
| 2 | 5.01 | 5.03 | 5.07 | 4.95 | 4.96 | 5.00 | 0.12 |
| 3 | 4.99 | 5.00 | 4.93 | 4.92 | 4.99 | 4.97 | 0.08 |
| 4 | 5.03 | 4.91 | 5.01 | 4.98 | 4.89 | 4.96 | 0.14 |
| 5 | 4.95 | 4.92 | 5.03 | 5.05 | 5.01 | 4.99 | 0.13 |
| 6 | 4.97 | 5.06 | 5.06 | 4.96 | 5.03 | 5.01 | 0.10 |
| 7 | 5.05 | 5.01 | 5.10 | 4.96 | 4.99 | 5.02 | 0.14 |
| 8 | 5.09 | 5.10 | 5.00 | 4.99 | 5.08 | 5.05 | 0.11 |
| 9 | 5.14 | 5.10 | 4.99 | 5.08 | 5.09 | 5.08 | 0.15 |
| 10 | 5.01 | 4.98 | 5.08 | 5.07 | 4.99 | 5.03 | 0.10 |
| | | | | | | 50.09 | 1.15 |

Example 15.3

# R-Chart Example (cont.)

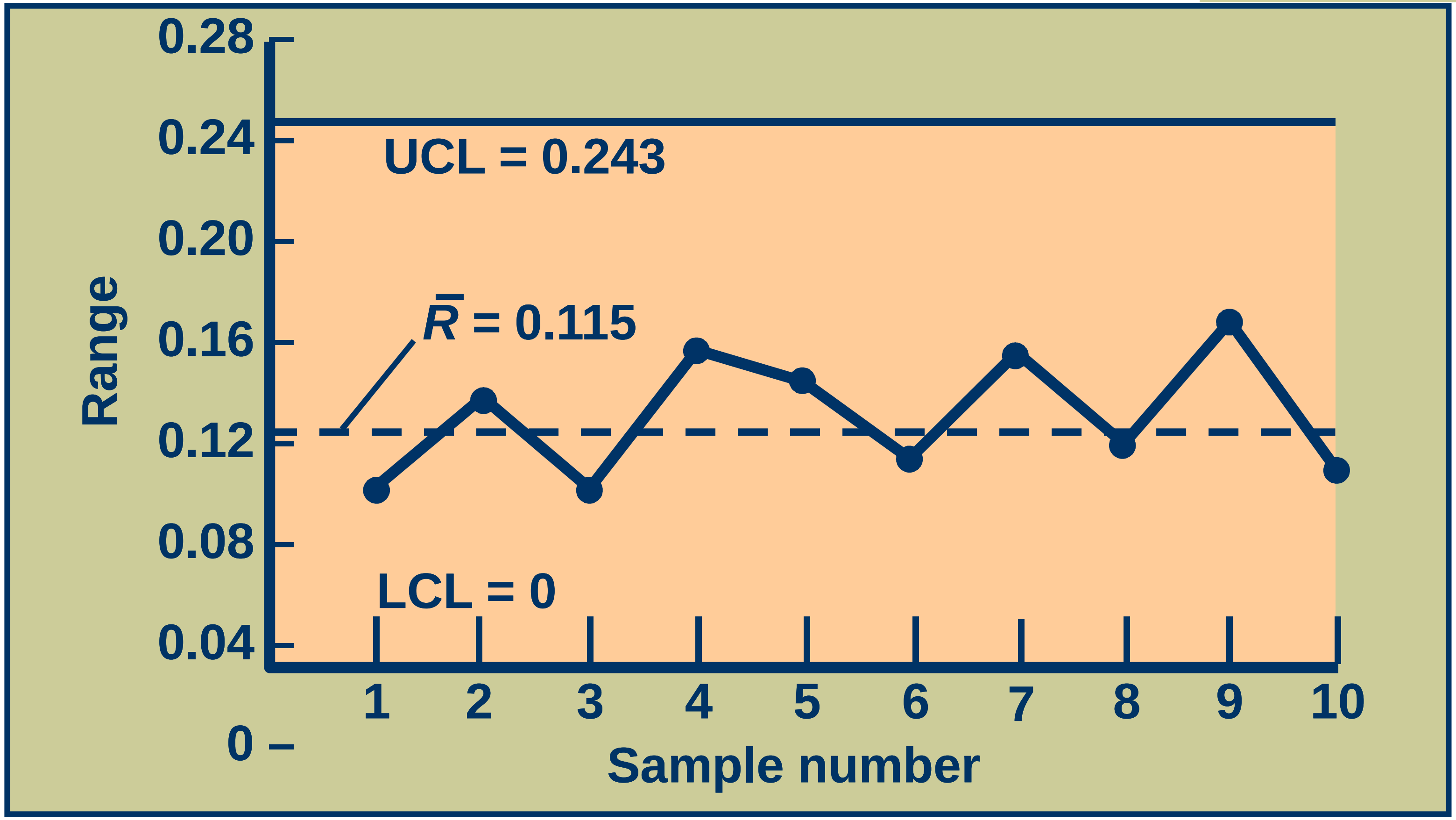
$$UCL = D_4\bar{R} = 2.11(0.115) = 0.243$$

$$LCL = D_3\bar{R} = 0(0.115) = 0$$

Retrieve Factor Values $D_3$ and $D_4$

Example 15.3

# R-Chart Example (cont.)



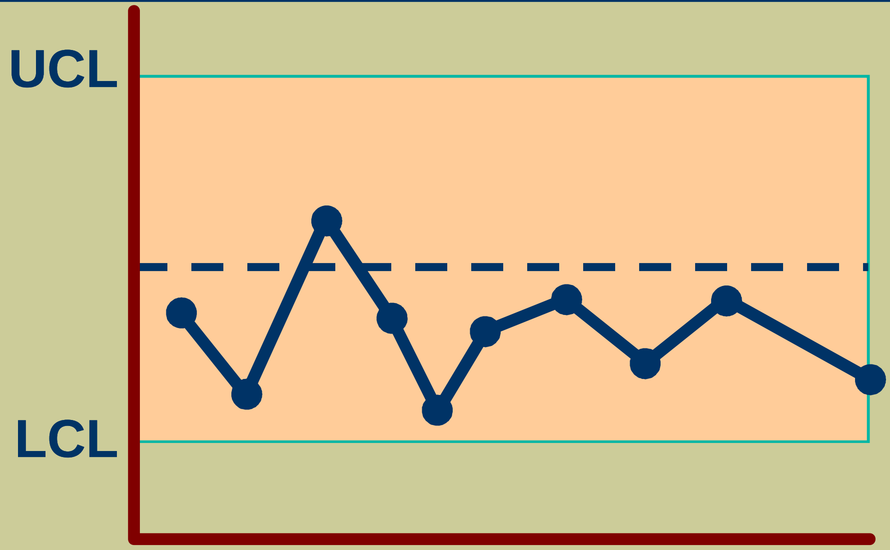
# Using x- bar and R-Charts Together

- Process average and process variability must be in control
- It is possible for samples to have very narrow ranges, but their averages might be beyond control limits
- It is possible for sample averages to be in control, but ranges might be very large
- It is possible for an R-chart to exhibit a distinct downward trend, suggesting some nonrandom cause is reducing variation

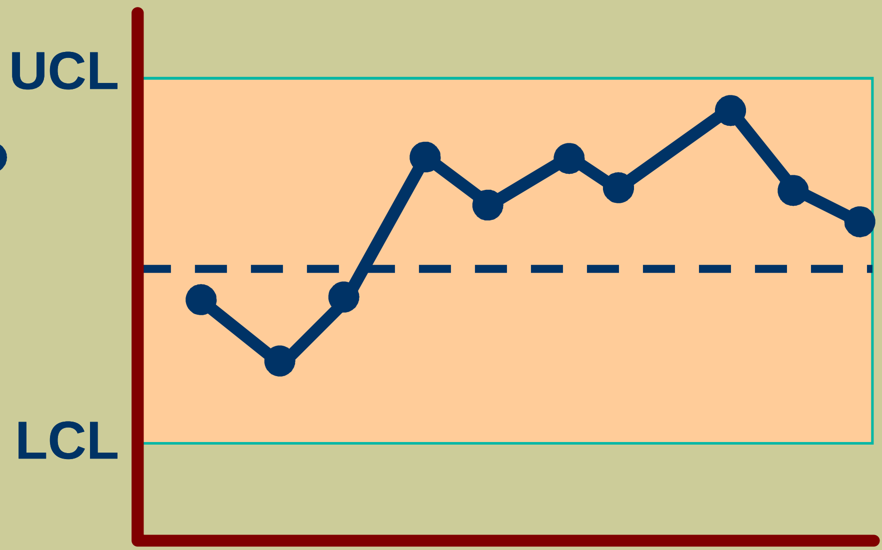
# Control Chart Patterns

- Run
  - sequence of sample values that display same characteristic
- Pattern test
  - determines if observations within limits of a control chart display a nonrandom pattern
- To identify a pattern:
  - 8 consecutive points on one side of the center line
  - 8 consecutive points up or down
  - 14 points alternating up or down
  - 2 out of 3 consecutive points in zone A (on one side of center line)
  - 4 out of 5 consecutive points in zone A or B (on one side of center line)

# Control Chart Patterns (cont.)

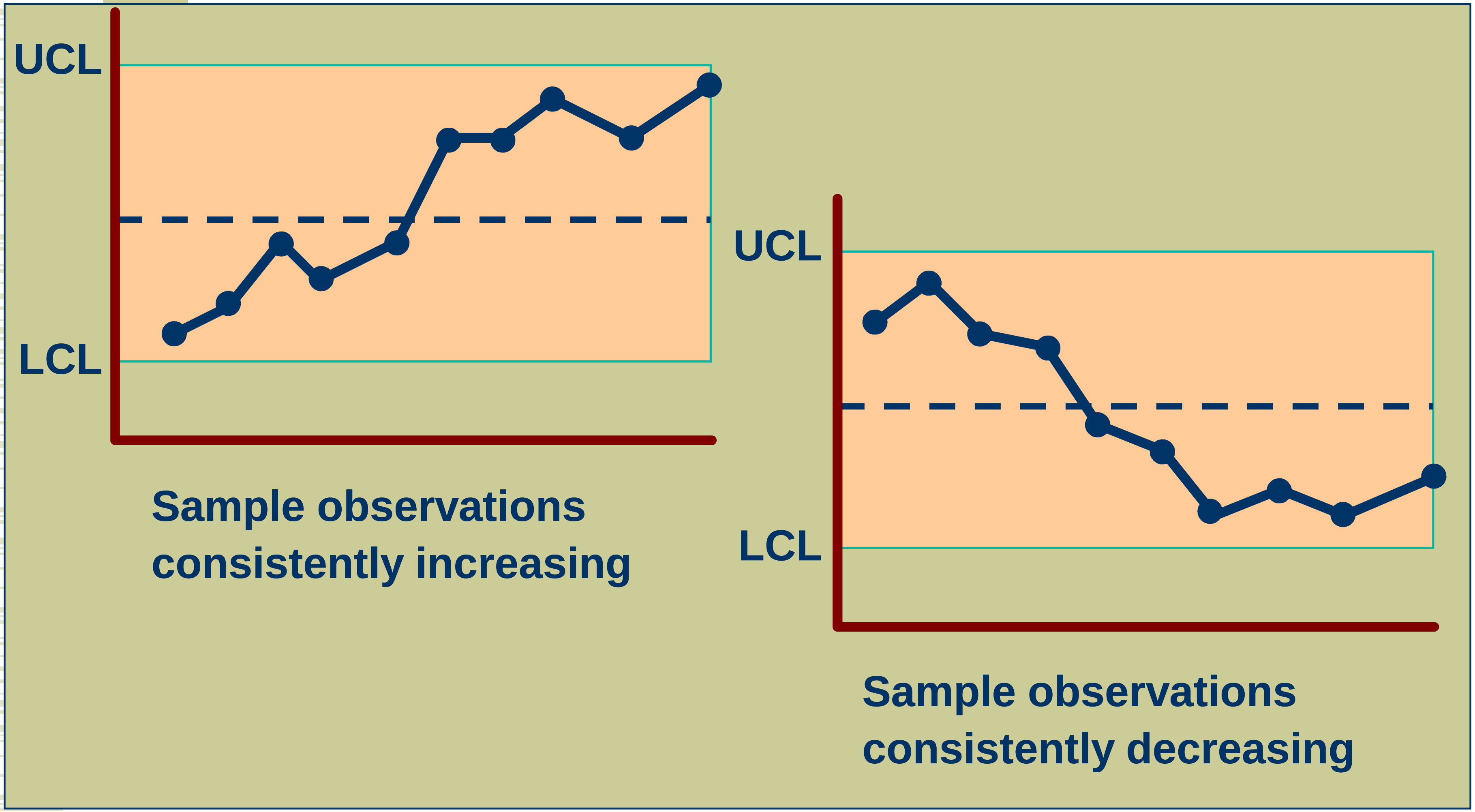



**Sample observations consistently below the center line**

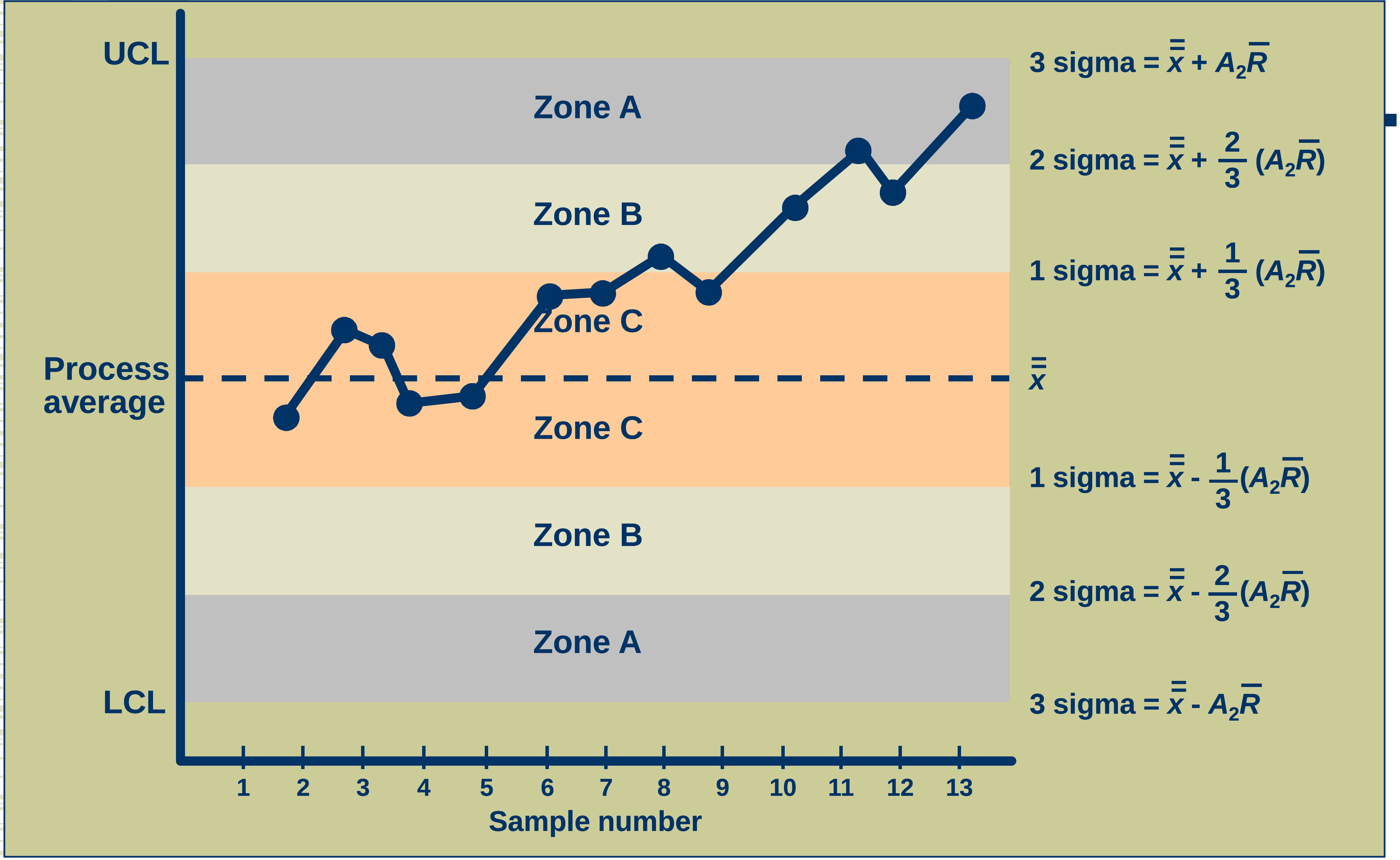



**Sample observations consistently above the center line**

# Control Chart Patterns (cont.)



# Zones for Pattern Tests



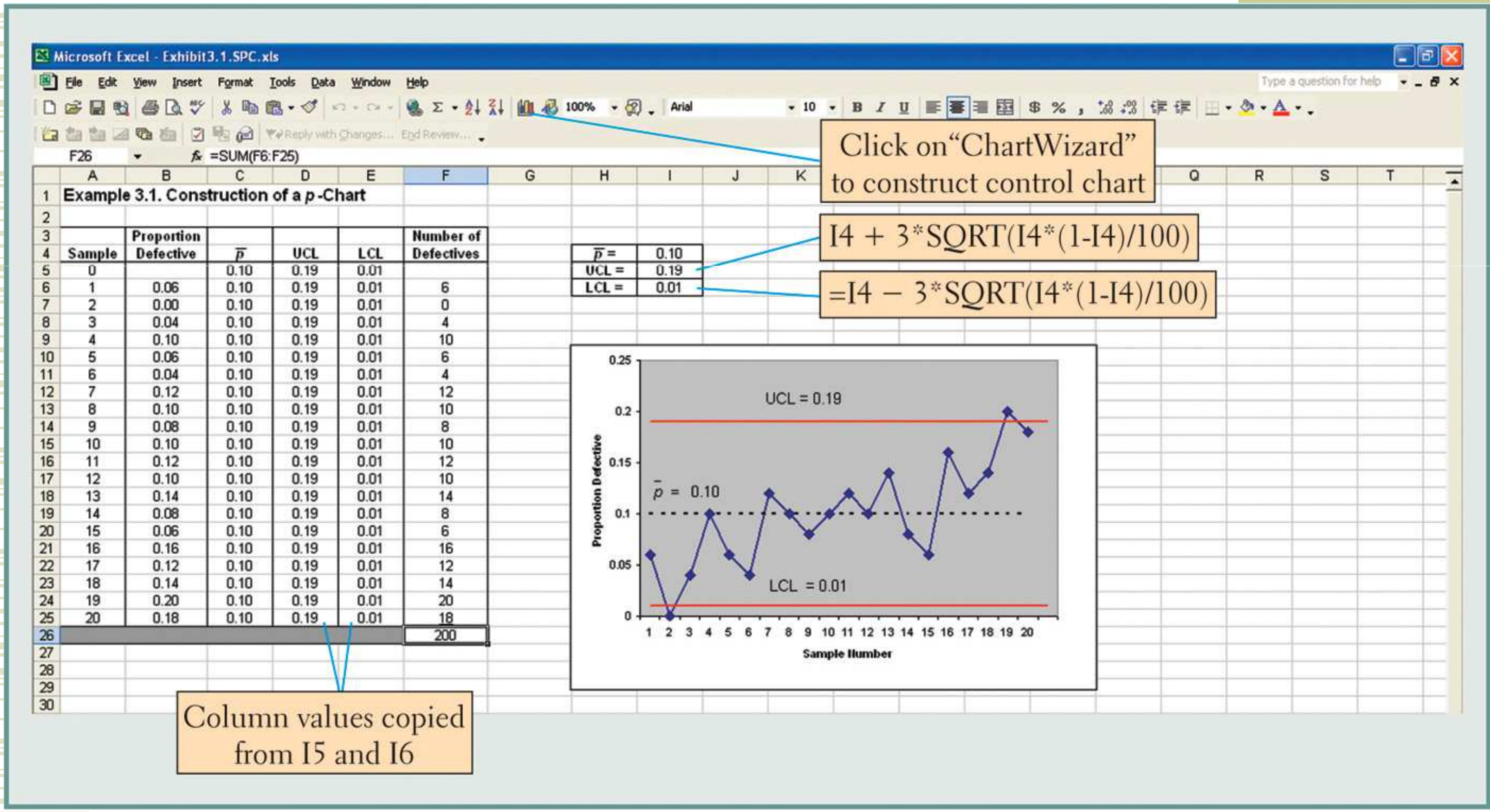
# Performing a Pattern Test

| SAMPLE | $\bar{x}$ | ABOVE/BELOW | UP/DOWN | ZONE |
|---|---|---|---|---|
| 1 | 4.98 | B | — | B |
| 2 | 5.00 | B | U | C |
| 3 | 4.95 | B | D | A |
| 4 | 4.96 | B | D | A |
| 5 | 4.99 | B | U | C |
| 6 | 5.01 | — | U | C |
| 7 | 5.02 | A | U | C |
| 8 | 5.05 | A | U | B |
| 9 | 5.08 | A | U | A |
| 10 | 5.03 | A | D | B |

# Sample Size Determination

- Attribute charts require larger sample sizes
  - 50 to 100 parts in a sample
- Variable charts require smaller samples
  - 2 to 10 parts in a sample

# SPC with Excel



Example 3.1. Construction of a p-Chart

| Sample | Proportion Defective | $\bar{p}$ | UCL | LCL | Number of Defectives |
|---|---|---|---|---|---|
| 0 | | 0.10 | 0.19 | 0.01 | |
| 1 | 0.06 | 0.10 | 0.19 | 0.01 | 6 |
| 2 | 0.00 | 0.10 | 0.19 | 0.01 | 0 |
| 3 | 0.04 | 0.10 | 0.19 | 0.01 | 4 |
| 4 | 0.10 | 0.10 | 0.19 | 0.01 | 10 |
| 5 | 0.06 | 0.10 | 0.19 | 0.01 | 6 |
| 6 | 0.04 | 0.10 | 0.19 | 0.01 | 4 |
| 7 | 0.12 | 0.10 | 0.19 | 0.01 | 12 |
| 8 | 0.10 | 0.10 | 0.19 | 0.01 | 10 |
| 9 | 0.08 | 0.10 | 0.19 | 0.01 | 8 |
| 10 | 0.10 | 0.10 | 0.19 | 0.01 | 10 |
| 11 | 0.12 | 0.10 | 0.19 | 0.01 | 12 |
| 12 | 0.10 | 0.10 | 0.19 | 0.01 | 10 |
| 13 | 0.14 | 0.10 | 0.19 | 0.01 | 14 |
| 14 | 0.08 | 0.10 | 0.19 | 0.01 | 8 |
| 15 | 0.06 | 0.10 | 0.19 | 0.01 | 6 |
| 16 | 0.16 | 0.10 | 0.19 | 0.01 | 16 |
| 17 | 0.12 | 0.10 | 0.19 | 0.01 | 12 |
| 18 | 0.14 | 0.10 | 0.19 | 0.01 | 14 |
| 19 | 0.20 | 0.10 | 0.19 | 0.01 | 20 |
| 20 | 0.18 | 0.10 | 0.19 | 0.01 | 18 |
| | | | | | 200 |

| | |
|---|---|
| $\bar{p}$ = | 0.10 |
| UCL = | 0.19 |
| LCL = | 0.01 |

# SPC with Excel and OM Tools

Microsoft Excel - Exhibit3.2.SPC.xls

**Xbar and R Charts** — OM Student - Examples 3.4 and 3.5

*Input:*

| | |
|---|---|
| No. of samples | 10 |
| Sample size | 5 |

*Output:*

| | X-Bar | Range |
|---|---|---|
| UCL | 5.08 | 0.24 |
| Mean | 5.01 | 0.12 |
| LCL | 4.94 | 0.00 |

*Table Values*

| | |
|---|---|
| N | 5 |
| A2 | 0.577 |
| D3 | 0.00 |
| D4 | 2.115 |

*Input the observations for each sample in the green shaded cells.*

| | *Observations* | | | | | *Calculations* | | *Xbar Chart* | | *R-chart* | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Sample | 1 | 2 | 3 | 4 | 5 | Sample Mean | Range | UCL | LCL | UCL | LCL |
| 1 | 5.02 | 5.01 | 4.94 | 4.99 | 4.96 | 4.98 | 0.08 | 5.08 | 4.94 | 0.243 | 0 |
| 2 | 5.01 | 5.03 | 5.07 | 4.95 | 4.96 | 5.00 | 0.12 | 5.08 | 4.94 | 0.243 | 0 |
| 3 | 4.99 | 5.00 | 4.93 | 4.92 | 4.99 | 4.97 | 0.08 | 5.08 | 4.94 | 0.243 | 0 |
| 4 | 5.03 | 4.91 | 5.01 | 4.98 | 4.89 | 4.96 | 0.14 | 5.08 | 4.94 | 0.243 | 0 |
| 5 | 4.95 | 4.92 | 5.03 | 5.05 | 5.01 | 4.99 | 0.13 | 5.08 | 4.94 | 0.243 | 0 |
| 6 | 4.97 | 5.06 | 5.06 | 4.96 | 5.03 | 5.02 | 0.10 | 5.08 | 4.94 | 0.243 | 0 |
| 7 | 5.05 | 5.01 | 5.10 | 4.96 | 4.99 | 5.02 | 0.14 | 5.08 | 4.94 | 0.243 | 0 |
| 8 | 5.09 | 5.10 | 5.00 | 4.99 | 5.08 | 5.05 | 0.11 | 5.08 | 4.94 | 0.243 | 0 |
| 9 | 5.14 | 5.10 | 4.99 | 5.08 | 5.09 | 5.08 | 0.15 | 5.08 | 4.94 | 0.243 | 0 |
| 10 | 5.01 | 4.98 | 5.08 | 5.07 | 4.99 | 5.03 | 0.10 | 5.08 | 4.94 | 0.243 | 0 |
| | | | | | Mean | 5.01 | 0.115 | | | | |

*Xbar chart formulas*

$LCL = \bar{\bar{x}} - A_2\bar{R}$

$UCL = \bar{\bar{x}} + A_2\bar{R}$

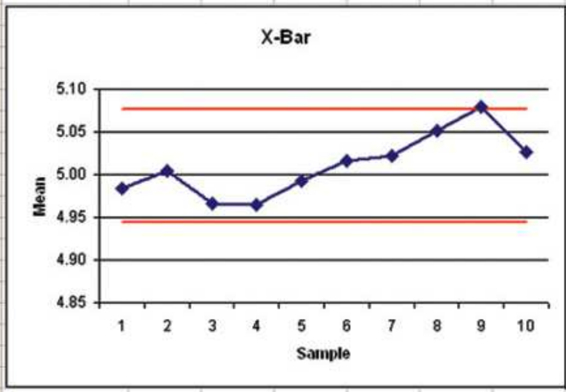
*R-chart formulas*

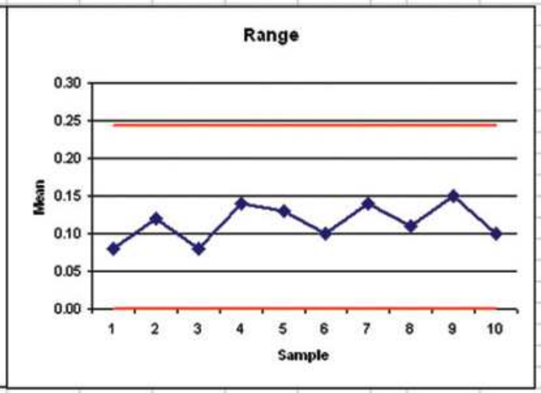
$LCL = D_3\bar{R}$

$UCL = D_4\bar{R}$

*Control Chart Factors for Xbar and R Charts*

| Sample size, n | Mean Factor, A2 | Upper Range, D4 | Lower Range, D3 |
|---|---|---|---|
| 2 | 1.88 | 3.268 | 0 |
| 3 | 1.023 | 2.574 | 0 |
| 4 | 0.729 | 2.282 | 0 |
| 5 | 0.577 | 2.115 | 0 |
| 6 | 0.483 | 2.004 | 0 |
| 7 | 0.419 | 1.924 | 0.076 |
| 8 | 0.373 | 1.864 | 0.136 |
| 9 | 0.337 | 1.816 | 0.184 |
| 10 | 0.308 | 1.777 | 0.223 |
| 11 | 0.285 | 1.744 | 0.256 |
| 12 | 0.266 | 1.716 | 0.284 |
| 13 | 0.249 | 1.692 | 0.308 |
| 14 | 0.235 | 1.671 | 0.329 |
| 15 | 0.223 | 1.652 | 0.348 |
| 16 | 0.212 | 1.636 | 0.364 |
| 17 | 0.203 | 1.621 | 0.379 |
| 18 | 0.194 | 1.608 | 0.392 |
| 19 | 0.187 | 1.596 | 0.404 |
| 20 | 0.180 | 1.586 | 0.414 |
| 21 | 0.173 | 1.575 | 0.425 |
| 22 | 0.167 | 1.566 | 0.434 |
| 23 | 0.162 | 1.557 | 0.443 |
| 24 | 0.157 | 1.548 | 0.452 |
| 25 | 0.153 | 1.541 | 0.459 |

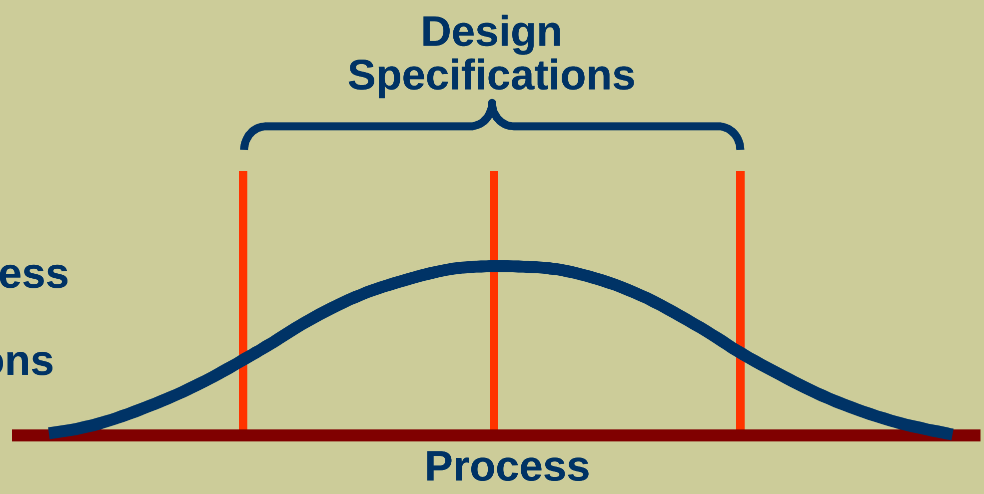


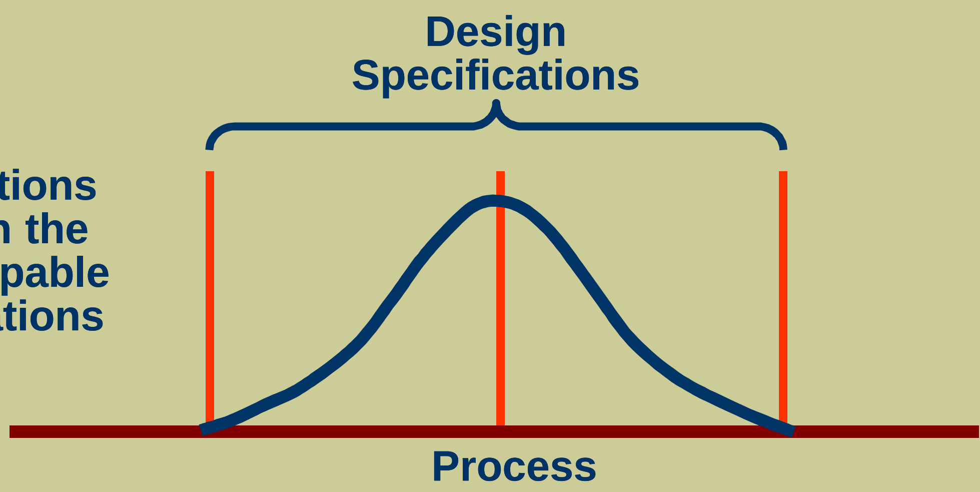
# Process Capability

- Tolerances
  - design specifications reflecting product requirements
- Process capability
  - range of natural variability in a process—what we measure with control charts

# Process Capability (cont.)



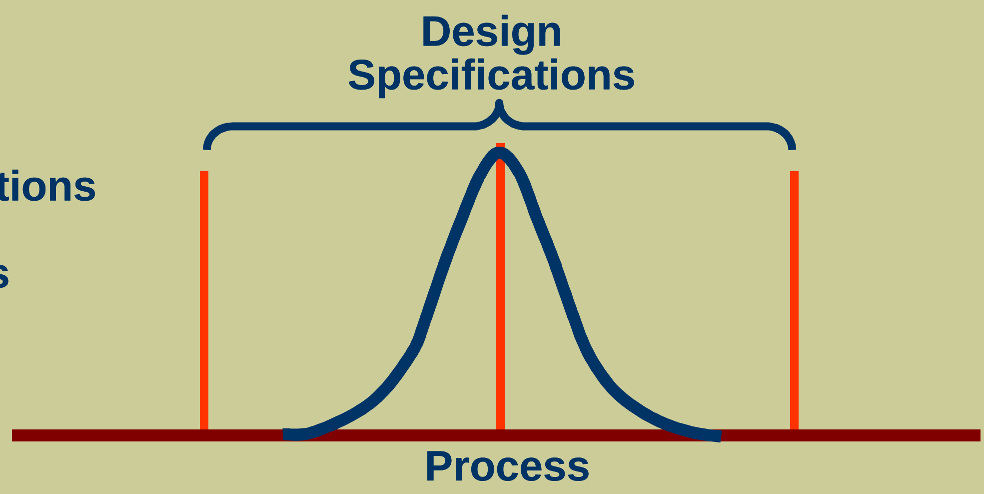

**(a) Natural variation exceeds design specifications; process is not capable of meeting specifications all the time.**



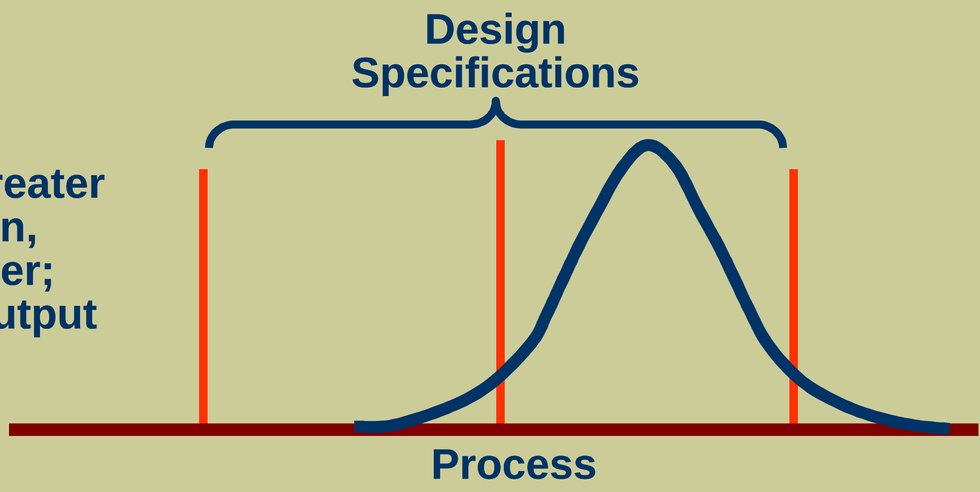

**(b) Design specifications and natural variation the same; process is capable of meeting specifications most of the time.**

# Process Capability (cont.)

**(c) Design specifications greater than natural variation; process is capable of always conforming to specifications.**




**(d) Specifications greater than natural variation, but process off center; capable but some output will not meet upper specification.**



# Process Capability Measures

## Process Capability Ratio

$$C_p = \frac{\text{tolerance range}}{\text{process range}}$$

$$= \frac{\text{upper specification limit - lower specification limit}}{6\sigma}$$

# Computing $C_p$

Net weight specification = 9.0 oz ± 0.5 oz

Process mean = 8.80 oz

Process standard deviation = 0.12 oz

$$C_p = \frac{\text{upper specification limit - lower specification limit}}{6\sigma}$$

$$= \frac{9.5 - 8.5}{6(0.12)} = 1.39$$

# Process Capability Measures

## *Process Capability Index*

$$C_{pk} = \text{minimum}\left[\frac{\bar{\bar{x}} - \text{lower specification limit}}{3\sigma}, \frac{\text{upper specification limit} - \bar{\bar{x}}}{3\sigma}\right]$$

# Computing $C_{pk}$

Net weight specification = 9.0 oz ± 0.5 oz

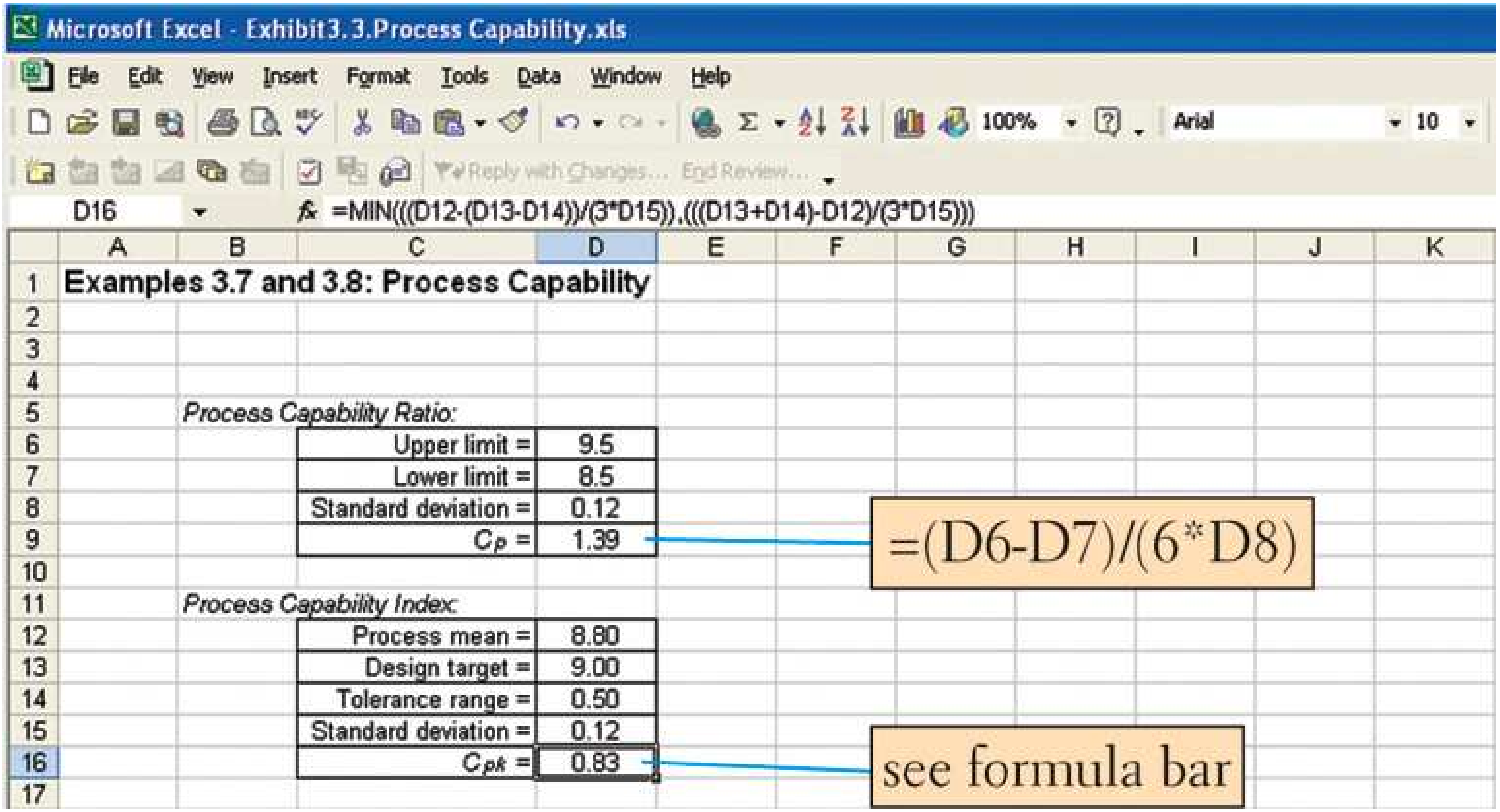
Process mean = 8.80 oz

Process standard deviation = 0.12 oz

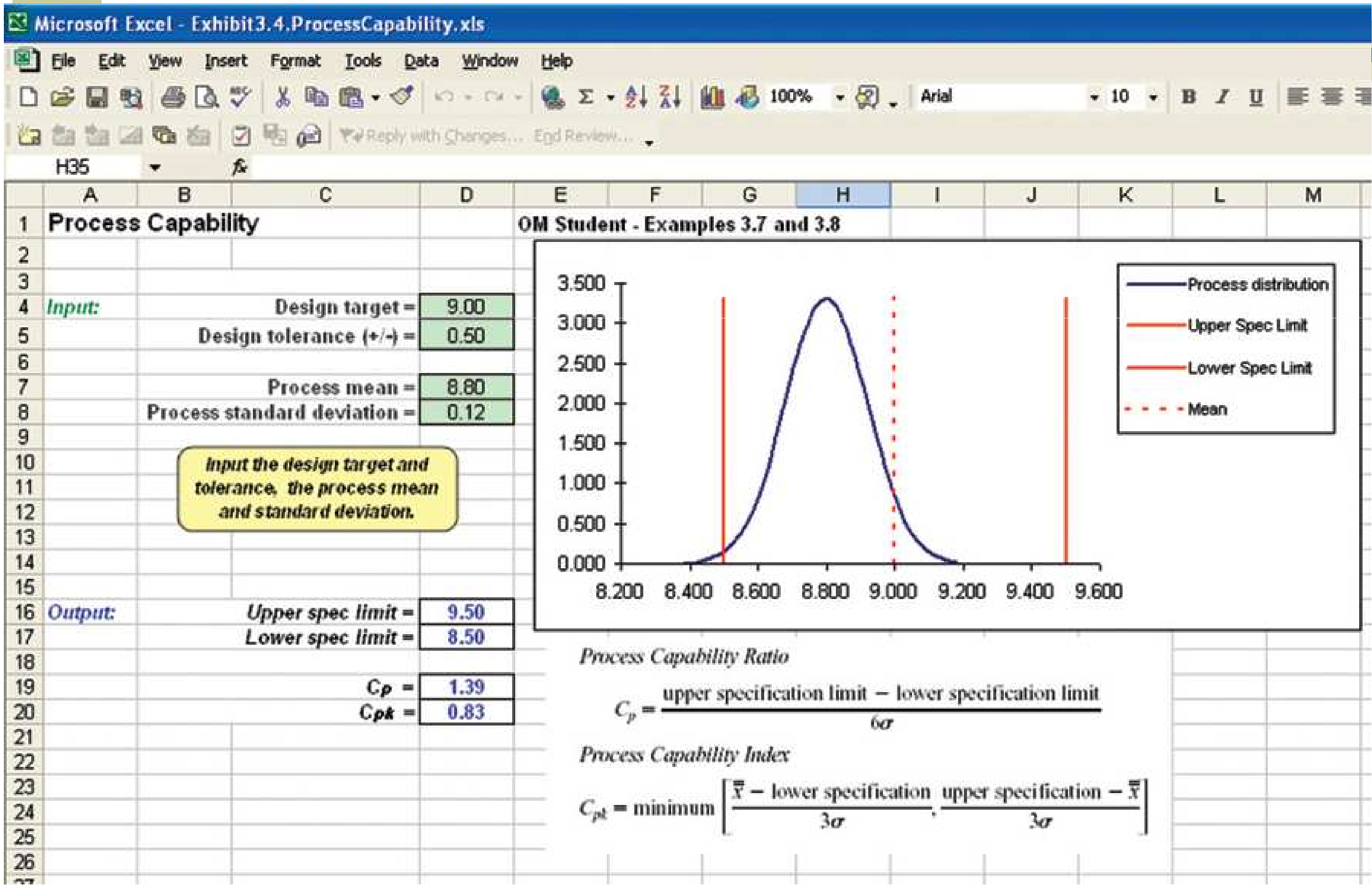
$$C_{pk} = \text{minimum}\left[\frac{\bar{\bar{x}} - \text{lower specification limit}}{3\sigma}, \frac{\text{upper specification limit} - \bar{\bar{x}}}{3\sigma}\right]$$

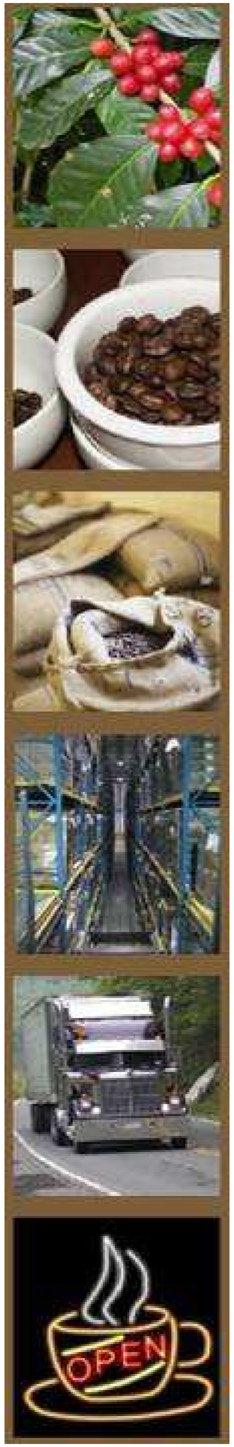
$$= \text{minimum}\left[\frac{8.80 - 8.50}{3(0.12)}, \frac{9.50 - 8.80}{3(0.12)}\right] = 0.83$$

# Process Capability with Excel



# Process Capability with Excel and OM Tools





# Chapter 3 Supplement

## *Acceptance Sampling*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Single-Sample Attribute Plan
- Operating Characteristic Curve
- Developing a Sampling Plan with Excel
- Average Outgoing Quality
- Double - and Multiple-Sampling Plans

# Acceptance Sampling

- Accepting or rejecting a production lot based on the number of defects in a sample
- Not consistent with TQM or Zero Defects philosophy
  - producer and customer agree on the number of acceptable defects
  - a means of identifying not preventing poor quality
  - percent of defective parts versus PPM
- Sampling plan
  - provides guidelines for accepting a lot

# Single–Sample Attribute Plan

- Single sampling plan
  - $N$ = lot size
  - $n$ = sample size (random)
  - $c$ = acceptance number
  - $d$ = number of defective items in sample
- If $d \leq c$, accept lot; else reject

# Producer's and Consumer's Risk

- AQL or acceptable quality level
  - proportion of defects consumer will accept in a given lot
- α or producer's risk
  - probability of rejecting a good lot
- LTPD or lot tolerance percent defective
  - limit on the number of defectives the customer will accept
- β or consumer's risk
  - probability of accepting a bad lot

# Producer’s and Consumer’s Risk (cont.)

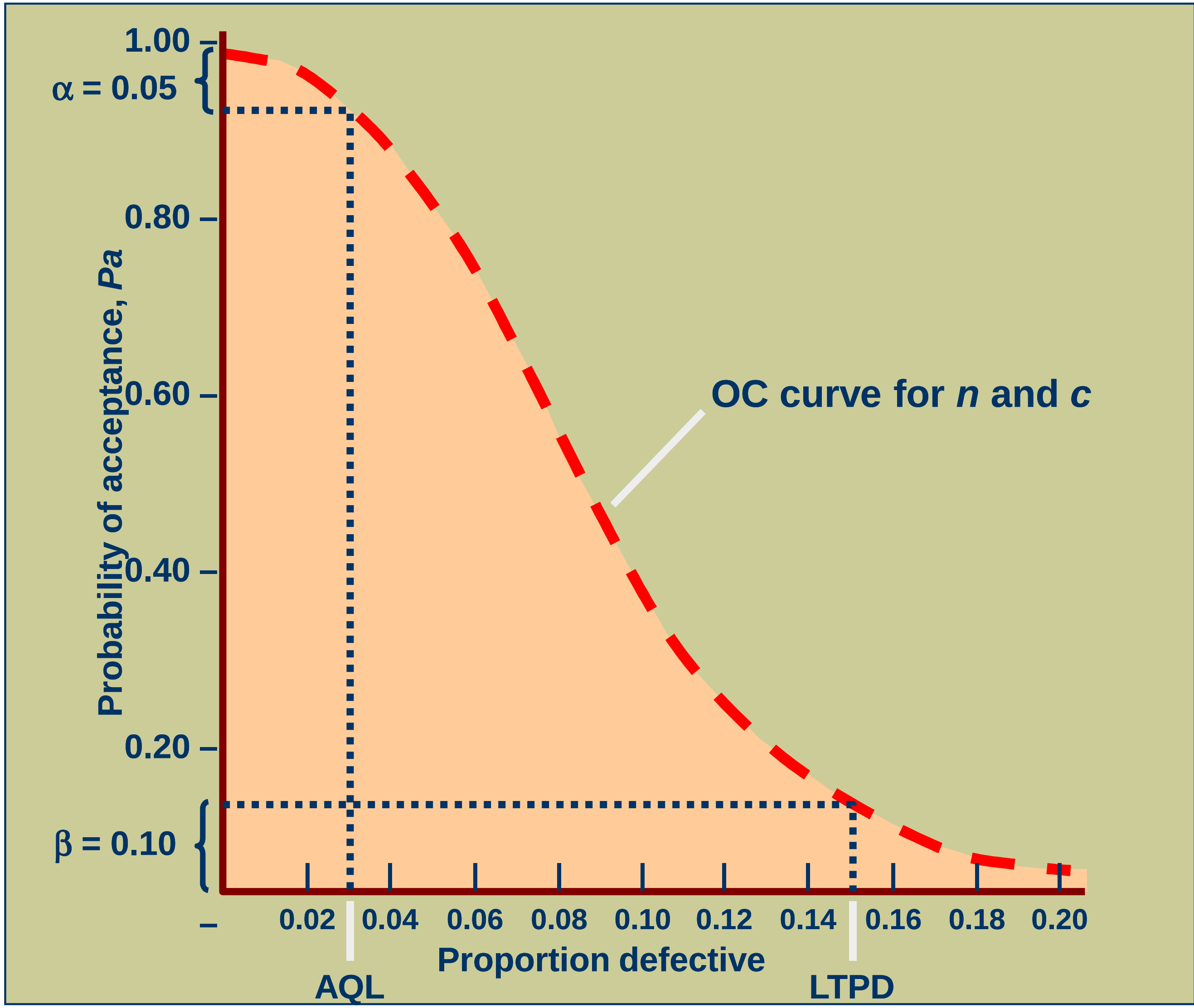
| | Accept | Reject |
|---|---|---|
| Good Lot | No Error | Type I Error<br>Producer’ Risk |
| Bad Lot | Type II Error<br>Consumer’s Risk | No Error |

**Sampling Errors**

# Operating Characteristic (OC) Curve

- shows probability of accepting lots of different quality levels with a specific sampling plan
- assists management to discriminate between good and bad lots
- exact shape and location of the curve is defined by the sample size (*n*) and acceptance level (*c*) for the sampling plan

# OC Curve (cont.)



# Developing a Sampling Plan with OM Tools

ABC Company produces mugs in lots of 10,000. Performance measures for quality of mugs sent to stores call for a producer's risk of 0.05 with an AQL of 1% defective and a consumer's risk of 0.10 with a LTPD of 5% defective. What size sample and what acceptance number should ABC use to achieve performance measures called for in the sampling plan?

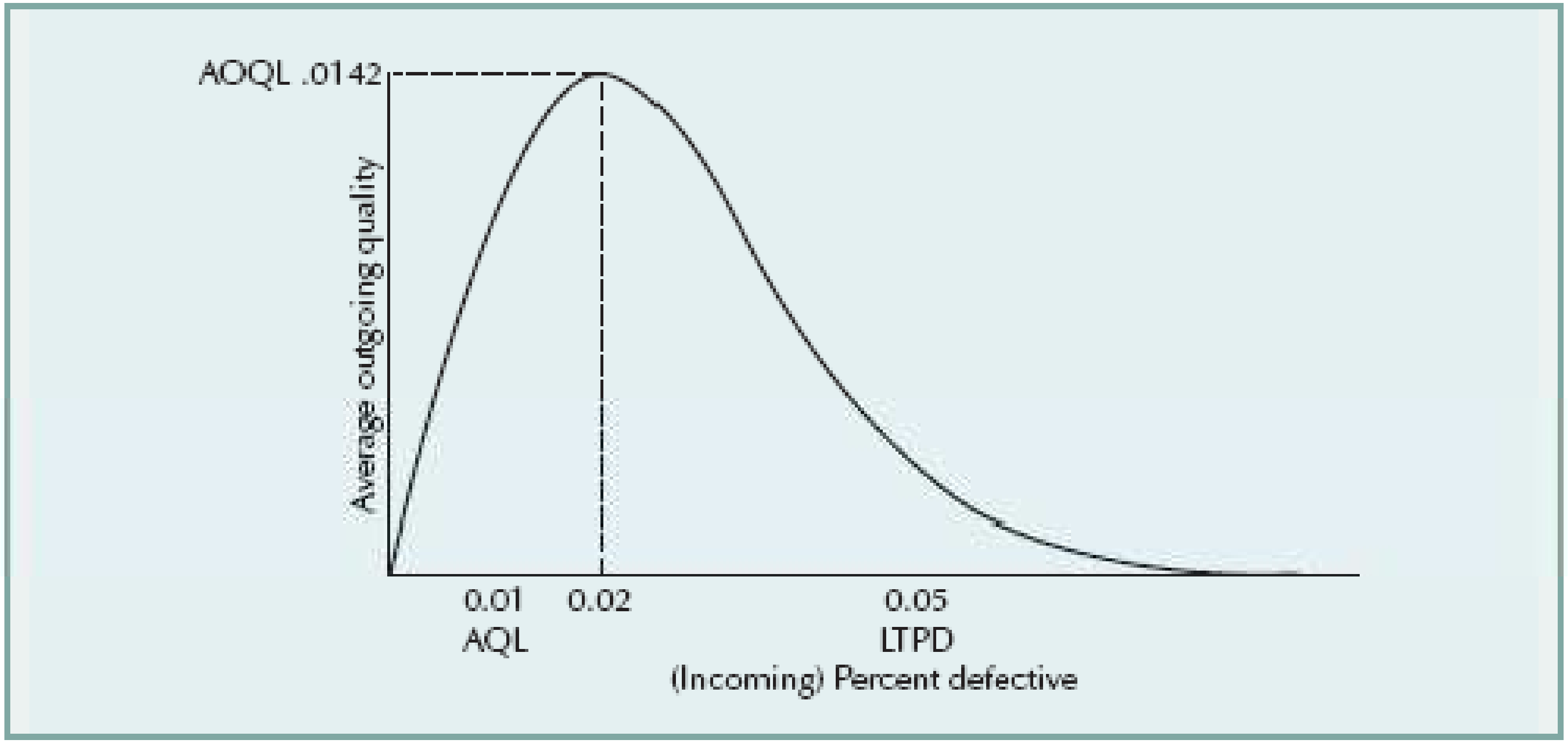
N = 10,000
α = 0.05
β = 0.10
AQL = 1%
LTPD = 5%

n = ?
c = ?

# Average Outgoing Quality (AOQ)

- Expected number of defective items that will pass on to customer with a sampling plan
- Average outgoing quality limit (AOQL)
  - maximum point on the curve
  - worst level of outgoing quality

# AOQ Curve



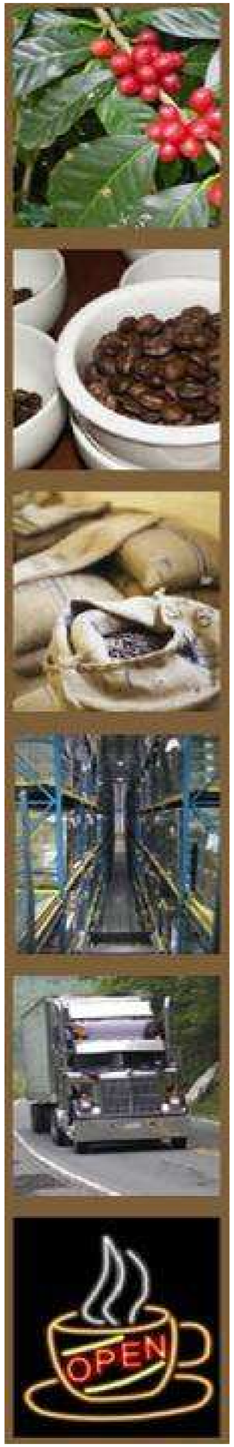
AOQL .0142
Average outgoing quality
0.01
AQL
0.02
0.05
LTPD
(Incoming) Percent defective

# Double-Sampling Plans

- Take small initial sample
  - If # defective ≤ lower limit, accept
  - If # defective > upper limit, reject
  - If # defective between limits, take second sample
- Accept or reject based on 2 samples
- Less costly than single-sampling plans

# Multiple-Sampling Plans

- Uses smaller sample sizes
- Take initial sample
  - If # defective ≤ lower limit, accept
  - If # defective > upper limit, reject
  - If # defective between limits, resample
- Continue sampling until accept or reject lot based on all sample data



# Chapter 4

## *Product Design*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Design Process
- Concurrent Design
- Technology in Design
- Design Reviews
- Design for Environment
- Design for Robustness
- Quality Function Deployment

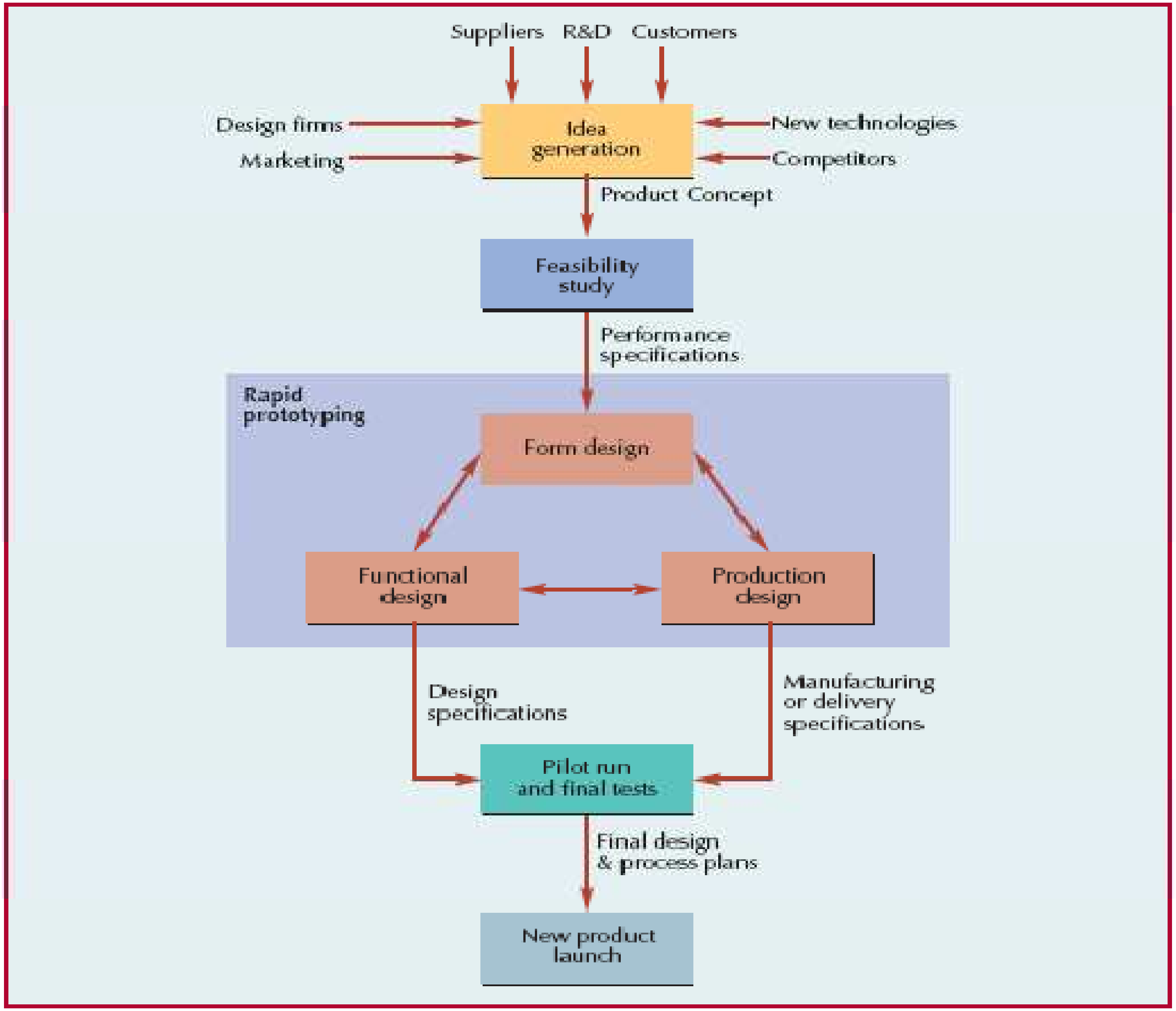
# Design Process

- Effective design can provide a competitive edge
  - matches product or service characteristics with customer requirements
  - ensures that customer requirements are met in the simplest and least costly manner
  - reduces time required to design a new product or service
  - minimizes revisions necessary to make a design workable

# Design Process (cont.)

- Product design
  - defines appearance of product
  - sets standards for performance
  - specifies which materials are to be used
  - determines dimensions and tolerances

# Design Process (cont.)



# Idea Generation

- Company's own R&D department
- Customer complaints or suggestions
- Marketing research
- Suppliers
- Salespersons in the field
- Factory workers
- New technological developments
- Competitors

# Idea Generation (cont.)

- Perceptual Maps
  - Visual comparison of customer perceptions
- Benchmarking
  - Comparing product/process against best-in-class
- Reverse engineering
  - Dismantling competitor’s product to improve your own product

# Perceptual Map of Breakfast Cereals

# Feasibility Study

- Market analysis
- Economic analysis
- Technical/strategic analyses
- Performance specifications

# Rapid Prototyping

- testing and revising a preliminary design model
- Build a prototype
  - form design
  - functional design
  - production design
- Test prototype
- Revise design
- Retest

# Form and Functional Design


- Form Design
  - how product will look?
- Functional Design
  - how product will perform?
    - reliability
    - maintainability
    - usability

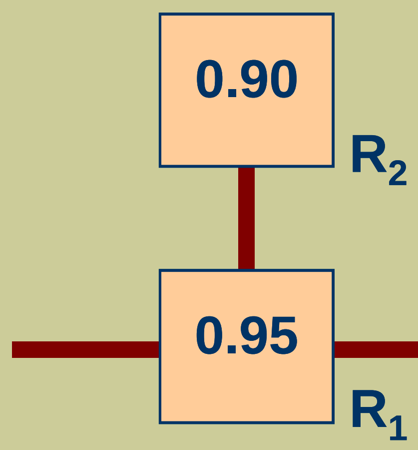
# Computing Reliability

**Components in series**


**0.90 x 0.90 = 0.81**

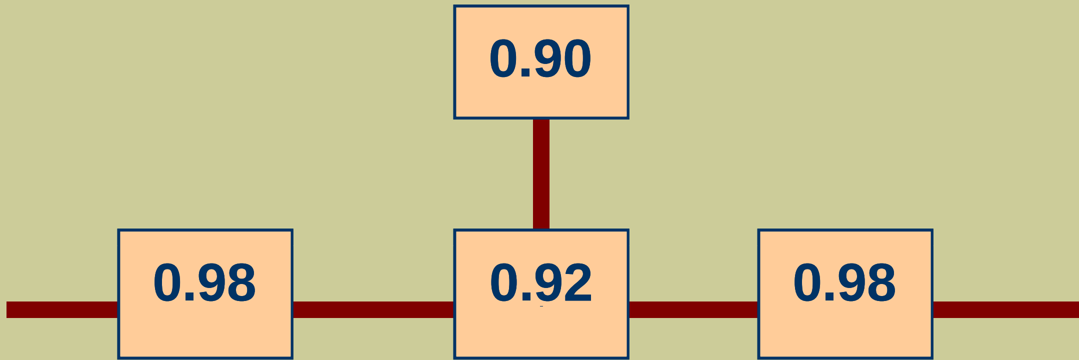
# Computing Reliability (cont.)

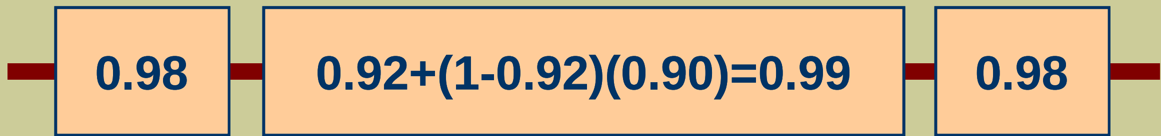
**Components in parallel**




**0.95 + 0.90(1-0.95) = 0.995**

# System Reliability




0.98 x 0.99 x 0.98 = 0.951

# System Availability (SA)

$$SA = \frac{MTBF}{MTBF + MTTR}$$

where:

MTBF = mean time between failures

MTTR = mean time to repair

# System Availability (cont.)

| PROVIDER | MTBF (HR) | MTTR (HR) |
|---|---|---|
| A | 60 | 4.0 |
| B | 36 | 2.0 |
| C | 24 | 1.0 |

$SA_A = 60 / (60 + 4) = .9375$ or 94%

$SA_B = 36 / (36 + 2) = .9473$ or 95%

$SA_C = 24 / (24 + 1) = .96$ or 96%

# Usability

- Ease of use of a product or service
  - ease of learning
  - ease of use
  - ease of remembering how to use
  - frequency and severity of errors
  - user satisfaction with experience

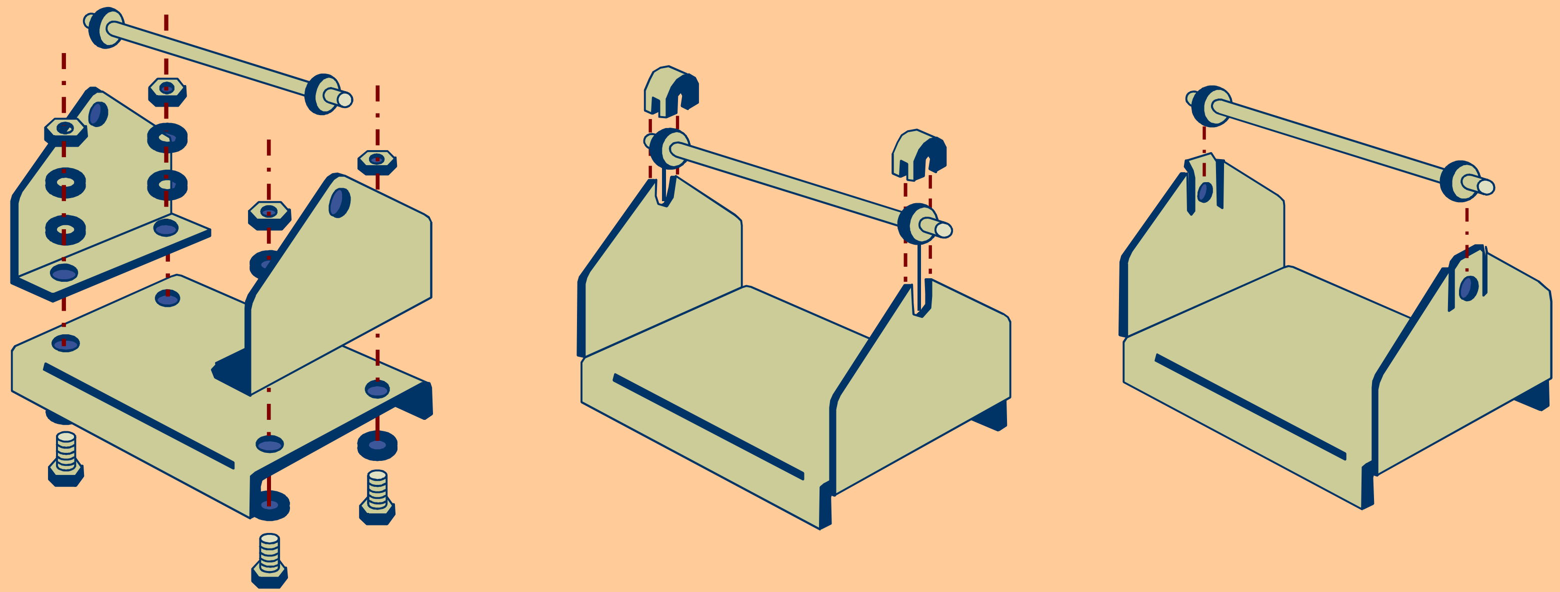
# Production Design

- How the product will be made
  - Simplification
    - reducing number of parts, assemblies, or options in a product
  - Standardization
    - using commonly available and interchangeable parts
  - Modular Design
    - combining standardized building blocks, or modules, to create unique finished products
  - Design for Manufacture (DFM)
    - Designing a product so that it can be produced easily and economically

# Design Simplification

*Source:* Adapted from G. Boothroyd and P. Dewhurst, "Product Design…. Key to Successful Robotic Assembly." *Assembly Engineering* (September 1986), pp. 90-93.

**(a) Original design** **(b) Revised design** **(c) Final design**



**Assembly using common fasteners**

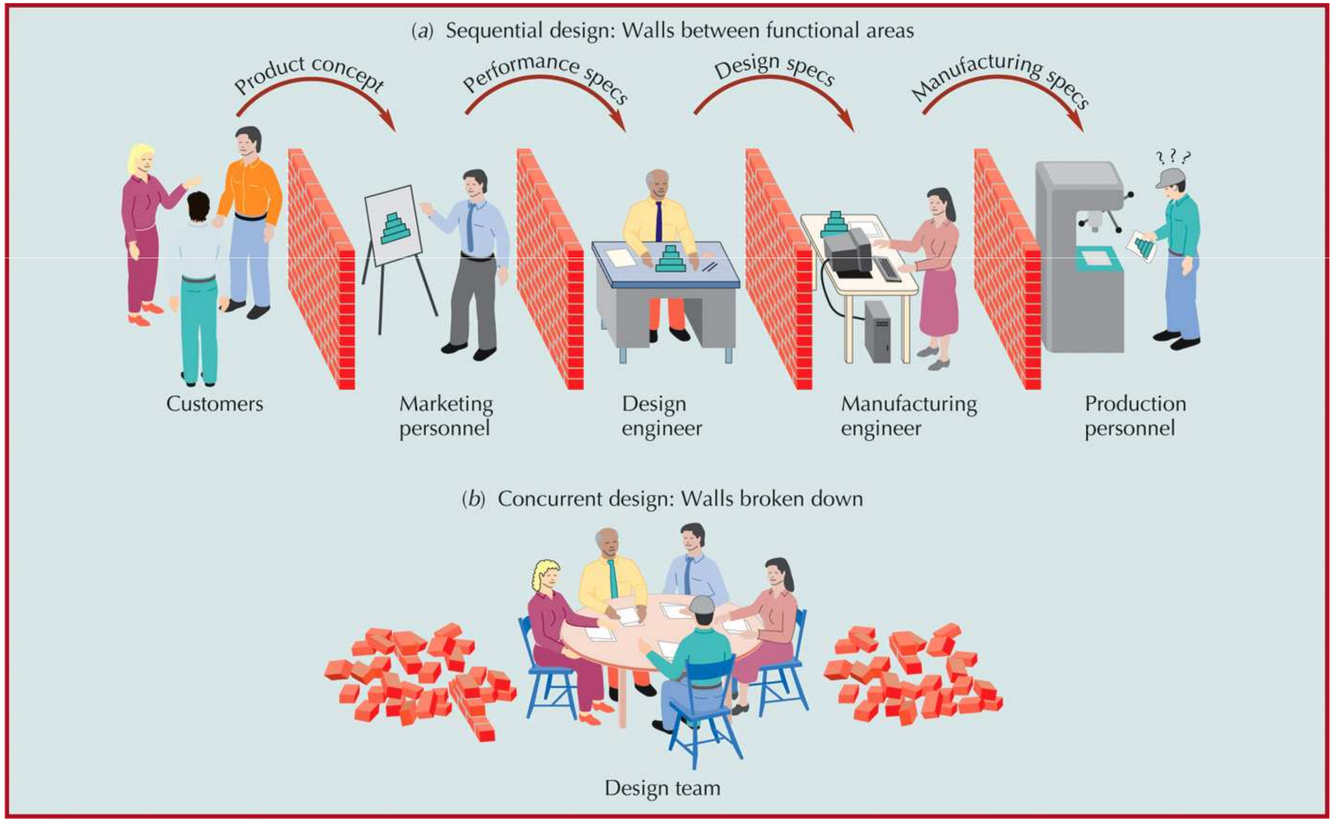
**One-piece base & elimination of fasteners**

**Design for push-and-snap assembly**

# Final Design and Process Plans

- Final design
  - detailed drawings and specifications for new product or service
- Process plans
  - workable instructions
    - necessary equipment and tooling
    - component sourcing recommendations
    - job descriptions and procedures
    - computer programs for automated machines

# Design Team



(a) Sequential design: Walls between functional areas
Product concept
Performance specs
Design specs
Manufacturing specs
Customers
Marketing personnel
Design engineer
Manufacturing engineer
Production personnel
(b) Concurrent design: Walls broken down
Design team

# Concurrent Design

- A new approach to design that involves simultaneous design of products and processes by design teams
- Improves quality of early design decisions
- Involves suppliers
- Incorporates production process
- Uses a price-minus system
- Scheduling and management can be complex as tasks are done in parallel
- Uses technology to aid design

# Technology in Design

- Computer Aided Design (CAD)
  - assists in creation, modification, and analysis of a design
  - computer-aided engineering (CAE)
    - tests and analyzes designs on computer screen
  - computer-aided manufacturing (CAD/CAM)
    - ultimate design-to-manufacture connection
  - product life cycle management (PLM)
    - managing entire lifecycle of a product
  - collaborative product design (CPD)

# Collaborative Product Design (CPD)

- A software system for collaborative design and development among trading partners
- With PML, manages product data, sets up project workspaces, and follows life cycle of the product
- Accelerates product development, helps to resolve product launch issues, and improves quality of design
- Designers can
  - conduct virtual review sessions
  - test “what if” scenarios
  - assign and track design issues
  - communicate with multiple tiers of suppliers
  - create, store, and manage project documents

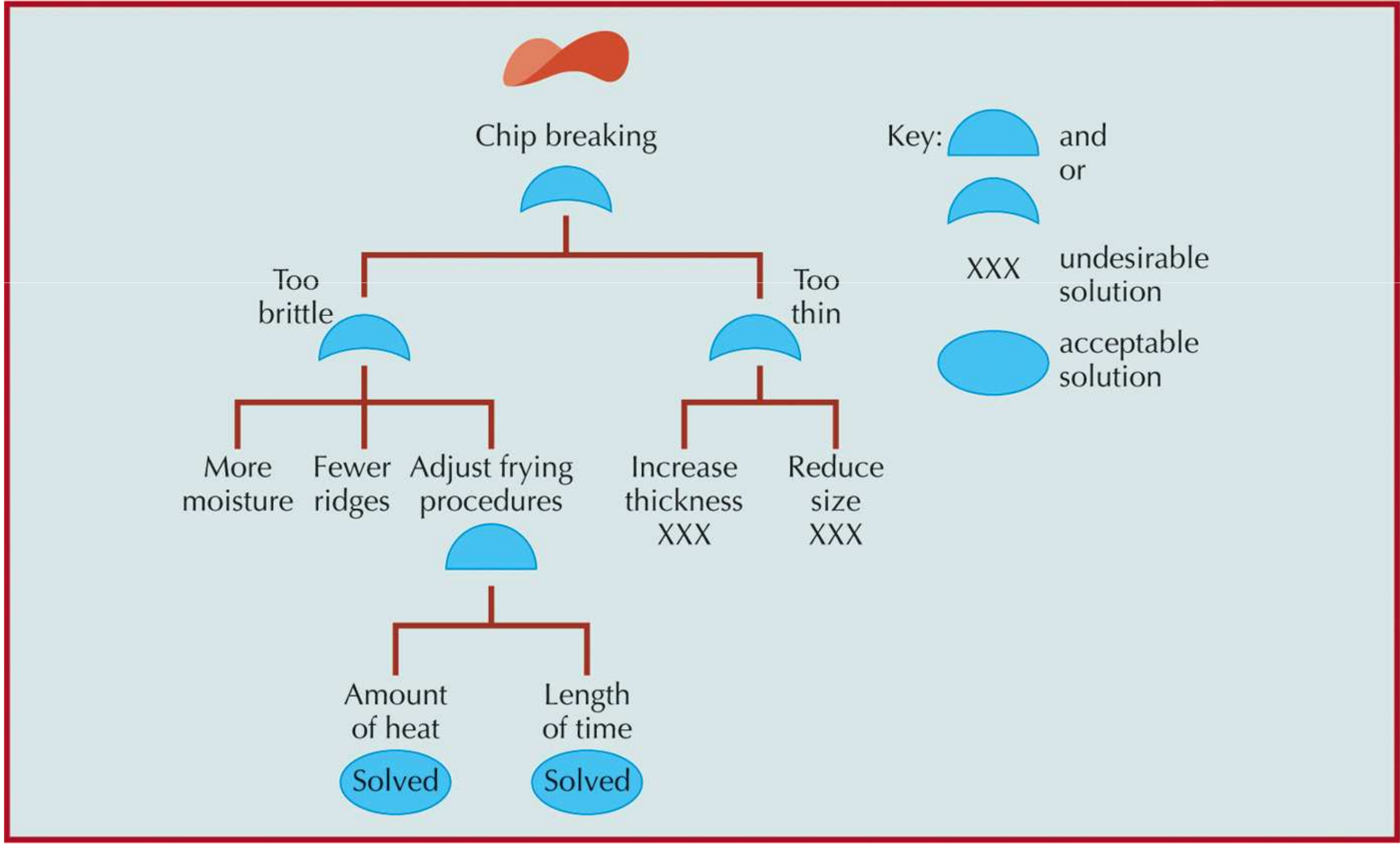
# Design Review

- Review designs to prevent *failures* and ensure *value*
  - Failure mode and effects analysis (FMEA)
    - a systematic method of analyzing product failures
  - Fault tree analysis (FTA)
    - a visual method for analyzing interrelationships among failures
  - Value analysis (VA)
    - helps eliminate unnecessary features and functions

# FMEA for Potato Chips

| Failure Mode | Cause of Failure | Effect of Failure | Corrective Action |
|---|---|---|---|
| Stale | ◆low moisture content<br>◆expired shelf life<br>◆poor packaging | ◆tastes bad<br>◆won't crunch<br>◆thrown out<br>◆lost sales | ◆add moisture<br>◆ cure longer<br>◆better package seal<br>◆shorter shelf life |
| Broken | ◆too thin<br>◆too brittle<br>◆rough handling<br>◆rough use<br>◆poor packaging | ◆can't dip<br>◆poor display<br>◆injures mouth<br>◆chocking<br>◆perceived as old<br>◆lost sales | ◆change recipe<br>◆change process<br>◆change packaging |
| Too Salty | ◆outdated receipt<br>◆process not in control<br>◆uneven distribution of salt | ◆eat less<br>◆drink more<br>◆health hazard<br>◆lost sales | ◆experiment with recipe<br>◆experiment with process<br>◆introduce low salt version |

# Fault tree analysis (FTA)



# Value analysis (VA)

- Can we do without it?
- Does it do more than is required?
- Does it cost more than it is worth?
- Can something else do a better job?
- Can it be made by
  - a less costly method?
  - with less costly tooling?
  - with less costly material?
- Can it be made cheaper, better, or faster by someone else?

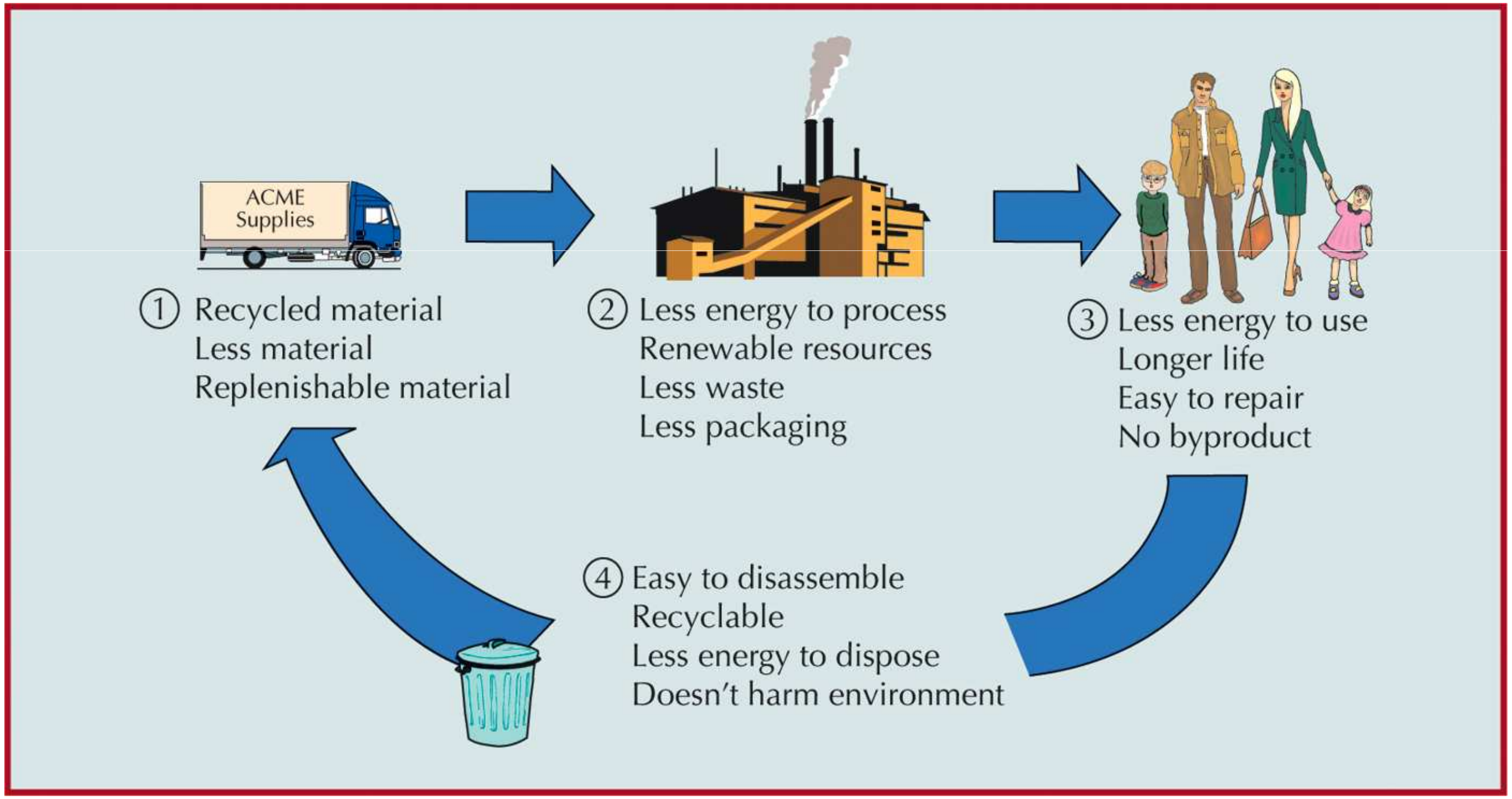
# Value analysis (VA) (cont.)

- Updated versions also include:
  - Is it recyclable or biodegradable?
  - Is the process sustainable?
  - Will it use more energy than it is worth?
  - Does the item or its by-product harm the environment?

# Design for Environment and Extended Producer Responsibility

- Design for environment
  - designing a product from material that can be recycled
  - design from recycled material
  - design for ease of repair
  - minimize packaging
  - minimize material and energy used during manufacture, consumption and disposal
- Extended producer responsibility
  - holds companies responsible for their product even after its useful life

# Design for Environment



# Sustainability

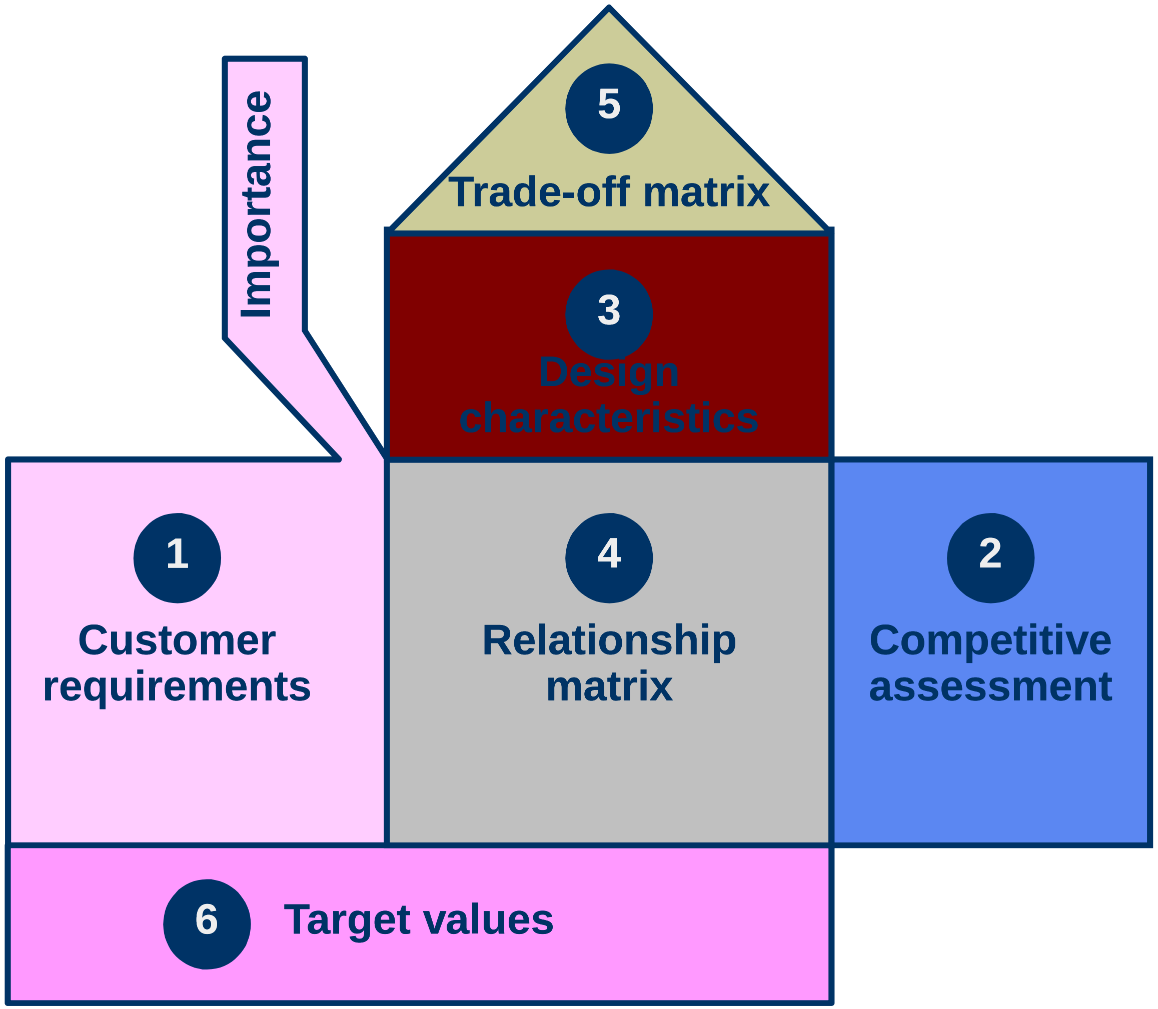
- Ability to meet present needs without compromising those of future generations
- Green product design
  - Use fewer materials
  - Use recycled materials or recovered components
  - Don't assume natural materials are always better
  - Don't forget energy consumption
  - Extend useful life of product
  - Involve entire supply chain
  - Change paradigm of design

*Source:* Adapted from the Business Social Responsibility Web site, www.bsr.org, accessed April 1, 2007.

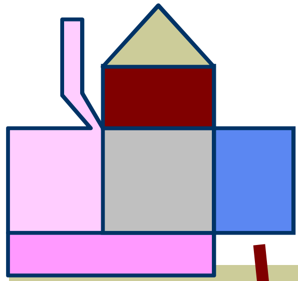
# Quality Function Deployment (QFD)

- Translates voice of customer into technical design requirements
- Displays requirements in matrix diagrams
  - first matrix called “house of quality”
  - series of connected houses

# House of Quality

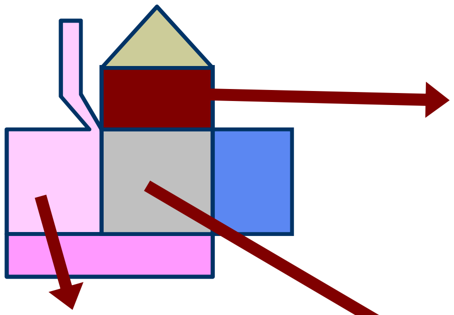


# Competitive Assessment of Customer Requirements



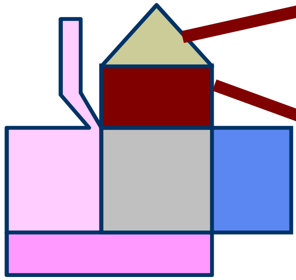
| | Customer Requirements | | Competitive Assessment 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|---|
| Irons well | Presses quickly | 9 | | B A | X | | |
| | Removes wrinkles | 8 | | AB | | X | |
| | Doesn't stick to fabric | 6 | | X | | BA | |
| | Provides enough steam | 8 | | | AB | | X |
| | Doesn't spot fabric | 6 | | | X AB | | |
| Easy and safe to use | Doesn't scorch fabric | 9 | | | A XB | | |
| | Heats quickly | 6 | | X | B | A | |
| | Automatic shut-off | 3 | | | | | ABX |
| | Quick cool-down | 3 | | X | A B | | |
| | Doesn't break when dropped | 5 | | AB | | X | |
| | Doesn't burn when touched | 5 | | AB X | | | |
| | Not too heavy | 8 | | X | | A | B |

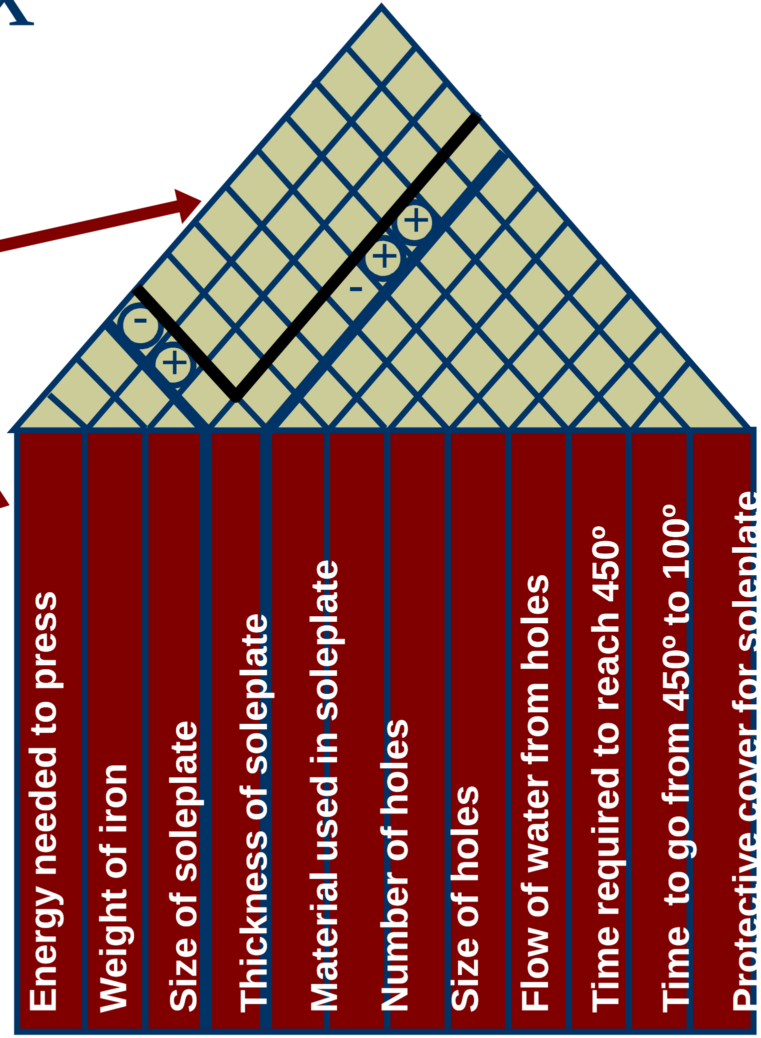
# From Customer Requirements to Design Characteristics



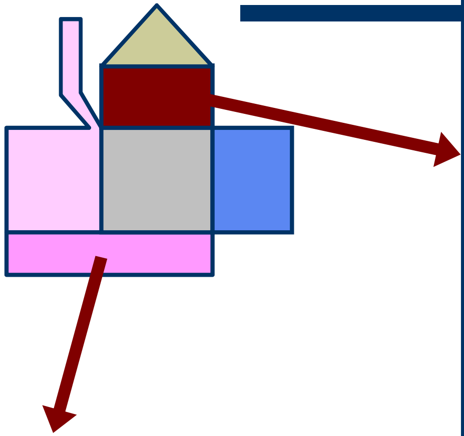
| Customer Requirements | | Energy needed to press | Weight of iron | Size of soleplate | Thickness of soleplate | Material used in soleplate | Number of holes | Size of holes | Flow of water from holes | Time required to reach 450° F | Time to go from 450° to 100° | Protective cover for soleplate | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Irons well | Presses quickly | - | O - | + | + | + | | | | - | | | |
| | Removes wrinkles | | O + | | + | | + | + | + | | | | |
| | Doesn't stick to fabric | | - | | | O + | | | + | | O + | + | |
| | Provides enough steam | | | + | | | + | + | + O | | | | |
| | Doesn't spot fabric | | | | | + O | - | - | - | | O | | |
| Easy and safe to use | Doesn't scorch fabric | | | | + | + | | | + | O - | + | | |
| | Heats quickly | | | - | - | | | | | + | | - | O |
| | Automatic shut-off | | | | O | | | | | | O | | + |
| | Quick cool-down | | | - | O - | + | | | | | + | | |
| | Doesn't break when dropped | | + | + | + | | | | | | | O + | |
| | Doesn't burn when touched | | O | | + | O | | | | | + | + | + |
| | Not too heavy | + | - | - | - | + | | | | | | - | |

# Tradeoff Matrix



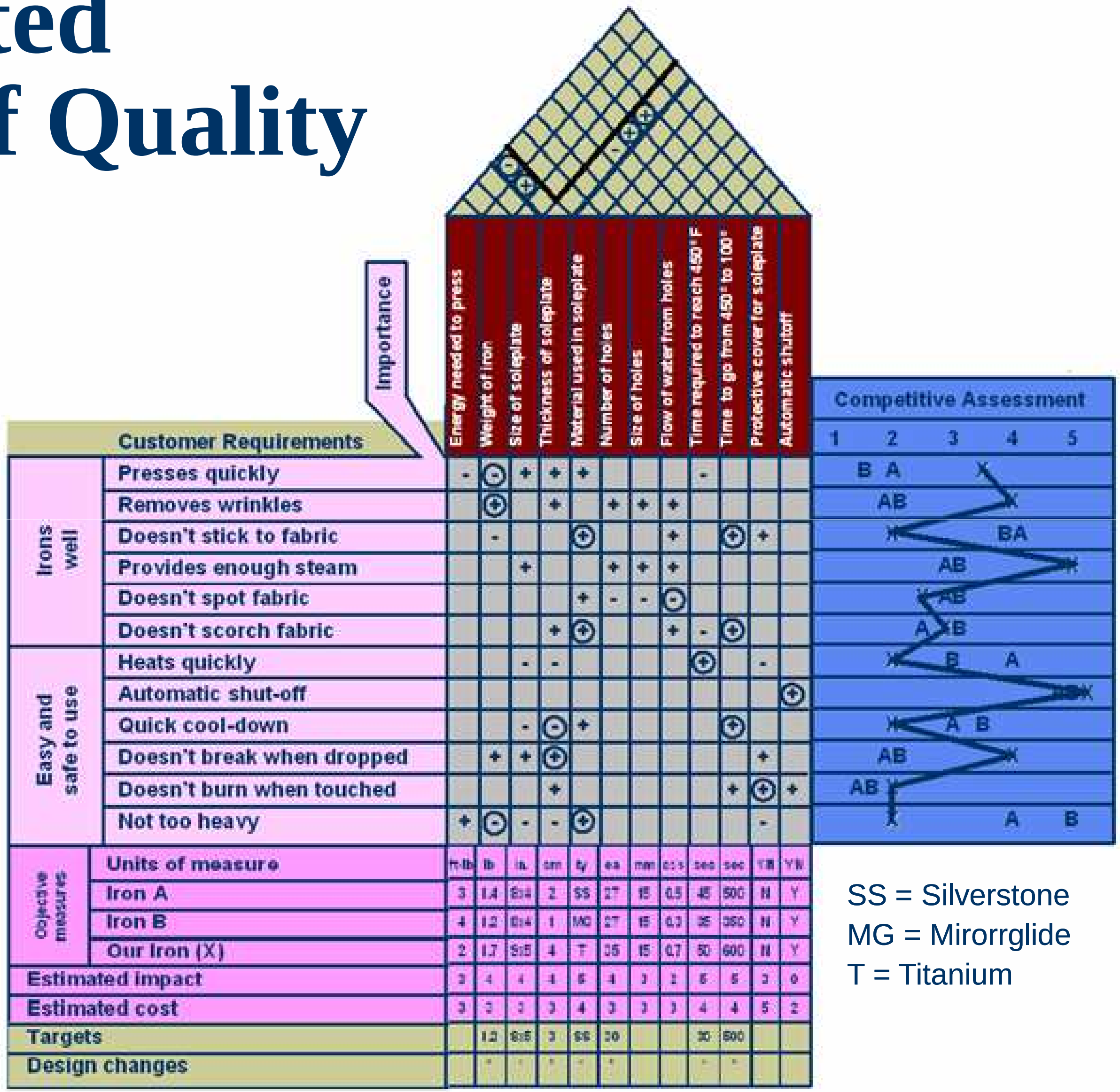


# Targeted Changes in Design



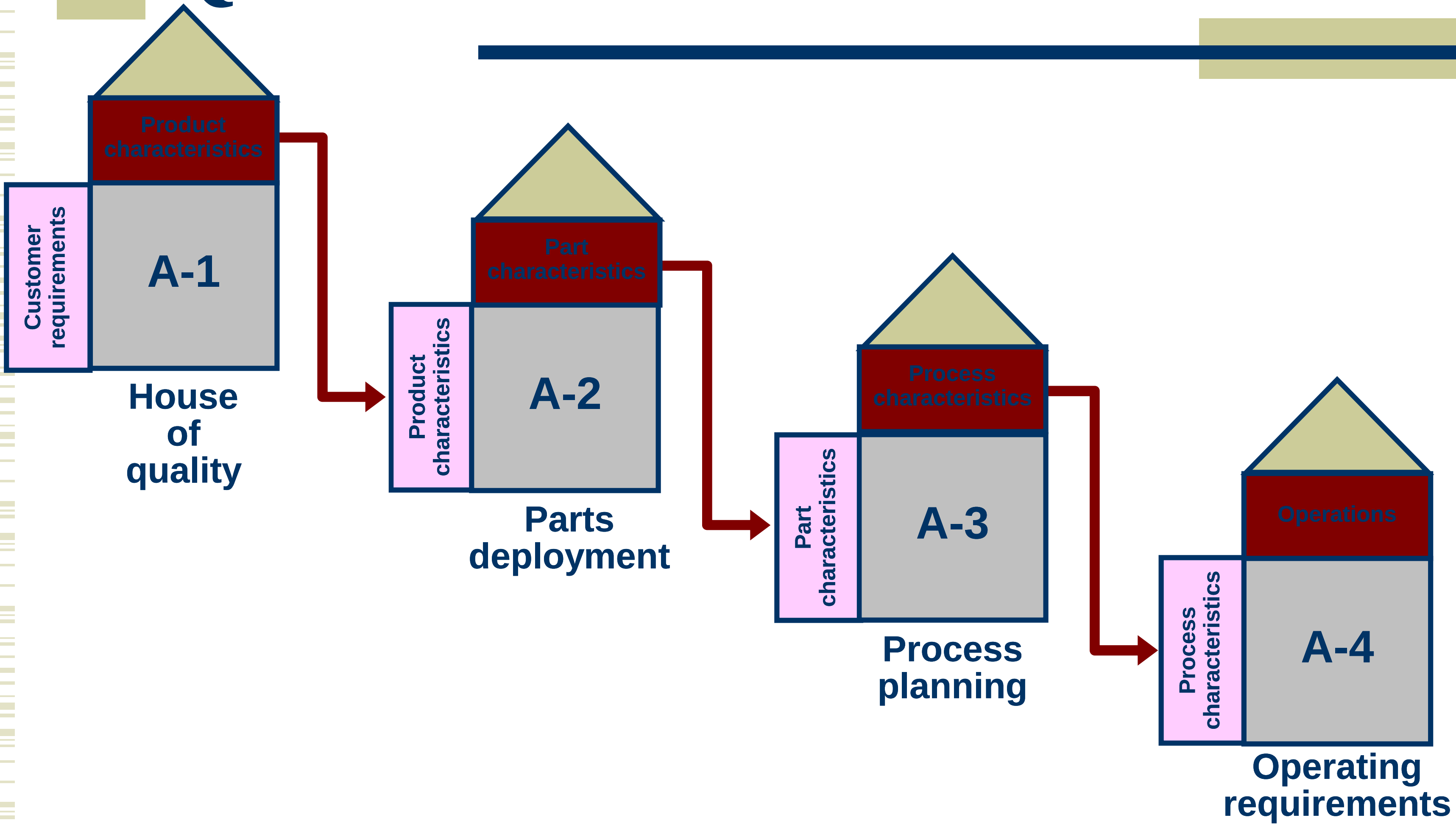
| | | Energy needed to press | Weight of iron | Size of soleplate | Thickness of soleplate | Material used in soleplate | Number of holes | Size of holes | Flow of water from holes | Time required to reach 450º | Time to go from 450º to 100º | Protective cover for soleplate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Objective measures | Units of measure | ft-lb | lb | in. | cm | ty | ea | mm | oz/s | sec | sec | Y/N | Y/N |
| | Iron A | 3 | 1.4 | 8x4 | 2 | SS | 27 | 15 | 0.5 | 45 | 500 | N | Y |
| | Iron B | 4 | 1.2 | 8x4 | 1 | MG | 27 | 15 | 0.3 | 35 | 350 | N | Y |
| | Our Iron (X) | 2 | 1.7 | 9x5 | 4 | T | 35 | 15 | 0.7 | 50 | 600 | N | Y |
| Estimated impact | | 3 | 4 | 4 | 4 | 5 | 4 | 3 | 2 | 5 | 5 | 3 | 0 |
| Estimated cost | | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 | 4 | 4 | 5 | 2 |
| Targets | | | 1.2 | 8x5 | 3 | SS | 30 | | | 30 | 500 | | |
| Design changes | | | * | * | * | * | * | | | * | * | | |

# Completed House of Quality




SS = Silverstone
MG = Mirorrglide
T = Titanium

# A Series of Connected QFD Houses



# Benefits of QFD

- Promotes better understanding of customer demands
- Promotes better understanding of design interactions
- Involves manufacturing in design process
- Provides documentation of design process

# Design for Robustness

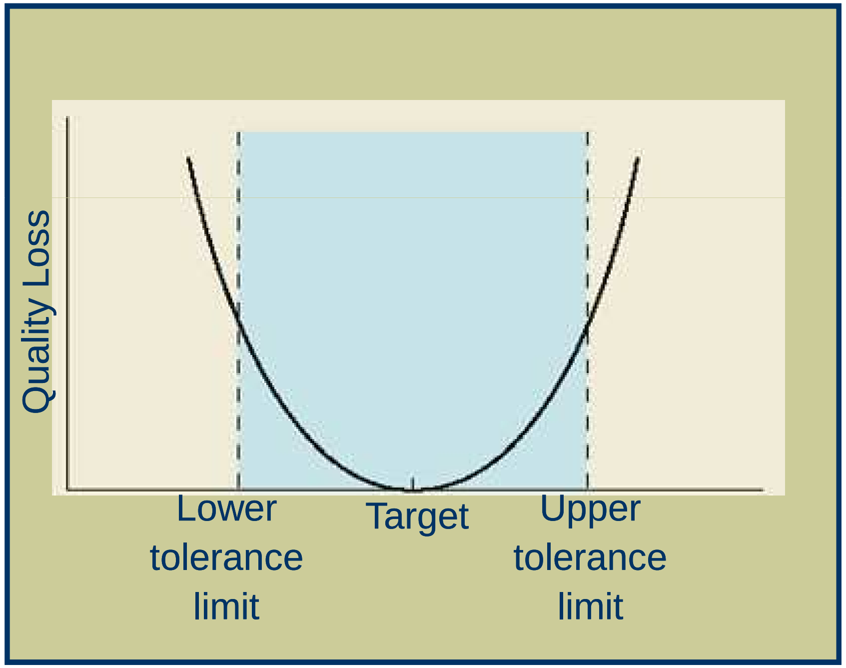
- Robust product
  - designed to withstand variations in environmental and operating conditions
- Robust design
  - yields a product or service designed to withstand variations
- Controllable factors
  - design parameters such as material used, dimensions, and form of processing
- Uncontrollable factors
  - user's control (length of use, maintenance, settings, etc.)

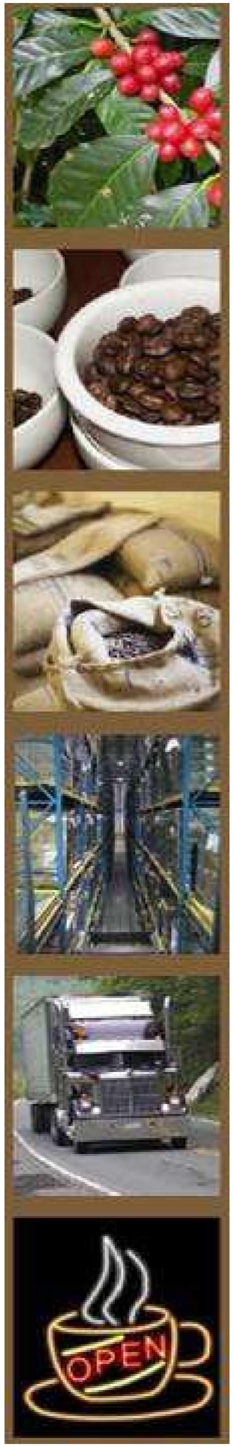
# Design for Robustness (cont.)

- Tolerance
  - allowable ranges of variation in the dimension of a part
- Consistency
  - consistent errors are easier to correct than random errors
  - *parts* within tolerances may yield *assemblies* that are not within limits
  - consumers prefer product characteristics near their ideal values

# Taguchi's Quality Loss Function

- Quantifies customer preferences toward quality
- Emphasizes that customer preferences are strongly oriented toward consistently
- Design for Six Sigma (DFSS)






# Chapter 5

## *Service Design*

***Operations Management***

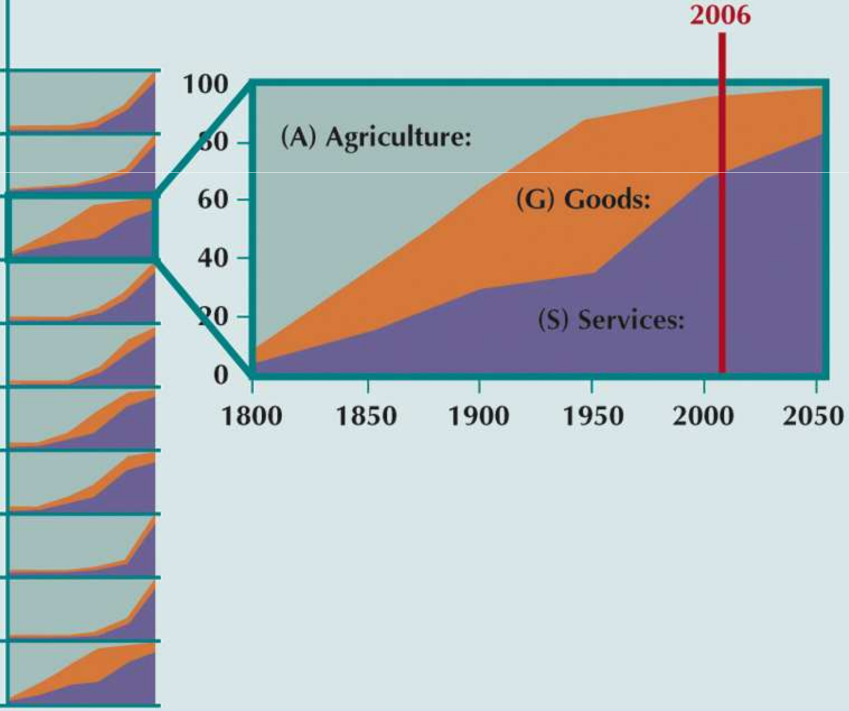
**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

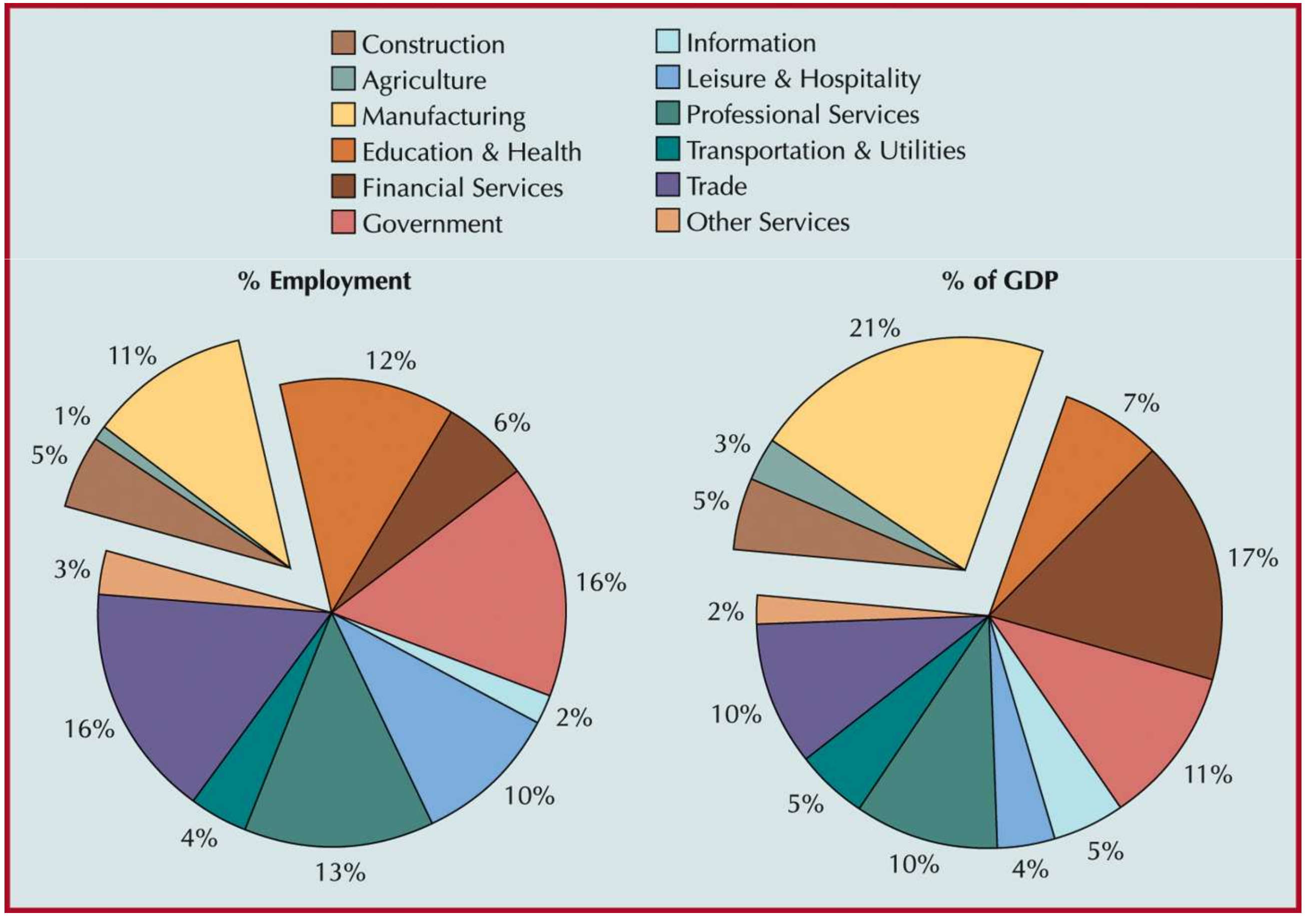
- Service Economy
- Characteristics of Services
- Service Design Process
- Tools for Service Design
- Waiting Line Analysis for Service Improvement

# Service Economy

| Nation | % World Labor | % Agriculture | % Goods | % Services |
|---|---|---|---|---|
| China | 21.0 | 50 | 15 | 35 |
| India | 17.0 | 60 | 17 | 23 |
| U.S. | 4.8 | 3 | 27 | 70 |
| Indonesia | 3.9 | 45 | 16 | 39 |
| Brazil | 3.0 | 23 | 24 | 53 |
| Russia | 2.5 | 12 | 23 | 65 |
| Japan | 2.4 | 5 | 25 | 70 |
| Nigeria | 2.2 | 70 | 10 | 20 |
| Bangledesh | 2.2 | 63 | 11 | 26 |
| Germany | 1.4 | 3 | 33 | 64 |




*Source:* U.S. Bureau of Labor Statistics, IBM Almaden Research Center

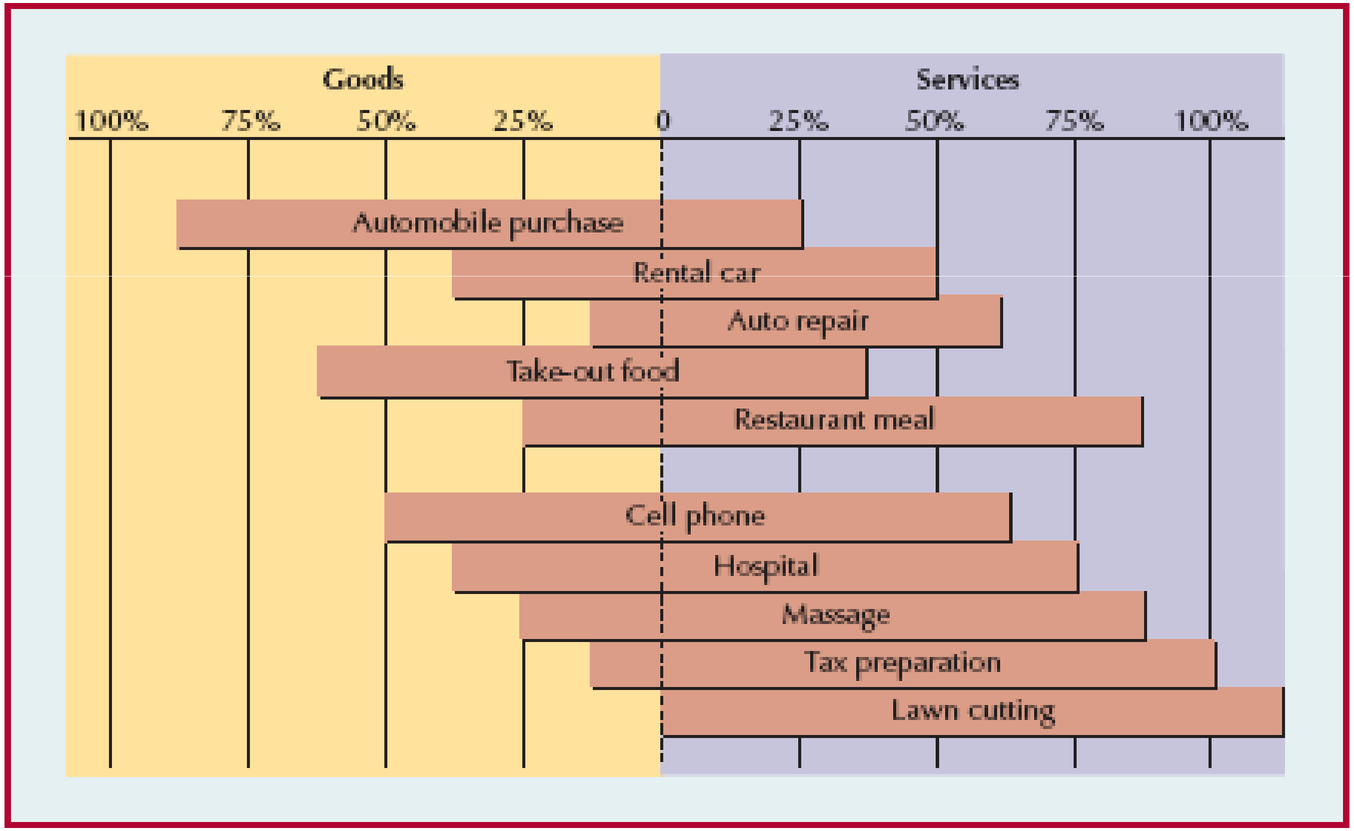


Construction
Agriculture
Manufacturing
Education & Health
Financial Services
Government
Information
Leisure & Hospitality
Professional Services
Transportation & Utilities
Trade
Other Services
% Employment
11%
12%
1%
6%
5%
3%
16%
16%
2%
10%
4%
13%
% of GDP
21%
7%
3%
5%
17%
2%
10%
11%
5%
5%
10%
4%

# Characteristics of Services

- Services
  - acts, deeds, or performances
- Goods
  - tangible objects
- Facilitating services
  - accompany almost all purchases of goods
- Facilitating goods
  - accompany almost all service purchases

# Continuum from Goods to Services

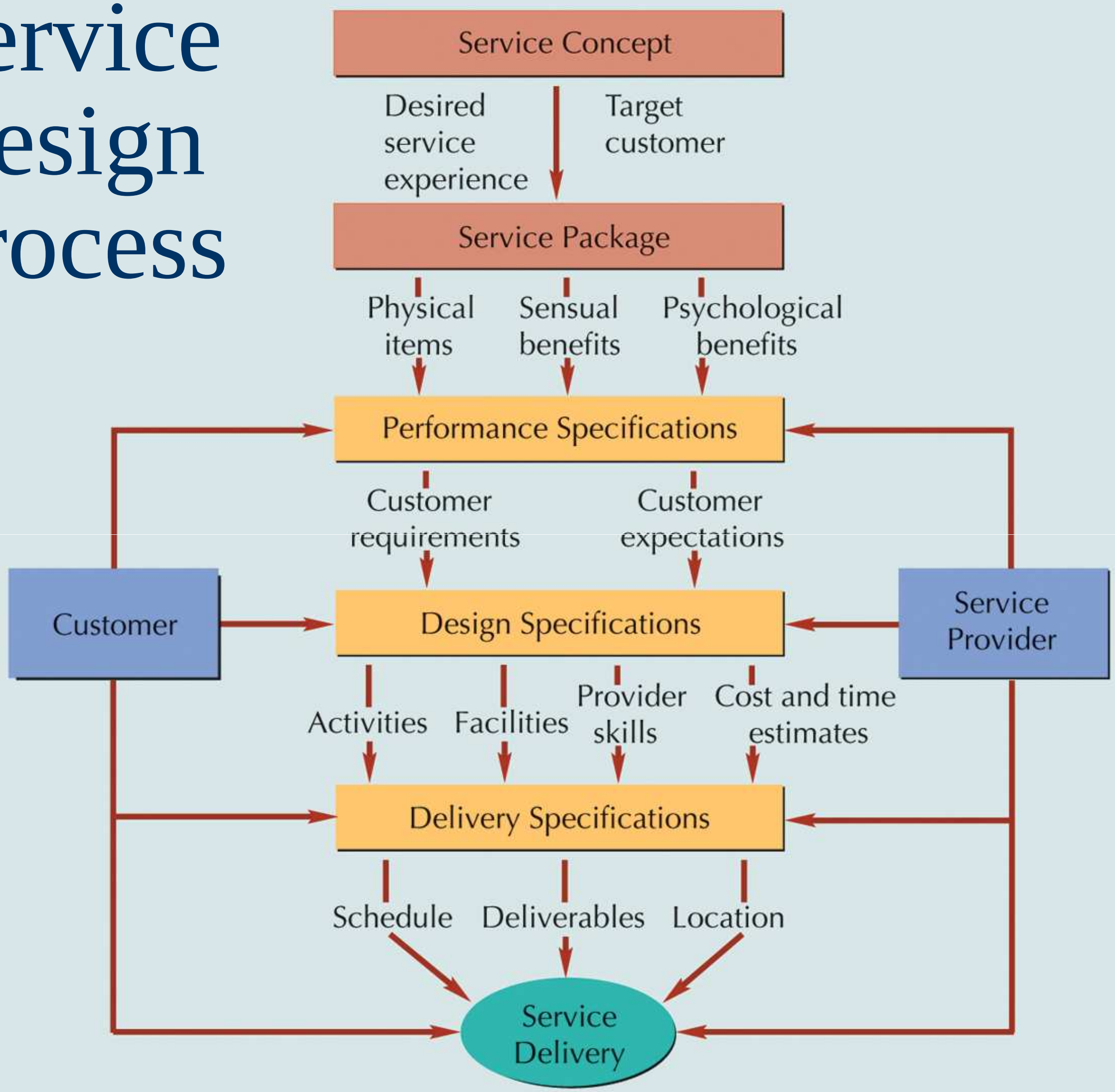



*Source:* Adapted from Earl W. Sasser, R.P. Olsen, and D. Daryl Wyckoff, *Management of Service Operations* (Boston: Allyn Bacon, 1978), p.11.

# Characteristics of Services (cont.)

- Services are intangible
- Service output is variable
- Services have higher customer contact
- Services are perishable
- Service inseparable from delivery
- Services tend to be decentralized and dispersed
- Services are consumed more often than products
- Services can be easily emulated

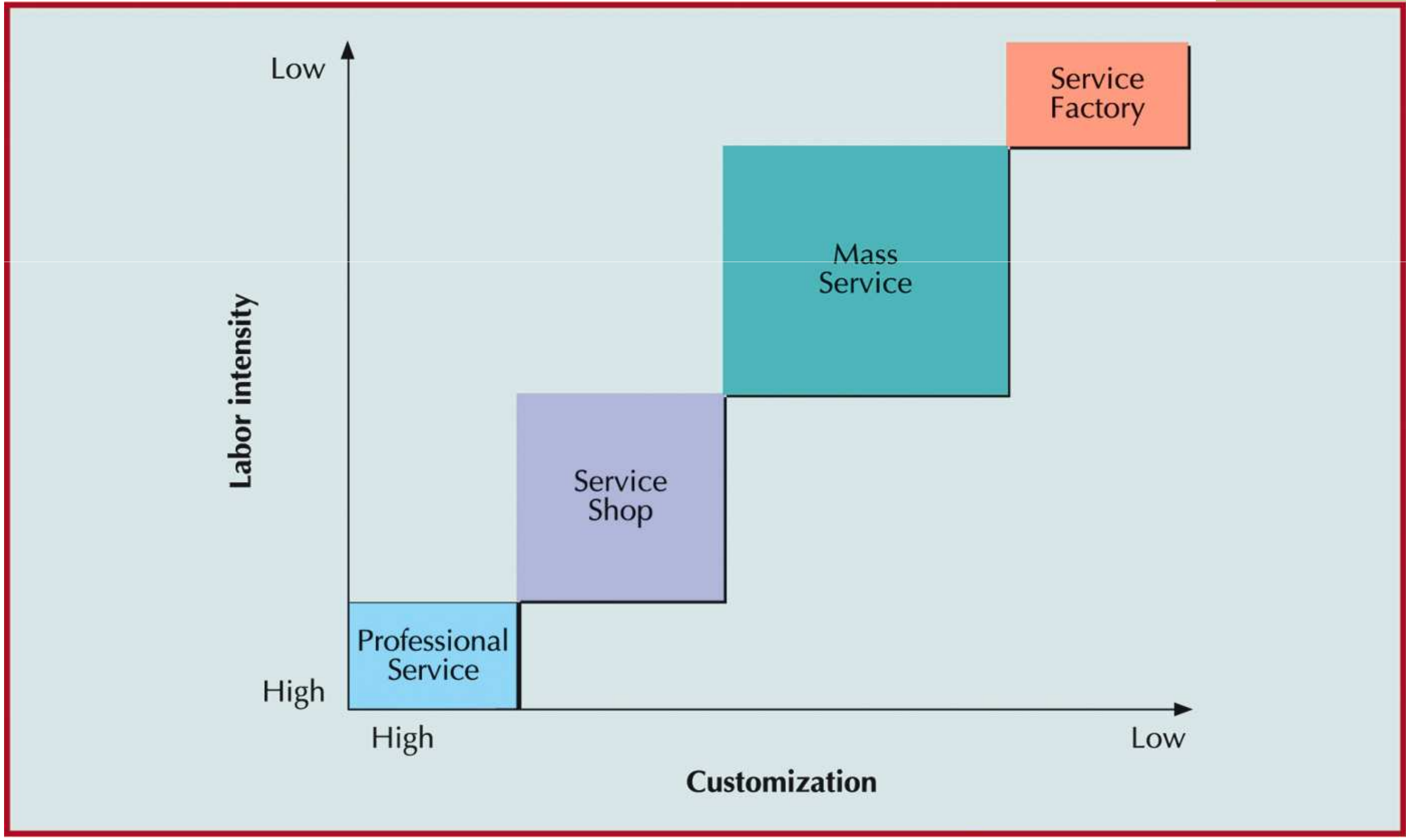
# Service Design Process



# Service Design Process (cont.)

- Service concept
  - purpose of a service; it defines target market and customer experience
- Service package
  - mixture of physical items, sensual benefits, and psychological benefits
- Service specifications
  - performance specifications
  - design specifications
  - delivery specifications

# Service Process Matrix



# High v. Low Contact Services

| Design Decision | High-Contact Service | Low-Contact Service |
|---|---|---|
| ◆ Facility location | ◆ Convenient to customer | Near labor or transportation source |
| Facility layout | Must look presentable, accommodate customer needs, and facilitate interaction with customer | Designed for efficiency |

Source: Adapted from R. Chase, N. Aquilano, and R. Jacobs, *Operations Management for Compensative Advantage* (New York:McGraw-Hill, 2001), p. 210

# High v. Low Contact Services (cont.)

| Design Decision | High-Contact Service | Low-Contact Service |
|---|---|---|
| ◆ Quality control | ◆ More variable since customer is involved in process; customer expectations and perceptions of quality may differ; customer present when defects occur | Measured against established standards; testing and rework possible to correct defects |
| Capacity | Excess capacity required to handle peaks in demand | Planned for average demand |

Source: Adapted from R. Chase, N. Aquilano, and R. Jacobs, *Operations Management for Compensative Advantage* (New York:McGraw-Hill, 2001), p. 210

# High v. Low Contact Services (cont.)

| Design Decision | High-Contact Service | Low-Contact Service |
|---|---|---|
| ◆ Worker skills | ◆ Must be able to interact well with customers and use judgment in decision making | Technical skills |
| Scheduling | Must accommodate customer schedule | Customer concerned only with completion date |

Source: Adapted from R. Chase, N. Aquilano, and R. Jacobs, *Operations Management for Compensative Advantage* (New York:McGraw-Hill, 2001), p. 210

# High v. Low Contact Services (cont.)

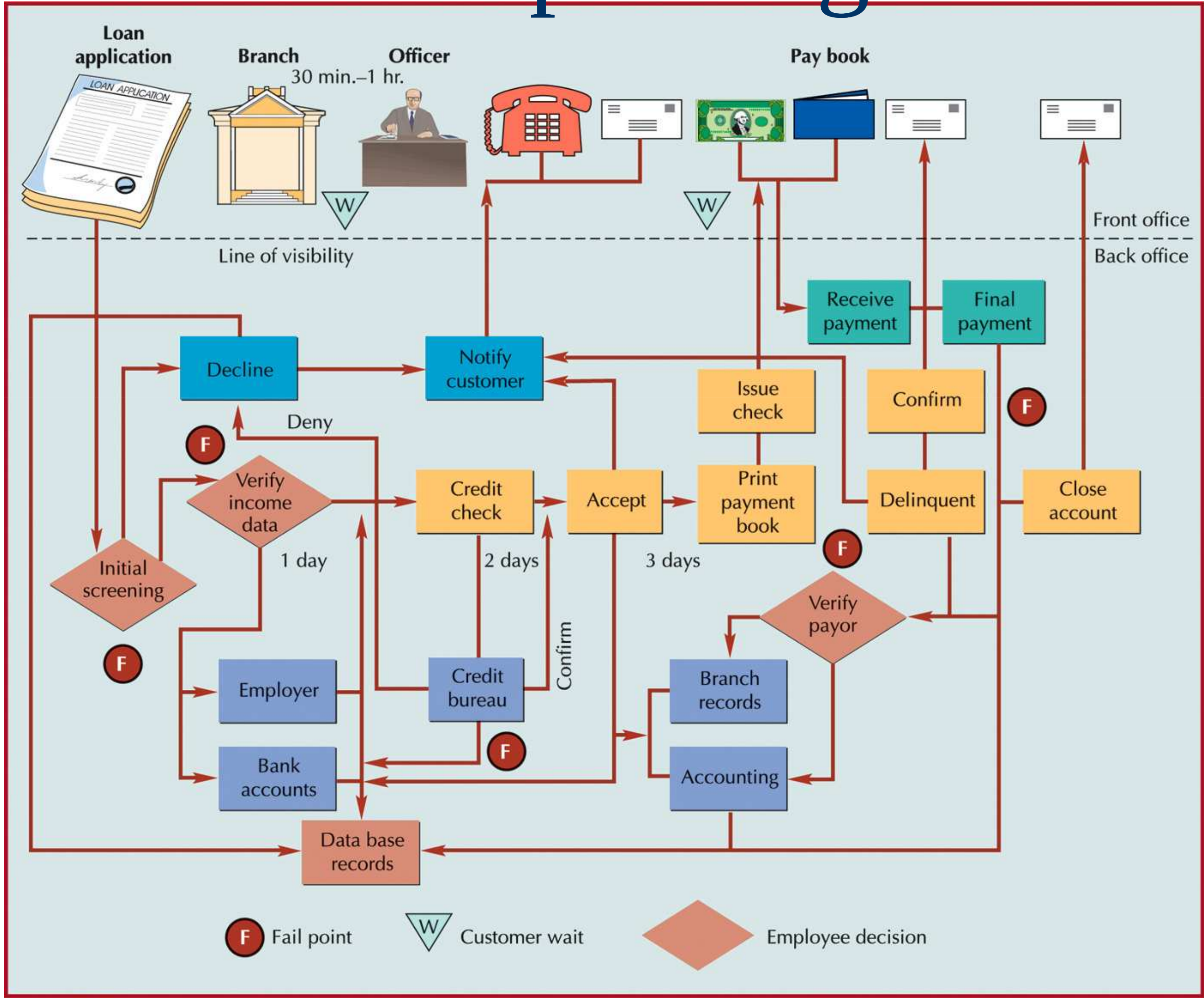
| Design Decision | High-Contact Service | Low-Contact Service |
|---|---|---|
| ◆ Service process | ◆ Mostly front-room activities; service may change during delivery in response to customer | Mostly back-room activities; planned and executed with minimal interference |
| Service package | Varies with customer; includes environment as well as actual service | Fixed, less extensive |

Source: Adapted from R. Chase, N. Aquilano, and R. Jacobs, *Operations Management for Compensative Advantage* (New York:McGraw-Hill, 2001), p. 210

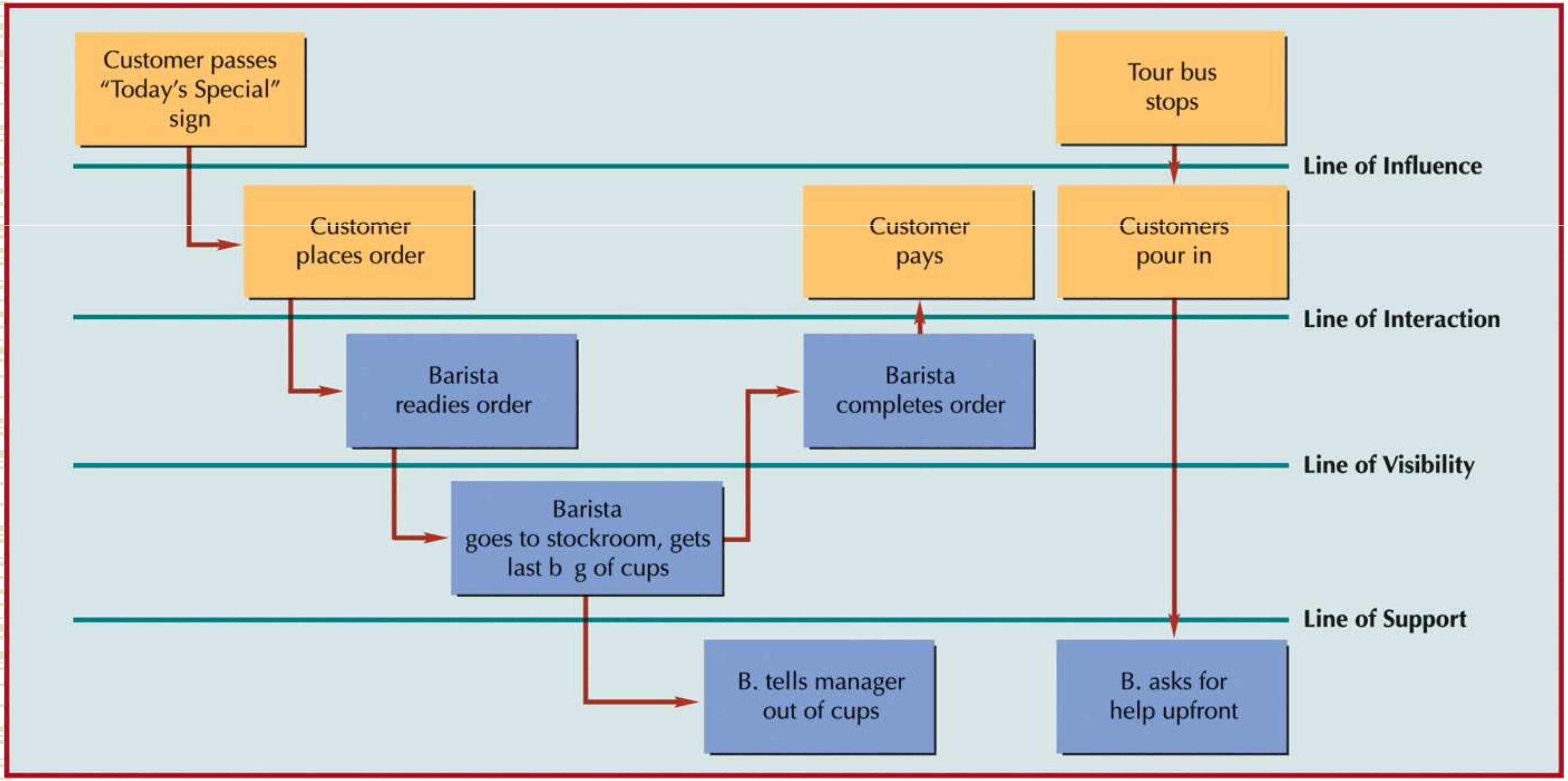
# Tools for Service Design

- Service blueprinting
  - line of influence
  - line of interaction
  - line of visibility
  - line of support
- Front-office/Back-office activities
- Servicescapes
  - space and function
  - ambient conditions
  - signs, symbols, and artifacts
- Quantitative techniques

# Service Blueprinting

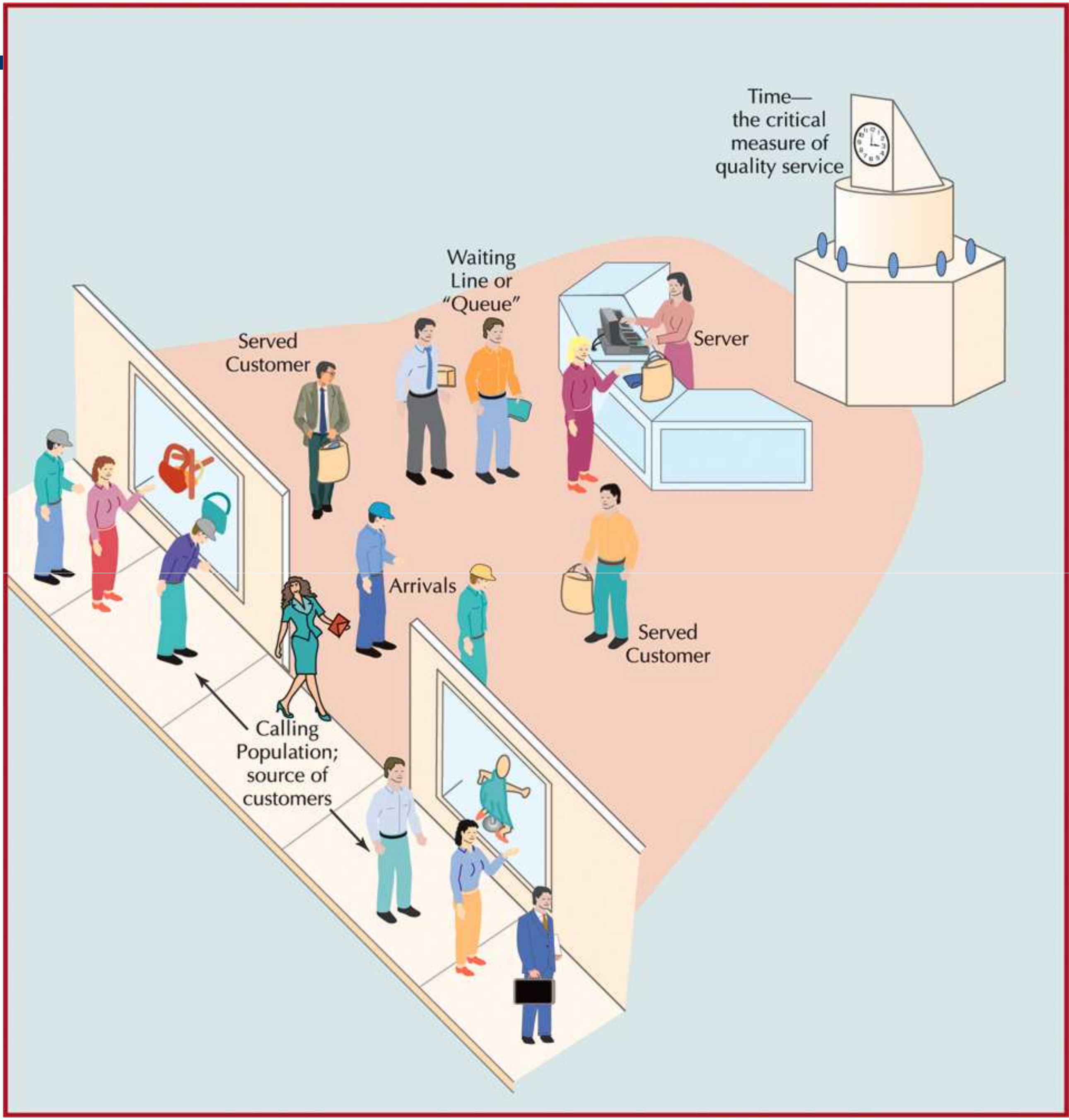


# Service Blueprinting (Con't)



# Elements of Waiting Line Analysis

- Operating characteristics
  - average values for characteristics that describe performance of waiting line system
- Queue
  - a single waiting line
- Waiting line system
  - consists of arrivals, servers, and waiting line structure
- Calling population
  - source of customers; infinite or finite


Time—
the critical
measure of
quality service
Waiting
Line or
"Queue"
Served
Customer
Server
Arrivals
Served
Customer
Calling
Population;
source of
customers

# Elements of Waiting Line Analysis (cont.)

- Arrival rate (λ)
  - frequency at which customers arrive at a waiting line according to a probability distribution, usually Poisson
- Service time (μ)
  - time required to serve a customer, usually described by negative exponential distribution
- Service rate must be shorter than arrival rate ($\lambda < \mu$)
- Queue discipline
  - order in which customers are served
- Infinite queue
  - can be of any length; length of a **finite** queue is limited

# Elements of Waiting Line Analysis (cont.)

(b) Multiple-server waiting line

(a) Single-server waiting line

- Channels
  - number of parallel servers for servicing customers
- Phases
  - number of servers in sequence a customer must go through

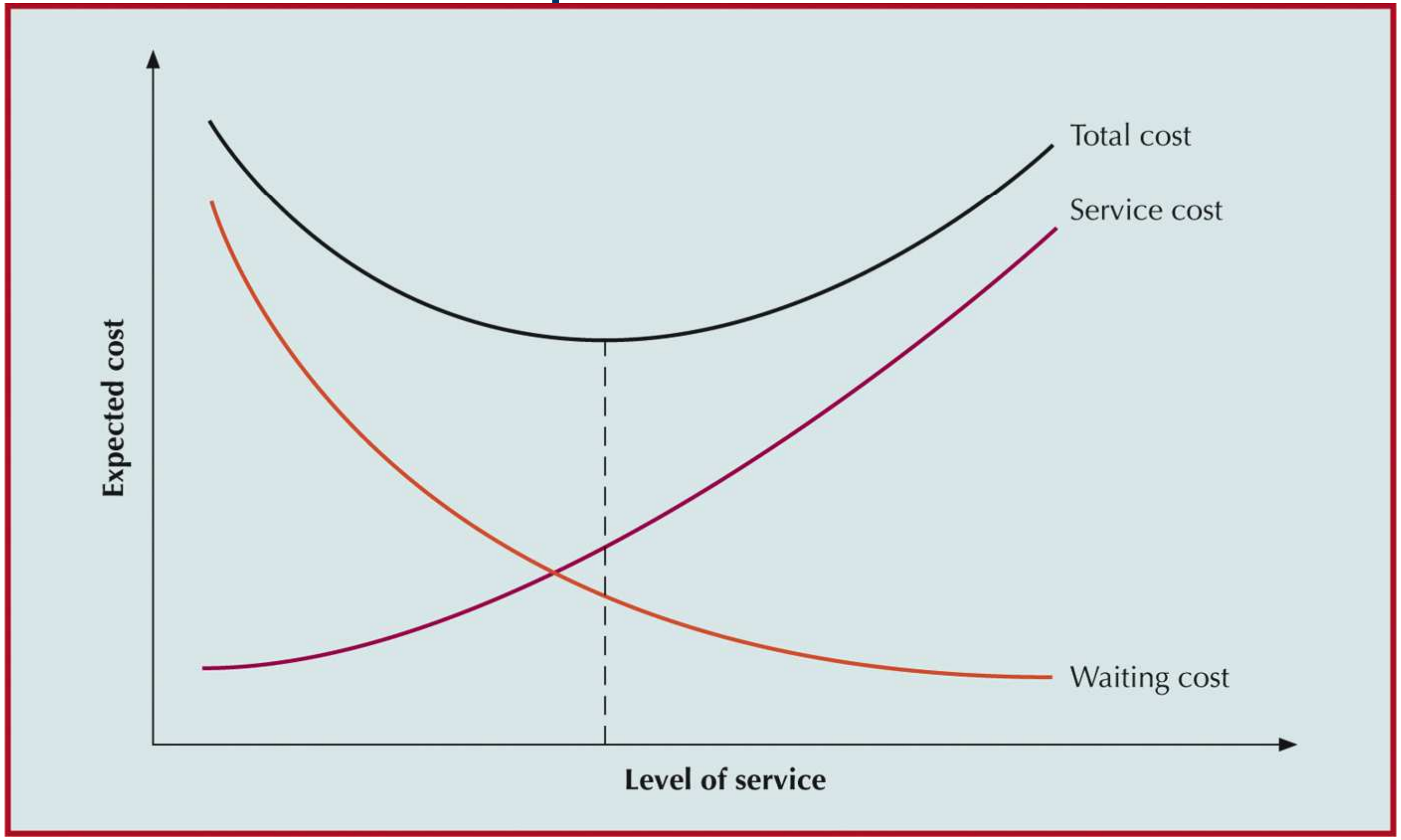
# Operating Characteristics

- *Operating characteristics* are assumed to approach a *steady state*

| Notation | Operating Characteristic |
|---|---|
| $L$ | Average number of customers in the system (waiting and being served) |
| $L_q$ | Average number of customers in the waiting line |
| $W$ | Average time a customer spends in the system (waiting and being served) |
| $W_q$ | Average time a customer spends waiting in line |
| $P_0$ | Probability of no (i.e., zero) customers in the system |
| $P_n$ | Probability of *n* customers in the system |
| $\rho$ | Utilization rate; the proportion of time the system is in use |

# Traditional Cost Relationships

- as service improves, cost increases



# Psychology of Waiting

- Waiting rooms
  - magazines and newspapers
  - televisions
- Bank of America
  - mirrors
- Supermarkets
  - magazines
  - “impulse purchases”
- Disney
  - costumed characters
  - mobile vendors
  - accurate wait times
  - special passes

# Psychology of Waiting (cont.)

- Preferential treatment
  - Grocery stores:  express lanes for customers with few purchases
  - Airlines/Car rental agencies:  special cards available to frequent-users or for an additional fee
  - Phone retailers:  route calls to more or less experienced salespeople based on customer's sales history
- Critical service providers
  - services of police department, fire department, etc.
  - waiting is unacceptable; cost is not important

# Waiting Line Models

- *Single-server* model
  - simplest, most basic waiting line structure
- Frequent variations (all with Poisson arrival rate)
  - exponential service times
  - general (unknown) distribution of service times
  - constant service times
  - exponential service times with finite queue
  - exponential service times with finite calling population

# Basic Single-Server Model

- Assumptions
  - Poisson arrival rate
  - exponential service times
  - first-come, first-served queue discipline
  - infinite queue length
  - infinite calling population
- Computations
  - $\lambda$ = mean arrival rate
  - $\mu$ = mean service rate
  - n = number of customers in line

# Basic Single-Server Model (cont.)

- probability that no customers are in queuing system

$$P_0 = \left(1 - \frac{\lambda}{\mu}\right)$$

- average number of customers in queuing system

$$L = \frac{\lambda}{\mu - \lambda}$$

- probability of *n* customers in queuing system

$$P_n = \left(\frac{\lambda}{\mu}\right)^n \cdot P_0 = \left(\frac{\lambda}{\mu}\right)^n \left(1 - \frac{\lambda}{\mu}\right)$$

- average number of customers in waiting line

$$L_q = \frac{\lambda^2}{\mu\,(\mu - \lambda)}$$

# Basic Single-Server Model (cont.)

- average time customer spends in queuing system

$$W = \frac{1}{\mu - \lambda} = \frac{L}{\lambda}$$

- average time customer spends waiting in line

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)}$$

- probability that server is busy and a customer has to wait (utilization factor)

$$\rho = \frac{\lambda}{\mu}$$

- probability that server is idle and customer can be served

$$I = 1 - \rho$$

$$= 1 - \frac{\lambda}{\mu} = P_0$$

# Basic Single-Server Model Example

$$P_0 = \left(1 - \frac{\lambda}{\mu}\right) = \left(1 - \frac{24}{30}\right)$$

$= 0.20$ probability of no customers in the system

$$L = \frac{\lambda}{\mu - \lambda} = \frac{24}{30 - 24}$$

$= 4$ customers on the average in the queuing system

$$L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{(24)^2}{30(30 - 24)}$$

$= 3.2$ customers on the average in the waiting line

# Basic Single-Server Model Example (cont.)

$$W = \frac{1}{\mu - \lambda} = \frac{1}{30 - 24}$$

= 0.167 hour (10 minutes) average time in the system per customer

$$W_q = \frac{\lambda}{\mu(\mu - \lambda)} = \frac{24}{30(30 - 24)}$$

= 0.133 hour (8 minutes) average time in the waiting line per customer

$$\rho = \frac{\lambda}{\mu} = \frac{24}{30}$$

= 0.80 probability that the server will be busy and the customer must wait

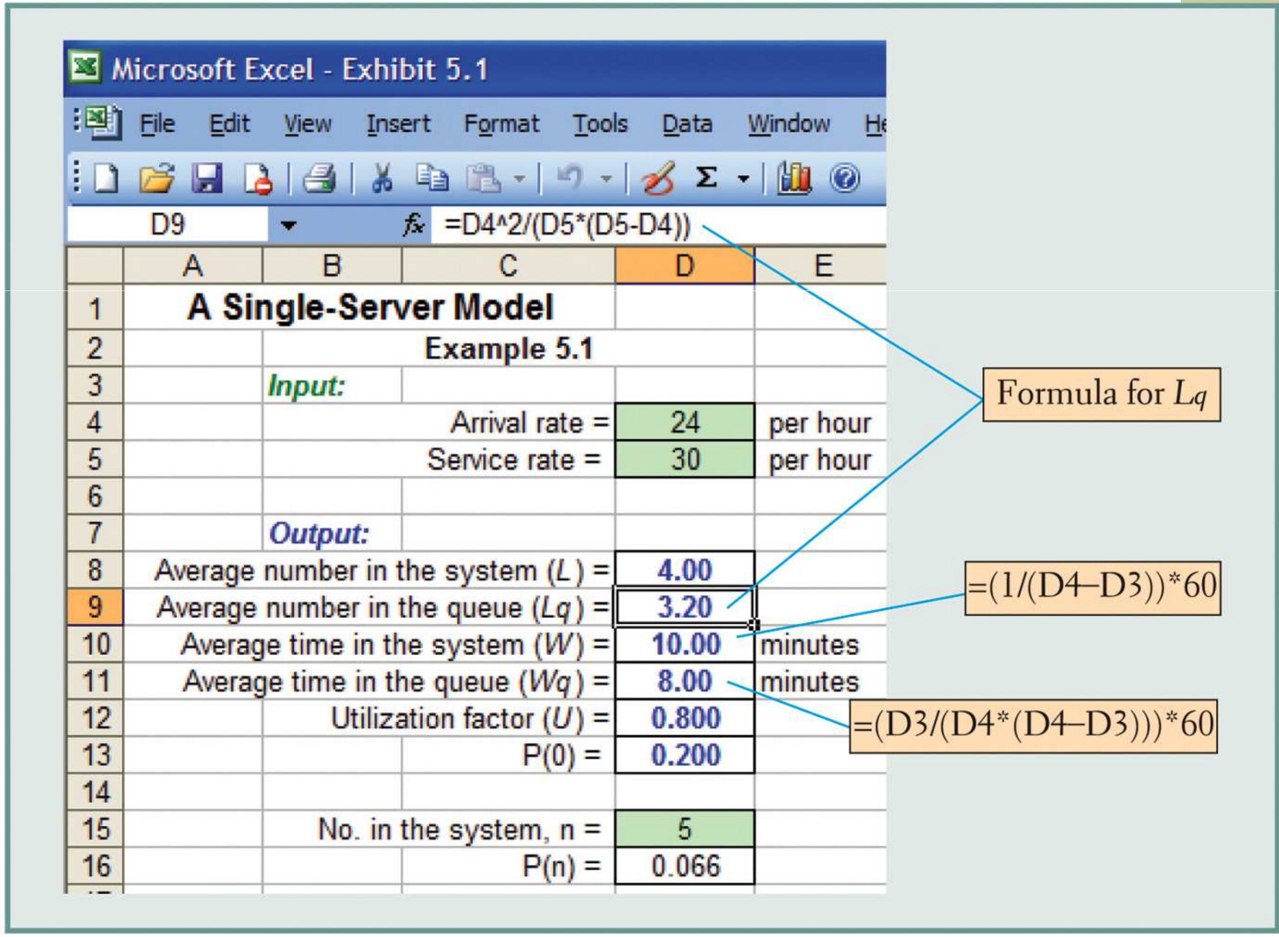
$$I = 1 - \rho = 1 - 0.80$$

= 0.20 probability that the server will be idle and a customer can be served

# Service Improvement Analysis

- waiting time (8 min.) is too long
  - hire assistant for cashier?
    - increased service rate
  - hire another cashier?
    - reduced arrival rate
- Is improved service worth the cost?

# Basic Single-Server Model Example: Excel



Microsoft Excel - Exhibit 5.1

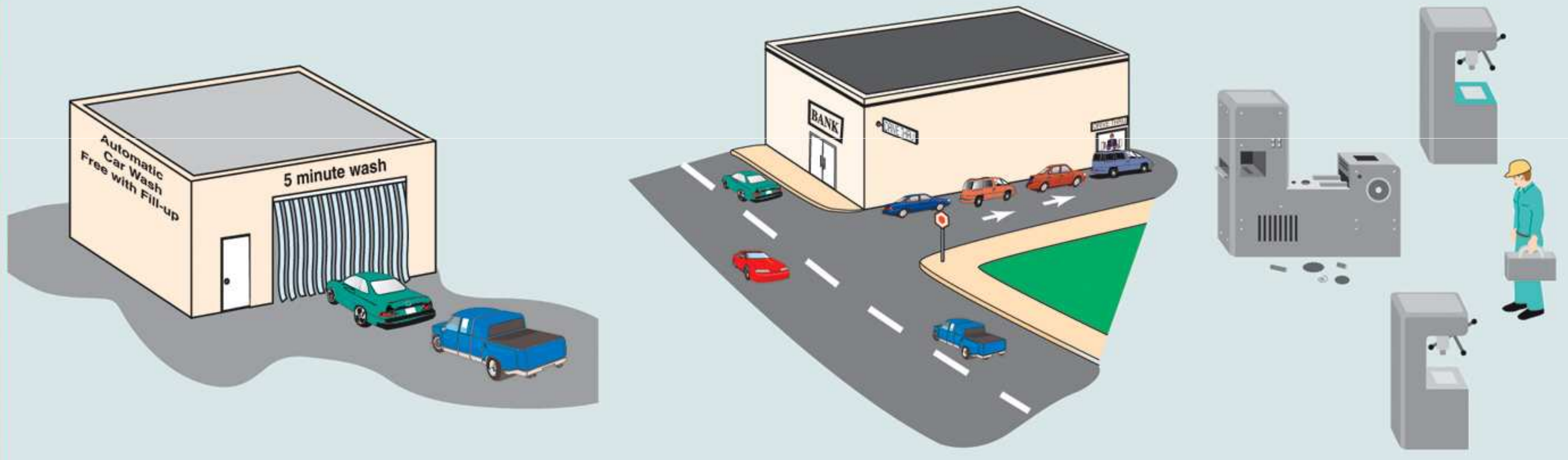
D9 =D4^2/(D5*(D5-D4))

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | A Single-Server Model | | | | |
| 2 | | | Example 5.1 | | |
| 3 | | *Input:* | | | |
| 4 | | | Arrival rate = | 24 | per hour |
| 5 | | | Service rate = | 30 | per hour |
| 6 | | | | | |
| 7 | | *Output:* | | | |
| 8 | Average number in the system (*L*) = | | | 4.00 | |
| 9 | Average number in the queue (*Lq*) = | | | 3.20 | |
| 10 | Average time in the system (*W*) = | | | 10.00 | minutes |
| 11 | Average time in the queue (*Wq*) = | | | 8.00 | minutes |
| 12 | Utilization factor (*U*) = | | | 0.800 | |
| 13 | | | P(0) = | 0.200 | |
| 14 | | | | | |
| 15 | | | No. in the system, n = | 5 | |
| 16 | | | P(n) = | 0.066 | |

# Advanced Single-Server Models

- Constant service times
  - occur most often when automated equipment or machinery performs service
- Finite queue lengths
  - occur when there is a physical limitation to length of waiting line
- Finite calling population
  - number of “customers” that can arrive is limited

# Advanced Single-Server Models (cont.)




(*a*) Single-Server, Constant Time

(*b*) Single-Server, Finite Queue

(*c*) Single-Server, Finite Calling Population

# Basic Multiple-Server Model

- single waiting line and service facility with several independent servers in parallel
- same assumptions as single-server model
- $s\mu > \lambda$
  - s = number of servers
  - servers must be able to serve customers faster than they arrive

# Basic Multiple-Server Model (cont.)

- probability that there are no customers in system

$$P_0 = \frac{1}{\left[\sum_{n=0}^{n=s-1} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right] + \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s \left(\frac{s\mu}{s\mu - \lambda}\right)}$$

- probability of *n* customers in system

$$P_n = \begin{cases} \dfrac{1}{s!\,s^{n-s}}\left(\dfrac{\lambda}{\mu}\right)^n P_0, & \text{for } n > s \\ \dfrac{1}{n!}\left(\dfrac{\lambda}{\mu}\right)^n P_0, & \text{for } n \le s \end{cases}$$

# Basic Multiple-Server Model (cont.)

- probability that customer must wait

$$P_w = \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s \frac{s\mu}{s\mu - \lambda} P_0$$

$$L_q = L - \frac{\lambda}{\mu}$$

$$L = \frac{\lambda\mu\,(\lambda/\mu)^s}{(s-1)!\,(s\mu-\lambda)^2} P_0 + \frac{\lambda}{\mu}$$

$$W_q = W - \frac{1}{\mu} = \frac{L_q}{\lambda}$$

$$W = \frac{L}{\lambda}$$

$$\rho = \frac{\lambda}{s\mu}$$

# Basic Multiple-Server Model Example

$\lambda = 10$ students per hour

$\mu = 4$ students per hour per service representative

$s = 3$ service representatives

$s\mu = (3)(4) = 12 \;(> \lambda = 10)$

# Basic Multiple-Server Model Example (cont.)

$$P_0 = \frac{1}{\left[\sum_{n=0}^{n=s-1} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n\right] + \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s\left(\frac{s\mu}{s\mu - \lambda}\right)}$$

$$= \frac{1}{\left[\frac{0}{0!}\left(\frac{10}{4}\right)^0 + \frac{1}{1!}\left(\frac{10}{4}\right)^1 + \frac{1}{2!}\left(\frac{10}{4}\right)^2\right] + \frac{1}{3!}\left(\frac{10}{4}\right)^3 \frac{3(4)}{3(4) - 10}}$$

$= 0.045$ probability that no customers are in the health service.

# Basic Multiple-Server Model Example (cont.)

$$L = \frac{\lambda\mu(\lambda/\mu)^s}{(s-1)!(s\mu-\lambda)^2}P_0 + \frac{\lambda}{\mu}$$

$$= \frac{(10)(4)(10/4)^3}{(3-1)![3(4)-10]^2}(0.045) + \frac{10}{4}$$

= 6 students in the health service

$$W = \frac{L}{\lambda}$$

$$= \frac{6}{10}$$

= 0.60 hour or 36 minutes in the health service

# Basic Multiple-Server Model Example (cont.)

$$L_q = L - \frac{\lambda}{\mu}$$

$$= 6 - \frac{10}{4}$$

$$= 3.5 \text{ students waiting to be served}$$

$$W_q = \frac{L_q}{\lambda}$$

$$= \frac{3.5}{10}$$

$$= 0.35 \text{ hour or 21 minutes waiting in line}$$

# Basic Multiple-Server Model Example (cont.)

$$P_w = \frac{1}{s!}\left(\frac{\lambda}{\mu}\right)^s \frac{s\mu}{s\mu - \lambda} P_0$$

$$= \frac{1}{3!}\left(\frac{10}{4}\right)^3 \frac{3(4)}{3(4) - (10)}(0.045)$$

= 0.703 probability that a student must wait for service (i.e., that there are three or more students in the system)

# Basic Multiple-Server Model Example (cont.)

- To cut wait time, add another service representative
  - now, $s = 4$
- Therefore:

$P_0$ = 0.073 probability that no students are in the health service

$L$ = 3.0 students in the health service

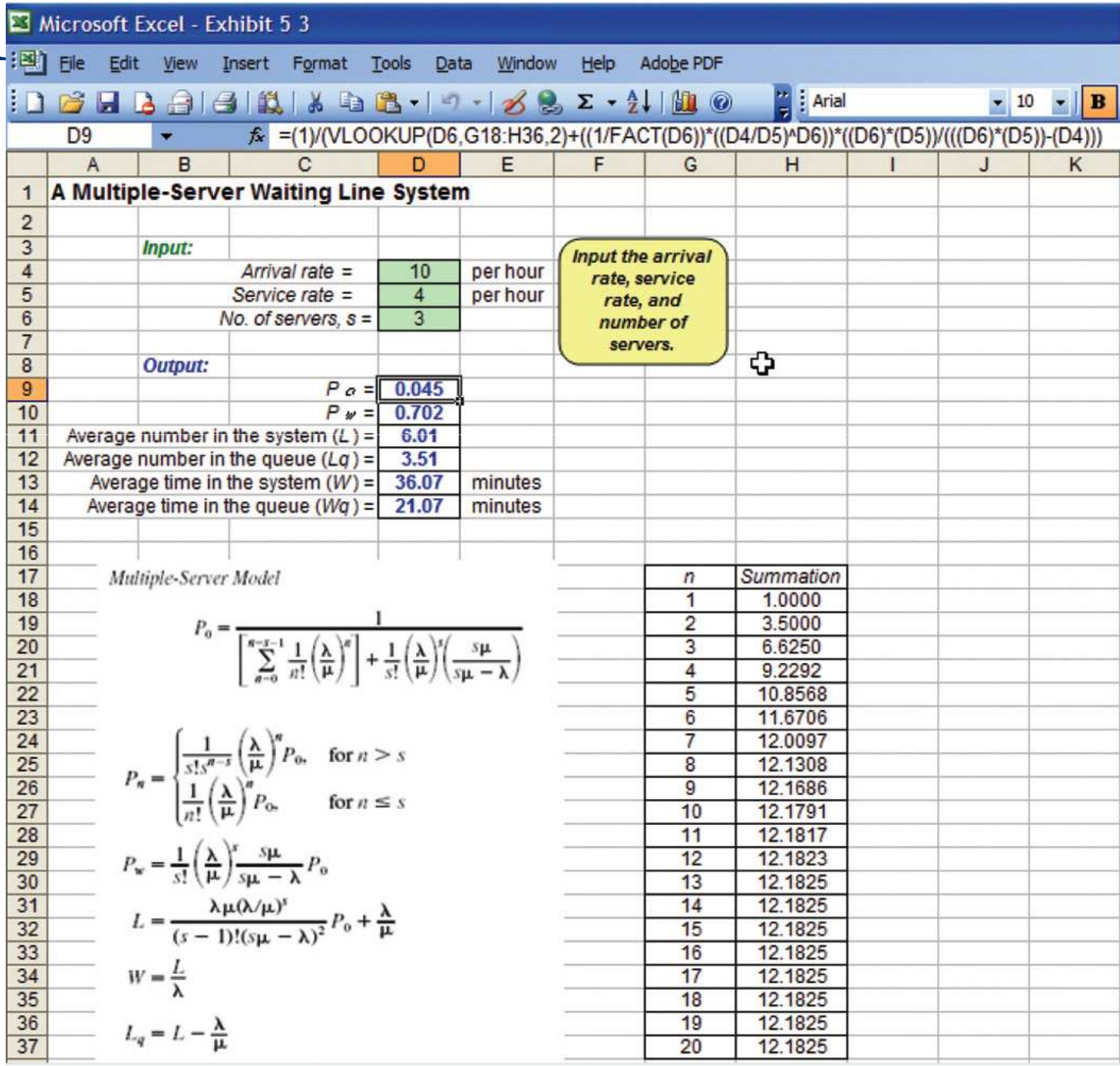
$W$ = 0.30 hour, or 18 minutes, in the health service

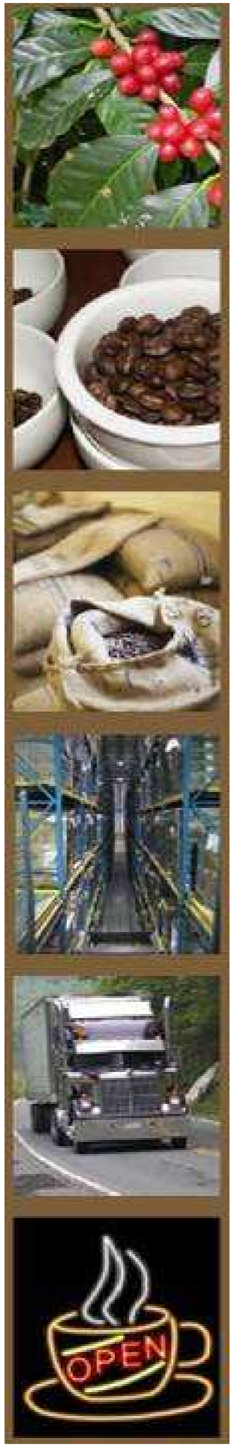
$L_q$ = 0.5 students waiting to be served

$W_q$ = 0.05 hour, or 3 minutes, waiting in line

$P_w$ = 0.31 probability that a student must wait for service

# Multiple-Server Waiting Line in Excel





# Chapter 6

## *Processes and Technology*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Process Planning
- Process Analysis
- Process Innovation
- Technology Decisions

# Process Planning

- Process
  - a group of related tasks with specific inputs and outputs
- Process design
  - what tasks need to be done and how they are coordinated among functions, people, and organizations
- Process strategy
  - an organization's overall approach for physically producing goods and services
- Process planning
  - converts designs into workable instructions for manufacture or delivery

# Process Strategy

- Vertical integration
  - extent to which firm will produce inputs and control outputs of each stage of production process
- Capital intensity
  - mix of capital (i.e., equipment, automation) and labor resources used in production process
- Process flexibility
  - ease with which resources can be adjusted in response to changes in demand, technology, products or services, and resource availability
- Customer involvement
  - role of customer in production process

# Outsourcing

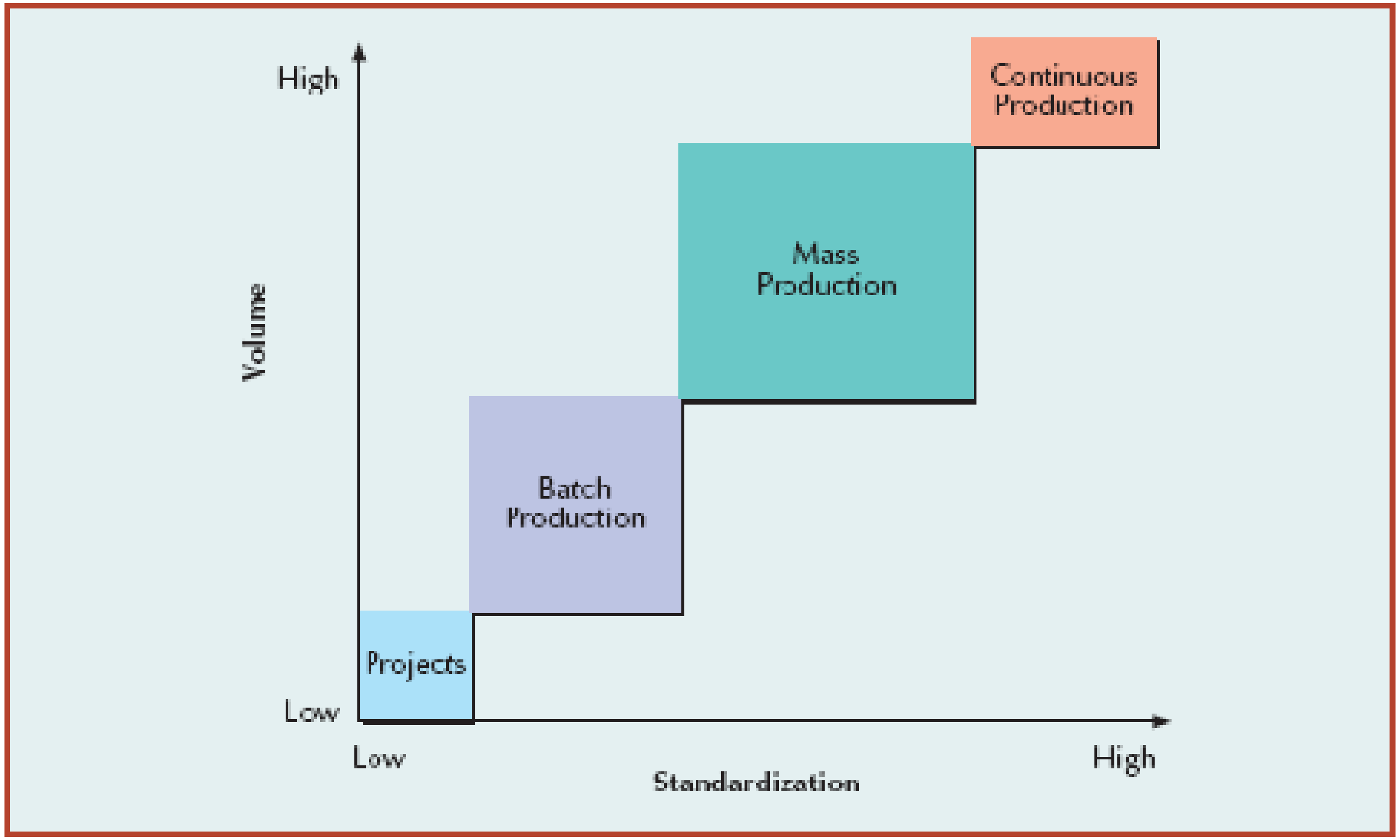
- Cost
- Capacity
- Quality
- Speed
- Reliability
- Expertise

# Process Selection

- Projects
  - one-of-a-kind production of a product to customer order
- Batch production
  - processes many different jobs at the same time in groups or batches
- Mass production
  - produces large volumes of a standard product for a mass market
- Continuous production
  - used for very-high volume commodity products

# Sourcing Continuum

# Product-Process Matrix




*Source:* Adapted from Robert Hayes and Steven Wheelwright, *Restoring the Competitive Edge Competing through Manufacturing* (New York, John Wiley & Sons, 1984), p. 209.

# Types of Processes

| | PROJECT | BATCH | MASS | **CONT.** |
|---|---|---|---|---|
| **Type of product** | Unique | Made-to-order (customized) | Made-to-stock (standardized ) | Commodity |
| **Type of customer** | One-at-a-time | Few individual customers | Mass market | Mass market |
| **Product demand** | Infrequent | Fluctuates | Stable | Very stable |

Source: Adapted from R. Chase, N. Aquilano, and R. Jacobs, *Operations Management for Competitive Advantage* (New York:McGraw-Hill, 2001), p. 210

# Types of Processes (cont.)

| | PROJECT | BATCH | MASS | **CONT.** |
|---|---|---|---|---|
| **Demand volume** | Very low | Low to medium | High | Very high |
| **No. of different products** | Infinite variety | Many, varied | Few | Very few |
| **Production system** | Long-term project | Discrete, job shops | Repetitive, assembly lines | Continuous, process industries |

Source: Adapted from R. Chase, N. Aquilano, and R. Jacobs, *Operations Management for Competitive Advantage* (New York:McGraw-Hill, 2001), p. 210

# Types of Processes (cont.)

| | PROJECT | BATCH | MASS | **CONT.** |
|---|---|---|---|---|
| **Equipment** | Varied | General-purpose | Special-purpose | Highly automated |
| **Primary type of work** | Specialized contracts | Fabrication | Assembly | Mixing, treating, refining |
| **Worker skills** | Experts, crafts-persons | Wide range of skills | Limited range of skills | Equipment monitors |

Source: Adapted from R. Chase, N. Aquilano, and R. Jacobs, *Operations Management for Competitive Advantage* (New York:McGraw-Hill, 2001), p. 210

# Types of Processes (cont.)

| | PROJECT | BATCH | MASS | CONT. |
|---|---|---|---|---|
| **Advantages** | Custom work, latest technology | Flexibility, quality | Efficiency, speed, low cost | Highly efficient, large capacity, ease of control |
| **Dis-advantages** | Non-repetitive, small customer base, expensive | Costly, slow, difficult to manage | Capital investment; lack of responsiveness | Difficult to change, far-reaching errors, limited variety |
| **Examples** | Construction, shipbuilding, spacecraft | Machine shops, print shops, bakeries, education | Automobiles, televisions, computers, fast food | Paint, chemicals, foodstuffs |

Source: Adapted from R. Chase, N. Aquilano, and R. Jacobs, *Operations Management for Competitive Advantage* (New York:McGraw-Hill, 2001), p. 210

# Process Selection with Break-Even Analysis

- examines cost trade-offs associated with demand volume
- Cost
  - Fixed costs
    - constant regardless of the number of units produced
  - Variable costs
    - vary with the volume of units produced
- Revenue
  - price at which an item is sold
- Total revenue
  - is price times volume sold
- Profit
  - difference between total revenue and total cost

# Process Selection with Break-Even Analysis (cont.)

Total cost = fixed cost + total variable cost

$$TC = c_f + vc_v$$

Total revenue = volume x price

$$TR = vp$$

Profit = total revenue - total cost

$$Z = TR - TC = vp - (c_f + vc_v)$$

# Process Selection with Break-Even Analysis (cont.)

$$TR = TC$$

$$vp = c_f + vc_v$$

$$vp - vc_v = c_f$$

$$v(p - c_v) = c_f$$

$$v = \frac{c_f}{p - c_v}$$

Solving for Break-Even Point (Volume)

# Break-Even Analysis: Example

Fixed cost = $c_f$ = \$2,000

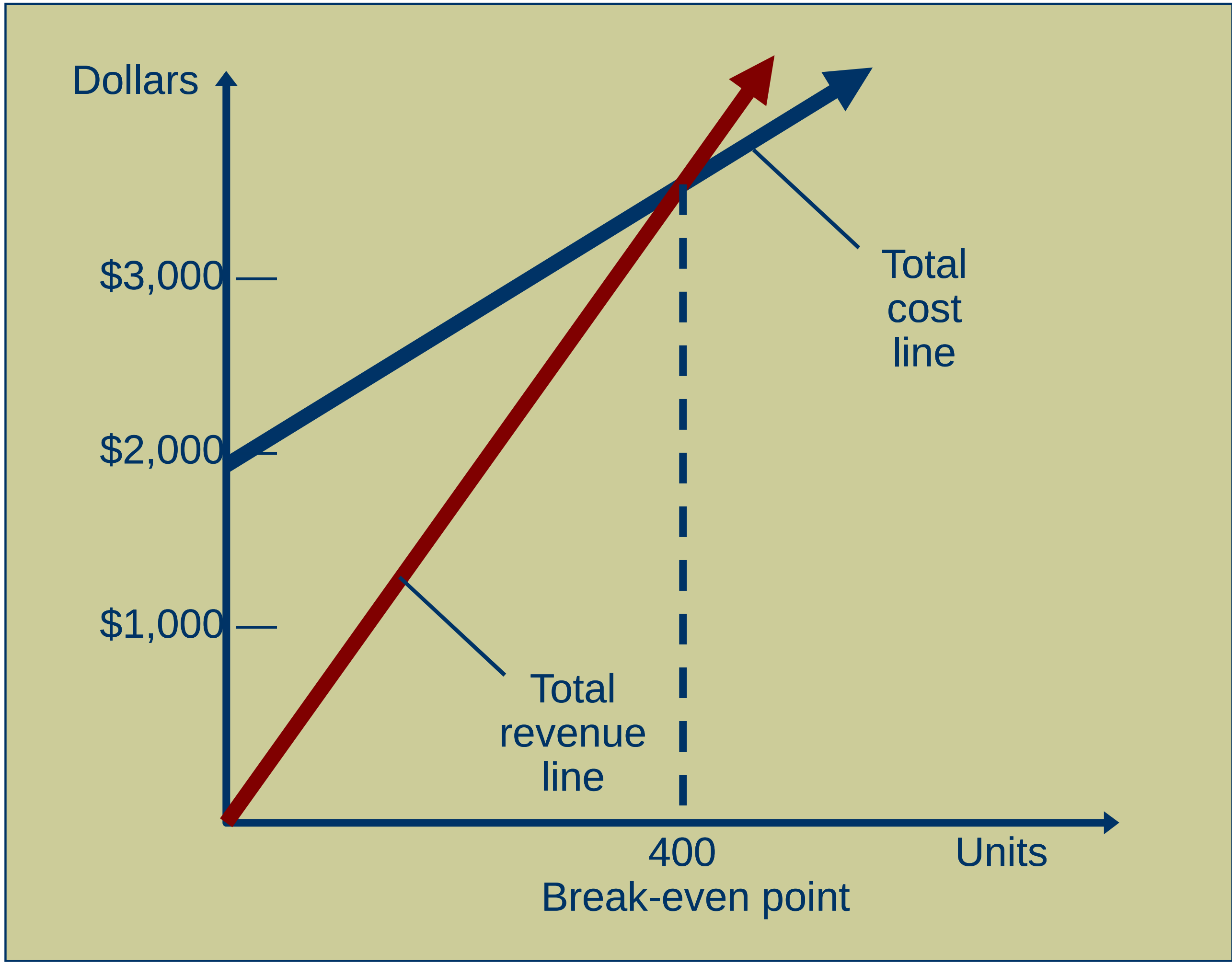
Variable cost = $c_v$ = \$5 per raft

Price = $p$ = \$10 per raft

Break-even point is

$$v = \frac{c_f}{p - c_v} = \frac{2000}{10 - 5} = 400 \text{ rafts}$$

# Break-Even Analysis: Graph



# Process Plans

- Set of documents that detail manufacturing and service delivery specifications
  - assembly charts
  - operations sheets
  - quality-control check-sheets

# Process Selection

*Process A* *Process B*

$\$2{,}000 + \$5v = \$10{,}000 + \$3v$

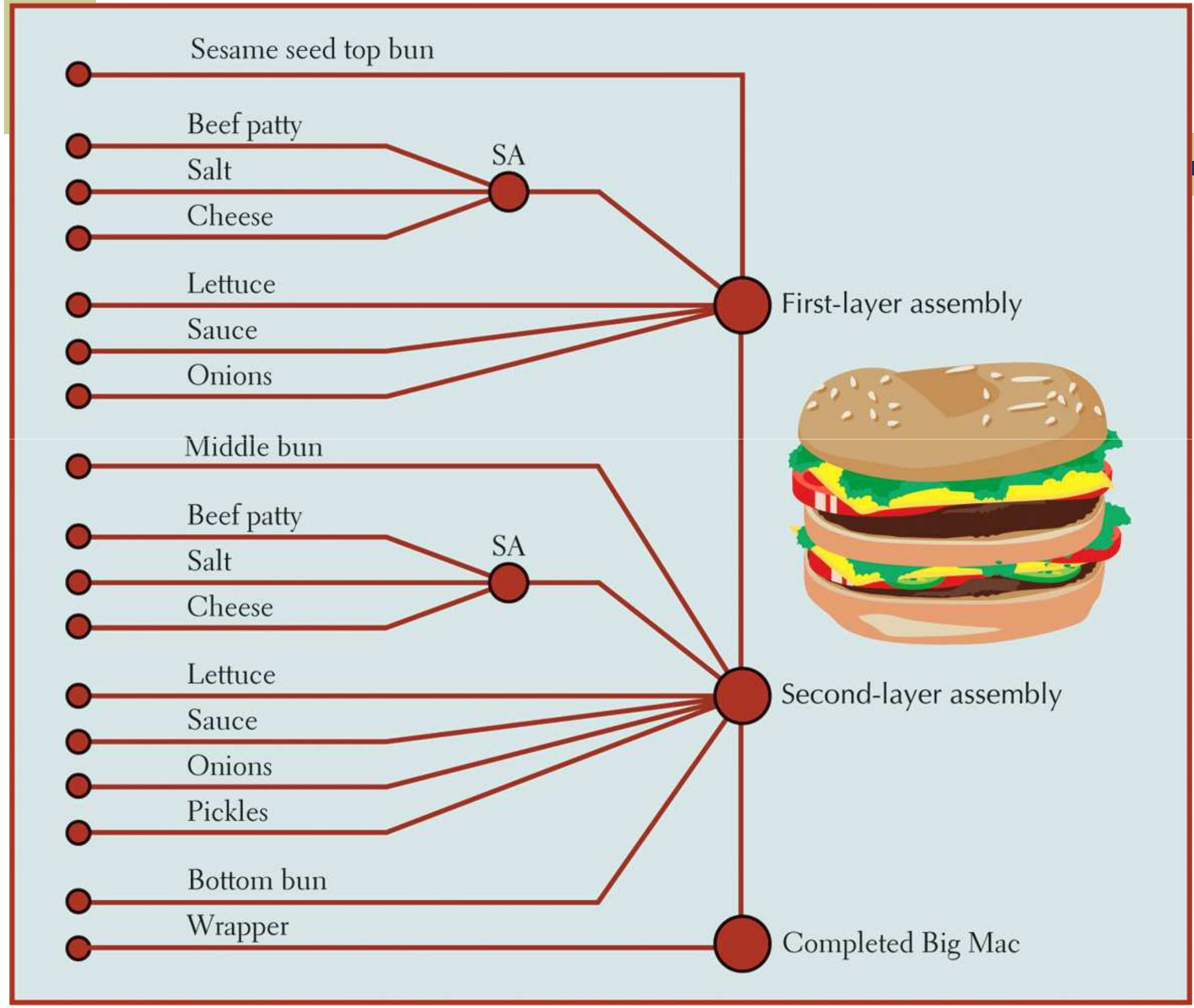
$\$2v = \$8{,}000$

$v = 4{,}000$ rafts

*Below or equal to 4,000, choose A*

*Above or equal to 4,000, choose B*

# Process Analysis




- systematic examination of all aspects of process to improve operation

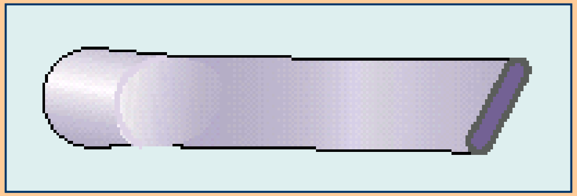
# An Operations Sheet for a Plastic Part

Part name: Crevice Tool

Part No.: 52074

Usage: Hand-Vac

Assembly No.: 520



| *Oper. No.* | *Description* | *Dept.* | *Machine/Tools* | *Time* |
|---|---|---|---|---|
| 10 | Pour in plastic bits | 041 | Injection molding | 2 min |
| 20 | Insert mold | 041 | #076 | 2 min |
| 30 | Check settings & start machine | 041 | 113, 67, 650 | 20 min |
| 40 | Collect parts & lay flat | 051 | Plastics finishing | 10 min |
| 50 | Remove & clean mold | 042 | Parts washer | 15 min |
| 60 | Break off rough edges | 051 | Plastics finishing | 10 min |

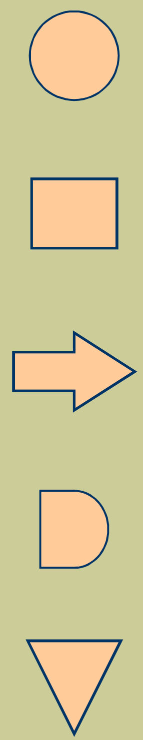
# Process Analysis

- Building a flowchart
  - Determine objectives
  - Define process boundaries
  - Define units of flow
  - Choose type of chart
  - Observe process and collect data
  - Map out process
  - Validate chart

# Process Flowcharts

- look at manufacture of product or delivery of service from broad perspective
- Incorporate
  - nonproductive activities (inspection, transportation, delay, storage)
  - productive activities (operations)

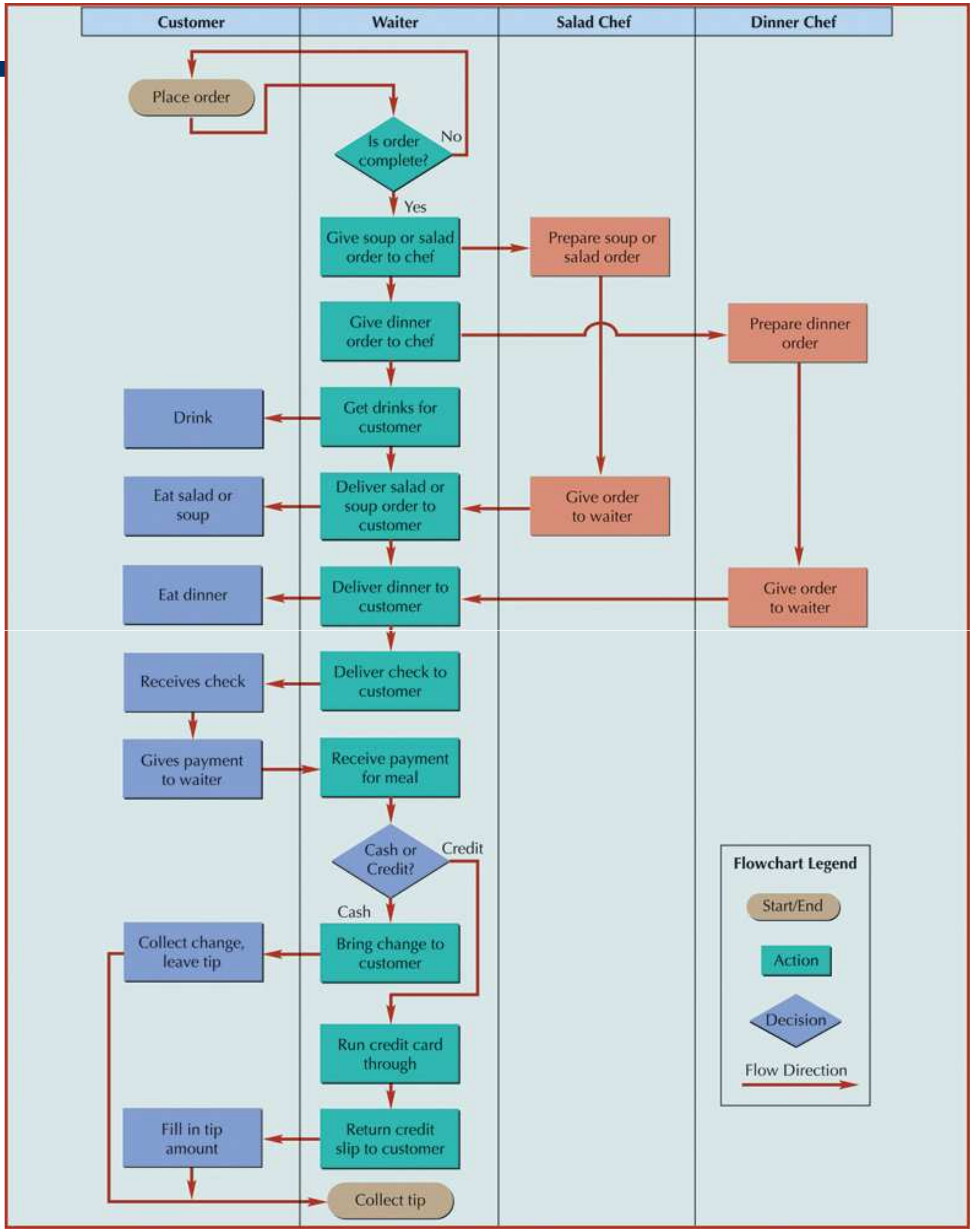
# Process Flowchart Symbols



- Operations
- Inspection
- Transportation
- Delay
- Storage

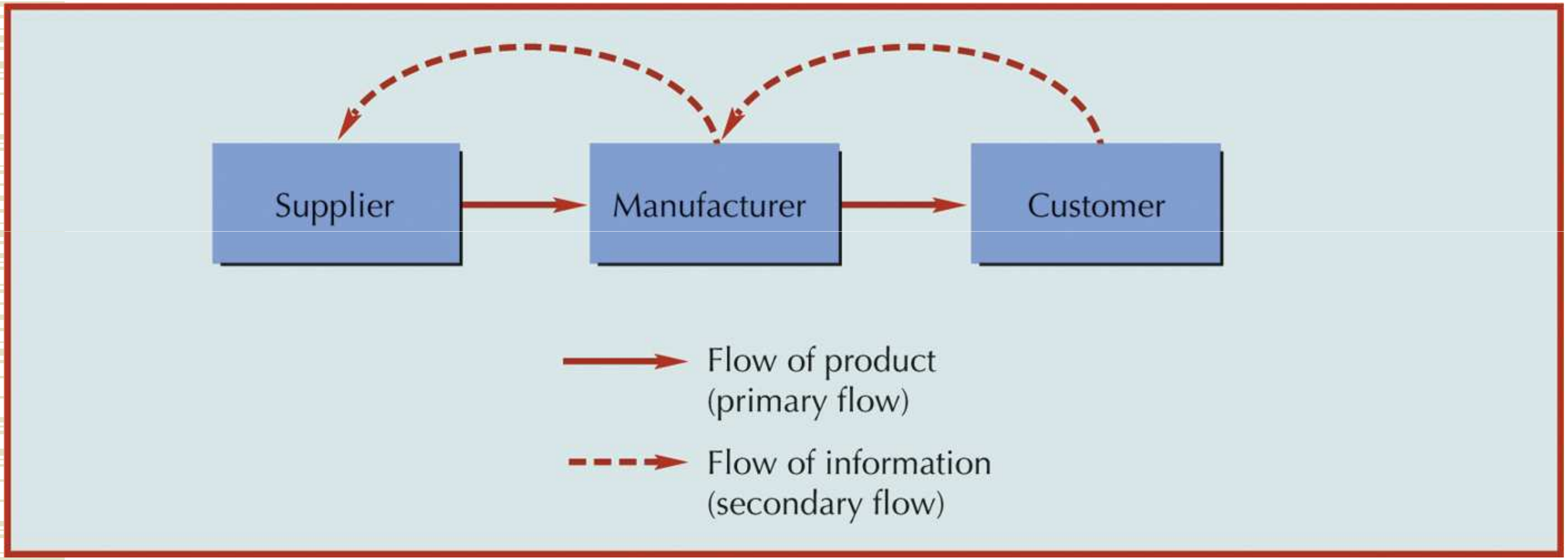
# Process Flowchart of Apple Processing

| Date: 9-30-06 | | | | | | Location: Graves Mountain | | |
|---|---|---|---|---|---|---|---|---|
| Analyst: TLR | | | | | | Process: Applesauce | | |
| Step | Operation | Transport | Inspect | Delay | Storage | Description of process | Time (min) | Distance (feet) |
| 1 | ● | | | | | Unload apples from truck | 20 | |
| 2 | | ● | | | | Move to inspection station | | 100 ft |
| 3 | | | ● | | | Weigh, inspect, sort | 30 | |
| 4 | | ● | | | | Move to storage | | 50 ft |
| 5 | | | | | ● | Wait until needed | 360 | |
| 6 | | ● | | | | Move to peeler | | 20 ft |
| 7 | ● | | | | | Peel and core apples | 15 | |
| 8 | | | | | ● | Soak in water until needed | 20 | |
| 9 | ● | | | | | Place on conveyor | 5 | |
| 10 | | ● | | | | Move to mixing area | | 20 ft |
| | Page 1 of 3 | | | | | Total | 450 | 190 ft |

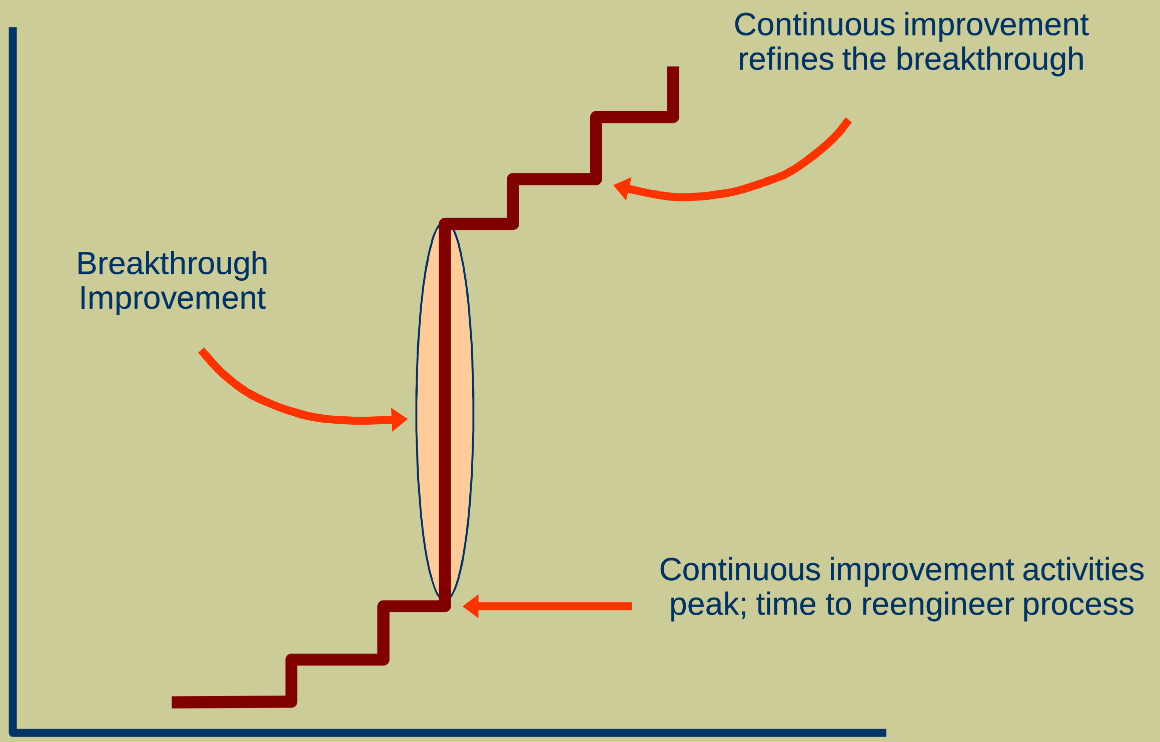


Customer
Waiter
Salad Chef
Dinner Chef
Place order
Is order complete?
No
Yes
Give soup or salad order to chef
Prepare soup or salad order
Give dinner order to chef
Prepare dinner order
Drink
Get drinks for customer
Eat salad or soup
Deliver salad or soup order to customer
Give order to waiter
Eat dinner
Deliver dinner to customer
Give order to waiter
Receives check
Deliver check to customer
Gives payment to waiter
Receive payment for meal
Cash or Credit?
Credit
Cash
Collect change, leave tip
Bring change to customer
Run credit card through
Fill in tip amount
Return credit slip to customer
Collect tip
Flowchart Legend
Start/End
Action
Decision
Flow Direction

# Simple Value Chain Flowchart

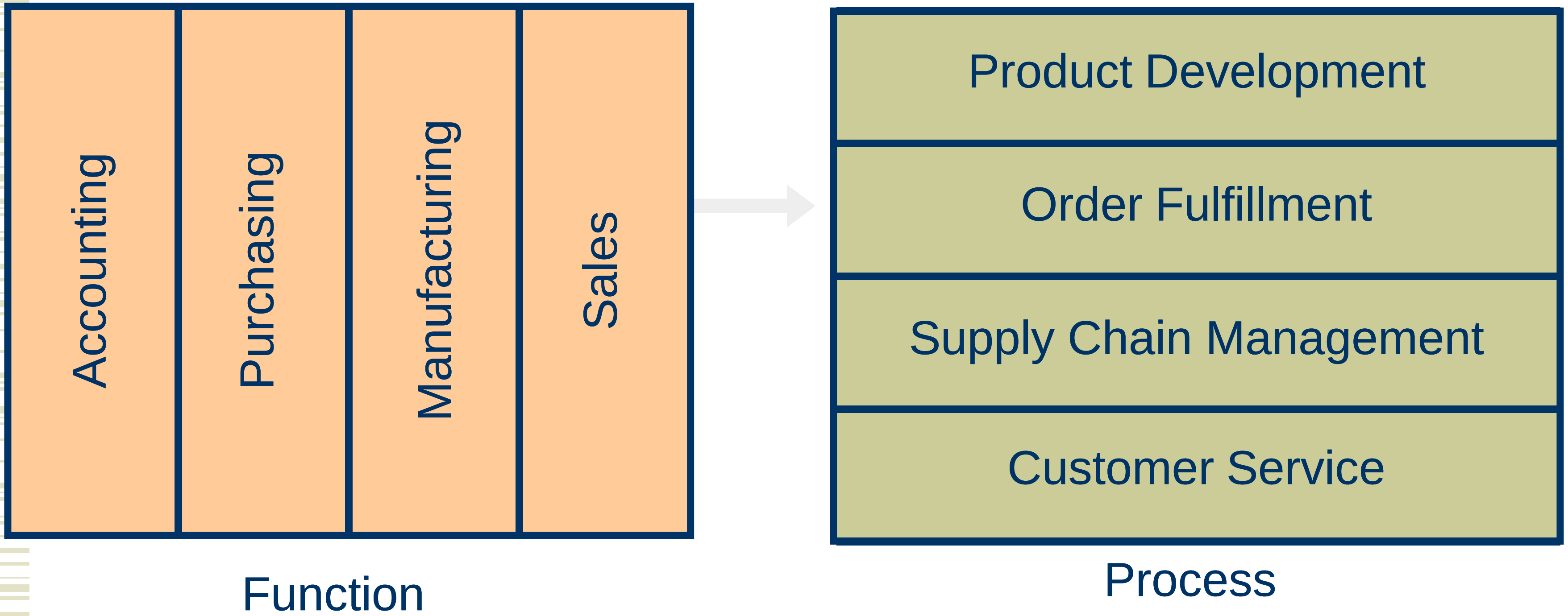


# Process Innovation

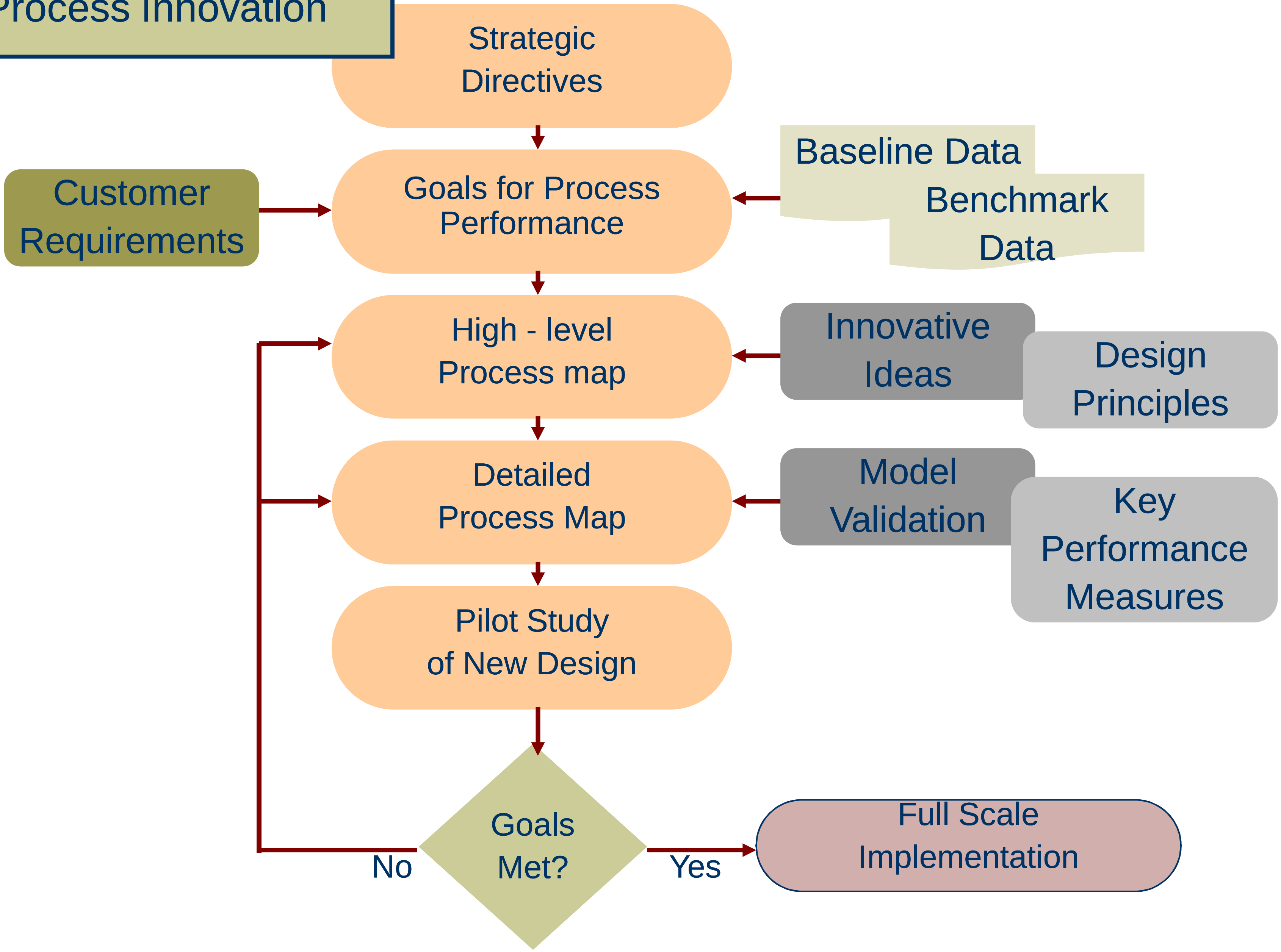



Total redesign of a process for breakthrough improvements

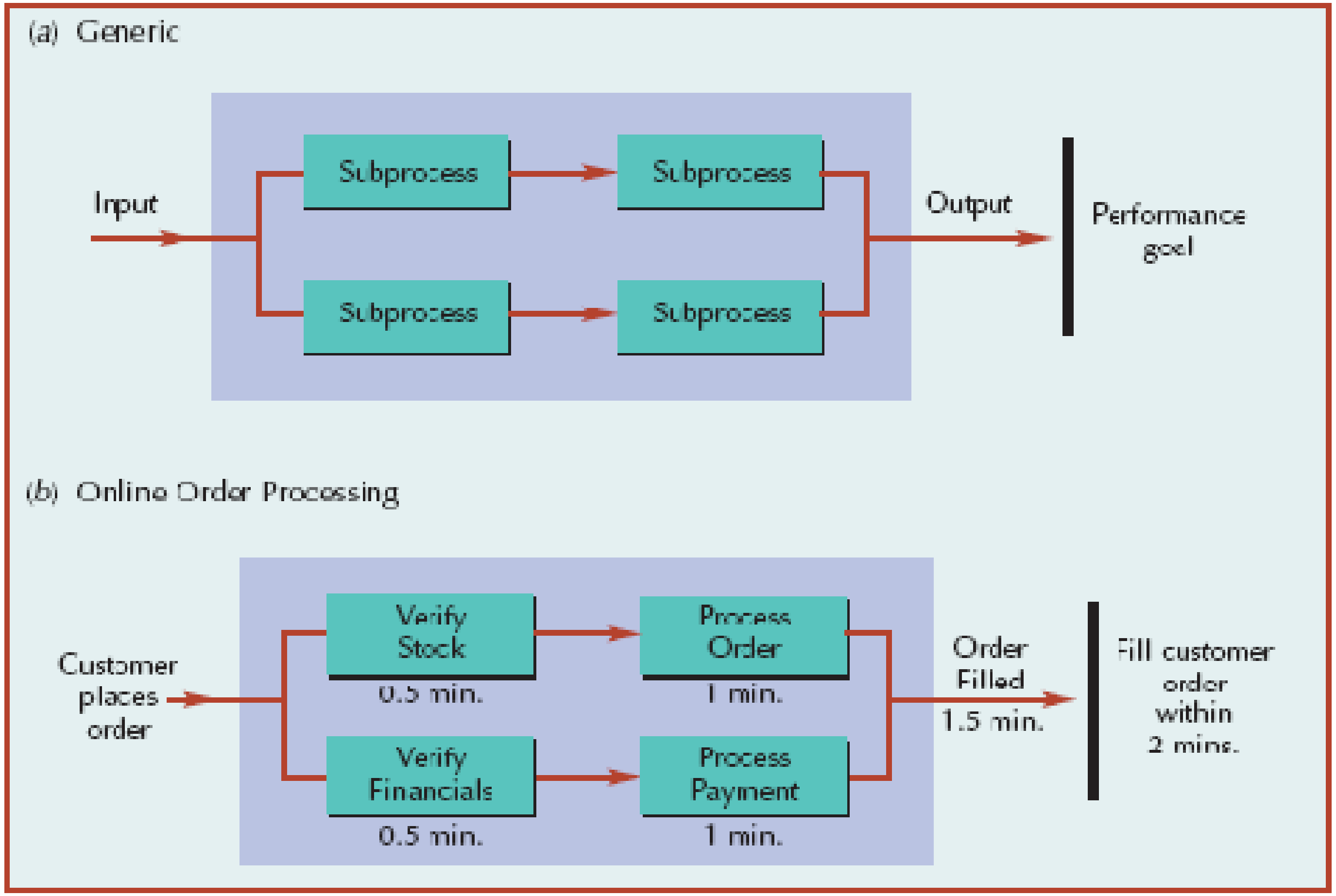
# From Function to Process



# Process Innovation



# High-Level Process Map



# Principles for Redesigning Processes

- Remove waste, simplify, and consolidate similar activities
- Link processes to create value
- Let the swiftest and most capable enterprise execute the process
- Flex process for any time, any place, any way
- Capture information digitally at the source and propagate it through process

# Principles for Redesigning Processes (cont.)

- Provide visibility through fresher and richer information about process status
- Fit process with sensors and feedback loops that can prompt action
- Add analytic capabilities to process
- Connect, collect, and create knowledge around process through all who touch it
- Personalize process with preferences and habits of participants

# Techniques for Generating Innovative Ideas

- Vary the entry point to a problem
  - in trying to untangle fishing lines, it's best to start from the fish, not the poles
- Draw analogies
  - a previous solution to an old problem might work
- Change your perspective
  - think like a customer
  - bring in persons who have no knowledge of process

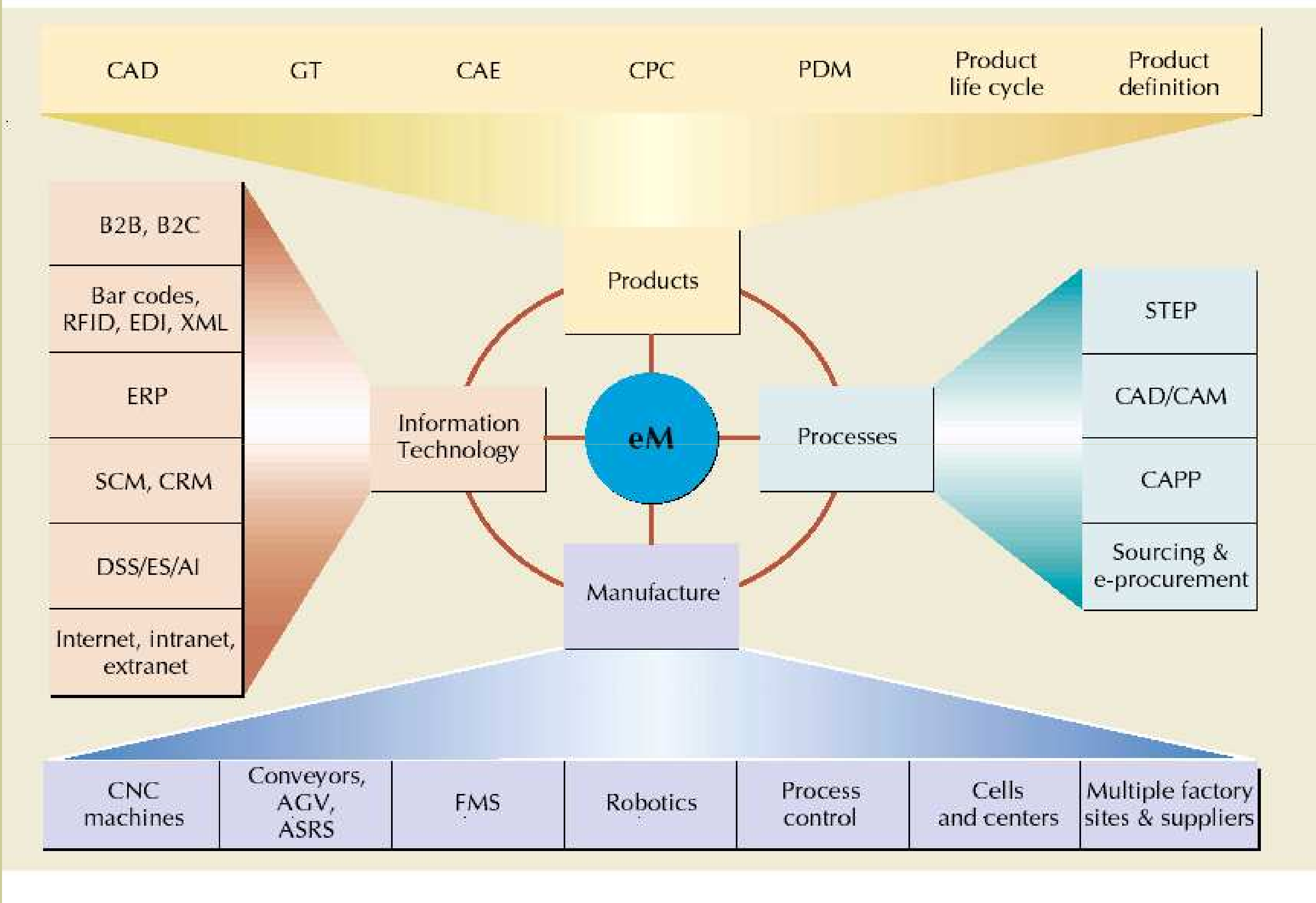
# Techniques for Generating Innovative Ideas (cont.)

- Try inverse brainstorming
  - what would *increase* cost
  - what would *displease* the customer
- Chain forward as far as possible
  - if I solve this problem, what is the next problem
- Use attribute brainstorming
  - how would this process operate if. . .
    - our workers were mobile and flexible
    - there were no monetary constraints
    - we had perfect knowledge

# Technology Decisions

- Financial justification of technology
  - Purchase cost
  - Operating Costs
  - Annual Savings
  - Revenue Enhancement
  - Replacement Analysis
  - Risk and Uncertainty
  - Piecemeal Analysis

# Components of e-Manufacturing



# A Technology Primer

## Product Technology

| | |
|---|---|
| Computer-aided design (CAD) | Creates and communicates designs electronically |
| Group technology (GT) | Classifies designs into families for easy retrieval and modification |
| Computer-aided engineering (CAE) | Tests functionality of CAD designs electronically |
| Collaborative product commerce (CPC) | Facilitates electronic communication and exchange of information among designers and suppliers |

# A Technology Primer (cont.)

| Product Technology | |
|---|---|
| Product data management (PDM) | Keeps track of design specs and revisions for the life of the product |
| Product life cycle management (PLM) | Integrates decisions of those involved in product development, manufacturing, sales, customer service, recycling, and disposal |
| Product configuration | Defines products "configured" by customers who have selected among various options, usually from a Web site |

# A Technology Primer (cont.)

| Process Technology | |
|---|---|
| Standard for exchange of product model data (STEP) | Set standards for communication among different CAD vendors; translates CAD data into requirements for automated inspection and manufacture |
| Computer-aided design and manufacture (CAD/CAM) | Electronic link between automated design (CAD) and automated manufacture (CAM) |
| Computer aided process (CAPP) | Generates process plans based on database of similar requirements |
| E-procurement | Electronic purchasing of items from e-marketplaces, auctions, or company websites |

# A Technology Primer (cont.)

| Manufacturing Technology | |
|---|---|
| Computer numerically control (CNC) | Machines controlled by software code to perform a variety of operations with the help of automated tool changers; also collects processing information and quality data |
| Flexible manufacturing system (FMS) | A collection of CNC machines connected by an automated material handling system to produce a wide variety of parts |
| Robots | Manipulators that can be programmed to perform repetitive tasks; more consistent than workers but less flexible |
| Conveyors | Fixed-path material handling; moves items along a belt or overhead chain; “reads” packages and diverts them to different directions; can be very fast |

# A Technology Primer (cont.)

| Manufacturing Technology | |
|---|---|
| Automatic guided vehicle (AGV) | A driverless truck that moves material along a specified path; directed by wire or tape embedded in floor or by radio frequencies; very flexible |
| Automated storage and retrieval system (ASRS) | An automated warehouse—some 26 stores high—in which items are placed in a carousel-type storage system and retrieved by fast-moving stacker cranes; controlled by computer |
| Process Control | Continuous monitoring of automated equipment; makes real-time decisions on ongoing operation, maintenance, and quality |
| Computer-integrated manufacturing (CIM) | Automated manufacturing systems integrated through computer technology; also called e-manufacturing |

# A Technology Primer (cont.)

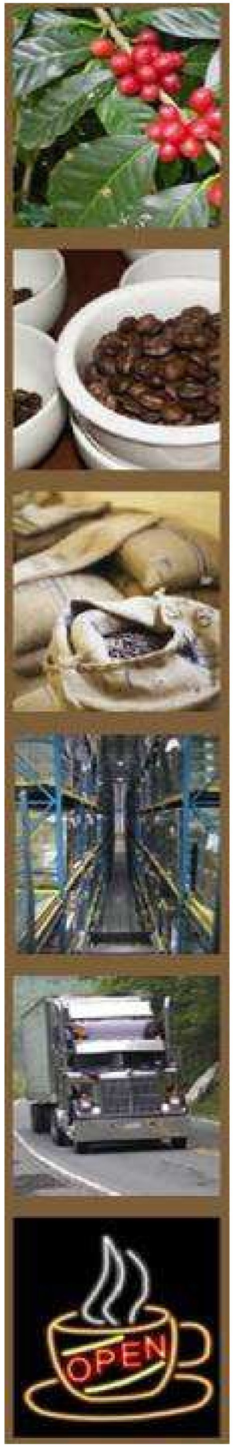
| Information Technology | |
|---|---|
| Business – to – Business (B2B) | Electronic transactions between businesses usually over the Internet |
| Business – to – Consumer (B2C) | Electronic transactions between businesses and their customers usually over the Internet |
| Internet | A global information system of computer networks that facilitates communication and data transfer |
| Intranet | Communication networks internal to an organization; can be password (i.e., firewall) protected sites on the Internet |
| Extranet | Intranets connected to the Internet for shared access with select suppliers, customers, and trading partners |

# A Technology Primer (cont.)

| Information Technology | |
|---|---|
| Bar Codes | A series of vertical lines printed on most packages that identifies item and other information when read by a scanner |
| Radio Frequency Identification tags (RFID) | An integrated circuit embedded in a tag that can send and receive information; a twenty-first century bar code with read/write capabilities |
| Electronic data interchange (EDI) | A computer-to-computer exchange of business documents over a proprietary network; very expensive and inflexible |
| Extensive markup language (XML) | A programming language that enables computer – to - computer communication over the Internet by tagging data before its is sent |
| Enterprise resource planning (ERP) | Software for managing basic requirements of an enterprise, including sales & marketing, finance and accounting, production & materials management, and human resources |

# A Technology Primer (cont.)

| Information Technology | |
|---|---|
| Supply chain management (SCM) | Software for managing flow of goods and information among a network of suppliers, manufacturers and distributors |
| Customer relationship management (CRM) | Software for managing interactions with customers and compiling and analyzing customer data |
| Decision support systems (DSS) | An information system that helps managers make decisions; includes a quantitative modeling component and an interactive component for what-if analysis |
| Expert systems (ES) | A computer system that uses an expert knowledge base to diagnose or solve a problem |
| Artificial intelligence (AI) | A field of study that attempts to replicate elements of human thought in computer processes; includes expert systems, genetic algorithms, neural networks, and fuzzy logic |



# Chapter 7

# *Capacity and Facilities*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

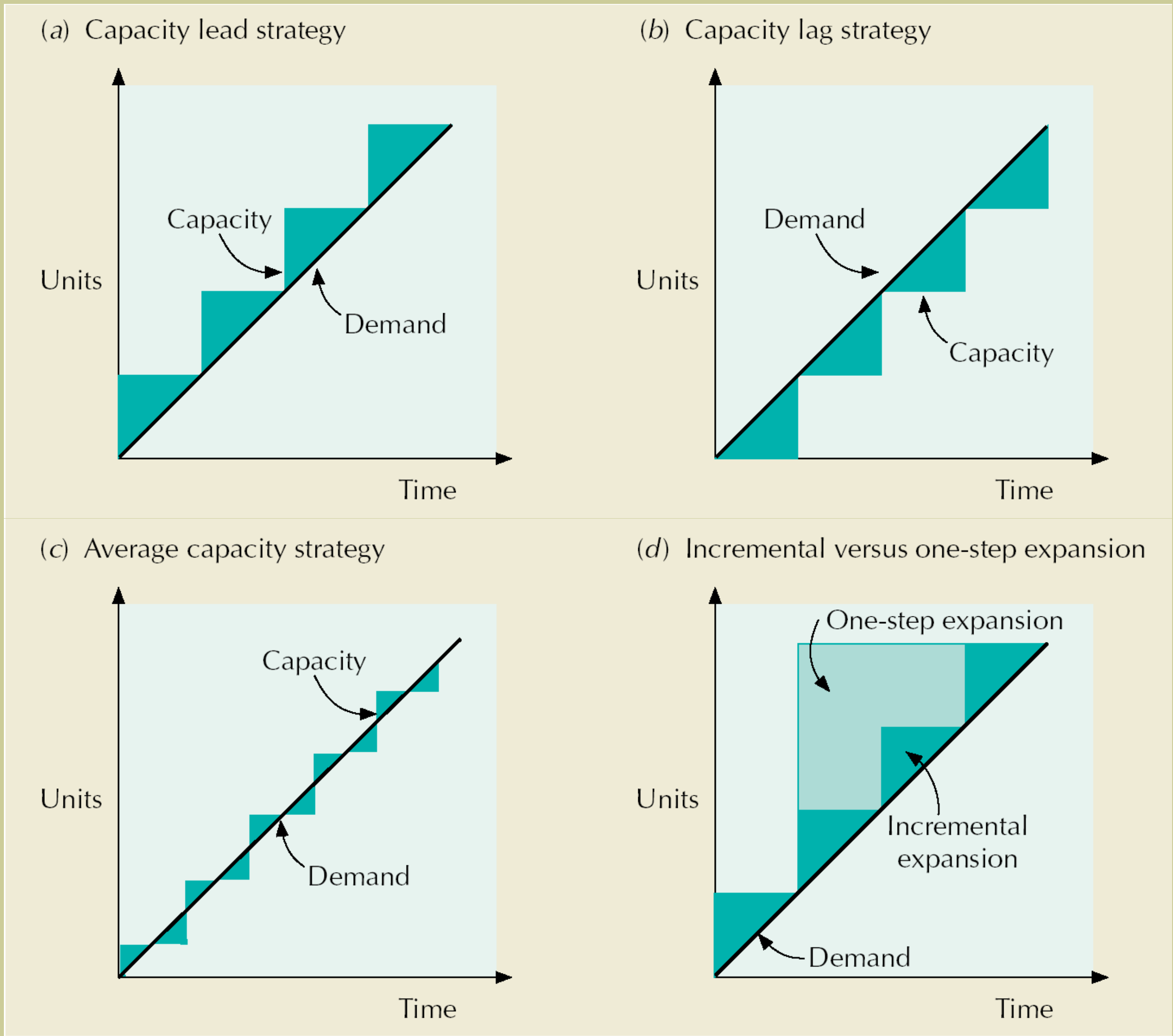
# Lecture Outline

- Capacity Planning
- Basic Layouts
- Designing Process Layouts
- Designing Service Layouts
- Designing Product Layouts
- Hybrid Layouts

# Capacity

- Maximum capability to produce
- Capacity planning
  - establishes overall level of productive resources for a firm
- 3 basic strategies for timing of capacity expansion in relation to steady growth in demand (lead, lag, and average)

# Capacity Expansion Strategies



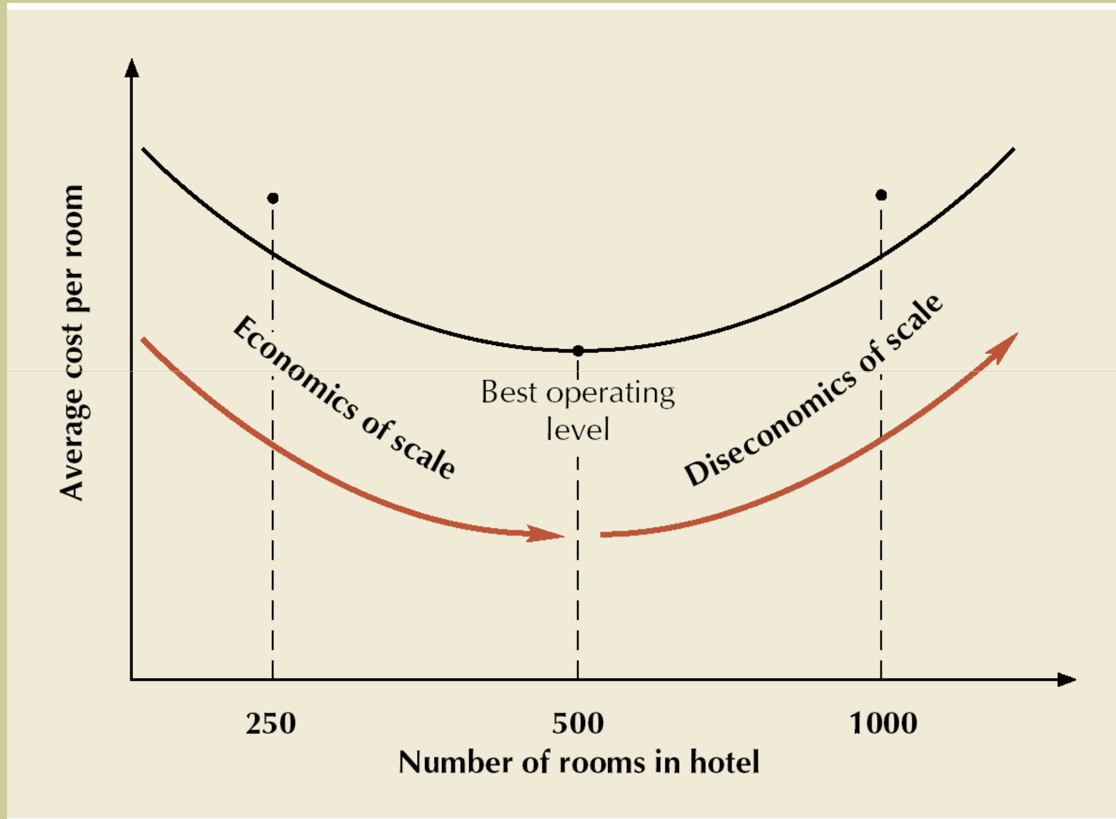
# Capacity (cont.)

- Capacity increase depends on
  - volume and certainty of anticipated demand
  - strategic objectives
  - costs of expansion and operation
- Best operating level
  - % of capacity utilization that minimizes unit costs
- Capacity cushion
  - % of capacity held in reserve for unexpected occurrences

# Economies of Scale

- it costs less per unit to produce high levels of output
  - fixed costs can be spread over a larger number of units
  - production or operating costs do not increase linearly with output levels
  - quantity discounts are available for material purchases
  - operating efficiency increases as workers gain experience

# Best Operating Level for a Hotel



# Machine Objectives of Facility Layout

Arrangement of areas within a facility to:

- Minimize material-handling costs
- Utilize space efficiently
- Utilize labor efficiently
- Eliminate bottlenecks
- Facilitate communication and interaction
- Reduce manufacturing cycle time
- Reduce customer service time
- Eliminate wasted or redundant movement
- Increase capacity
- Facilitate entry, exit, and placement of material, products, and people
- Incorporate safety and security measures
- Promote product and service quality
- Encourage proper maintenance activities
- Provide a visual control of activities
- Provide flexibility to adapt to changing conditions

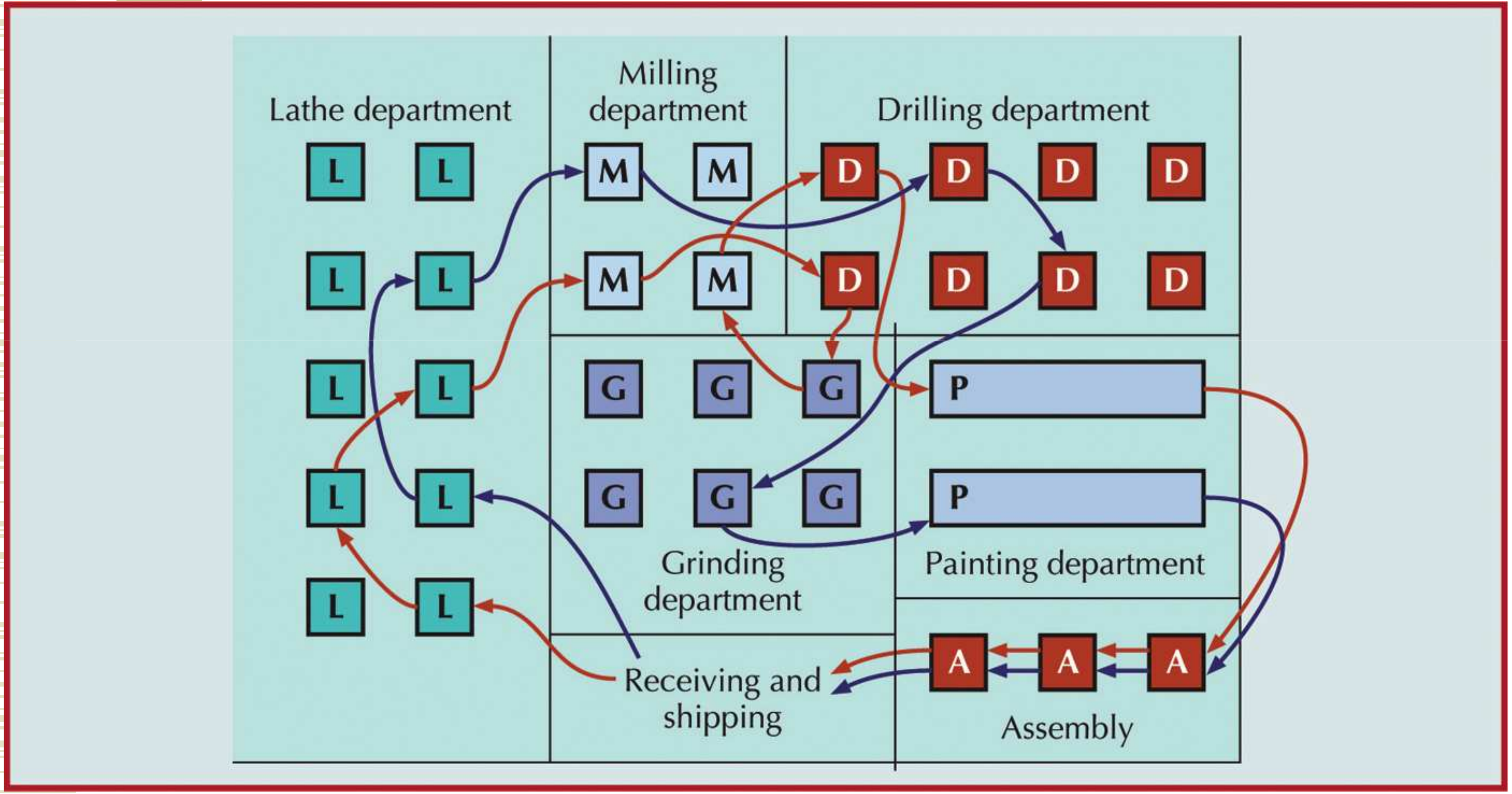
# BASIC LAYOUTS

- Process layouts
  - group similar activities together according to process or function they perform
- Product layouts
  - arrange activities in line according to sequence of operations for a particular product or service
- Fixed-position layouts
  - are used for projects in which product cannot be moved

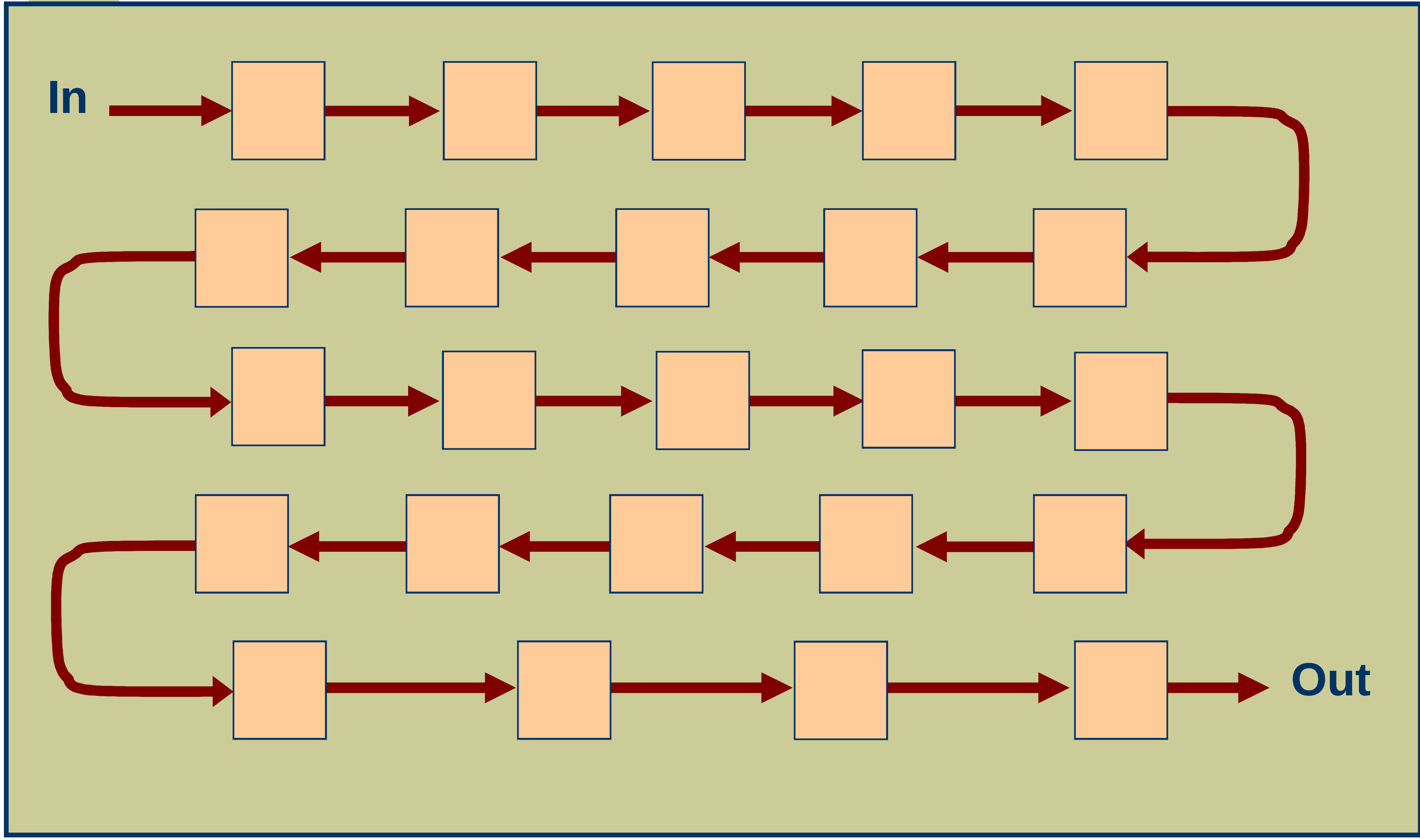
# Process Layout in Services

| | | |
|---|---|---|
| Women's lingerie | Shoes | Housewares |
| Women's dresses | Cosmetics and jewelry | Children's department |
| Women's sportswear | Entry and display area | Men's department |

# Manufacturing Process Layout



# A Product Layout



# Comparison of Product and Process Layouts

| | Product | Process |
|---|---|---|
| Description | Sequential arrangement of activities | Functional grouping of activities |
| Type of process | Continuous, mass production, mainly assembly | Intermittent, job shop, batch production, mainly fabrication |
| Product | Standardized, made to stock | Varied, made to order |
| Demand | Stable | Fluctuating |
| Volume | High | Low |
| Equipment | Special purpose | General purpose |

# Comparison of Product and Process Layouts

| | Product | Process |
|---|---|---|
| Workers | Limited skills | Varied skills |
| Inventory | Low in-process, high finished goods | High in-process, low finished goods |
| Storage space | Small | Large |
| Material handling | Fixed path (conveyor) | Variable path (forklift) |
| Aisles | Narrow | Wide |
| Scheduling | Part of balancing | Dynamic |
| Layout decision | Line balancing | Machine location |
| Goal | Equalize work at each station | Minimize material handling cost |
| Advantage | Efficiency | Flexibility |

# Fixed-Position Layouts

- Typical of projects in which product produced is too fragile, bulky, or heavy to move
- Equipment, workers, materials, other resources brought to the site
- Low equipment utilization
- Highly skilled labor
- Typically low fixed cost
- Often high variable costs

# Designing Process Layouts

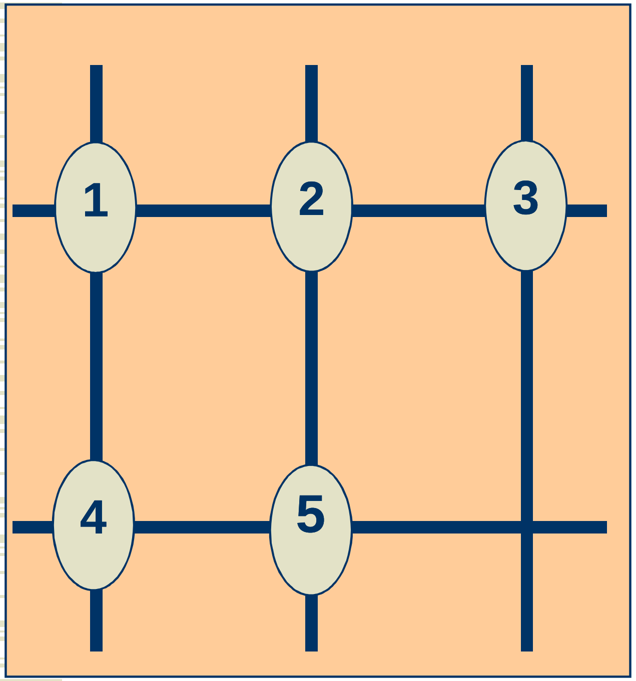
- Goal: minimize material handling costs
- Block Diagramming
  - minimize nonadjacent loads
  - use when quantitative data is available
- Relationship Diagramming
  - based on location preference between areas
  - use when quantitative data is not available

# Block Diagramming

- Unit load
  - quantity in which material is normally moved
- Nonadjacent load
  - distance farther than the next block

- STEPS
  - create load summary chart
  - calculate composite (two way) movements
  - develop trial layouts minimizing number of nonadjacent loads

# Block Diagramming: Example



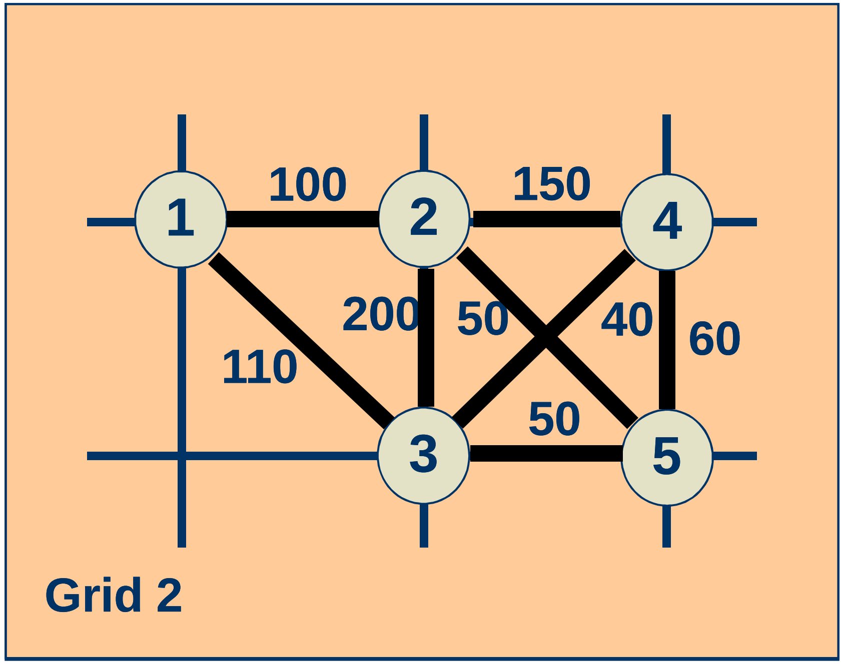

**Load Summary Chart**

| FROM/TO | DEPARTMENT | | | | |
|---|---|---|---|---|---|
| ***Department*** | ***1*** | ***2*** | ***3*** | ***4*** | ***5*** |
| 1 | — | 100 | 50 | | |
| 2 | | — | 200 | 50 | |
| 3 | 60 | | — | 40 | 50 |
| 4 | | 100 | | — | 60 |
| 5 | | | 50 | | — |

# Block Diagramming: Example (cont.)

| | | |
|---|---|---|
| 2 ↔ 3 | 200 loads |
| 2 ↔ 4 | 150 loads |
| 1 ↔ 3 | 110 loads |
| 1 ↔ 2 | 100 loads |
| 4 ↔ 5 | 60 loads |
| 3 ↔ 5 | 50 loads |
| 2 ↔ 5 | 50 loads |
| 3 ↔ 4 | 40 loads |
| 1 ↔ 4 | 0 loads |
| 1 ↔ 5 | 0 loads |

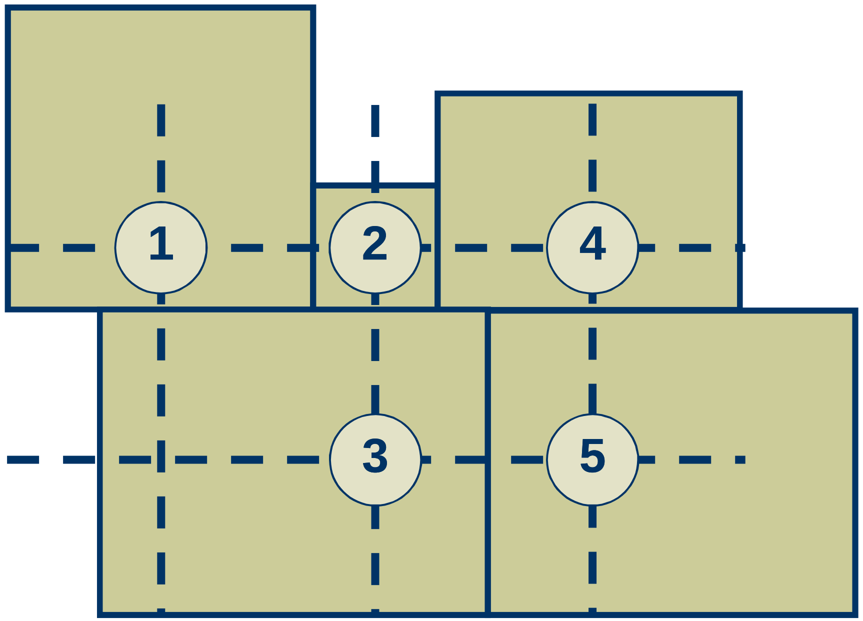
Nonadjacent Loads:
0



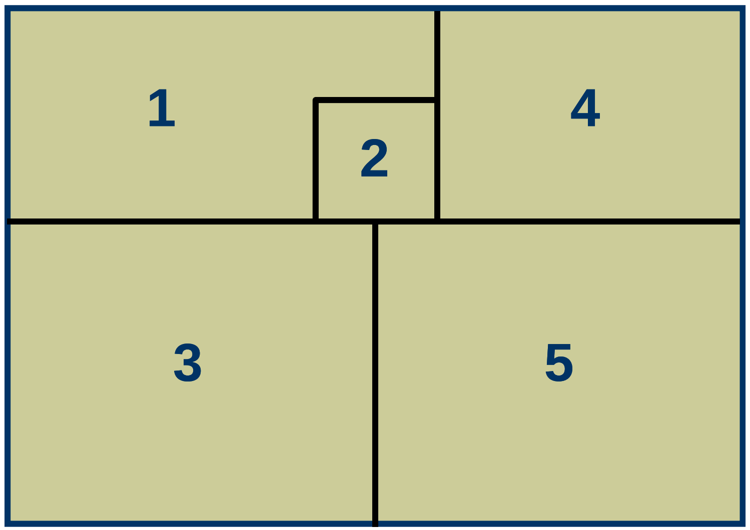
# Block Diagramming: Example (cont.)

- Block Diagram
  - type of schematic layout diagram; includes space requirements

**(a) Initial block diagram**

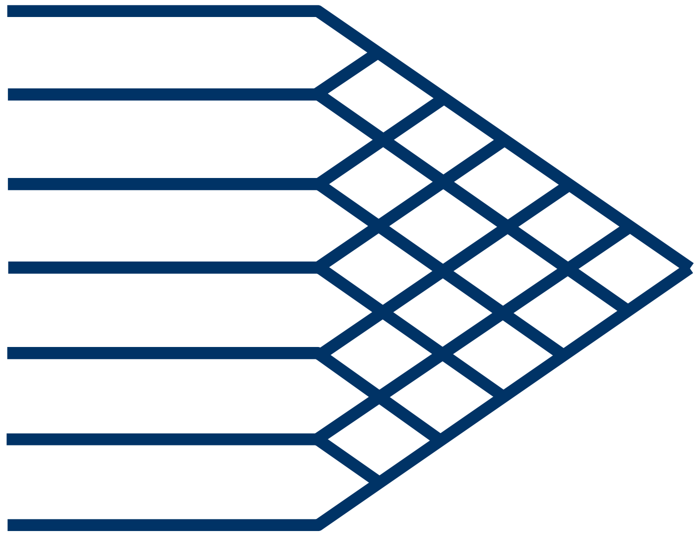



**(b) Final block diagram**

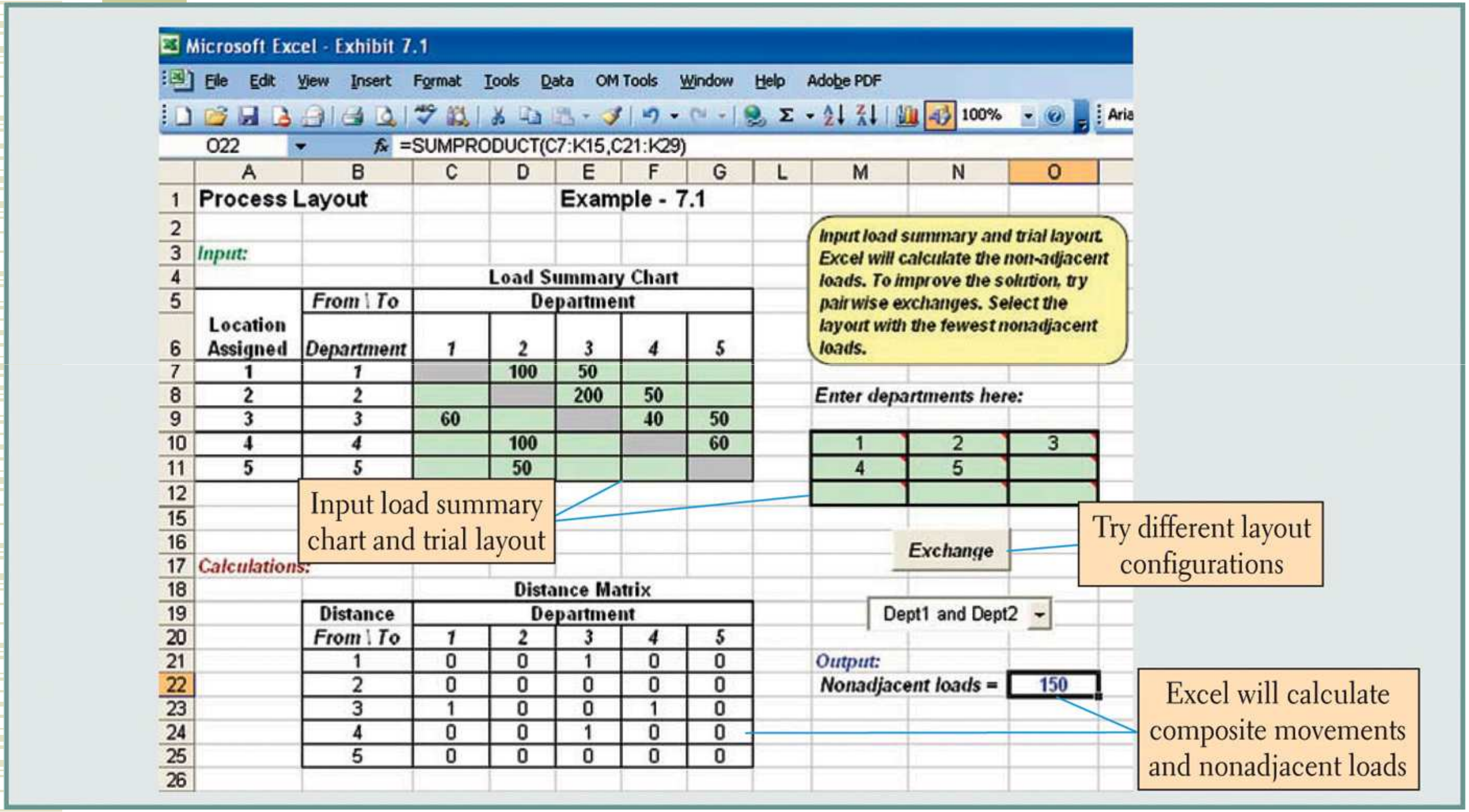


# Relationship Diagramming

- Schematic diagram that uses weighted lines to denote location preference
- Muther's grid
  - format for displaying manager preferences for department locations



# Relationship Diagramming: Excel




Load Summary Chart

| Location Assigned | From \ To Department | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| 1 | 1 | | 100 | 50 | | |
| 2 | 2 | | | 200 | 50 | |
| 3 | 3 | 60 | | | 40 | 50 |
| 4 | 4 | | 100 | | | 60 |
| 5 | 5 | | 50 | | | |

Enter departments here:

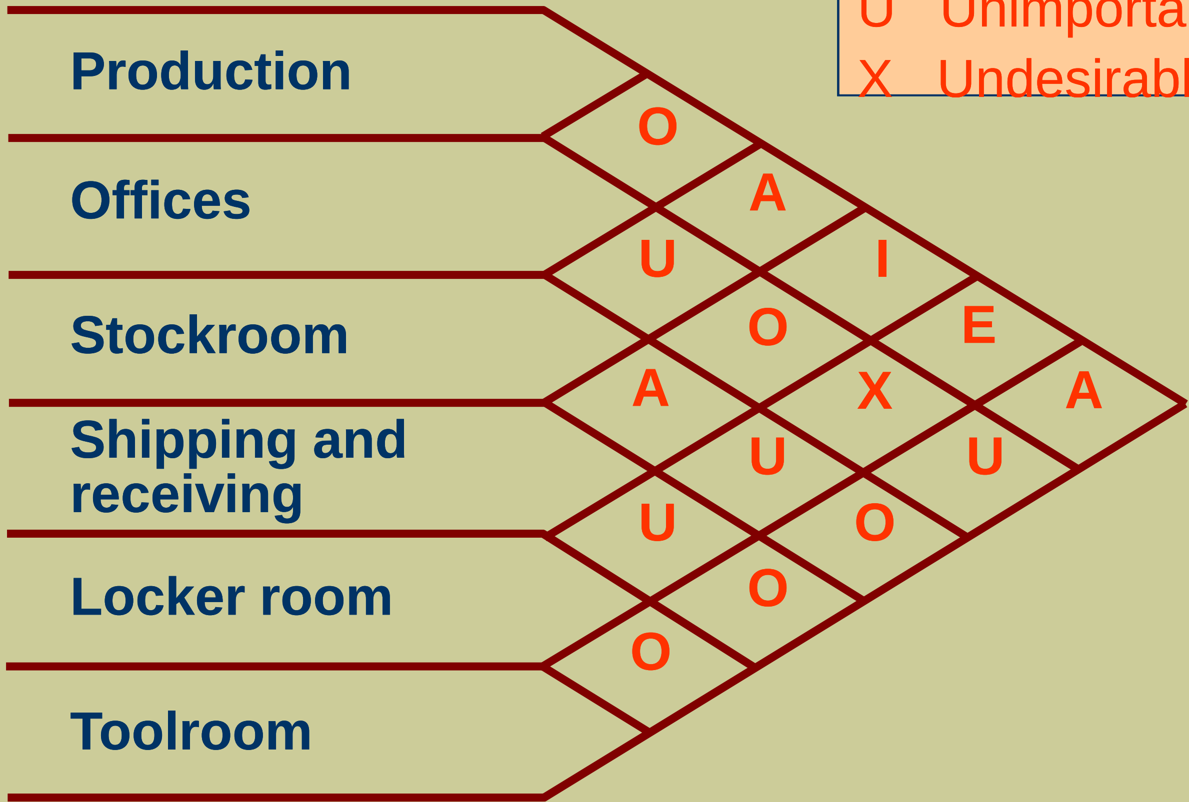
| | | |
|---|---|---|
| 1 | 2 | 3 |
| 4 | 5 | |
| | | |

Distance Matrix

| Distance From \ To | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 |
| 2 | 0 | 0 | 0 | 0 | 0 |
| 3 | 1 | 0 | 0 | 1 | 0 |
| 4 | 0 | 0 | 1 | 0 | 0 |
| 5 | 0 | 0 | 0 | 0 | 0 |

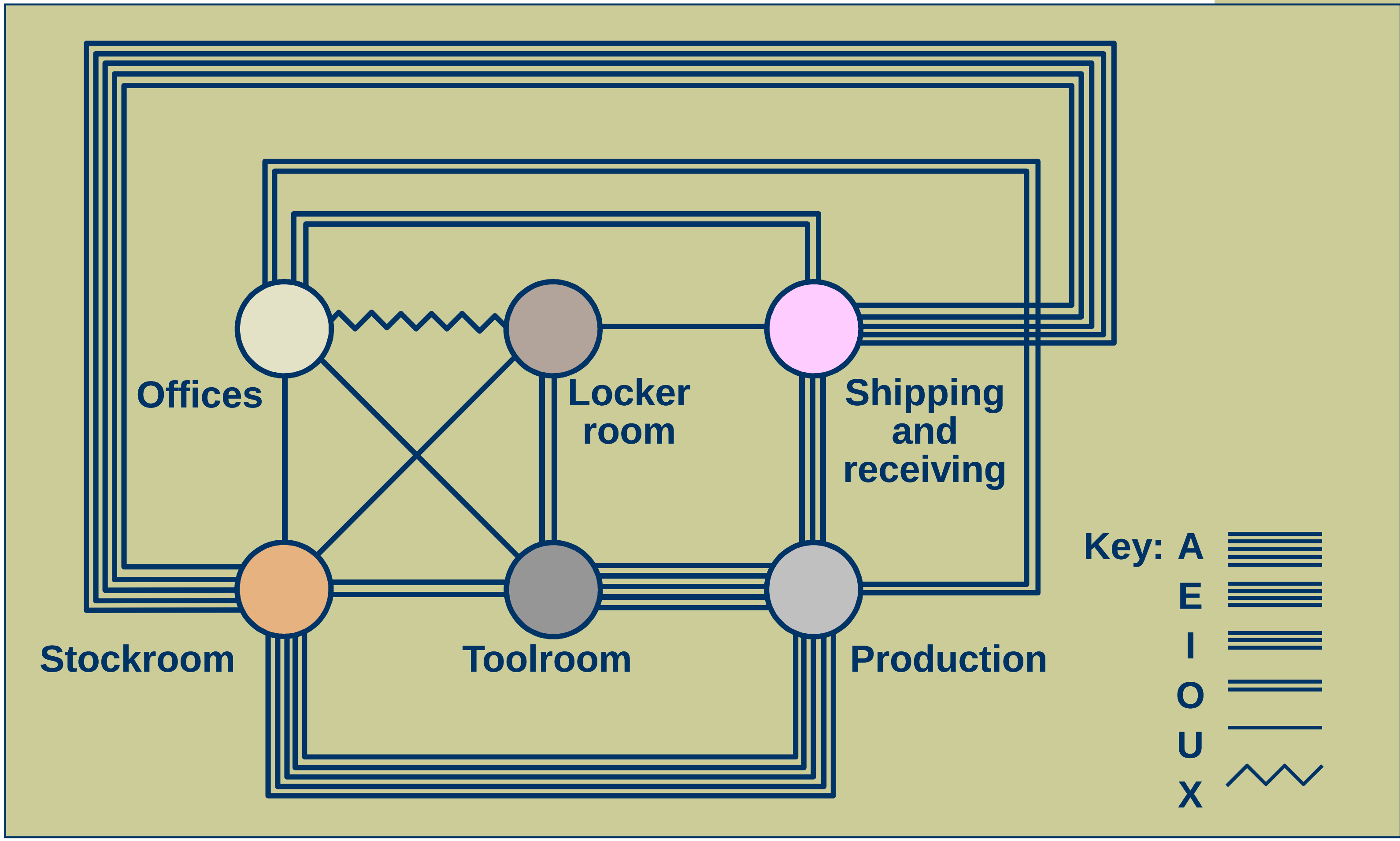
# Relationship Diagramming:

A Absolutely necessary
E Especially important
I Important
O Okay
U Unimportant
X Undesirable



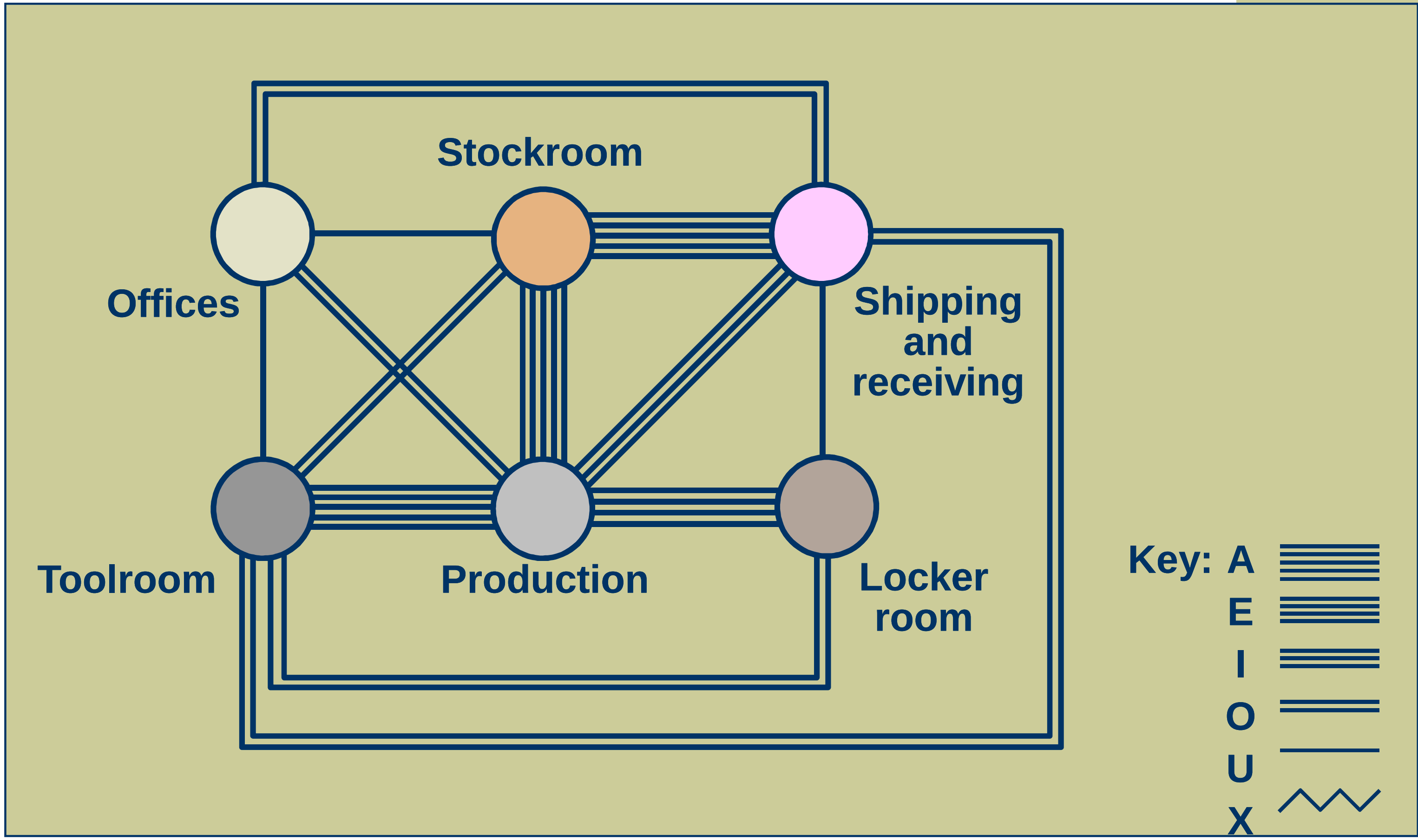
# Relationship Diagrams: Example (cont.)

**(a) Relationship diagram of original layout**



# Relationship Diagrams: Example (cont.)

**(b) Relationship diagram of revised layout**



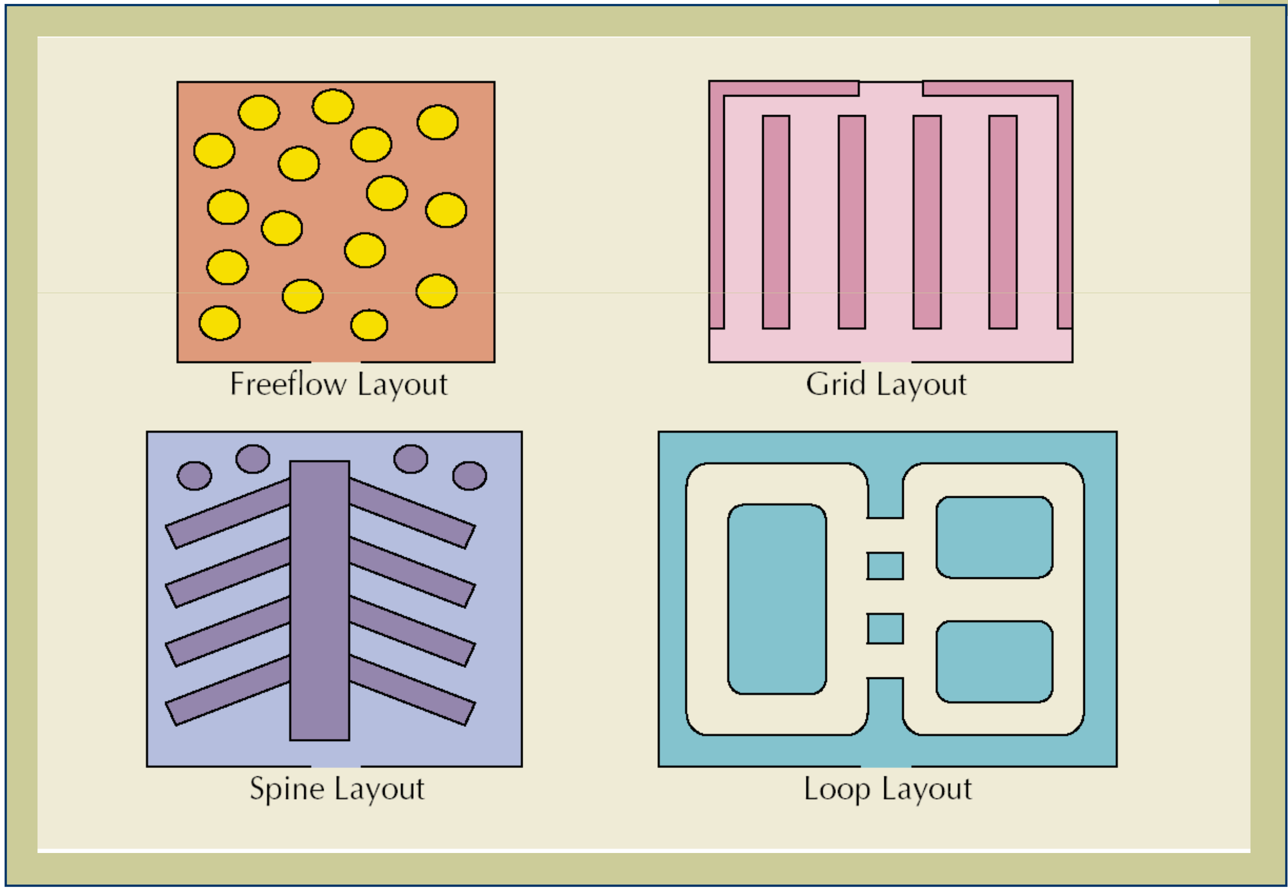
# Computerized layout Solutions

- CRAFT
  - Computerized Relative Allocation of Facilities Technique
- CORELAP
  - Computerized Relationship Layout Planning
- PROMODEL and EXTEND
  - visual feedback
  - allow user to quickly test a variety of scenarios
- Three-D modeling and CAD
  - integrated layout analysis
  - available in VisFactory and similar software

# Designing Service Layouts

- Must be both attractive and functional
- Types
  - Free flow layouts
    - encourage browsing, increase impulse purchasing, are flexible and visually appealing
  - Grid layouts
    - encourage customer familiarity, are low cost, easy to clean and secure, and good for repeat customers
  - Loop and Spine layouts
    - both increase customer sightlines and exposure to products, while encouraging customer to circulate through the entire store

# Types of Store Layouts



# Designing Product Layouts

- Objective
  - Balance the assembly line
- Line balancing
  - tries to equalize the amount of work at each workstation
- Precedence requirements
  - physical restrictions on the order in which operations are performed
- Cycle time
  - maximum amount of time a product is allowed to spend at each workstation

# Cycle Time Example

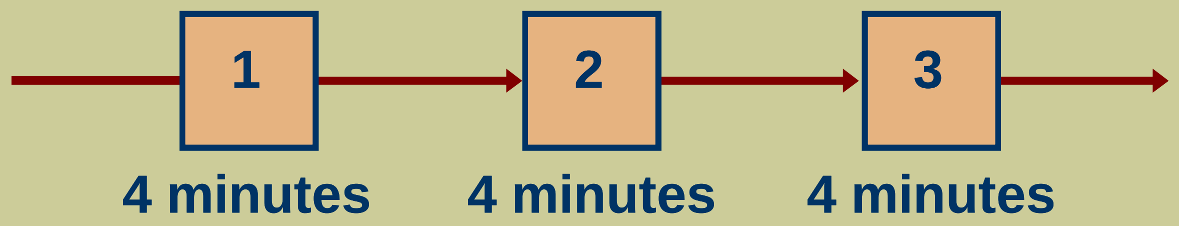
$$C_d = \frac{\text{production time available}}{\text{desired units of output}}$$

$$C_d = \frac{(8 \text{ hours x } 60 \text{ minutes / hour})}{(120 \text{ units})}$$

$$C_d = \frac{480}{120} = 4 \text{ minutes}$$

# Flow Time vs Cycle Time

- Cycle time = max time spent at any station
- Flow time = time to complete all stations




**Flow time = 4 + 4 + 4 = 12 minutes**
**Cycle time = max (4, 4, 4) = 4 minutes**

# Efficiency of Line and Balance Delay

**Efficiency**

$$E = \frac{\sum_{i=1}^{i} t_i}{nC_a}$$

**Minimum number of workstations**

$$N = \frac{\sum_{i=1}^{i} t_i}{C_d}$$

**where**

**$t_i$ = completion time for element $i$**
**$j$ = number of work elements**
**$n$ = actual number of workstations**
**$C_a$ = actual cycle time**
**$C_d$ = desired cycle time**

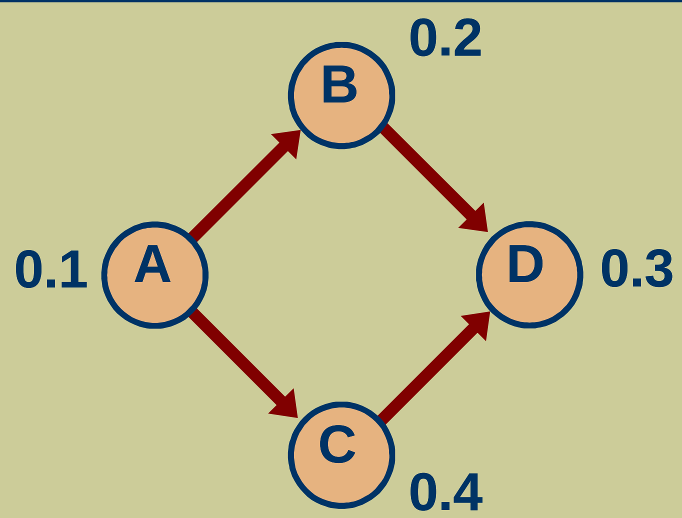
- Balance delay
  - total idle time of line
  - calculated as (1 - efficiency)

# Line Balancing Procedure

1. Draw and label a precedence diagram
2. Calculate desired cycle time required for line
3. Calculate theoretical minimum number of workstations
4. Group elements into workstations, recognizing cycle time and precedence constraints
5. Calculate efficiency of line
6. Determine if theoretical minimum number of workstations or an acceptable efficiency level has been reached. If not, go back to step 4.

# Line Balancing: Example

| | WORK ELEMENT | PRECEDENCE | TIME (MIN) |
|---|---|---|---|
| A | Press out sheet of fruit | — | 0.1 |
| B | Cut into strips | A | 0.2 |
| C | Outline fun shapes | A | 0.4 |
| D | Roll up and package | B, C | 0.3 |



# Line Balancing: Example (cont.)

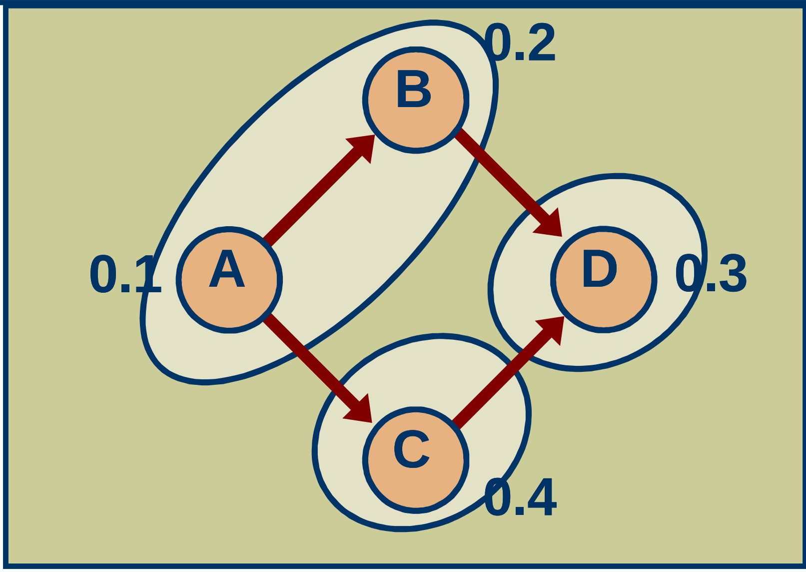
| | WORK ELEMENT | PRECEDENCE | TIME (MIN) |
|---|---|---|---|
| A | Press out sheet of fruit | — | 0.1 |
| B | Cut into strips | A | 0.2 |
| C | Outline fun shapes | A | 0.4 |
| D | Roll up and package | B, C | 0.3 |

$$C_d = \frac{\text{40 hours x 60 minutes / hour}}{\text{6,000 units}} = \frac{2400}{6000} = 0.4 \text{ minute}$$

$$N = \frac{0.1 + 0.2 + 0.3 + 0.4}{0.4} = \frac{1.0}{0.4} = 2.5 \rightarrow 3 \text{ workstations}$$

# Line Balancing: Example (cont.)

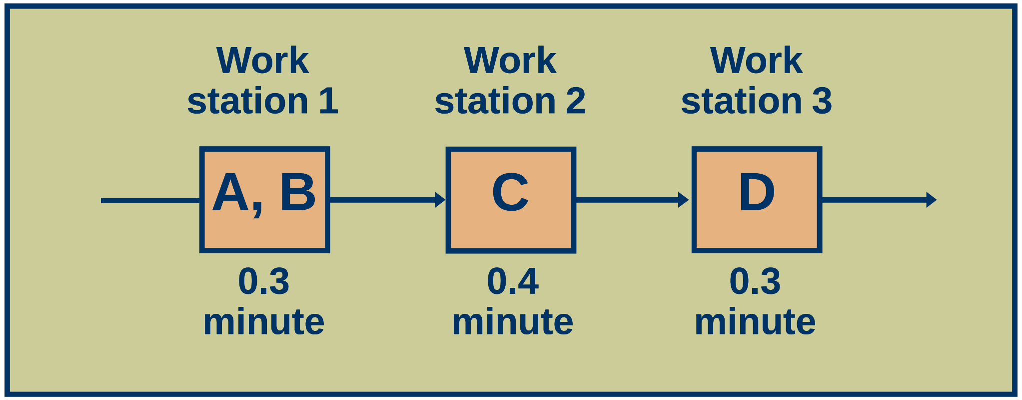
| WORKSTATION | ELEMENT | REMAINING TIME | REMAINING ELEMENTS |
|---|---|---|---|
| 1 | A | 0.3 | B, C |
| | B | 0.1 | C, D |
| 2 | C | 0.0 | D |
| 3 | D | 0.1 | none |




$C_d = 0.4$

$N = 2.5$

# Line Balancing: Example (cont.)




$C_d = 0.4$

$N = 2.5$

$$E = \frac{0.1 + 0.2 + 0.3 + 0.4}{3(0.4)} = \frac{1.0}{1.2} = 0.833 = 83.3\%$$

# Computerized Line Balancing

- Use heuristics to assign tasks to workstations
  - Longest operation time
  - Shortest operation time
  - Most number of following tasks
  - Least number of following tasks
  - Ranked positional weight

# Hybrid Layouts

- Cellular layouts
  - group dissimilar machines into work centers (called cells) that process families of parts with similar shapes or processing requirements
- Production flow analysis (PFA)
  - reorders part routing matrices to identify families of parts with similar processing requirements
- Flexible manufacturing system
  - automated machining and material handling systems which can produce an enormous variety of items
- Mixed-model assembly line
  - processes more than one product model in one line

# Cellular Layouts

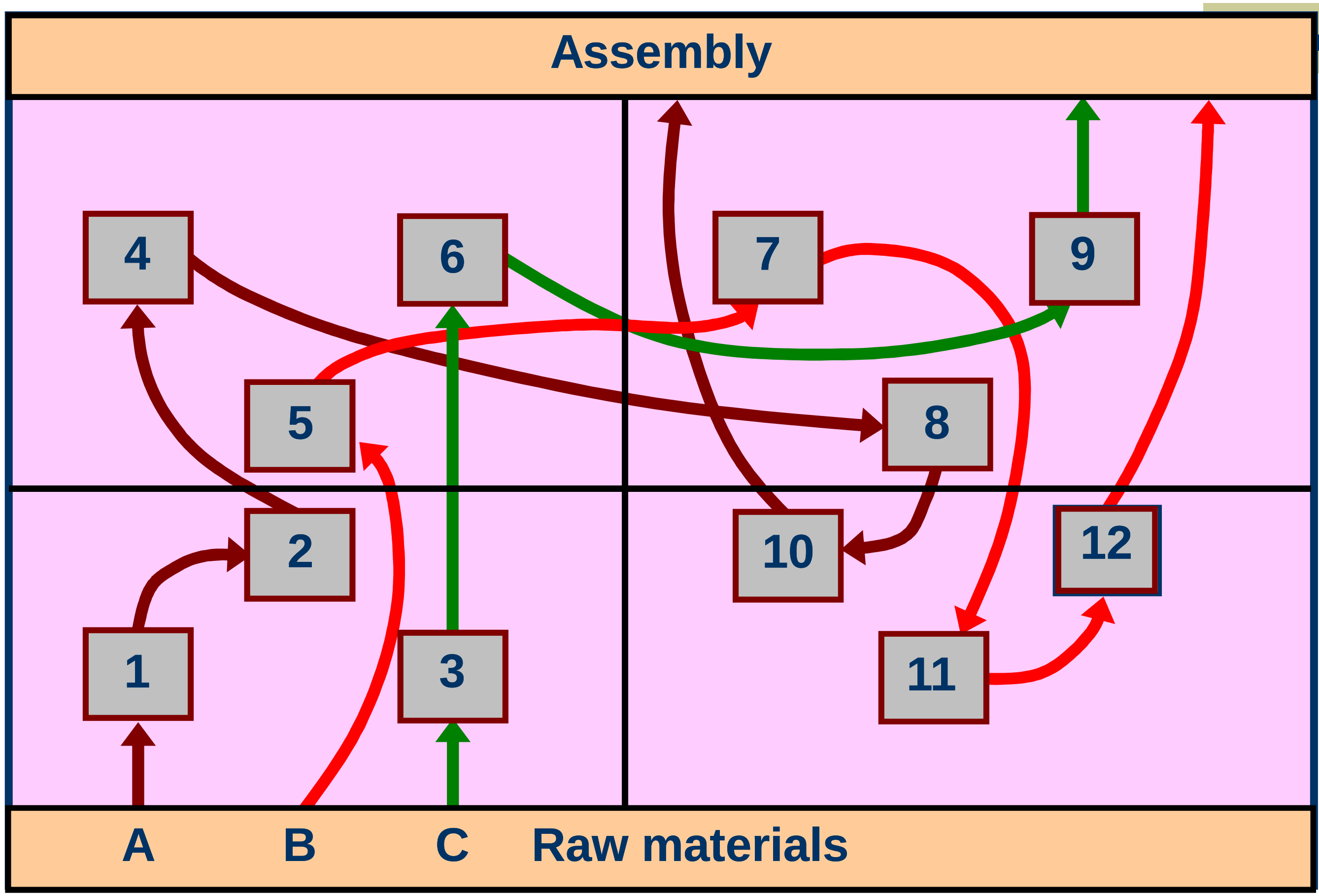
1. Identify families of parts with similar flow paths
2. Group machines into cells based on part families
3. Arrange cells so material movement is minimized
4. Locate large shared machines at point of use

# Parts Families


A family of similar parts

A family of related grocery items

# Original Process Layout

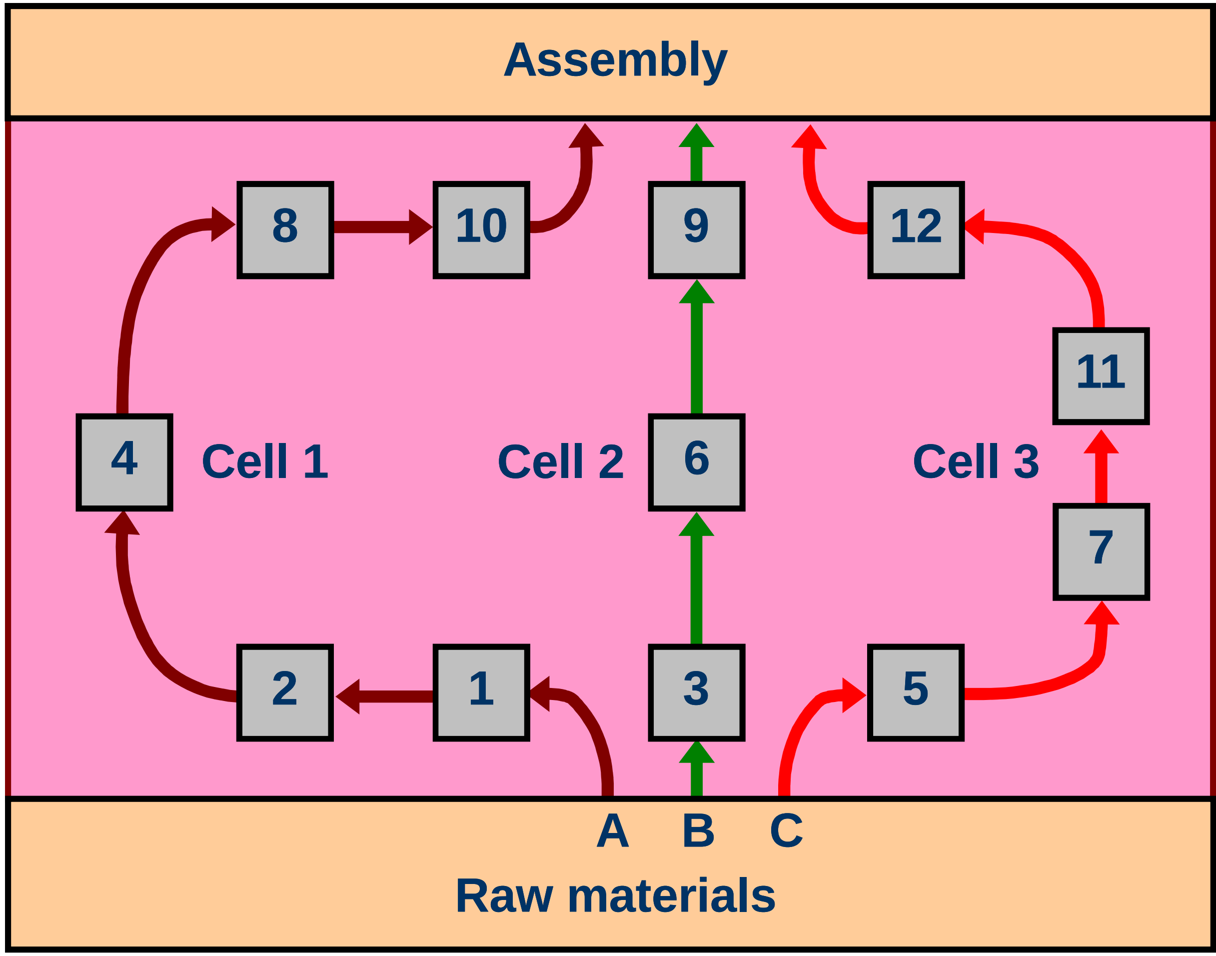


# Part Routing Matrix

| Parts | Machines | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| A | x | x | | x | | | | x | | x | | |
| B | | | | | x | | x | | | | x | x |
| C | | | x | | | x | | | x | | | |
| D | x | x | | x | | | | x | | x | | |
| E | | | | x | x | | | | | | | x |
| F | x | | | x | | | | x | | | | |
| G | | | x | | | x | | | x | | | x |
| H | | | | | | | x | | | | x | x |

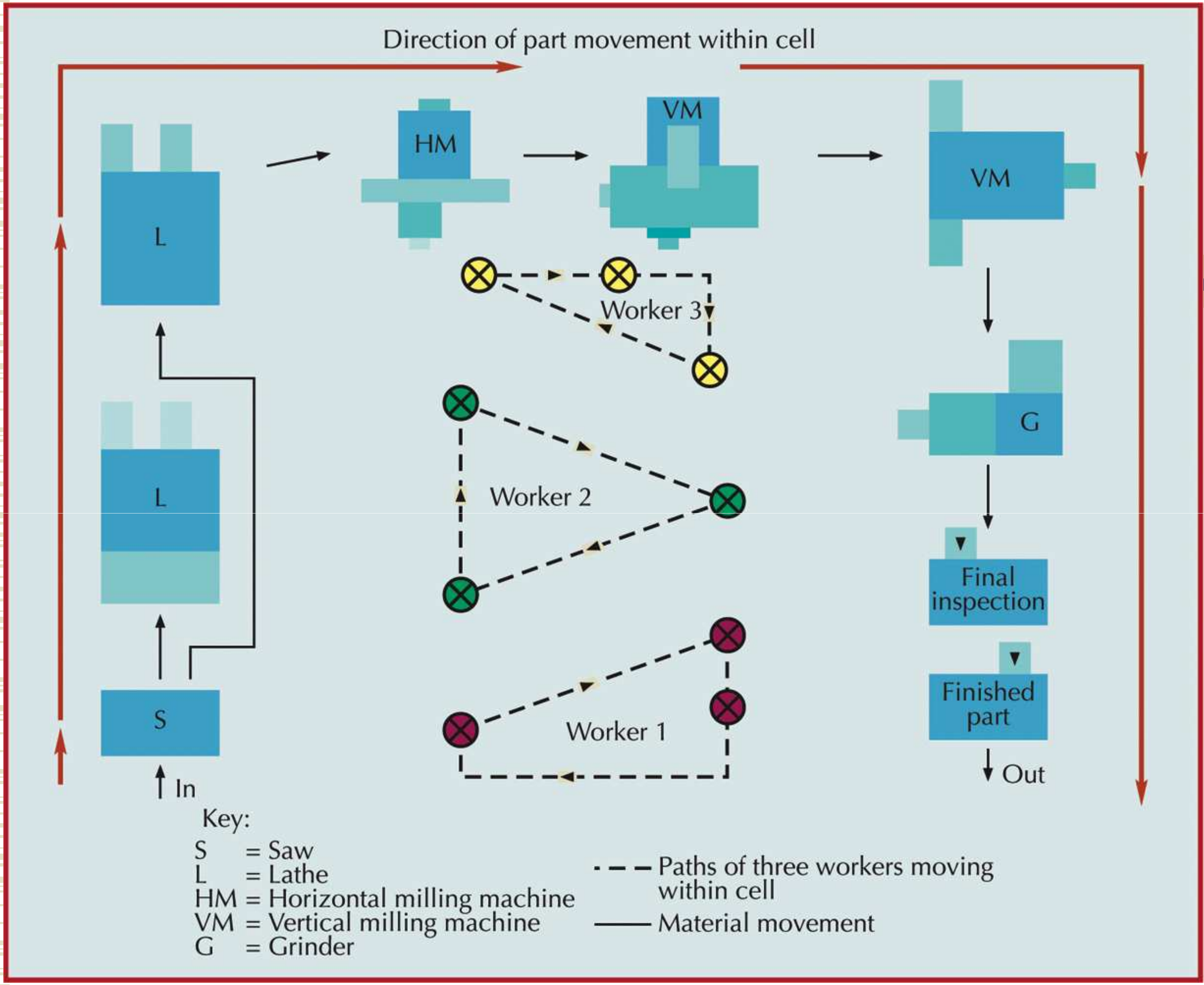
Figure 5.8

# Revised Cellular Layout



# Reordered Routing Matrix

| Parts | Machines | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 4 | 8 | 10 | 3 | 6 | 9 | 5 | 7 | 11 | 12 |
| A | x | x | x | x | x | | | | | | | |
| D | x | x | x | x | x | | | | | | | |
| F | x | | x | x | | | | | | | | |
| C | | | | | | x | x | x | | | | |
| G | | | | | | x | x | x | | | | x |
| B | | | | | | | | | x | x | x | x |
| H | | | | | | | | | | x | x | x |
| E | | | | | | | x | | x | | | x |

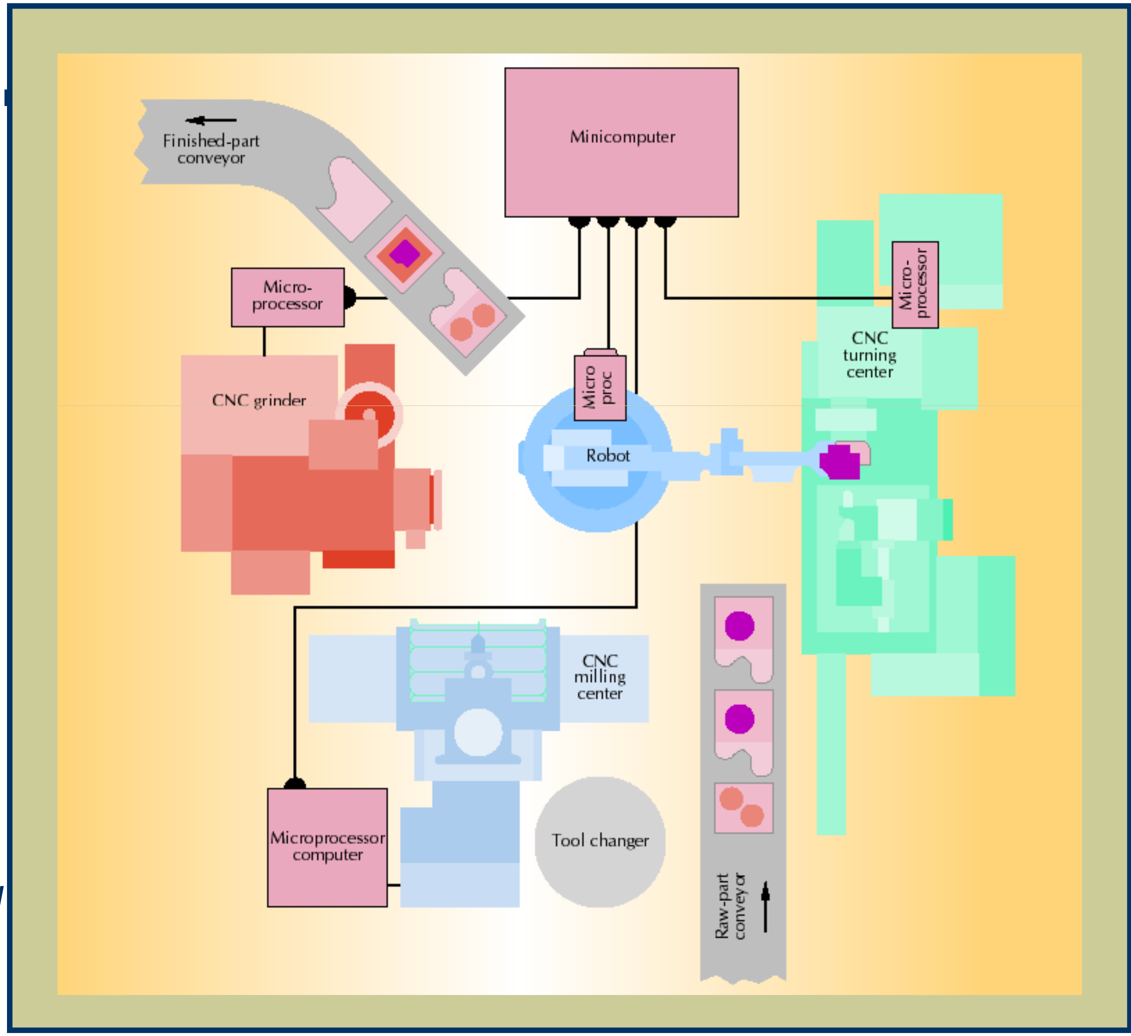


Direction of part movement within cell
L
HM
VM
VM
L
Worker 3
Worker 2
G
Final inspection
Finished part
S
Worker 1
In
Out
Key:
S = Saw
L = Lathe
HM = Horizontal milling machine
VM = Vertical milling machine
G = Grinder
Paths of three workers moving within cell
Material movement

# Advantages and Disadvantages of Cellular Layouts

- ***Advantages***
  - ***Reduced material handling and transit time***
  - ***Reduced setup time***
  - ***Reduced work-in-process inventory***
  - ***Better use of human resources***
  - ***Easier to control***
  - ***Easier to automate***
- ***Disadvantages***
  - ***Inadequate part families***
  - ***Poorly balanced cells***
  - ***Expanded training and scheduling of workers***
  - ***Increased capital investment***

# Automated Manufacturing Cell

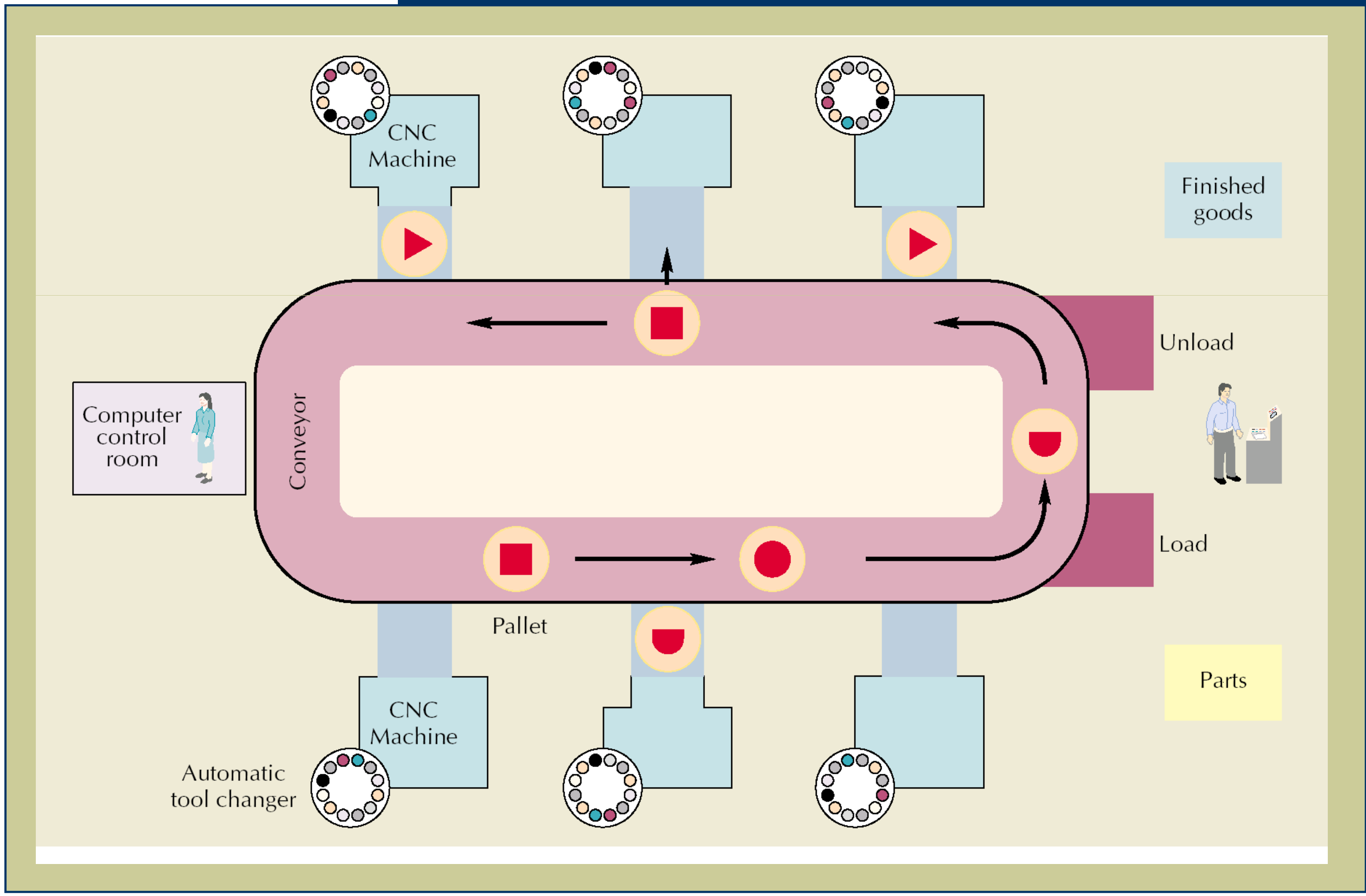



*Source:* J. T. Black, "Cellular Manufacturing Systems Reduce Setup Time, Make Small Lot Production Economical." *Industrial Engineering* (November 1983)

# Flexible Manufacturing Systems (FMS)

- FMS consists of numerous programmable machine tools connected by an automated material handling system and controlled by a common computer network
- FMS combines flexibility with efficiency
- FMS layouts differ based on
  - variety of parts that the system can process
  - size of parts processed
  - average processing time required for part completion

# Full-Blown FMS

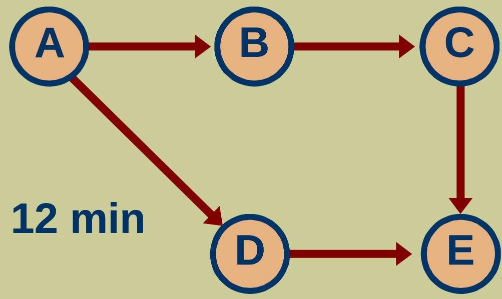


# Mixed Model Assembly Lines

- Produce multiple models in any order on one assembly line
- Issues in mixed model lines
  - Line balancing
  - U-shaped lines
  - Flexible workforce
  - Model sequencing

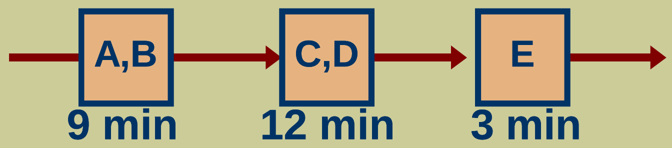
# Balancing U-Shaped Lines

**Precedence diagram:**



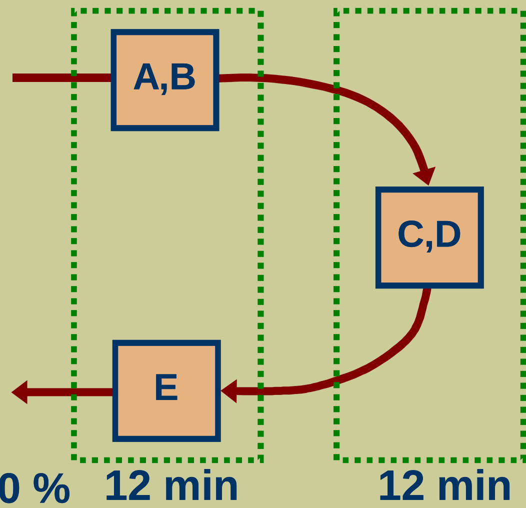

Cycle time = 12 min

**(a) Balanced for a straight line**

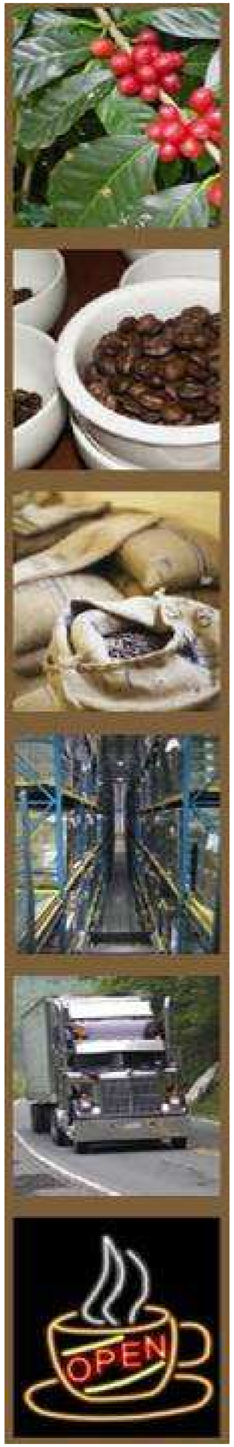



$$\text{Efficiency} = \frac{24}{3(12)} = \frac{24}{36} = .6666 = 66.7\ \%$$

**(b) Balanced for a U-shaped line**




$$\text{Efficiency} = \frac{24}{2(12)} = \frac{24}{24} = 100\ \%$$



# Chapter 7 Supplement

## *Facility Location Models*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Types of Facilities
- Site Selection: Where to Locate
- Location Analysis Techniques

# Types of Facilities

- Heavy-manufacturing facilities
  - large, require a lot of space, and are expensive
- Light-industry facilities
  - smaller, cleaner plants and usually less costly
- Retail and service facilities
  - smallest and least costly

# Factors in Heavy Manufacturing Location

- Construction costs
- Land costs
- Raw material and finished goods shipment modes
- Proximity to raw materials
- Utilities
- Means of waste disposal
- Labor availability

# Factors in Light Industry Location

- Land costs
- Transportation costs
- Proximity to markets
  - depending on delivery requirements including frequency of delivery required by customer

# Factors in Retail Location

- Proximity to customers
- Location is everything

# Site Selection: Where to Locate

- Infrequent but important
  - being "in the right place at the right time"
- Must consider other factors, especially financial considerations
- Location decisions made more often for service operations than manufacturing facilities
- Location criteria for service
  - access to customers
- Location criteria for manufacturing facility
  - nature of labor force
  - labor costs
  - proximity to suppliers and markets
  - distribution and transportation costs
  - energy availability and cost
  - community infrastructure
  - quality of life in community
  - government regulations and taxes

# Global Location Factors

- Government stability
- Government regulations
- Political and economic systems
- Economic stability and growth
- Exchange rates
- Culture
- Climate
- Export/import regulations, duties and tariffs
- Raw material availability
- Number and proximity of suppliers
- Transportation and distribution system
- Labor cost and education
- Available technology
- Commercial travel
- Technical expertise
- Cross-border trade regulations
- Group trade agreements

# Regional and Community Location Factors in U.S.

- Labor (availability, education, cost, and unions)
- Proximity of customers
- Number of customers
- Construction/leasing costs
- Land cost
- Modes and quality of transportation
- Transportation costs
- Community government Local business regulations
- Government services (e.g., Chamber of Commerce)

# Regional and Community Location Factors in U.S. (cont.)

- Business climate
- Community services
- Incentive packages
- Government regulations
- Environmental regulations
- Raw material availability
- Commercial travel
- Climate
- Infrastructure (e.g., roads, water, sewers)
- Quality of life
- Taxes
- Availability of sites
- Financial services
- Community inducements
- Proximity of suppliers
- Education system

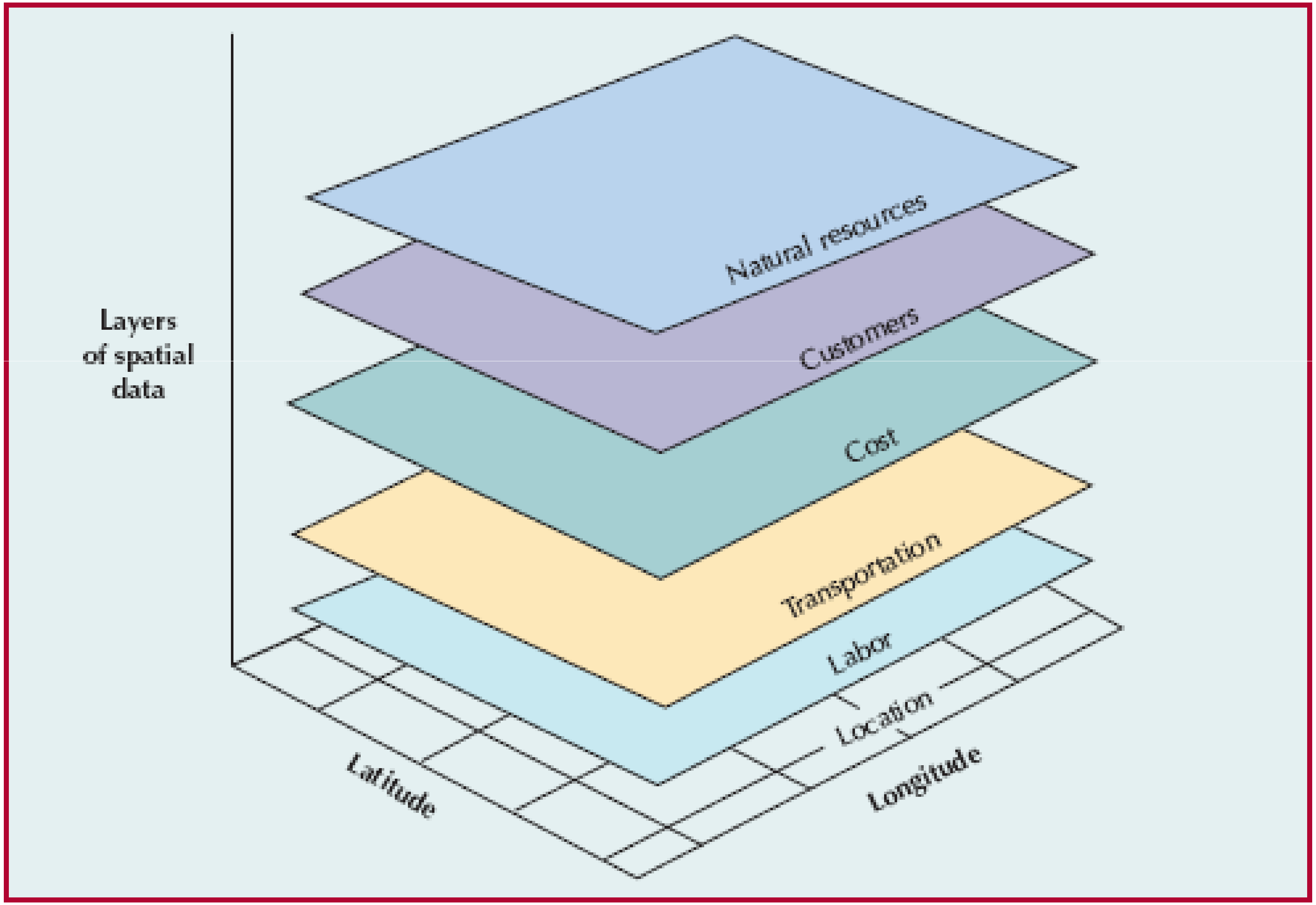
# Location Incentives

- Tax credits
- Relaxed government regulation
- Job training
- Infrastructure improvement
- Money

# Geographic Information Systems (GIS)

- Computerized system for storing, managing, creating, analyzing, integrating, and digitally displaying geographic, i.e., spatial, data
- Specifically used for site selection
- enables users to integrate large quantities of information about potential sites and analyze these data with many different, powerful analytical tools

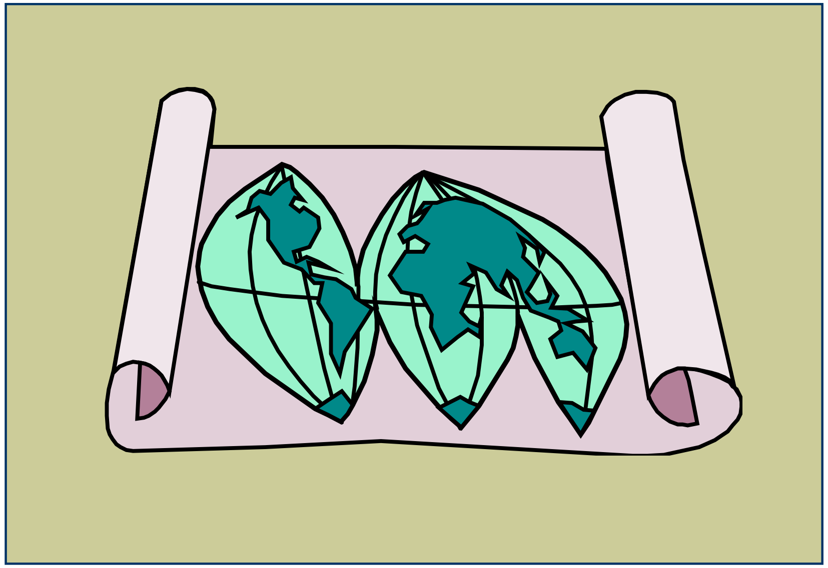
# GIS Diagram



Layers
of spatial
data
Natural resources
Customers
Cost
Transportation
Labor
Location
Latitude
Longitude

# Location Analysis Techniques

- Location factor rating
- Center-of-gravity
- Load-distance



# Location Factor Rating

- Identify important factors
- Weight factors (0.00 - 1.00)
- Subjectively score each factor (0 - 100)
- Sum weighted scores

# Location Factor Rating: Example

| LOCATION FACTOR | WEIGHT | SCORES (0 TO 100) Site 1 | Site 2 | Site 3 |
|---|---|---|---|---|
| Labor pool and climate | .30 | 80 | 65 | 90 |
| Proximity to suppliers | .20 | 100 | 91 | 75 |
| Wage rates | .15 | 60 | 95 | 72 |
| Community environment | .15 | 75 | 80 | 80 |
| Proximity to customers | .10 | 65 | 90 | 95 |
| Shipping modes | .05 | 85 | 92 | 65 |
| Air service | .05 | 50 | 65 | 90 |

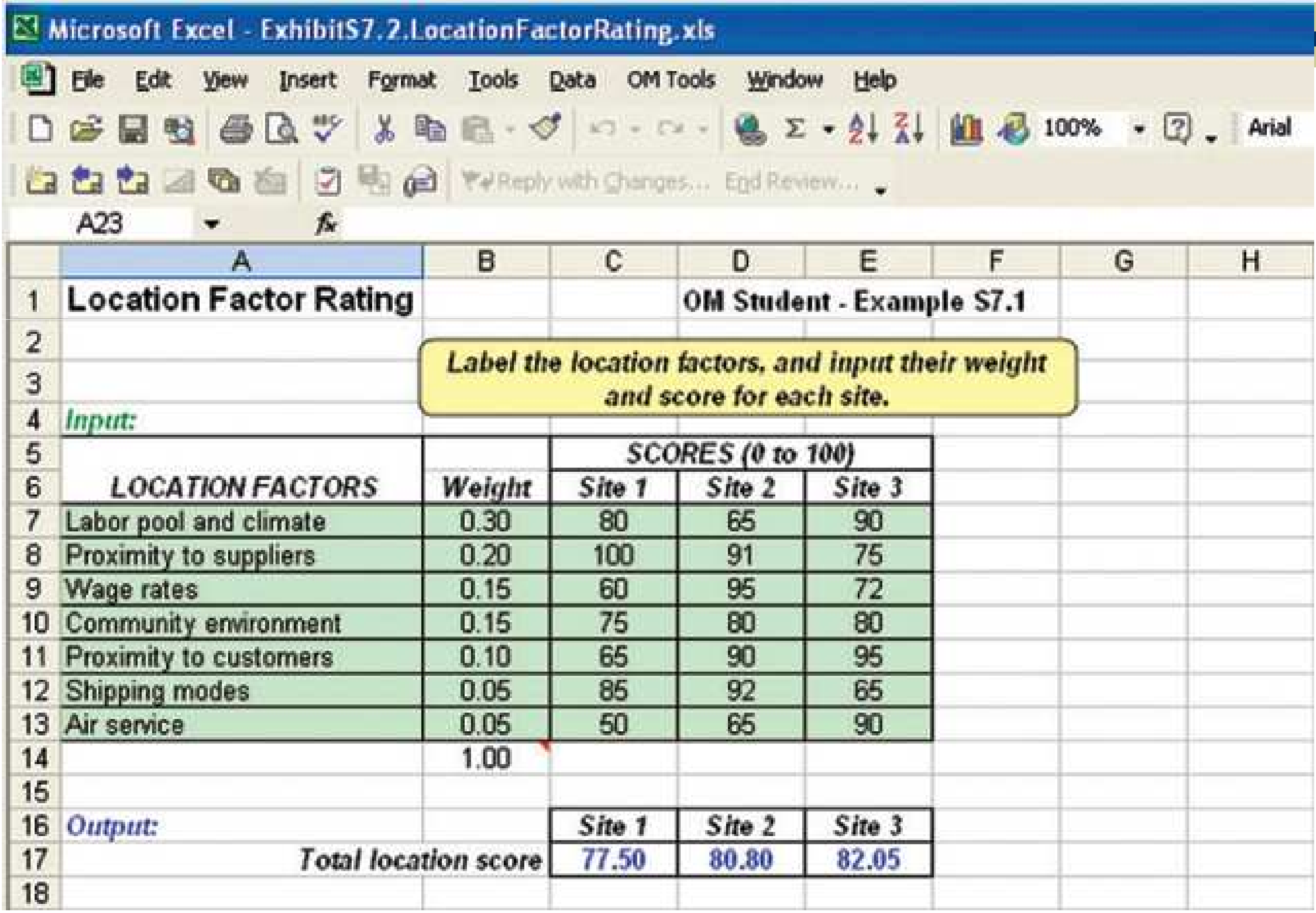
**Weighted Score for "Labor pool and climate" for Site 1 = (0.30)(80) = 24**

# Location Factor Rating: Example (cont.)

| WEIGHTED SCORES | | |
|---|---|---|
| *Site 1* | *Site 2* | *Site 3* |
| 24.00 | 19.50 | 27.00 |
| 20.00 | 18.20 | 15.00 |
| 9.00 | 14.25 | 10.80 |
| 11.25 | 12.00 | 12.00 |
| 6.50 | 9.00 | 9.50 |
| 4.25 | 4.60 | 3.25 |
| 2.50 | 3.25 | 4.50 |
| 77.50 | 80.80 | 82.05 |

Site 3 has the highest factor rating

# Location Factor Rating with Excel and OM Tools

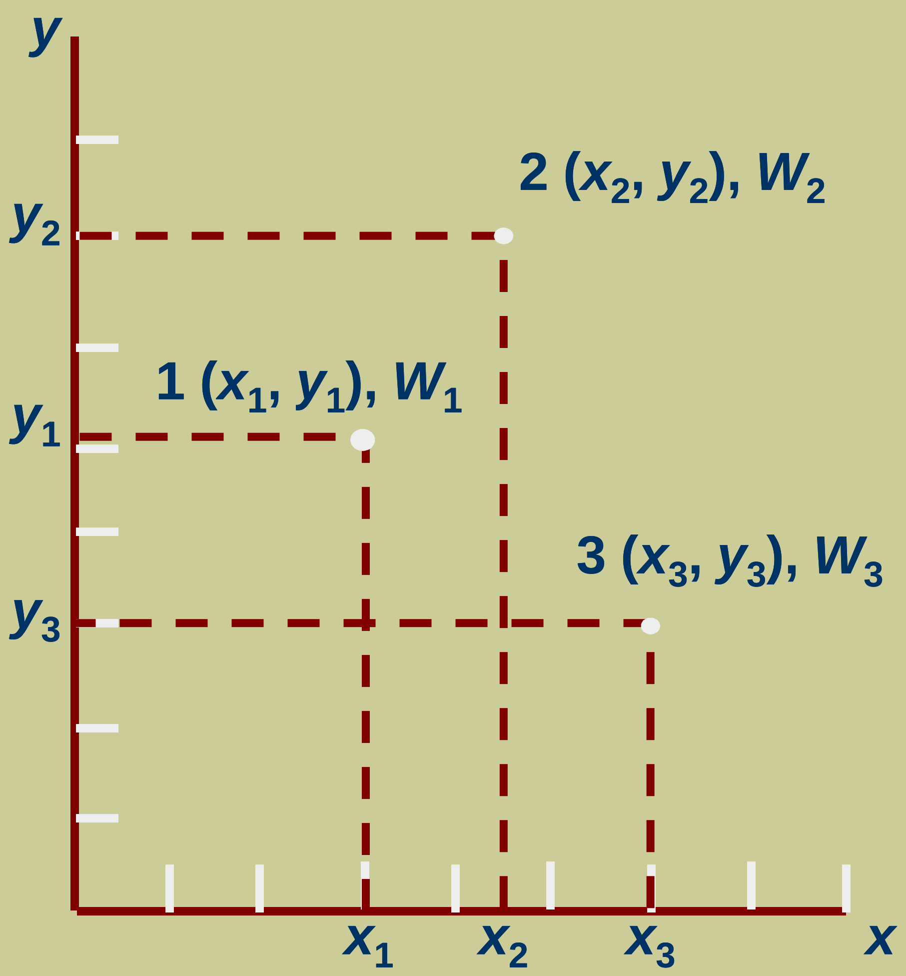



| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | Location Factor Rating | | | OM Student - Example S7.1 | | | | |
| 2 | | Label the location factors, and input their weight and score for each site. | | | | | | |
| 3 | | | | | | | | |
| 4 | *Input:* | | | | | | | |
| 5 | | | *SCORES (0 to 100)* | | | | | |
| 6 | *LOCATION FACTORS* | *Weight* | *Site 1* | *Site 2* | *Site 3* | | | |
| 7 | Labor pool and climate | 0.30 | 80 | 65 | 90 | | | |
| 8 | Proximity to suppliers | 0.20 | 100 | 91 | 75 | | | |
| 9 | Wage rates | 0.15 | 60 | 95 | 72 | | | |
| 10 | Community environment | 0.15 | 75 | 80 | 80 | | | |
| 11 | Proximity to customers | 0.10 | 65 | 90 | 95 | | | |
| 12 | Shipping modes | 0.05 | 85 | 92 | 65 | | | |
| 13 | Air service | 0.05 | 50 | 65 | 90 | | | |
| 14 | | 1.00 | | | | | | |
| 15 | | | | | | | | |
| 16 | *Output:* | | *Site 1* | *Site 2* | *Site 3* | | | |
| 17 | *Total location score* | | 77.50 | 80.80 | 82.05 | | | |
| 18 | | | | | | | | |

# Center-of-Gravity Technique

- Locate facility at center of movement in geographic area
- Based on weight and distance traveled; establishes grid-map of area
- Identify coordinates and weights shipped for each location

# Grid-Map Coordinates




$$x = \frac{\sum_{i=1}^{n} x_i W_i}{\sum_{i=1}^{n} W_i} \qquad y = \frac{\sum_{i=1}^{n} y_i W_i}{\sum_{i=1}^{n} W_i}$$

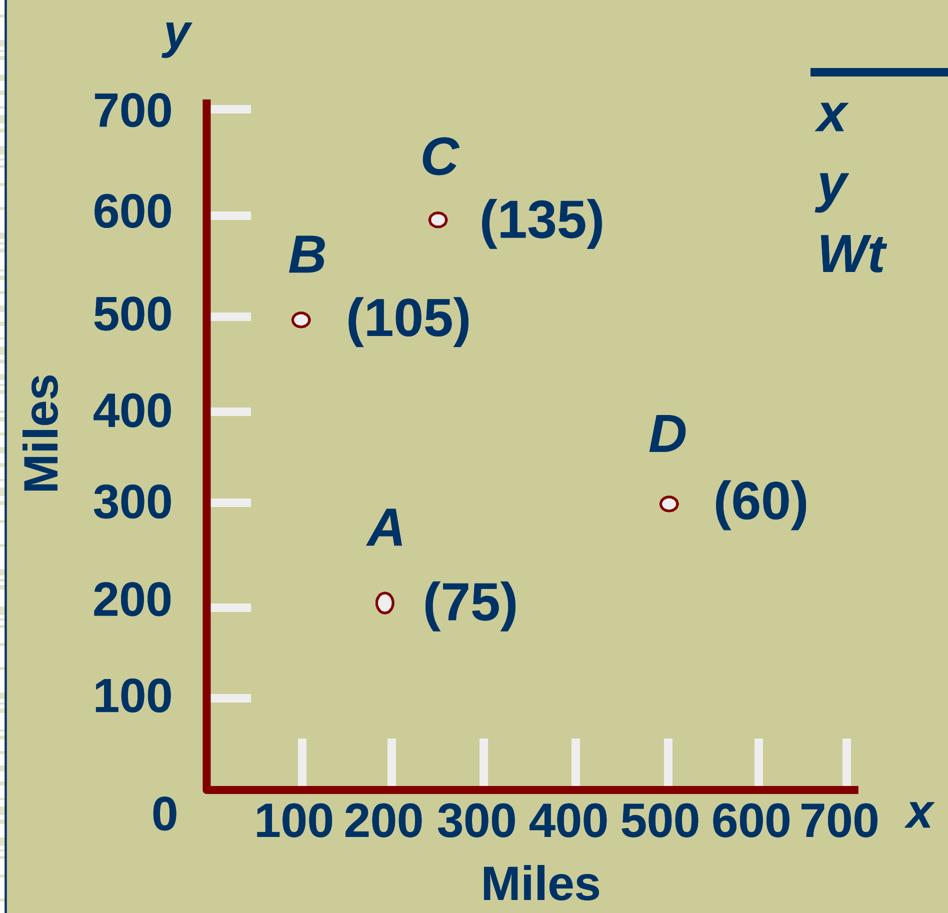
where,

$x, y$ = coordinates of new facility at center of gravity

$x_i, y_i$ = coordinates of existing facility $i$

$W_i$ = annual weight shipped from facility $i$

# Center-of-Gravity Technique: Example




| | A | B | C | D |
|---|---|---|---|---|
| *x* | 200 | 100 | 250 | 500 |
| *y* | 200 | 500 | 600 | 300 |
| *Wt* | 75 | 105 | 135 | 60 |

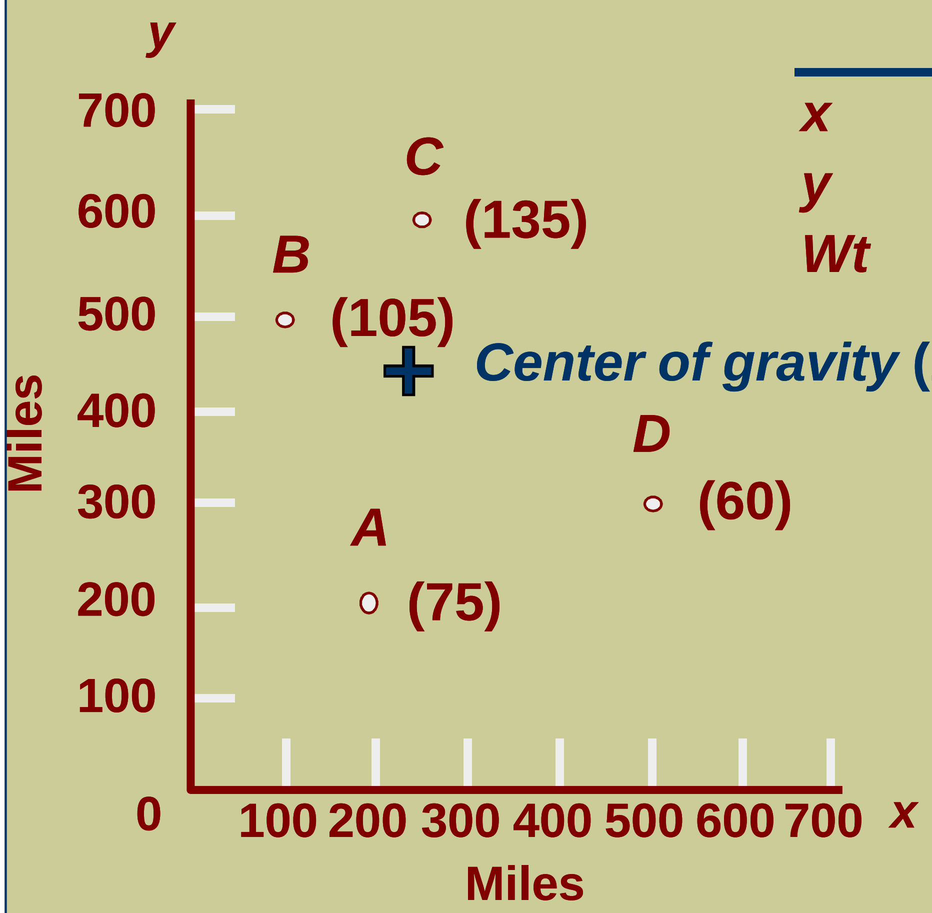
# Center-of-Gravity Technique: Example (cont.)

$$x = \frac{\sum_{i=1}^{n} x_i W_i}{\sum_{i=1}^{n} W_i} = \frac{(200)(75) + (100)(105) + (250)(135) + (500)(60)}{75 + 105 + 135 + 60} = 238$$

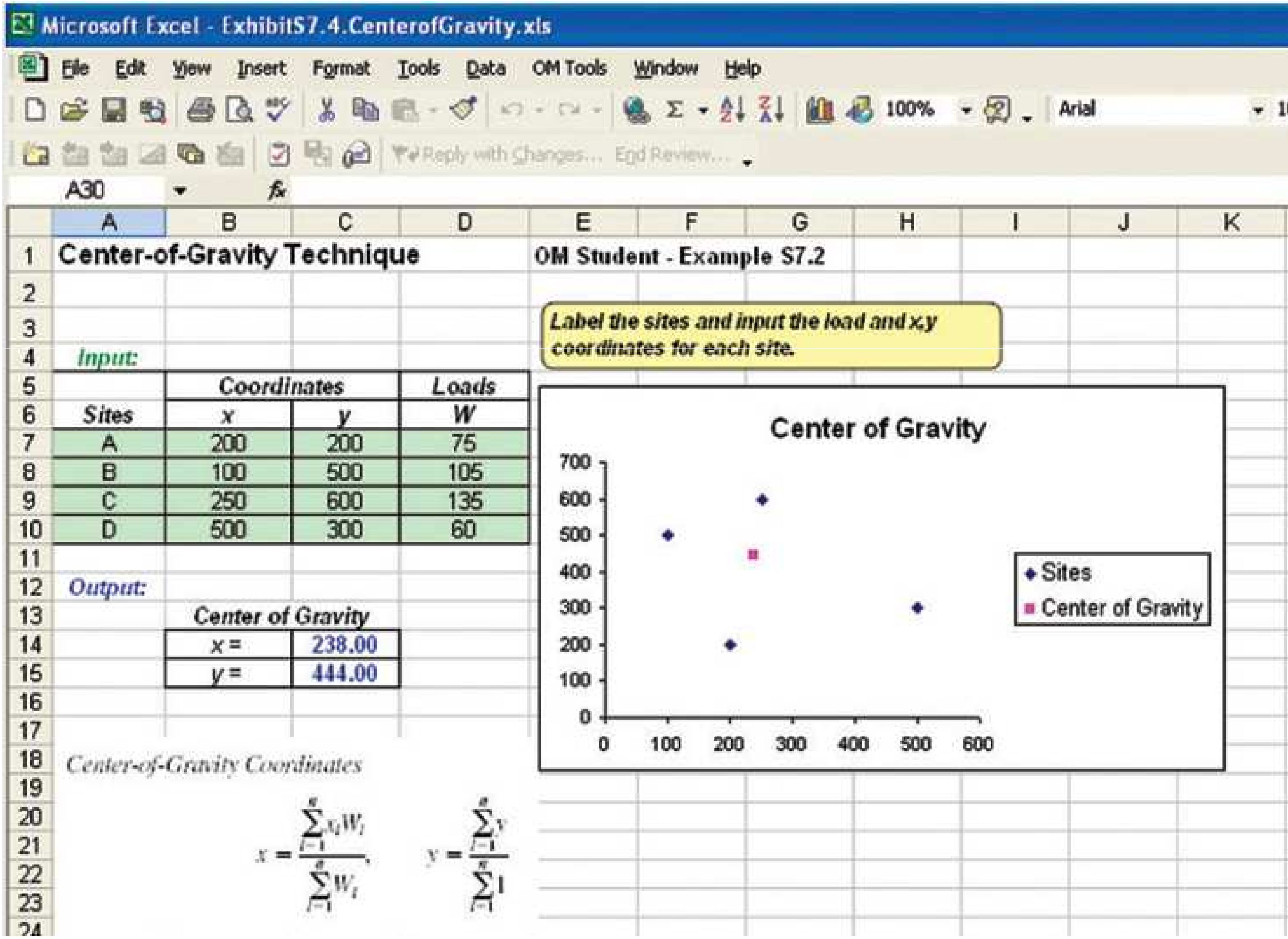
$$y = \frac{\sum_{i=1}^{n} y_i W_i}{\sum_{i=1}^{n} W_i} = \frac{(200)(75) + (500)(105) + (600)(135) + (300)(60)}{75 + 105 + 135 + 60} = 444$$

# Center-of-Gravity Technique: Example (cont.)

| | A | B | C | D |
|---|---|---|---|---|
| *x* | 200 | 100 | 250 | 500 |
| *y* | 200 | 500 | 600 | 300 |
| *Wt* | 75 | 105 | 135 | 60 |



# Center-of-Gravity Technique with Excel and OM Tools



# Load-Distance Technique

- Compute (Load x Distance) for each site
- Choose site with lowest (Load x Distance)
- Distance can be actual or straight-line

# Load-Distance Calculations

$$LD = \sum_{i=1}^{n} l_i d_i$$

where,

$LD$ = load-distance value

$l_i$ = load expressed as a weight, number of trips or units being shipped from proposed site and location $i$

$d_i$ = distance between proposed site and location $i$

$$d_i = \sqrt{(x_i - x)^2 + (y_i - y)^2}$$

where,

$(x,y)$ = coordinates of proposed site

$(x_i, y_i)$ = coordinates of existing facility

# Load-Distance: Example

**Potential Sites**

| Site | X | Y |
|---|---|---|
| 1 | 360 | 180 |
| 2 | 420 | 450 |
| 3 | 250 | 400 |

**Suppliers**

| | A | B | C | D |
|---|---|---|---|---|
| X | 200 | 100 | 250 | 500 |
| Y | 200 | 500 | 600 | 300 |
| Wt | 75 | 105 | 135 | 60 |

**Compute distance from each site to each supplier**

Site 1 $d_A = \sqrt{(x_A - x_1)^2 + (y_A - y_1)^2} = \sqrt{(200-360)^2 + (200-180)^2} = 161.2$

$d_B = \sqrt{(x_B - x_1)^2 + (y_B - y_1)^2} = \sqrt{(100-360)^2 + (500-180)^2} = 412.3$

$d_C = 434.2$ $d_D = 184.4$

# Load-Distance: Example (cont.)

**Site 2** $d_A = 333$ $d_B = 323.9$ $d_C = 226.7$ $d_D = 170$

**Site 3** $d_A = 206.2$ $d_B = 180.3$ $d_C = 200$ $d_D = 269.3$

**Compute load-distance**

$$LD = \sum_{i=1}^{n} l_i d_i$$

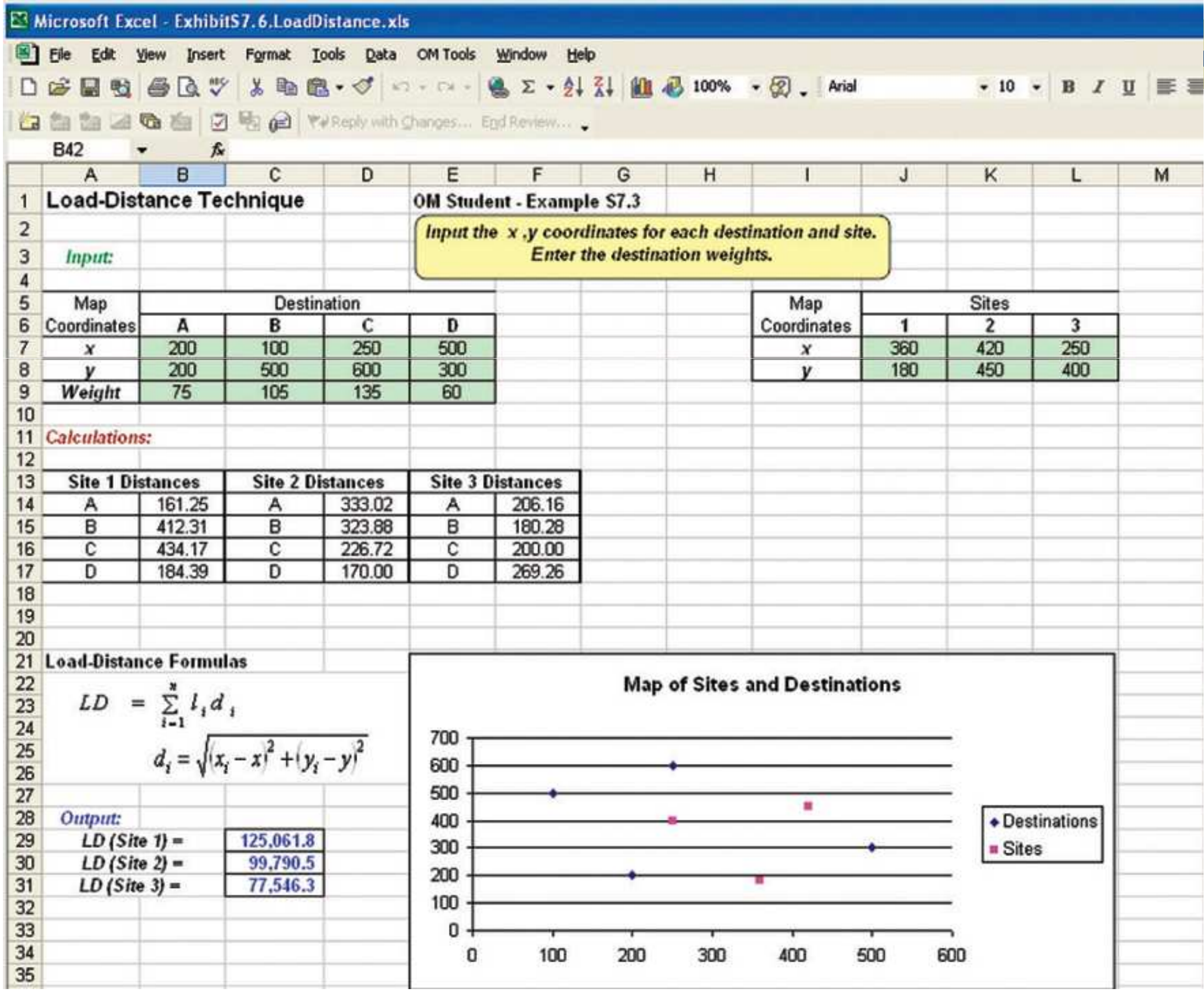
**Site 1 = (75)(161.2) + (105)(412.3) + (135)(434.2) + (60)(434.4) = 125,063**

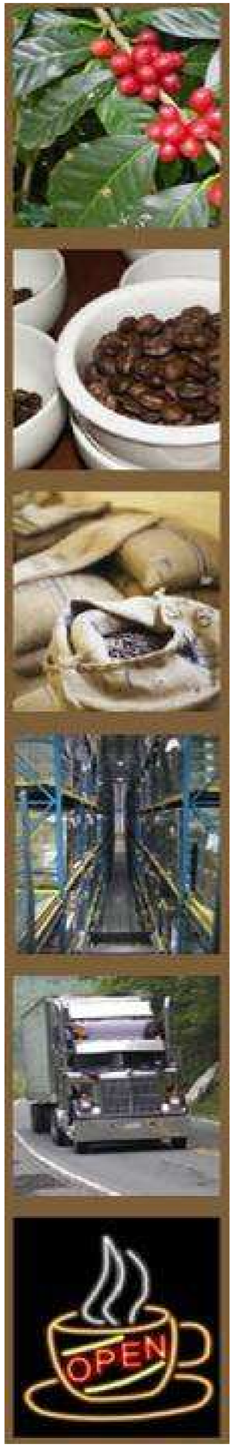
**Site 2 = (75)(333) + (105)(323.9) + (135)(226.7) + (60)(170) = 99,789**

**Site 3 = (75)(206.2) + (105)(180.3) + (135)(200) + (60)(269.3) = 77,555***

*** Choose site 3**

# Load-Distance Technique with Excel and OM Tools





# Chapter 8

## *Human Resources*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Human Resources and Quality Management
- Changing Nature of Human Resources Management
- Contemporary Trends in Human Resources Management
- Employee Compensation
- Managing Diversity in Workplace
- Job Design
- Job Analysis
- Learning Curves

# Human Resources and Quality Management

- Employees play important role in quality management
- Malcolm Baldrige National Quality Award winners have a pervasive human resource focus
- Employee training and education are recognized as necessary long-term investments
- Employees have power to make decisions that will improve quality and customer service
- Strategic goals for quality and customer satisfaction require teamwork and group participation

# Changing Nature of Human Resources Management

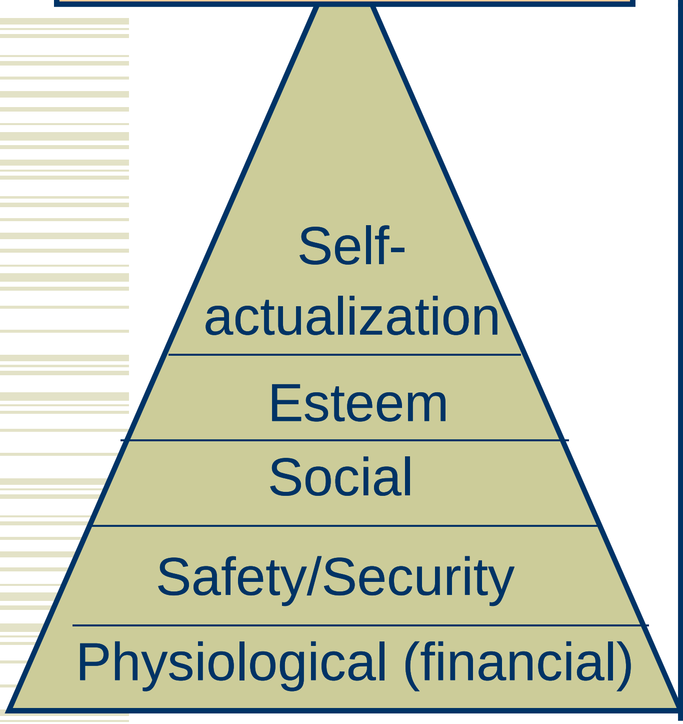
- Scientific management
  - Breaking down jobs into elemental activities and simplifying job design
- Jobs
  - Comprise a set of tasks, elements, and job motions (basic physical movements)
- In a *piece-rate wage system*, pay is based on output
- Assembly-line
  - Production meshed with principles of scientific management
- Advantages of task specialization
  - High output, low costs, and minimal training
- Disadvantages of task specialization
  - Boredom, lack of motivation, and physical and mental fatigue

# Employee Motivation

- Motivation
  - willingness to work hard because that effort satisfies an employee need
- Improving Motivation
  - positive reinforcement and feedback
  - effective organization and discipline
  - fair treatment of people
  - satisfaction of employee needs
  - setting of work-related goals
- Improving Motivation (cont.)
  - design of jobs to fit employee
  - work responsibility
  - empowerment
  - restructuring of jobs when necessary
  - rewards based on company as well as individual performance
  - achievement of company goals

# Evolution of Theories of Employee Motivation

**Abraham Maslow's Pyramid of Human Needs**




**Douglas McGregor's Theory X and Theory Y**

- Theory X Employee
  - Dislikes work
  - Must be coerced
  - Shirks responsibility
  - Little ambition
  - Security top motivator
- Theory Y Employee
  - Work is natural
  - Self-directed
  - Controlled
  - Accepts responsibility
  - Makes good decisions

**Frederick Herzberg's Hygiene/Motivation Theories**

- Hygiene Factors
  - Company policies
  - Supervision
  - Working conditions
  - Interpersonal relations
  - Salary, status, security
- Motivation Factors
  - Achievement
  - Recognition
  - Job interest
  - Responsibility
  - Growth
  - Advancement

# Contemporary Trends in Human Resources Management

- Job training
  - extensive and varied
  - two of Deming's 14 points refer to employee education and training
- Cross Training
  - an employee learns more than one job
- Job rotation
  - horizontal movement between two or more jobs according to a plan
- Empowerment
  - giving employees authority to make decisions
- Teams
  - group of employees work on problems in their immediate work area

# Contemporary Trends in Human Resources Management (cont.)

- Job enrichment
  - vertical enlargement
    - allows employees control over their work
  - horizontal enlargement
    - an employee is assigned a complete unit of work with defined start and end
- Flexible time
  - part of a daily work schedule in which employees can choose time of arrival and departure
- Alternative workplace
  - nontraditional work location
- Telecommuting
  - employees work electronically from a location they choose
- Temporary and part-time employees
  - mostly in fast-food and restaurant chains, retail companies, package delivery services, and financial firms

# Employee Compensation

- Types of pay
  - hourly wage
    - the longer someone works, the more s/he is paid
  - individual incentive or piece rate
    - employees are paid for the number of units they produce during the workday
  - straight salary
    - common form of payment for management
  - commissions
    - usually applied to sales and salespeople

# Employee Compensation (cont.)

- Gainsharing
  - an incentive plan joins employees in a common effort to achieve company goals in which they share in the gains
- Profit sharing
  - sets aside a portion of profits for employees at year’s end

# Managing Diversity in Workplace

- Workforce has become more diverse
  - 4 out of every 10 people entering workforce during the decade from 1998 to 2008 will be members of minority groups
  - In 2000 U.S. Census showed that some minorities, primarily Hispanic and Asian, are becoming majorities
- Companies must develop a strategic approach to managing diversity

# Affirmative Actions vs. Managing Diversity

- Affirmative action
  - an outgrowth of laws and regulations
  - government initiated and mandated
  - contains goals and timetables designed to increase level of participation by women and minorities to attain parity levels in a company's workforce
  - not directly concerned with increasing company success or increasing profits
- Managing diversity
  - process of creating a work environment in which all employees can contribute to their full potential in order to achieve a company's goals
  - voluntary in nature, not mandated
  - seeks to improve internal communications and interpersonal relationships, resolve conflict, and increase product quality, productivity, and efficiency

# Diversity Management Programs

- Education
- Awareness
- Communication
- Fairness
- Commitment

# Global Diversity Issues

- Cultural, language, geography
  - significant barriers to managing a globally diverse workforce
- E-mails, faxes, Internet, phones, air travel
  - make managing a global workforce possible but not necessarily effective
- How to deal with diversity?
  - identify critical cultural elements
  - learn informal rules of communication
  - use a third party who is better able to bridge cultural gap
  - become culturally aware and learn foreign language
  - teach employees cultural norm of organization

# Attributes of Good Job Design

- An appropriate degree of repetitiveness
- An appropriate degree of attention and mental absorption
- Some employee responsibility for decisions and discretion
- Employee control over their own job
- Goals and achievement feedback
- A perceived contribution to a useful product or service
- Opportunities for personal relationships and friendships
- Some influence over the way work is carried out in groups
- Use of skills

# Factors in Job Design

- Task analysis
  - how tasks fit together to form a job
- Worker analysis
  - determining worker capabilities and responsibilities for a job
- Environment analysis
  - physical characteristics and location of a job
- Ergonomics
  - fitting task to person in a work environment
- Technology and automation
  - broadened scope of job design

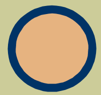
# Elements of Job Design

| Task Analysis | Worker Analysis | Environmental Analysis |
|---|---|---|
| • Description of tasks to be performed | • Capability requirements | • Workplace location |
| • Task sequence | • Performance requirements | • Process location |
| • Function of tasks | • Evaluation | • Temperature and humidity |
| • Frequency of tasks | • Skill level | • Lighting |
| • Criticality of tasks | • Job training | • Ventilation |
| • Relationship with other jobs/tasks | • Physical requirements | • Safety |
| • Performance requirements | • Mental stress | • Logistics |
| • Information requirements | • Boredom | • Space requirements |
| • Control requirements | • Motivation | • Noise |
| • Error possibilities | • Number of workers | • Vibration |
| • Task duration(s) | • Level of responsibility | |
| • Equipment requirements | • Monitoring level | |
| | • Quality responsibility | |
| | • Empowerment level | |

# Job Analysis

- Method Analysis (work methods)
  - Study methods used in the work included in the job to see how it should be done
  - Primary tools are a variety of charts that illustrate in different ways how a job or work process is done

# Process Flowchart Symbols

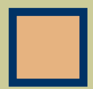


***Operation:***

An activity directly contributing to product or service

***Transportation:***

Moving the product or service from one location to another

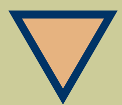


***Inspection:***

Examining the product or service for completeness, irregularities, or quality

***Delay:***

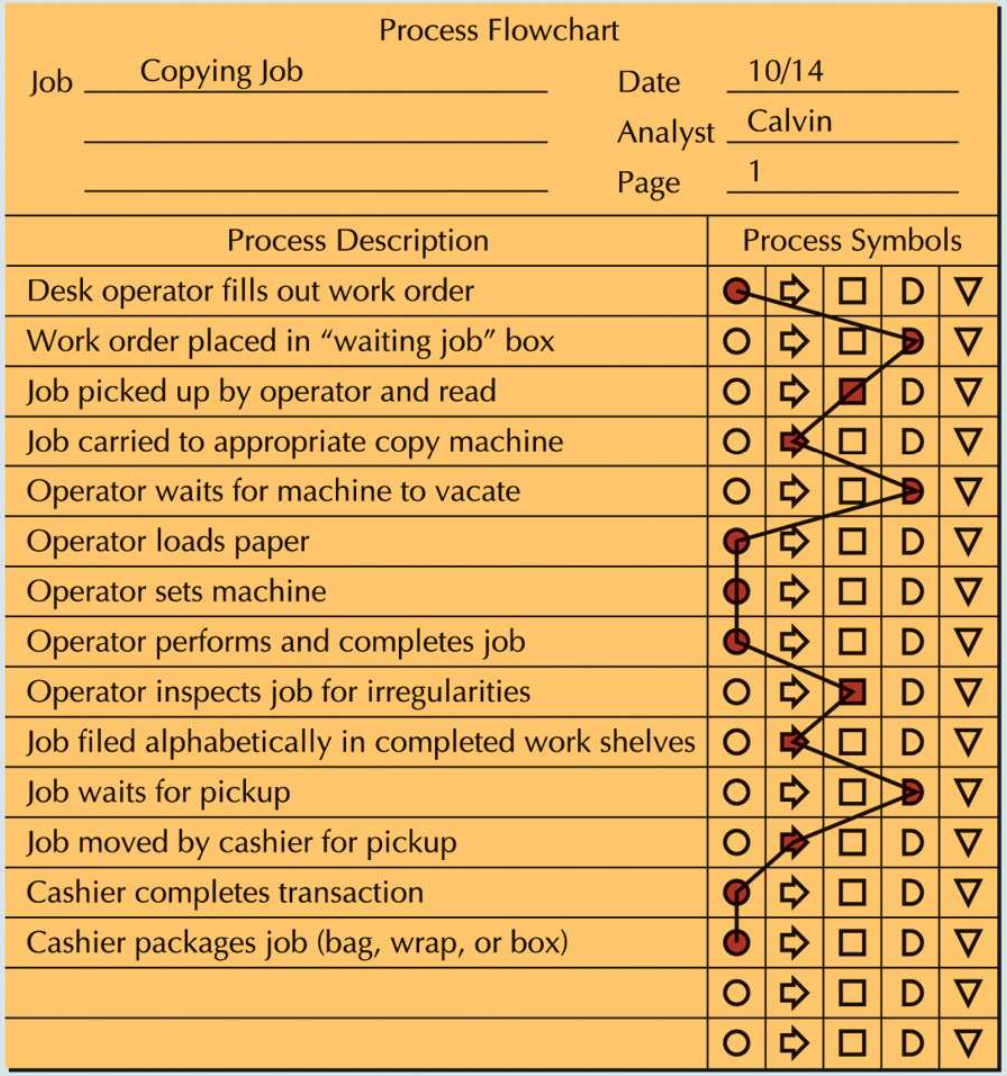
Process having to wait



***Storage:***

Store of the product or service

# Process Flowchart



# Worker-Machine Chart

| Job Photo-Id Cards | | | Date 10/14 |
|---|---|---|---|
| **Time (min)** | **Operator** | **Time (min)** | **Photo Machine** |
| – 1 – 2 | *Key in customer data on card* | *2.6* | *Idle* |
| | *Feed data card in* | *0.4* | *Accept card* |
| – 3 | *Position customer for photo* | *1.0* | *Idle* |
| | *Take picture* | *0.6* | *Begin photo process* |
| – 4 – 5 – 6 | *Idle* | *3.4* | *Photo/card processed* |
| – 7 | *Inspect card & trim edges* | *1.2* | *Idle* |
| – 8 | | | |

– 9

# Worker-Machine Chart: Summary

| Summary | | | | |
|---|---|---|---|---|
| | Operator Time | % | Photo Machine Time | % |
| Work | *5.8* | *63* | *4.8* | *52* |
| Idle | *3.4* | *37* | *4.4* | *48* |
| Total | *9.2 min* | *100%* | *9.2 Min* | *100%* |

# Motion Study

- Used to ensure efficiency of motion in a job
- Frank & Lillian Gilbreth
- Find one “best way” to do task
- Use videotape to study motions

# General Guidelines for Motion Study

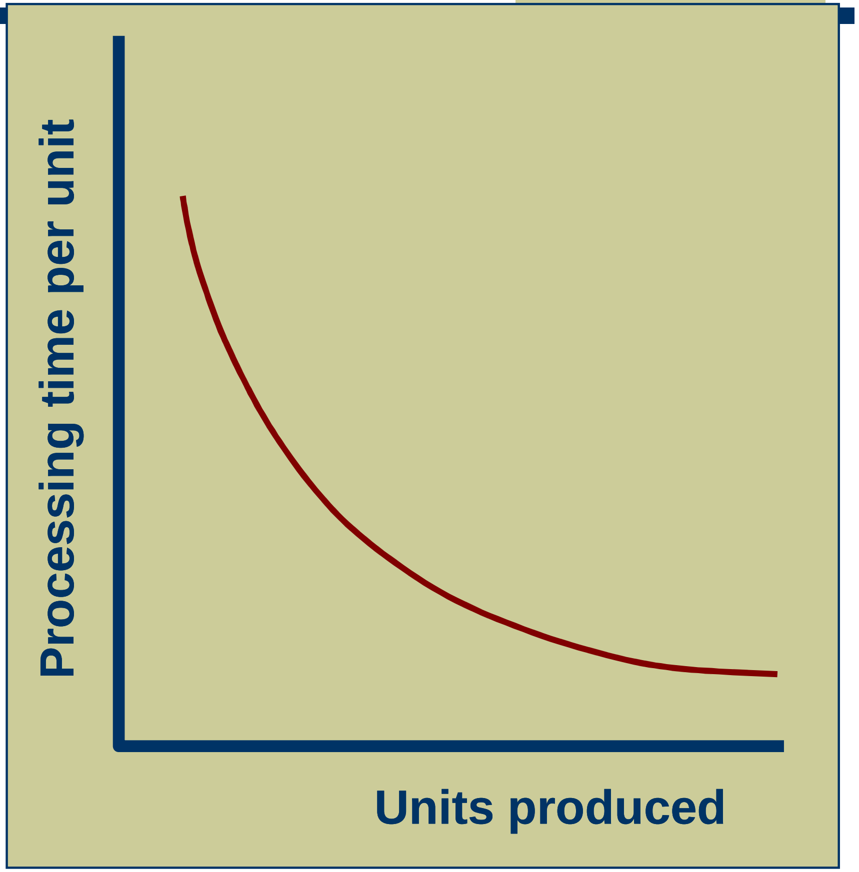
- Efficient Use Of Human Body
  - Work
    - simplified, rhythmic and symmetric
  - Hand/arm motions
    - coordinated and simultaneous
  - Employ full extent of physical capabilities
  - Conserve energy
    - use machines, minimize distances, use momentum
  - Tasks
    - simple, minimal eye contact and muscular effort, no unnecessary motions, delays or idleness

# General Guidelines for Motion Study

- Efficient Arrangement of Workplace
  - Tools, material, equipment - designated, easily accessible location
  - Comfortable and healthy seating and work area
- Efficient Use of Equipment
  - Equipment and mechanized tools enhance worker abilities
  - Use foot-operated equipment to relieve hand/arm stress
  - Construct and arrange equipment to fit worker use

# Learning Curves

- Illustrates improvement rate of workers as a job is repeated
- Processing time per unit decreases by a constant percentage each time output doubles



# Learning Curves (cont.)

Time required for the $n^{th}$ unit =

$$t_n = t_1 n^b$$

where:

$t_n$ = time required for $n^{th}$ unit produced
$t_1$ = time required for first unit produced
$n$ = cumulative number of units produced
$b = \frac{\ln r}{\ln 2}$ where $r$ is the learning curve percentage (decimal coefficient)

# Learning Curve Effect

**Contract to produce 36 computers.**

**$t_1$ = 18 hours, learning rate = 80%**

**What is time for 9th, 18th, 36th units?**

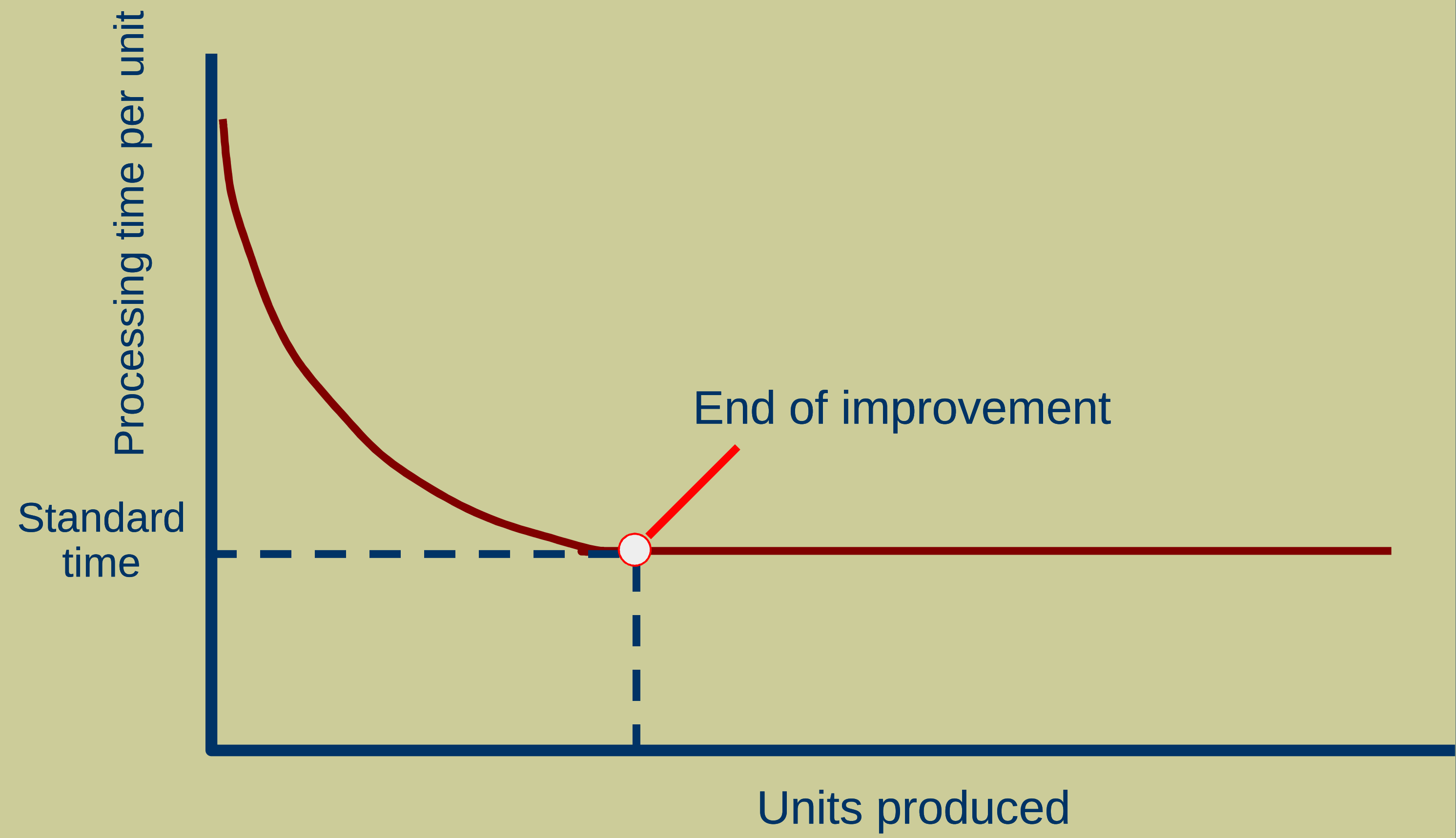
$$t_9 = (18)(9)^{\ln(0.8)/\ln 2} = (18)(9)^{-0.322}$$

$$= (18)/(9)^{0.322} = (18)(0.493) = 8.874\text{hrs}$$

$$t_{18} = (18)(18)^{\ln(0.8)/\ln 2} = (18)(0.394) = 7.092\text{hrs}$$

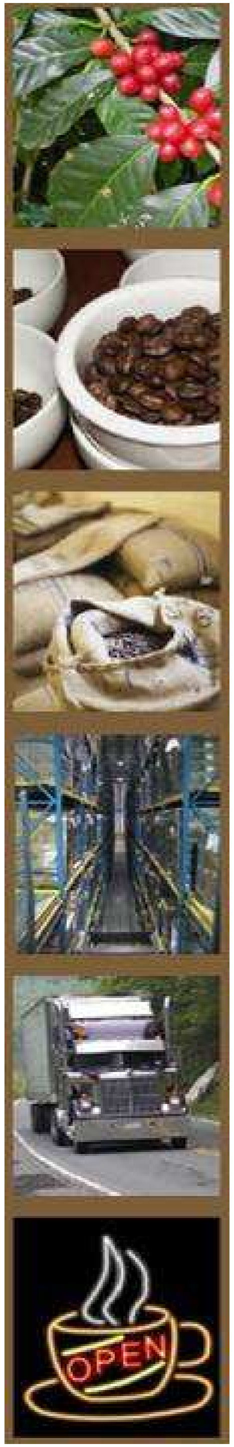
$$t_{36} = (18)(36)^{\ln(0.8)/\ln 2} = (18)(0.315) = 5.674\text{hrs}$$

# Learning Curve for Mass Production Job



# Learning Curves (cont.)

- Advantages
  - planning labor
  - planning budget
  - determining scheduling requirements
- Limitations
  - product modifications negate learning curve effect
  - improvement can derive from sources besides learning
  - industry-derived learning curve rates may be inappropriate



# Chapter 8 Supplement

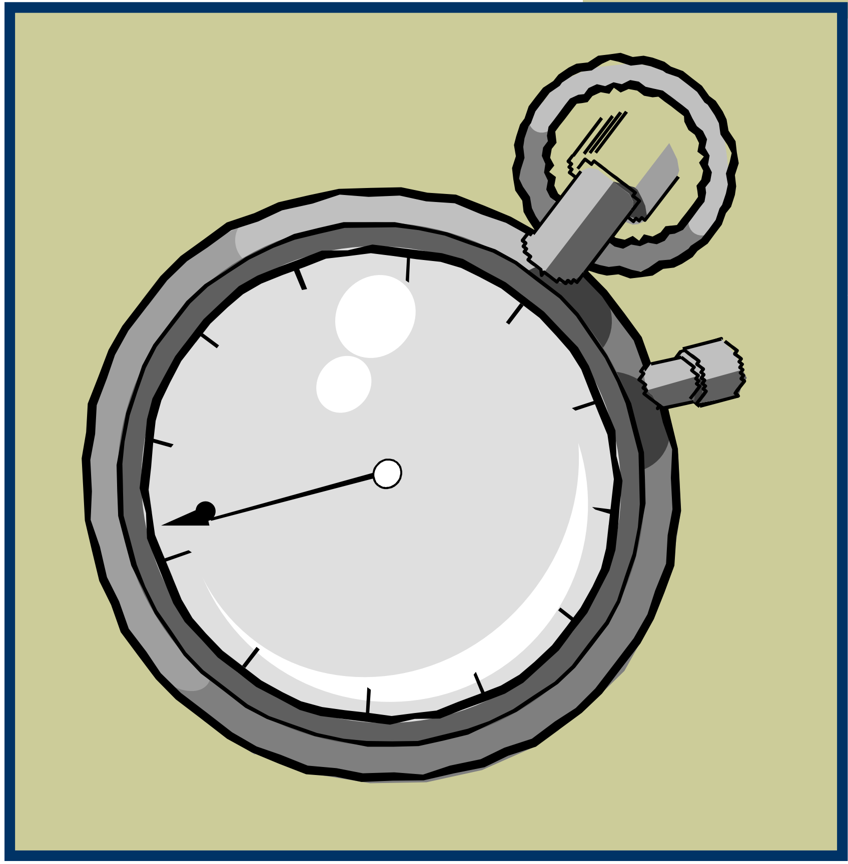
## *Work Measurement*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Time Studies
- Work Sampling



# Work Measurement

- Determining how long it takes to do a job
- Growing importance in service sector
  - Services tend to be labor-intensive
  - Service jobs are often repetitive
- Time studies
  - Standard time
    - is time required by an average worker to perform a job once
  - Incentive piece-rate wage system based on time study

# Stopwatch Time Study Basic Steps

1. Establish standard job method
2. Break down job into elements
3. Study job
4. Rate worker’s performance (RF)
5. Compute average time (t)

# Stopwatch Time Study Basic Steps (cont.)

6. Compute normal time

Normal Time = (Elemental average) x (rating factor)

$$Nt = (\bar{t})(RF)$$

Normal Cycle Time = NT = $\Sigma Nt$

7. Compute standard time

Standard Time = (normal cycle time) x (1 + allowance factor)

$$ST = (NT)(1 + AF)$$

# Performing a Time Study

| Time Study Observation Sheet | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Identification of operation | | | *Sandwich Assembly* | | | | | | | | | | | Date 5/17 | | |
| | | | Operator *Smith* | | | | Approval *Jones* | | | | | | | Observer *Russell* | | |
| | | | Cycles | | | | | | | | | | | Summary | | |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Σ t | $\bar{t}$ | RF | Nt |
| 1 | *Grasp and lay out bread slices* | t | *.04* | *.05* | *.05* | *.04* | *.06* | *.05* | *.06* | *.06* | *.07* | *.05* | *.53* | *.053* | *1.05* | *.056* |
| | | R | *.04* | *.38* | *.72* | *1.05* | *1.40* | *1.76* | *2.13* | *2.50* | *2.89* | *3.29* | | | | |
| 2 | *Spread mayonnaise on both slices* | t | *.07* | *.06* | *.07* | *.08* | *.07* | *.07* | *.08* | *.10* | *.09* | *.08* | *.77* | *.077* | *1.00* | *.077* |
| | | R | *.11* | *.44* | *.79* | *1.13* | *1.47* | *1.83* | *2.21* | *2.60* | *2.98* | *3.37* | | | | |
| 3 | *Place ham, cheese, and lettuce on bread* | t | *.12* | *.11* | *.14* | *.12* | *.13* | *.13* | *.13* | *.12* | *.14* | *.14* | *1.28* | *1.28* | *1.10* | *.141* |
| | | R | *.23* | *.55* | *.93* | *1.25* | *1.60* | *1.96* | *2.34* | *2.72* | *3.12* | *3.51* | | | | |
| 4 | *Place top on sandwich, Slice, and stack* | t | *.10* | *.12* | *.08* | *.09* | *.11* | *.11* | *.10* | *.10* | *.12* | *.10* | *1.03* | *1.03* | *1.10* | *.113* |
| | | R | *.33* | *.67* | *1.01* | *1.34* | *1.71* | *2.07* | *2.44* | *2.82* | *3.24* | *3.61* | | | | |

# Performing a Time Study (cont.)

$$\text{Average element time} = \bar{t} = \frac{\Sigma t}{10} = \frac{0.53}{10} = 0.053$$

Normal time = (Elemental average)(rating factor)

$$Nt = (\bar{t})(RF) = (0.053)(1.05) = 0.056$$

$$\text{Normal Cycle Time} = NT = \Sigma Nt = 0.387$$

$$ST = (NT)(1 + AF) = (0.387)(1+0.15) = 0.445 \text{ min}$$

# Performing a Time Study (cont.)

***How many sandwiches can be made in 2 hours?***

$$\frac{120 \text{ min}}{0.445 \text{ min/sandwich}} = 269.7 \text{ or } 270 \text{ sandwiches}$$

Example 17.3

# Number of Cycles

To determine sample size:

$$n = \left( \frac{zs}{e\bar{T}} \right)^2$$

where

$z =$ number of standard deviations from the mean in a normal distribution reflecting a level of statistical confidence

$$s = \sqrt{\frac{\Sigma(x_i - \bar{x})^2}{n - 1}}$$ = sample standard deviation from sample time study

$\bar{T} =$ average job cycle time from the sample time study

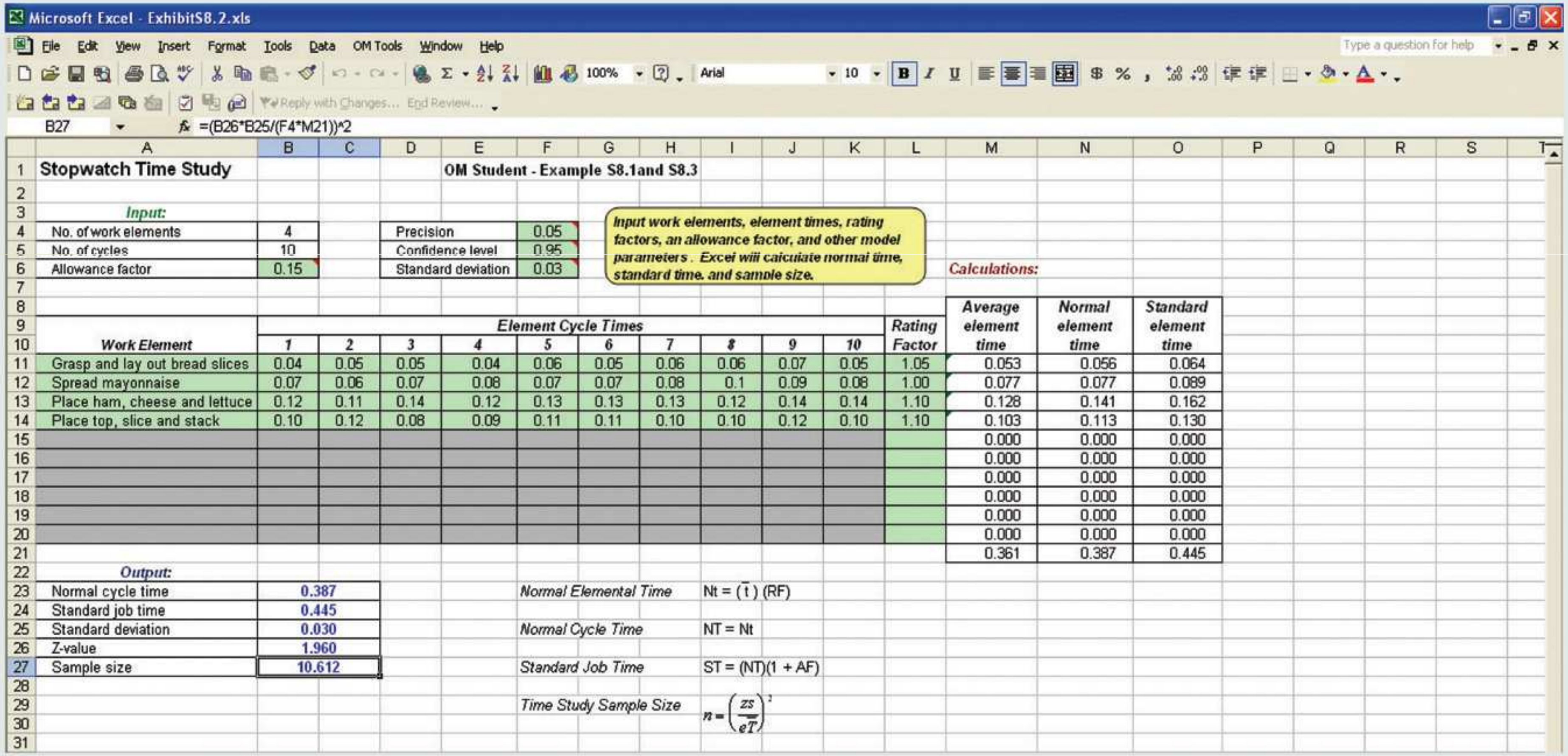
$e =$ degree of error from true mean of distribution

# Number of Cycles: Example

- Average cycle time = 0.361
- Computed standard deviation = 0.03
- Company wants to be 95% confident that computed time is within 5% of true average time

$$n = \left(\frac{zs}{e\bar{T}}\right)^2 = \left(\frac{(1.96)(0.03)}{(0.05)(0.361)}\right)^2 = 10.61 \text{ or } 11$$

# Number of Cycles: Example (cont.)



Microsoft Excel - ExhibitS8.2.xls

B27 =(B26*B25/(F4*M21))^2

**Stopwatch Time Study** OM Student - Example S8.1and S8.3

*Input:*

| | |
|---|---|
| No. of work elements | 4 |
| No. of cycles | 10 |
| Allowance factor | 0.15 |

| | |
|---|---|
| Precision | 0.05 |
| Confidence level | 0.95 |
| Standard deviation | 0.03 |

*Input work elements, element times, rating factors, an allowance factor, and other model parameters. Excel will calculate normal time, standard time, and sample size.*

*Calculations:*

| Work Element | Element Cycle Times 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Rating Factor | Average element time | Normal element time | Standard element time |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Grasp and lay out bread slices | 0.04 | 0.05 | 0.05 | 0.04 | 0.06 | 0.05 | 0.06 | 0.06 | 0.07 | 0.05 | 1.05 | 0.053 | 0.056 | 0.064 |
| Spread mayonnaise | 0.07 | 0.06 | 0.07 | 0.08 | 0.07 | 0.07 | 0.08 | 0.1 | 0.09 | 0.08 | 1.00 | 0.077 | 0.077 | 0.089 |
| Place ham, cheese and lettuce | 0.12 | 0.11 | 0.14 | 0.12 | 0.13 | 0.13 | 0.13 | 0.12 | 0.14 | 0.14 | 1.10 | 0.128 | 0.141 | 0.162 |
| Place top, slice and stack | 0.10 | 0.12 | 0.08 | 0.09 | 0.11 | 0.11 | 0.10 | 0.10 | 0.12 | 0.10 | 1.10 | 0.103 | 0.113 | 0.130 |
| | | | | | | | | | | | | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | | 0.000 | 0.000 | 0.000 |
| | | | | | | | | | | | | 0.361 | 0.387 | 0.445 |

*Output:*

| | |
|---|---|
| Normal cycle time | 0.387 |
| Standard job time | 0.445 |
| Standard deviation | 0.030 |
| Z-value | 1.960 |
| Sample size | 10.612 |

| | |
|---|---|
| *Normal Elemental Time* | $Nt = (\bar{t})(RF)$ |
| *Normal Cycle Time* | $NT = \sum Nt$ |
| *Standard Job Time* | $ST = (NT)(1 + AF)$ |
| *Time Study Sample Size* | $n = \left(\frac{zs}{e\bar{T}}\right)^2$ |

# Developing Time Standards without a Time Study

- Elemental standard time files
  - predetermined job element times
- Predetermined motion times
  - predetermined times for basic micro-motions
- Time measurement units
  - TMUs = 0.0006 minute
  - 100,000 TMU = 1 hour
- Advantages
  - worker cooperation unnecessary
  - workplace uninterrupted
  - performance ratings unnecessary
  - consistent
- Disadvantages
  - ignores job context
  - may not reflect skills and abilities of local workers

# MTM Table for MOVE

TIME (TMU) WEIGHT ALLOWANCE

| DISTANCE MOVED (INCHES) | A | B | C | *Hand in motion B* | *Weight (lb) up to:* | *Dynamic factor* | *Static constant TMU* |
|---|---|---|---|---|---|---|---|
| 3/4 or less | 2.0 | 2.0 | 2.0 | | | | |
| 1 | 2.5 | 2.9 | 3.4 | 2.3 | 2.5 | 1.00 | 0 |
| 2 | 3.6 | 4.6 | 5.2 | 2.9 | | | |
| 3 | 4.9 | 5.7 | 6.7 | 3.6 | 7.5 | 1.06 | 2.2 |
| 4 | 6.1 | 6.9 | 8.0 | 4.3 | | | |
| … | | | | | | | |
| 20 | 19.2 | 18.2 | 22.1 | 15.6 | 37.5 | 1.39 | 12.5 |

A. Move object to other hand or against stop

B. Move object to approximate or indefinite location

C. Move object to exact location

Source: MTM Association for Standards and Research.

# Work Sampling

- Determines the proportion of time a worker spends on activities
- Primary uses of work sampling are to determine
  - ratio delay
    - percentage of time a worker or machine is delayed or idle
  - analyze jobs that have non-repetitive tasks
- Cheaper, easier approach to work measurement

# Steps of Work Sampling

1. Define job activities
2. Determine number of observations in work sample

$$n = \left(\frac{z}{e}\right)^2 p(1 - p)$$

where

$n$ = sample size (number of sample observations)

$z$ = number of standard deviations from mean for desired level of confidence

$e$ = degree of allowable error in sample estimate

$p$ = proportion of time spent on a work activity estimated prior to calculating work sample

# Steps of Work Sampling (cont.)

3. Determine length of sampling period
4. Conduct work sampling study; record observations
5. Periodically re-compute number of observations

# Work Sampling: Example

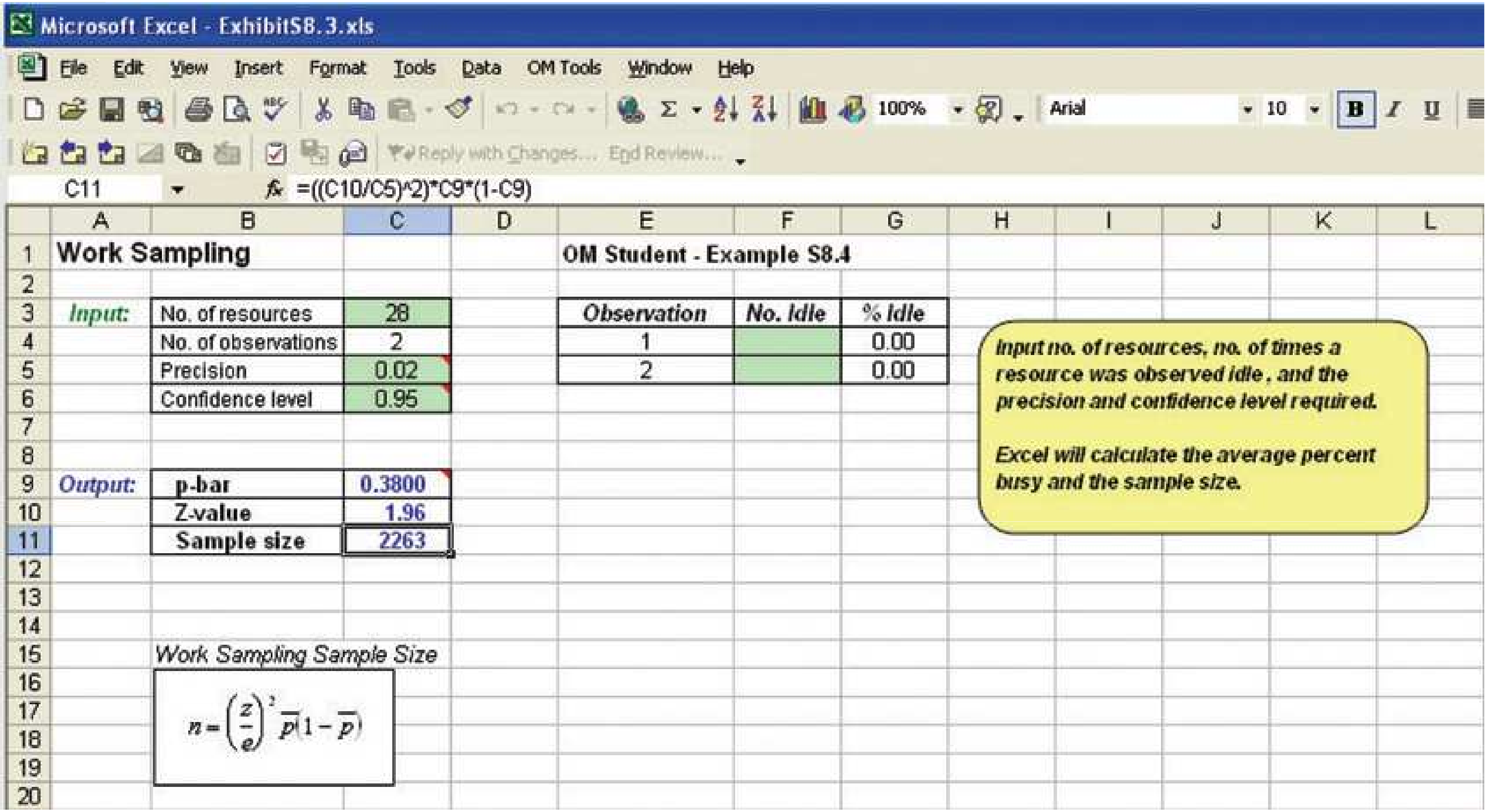
What percent of time is spent looking up information? Current estimate is $p$ = 30%

Estimate within +/- 2%, with 95% confidence

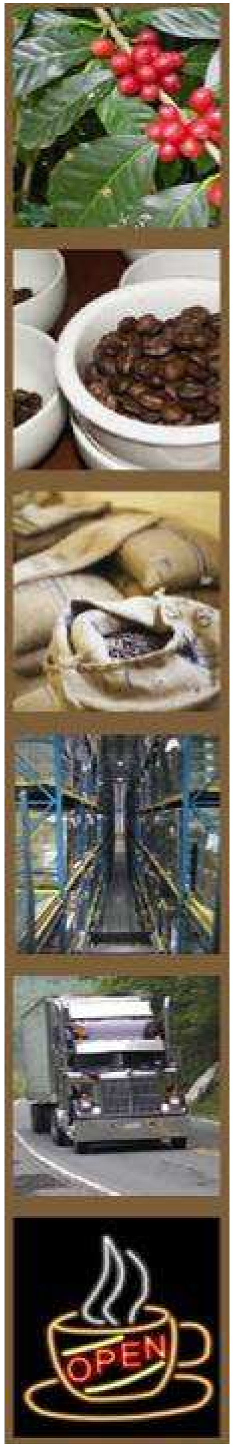
$$n = \left(\frac{z}{e}\right)^2 p(1 - p) = \left(\frac{1.96}{0.02}\right)^2 (0.3)(0.7) = 2016.84 \text{ or } 2017$$

After 280 observations, $p$ = 38%

$$n = \left(\frac{z}{e}\right)^2 p(1 - p) = \left(\frac{1.96}{0.02}\right)^2 (0.38)(0.62) = 2263$$



Microsoft Excel - ExhibitS8.3.xls
File Edit View Insert Format Tools Data OM Tools Window Help
C11
=((C10/C5)^2)*C9*(1-C9)
Work Sampling
OM Student - Example S8.4
Input:
No. of resources 28
No. of observations 2
Precision 0.02
Confidence level 0.95
Observation
No. Idle
% Idle
1 0.00
2 0.00
Input no. of resources, no. of times a resource was observed idle, and the precision and confidence level required.
Excel will calculate the average percent busy and the sample size.
Output:
p-bar 0.3800
Z-value 1.96
Sample size 2263
Work Sampling Sample Size
$n = \left(\frac{z}{e}\right)^2 \bar{p}(1-\bar{p})$



# Chapter 9

## *Project Management*

*Operations Management*

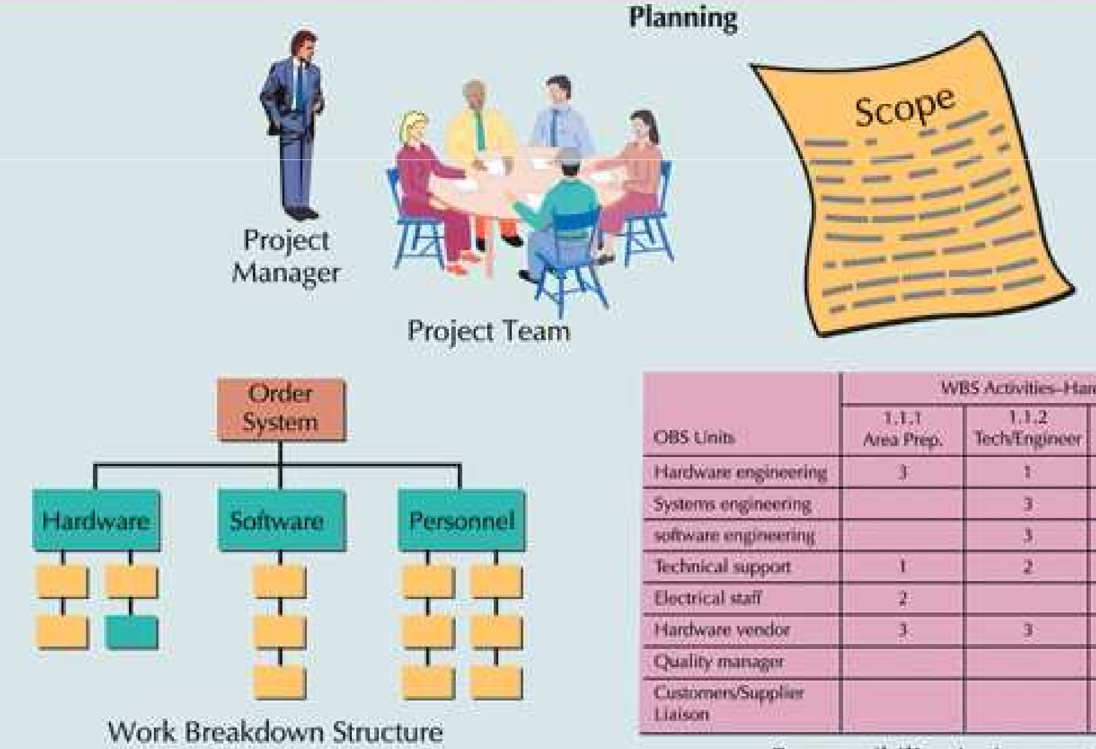
**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Project Planning
- Project Scheduling
- Project Control
- CPM/PERT
- Probabilistic Activity Times
- Microsoft Project
- Project Crashing and Time-Cost Trade-off

# Project Management Process

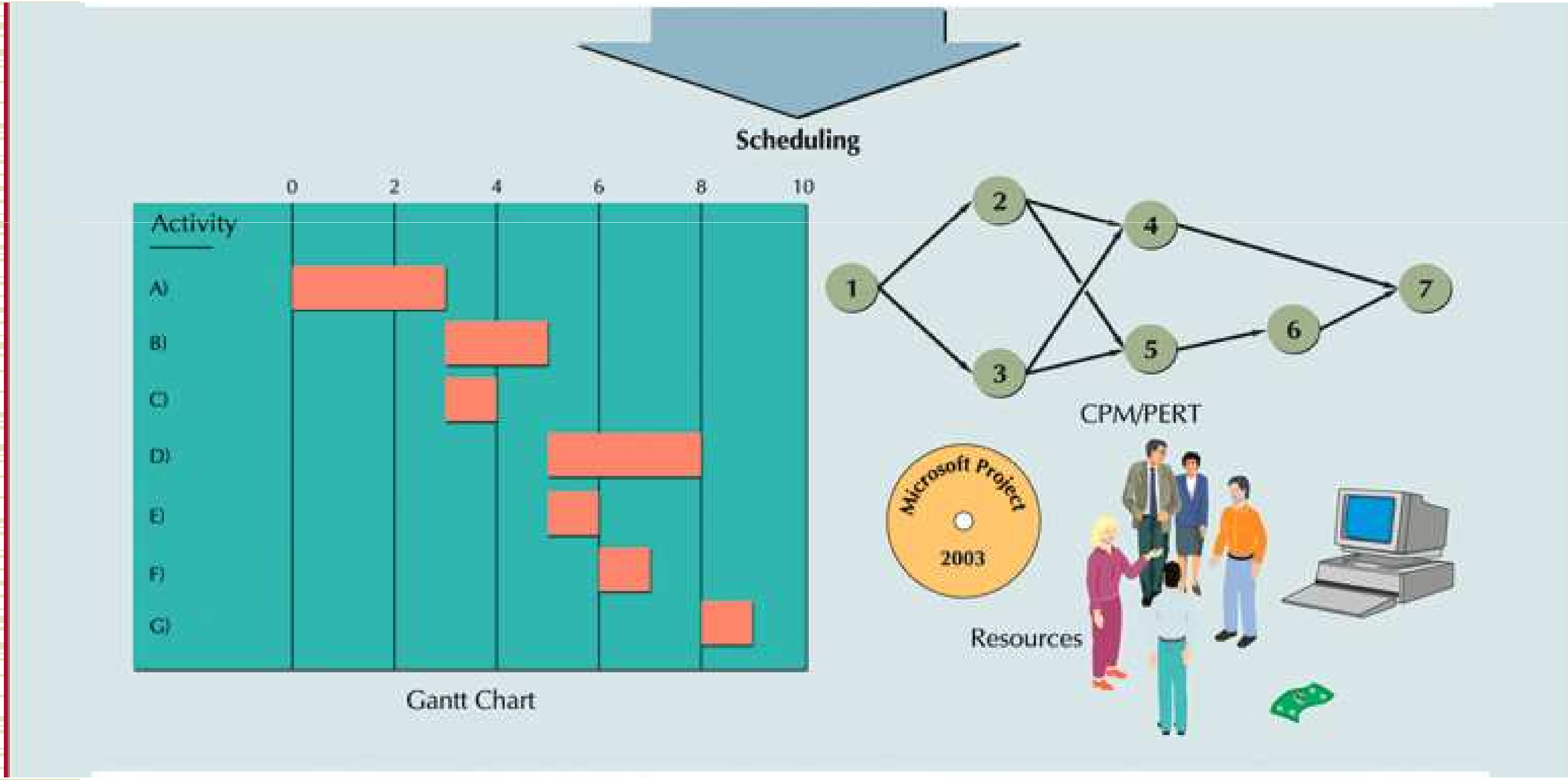
- Project
  - unique, one-time operational activity or effort



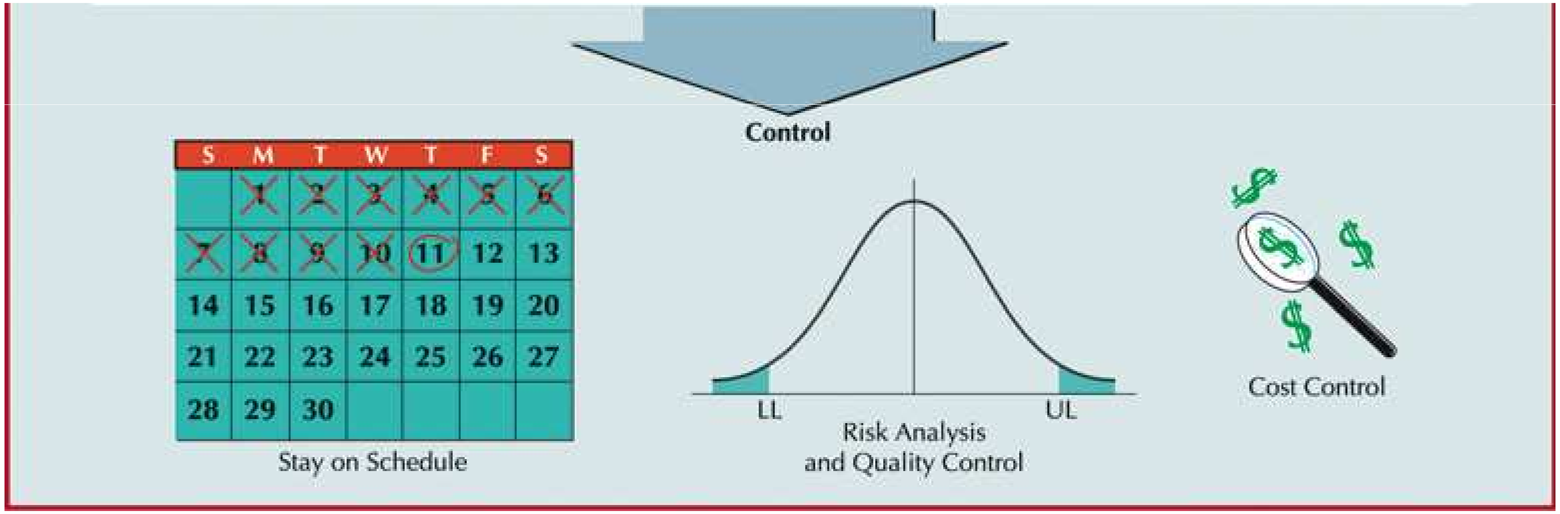

| OBS Units | WBS Activities–Hardware/Installation 1.1.1 Area Prep. | 1.1.2 Tech/Engineer | 1.1.3 Wiring | 1.1.4 Connections |
|---|---|---|---|---|
| Hardware engineering | 3 | 1 | 1 | 1 |
| Systems engineering | | 3 | | 3 |
| software engineering | | 3 | | |
| Technical support | 1 | 2 | | 2 |
| Electrical staff | 2 | | 2 | 2 |
| Hardware vendor | 3 | 3 | 3 | 3 |
| Quality manager | | | | 3 |
| Customers/Supplier Liaison | | | | 3 |

Responsibility Assignment Matrix

# Project Management Process (cont.)



# Project Management Process (cont.)



# Project Elements

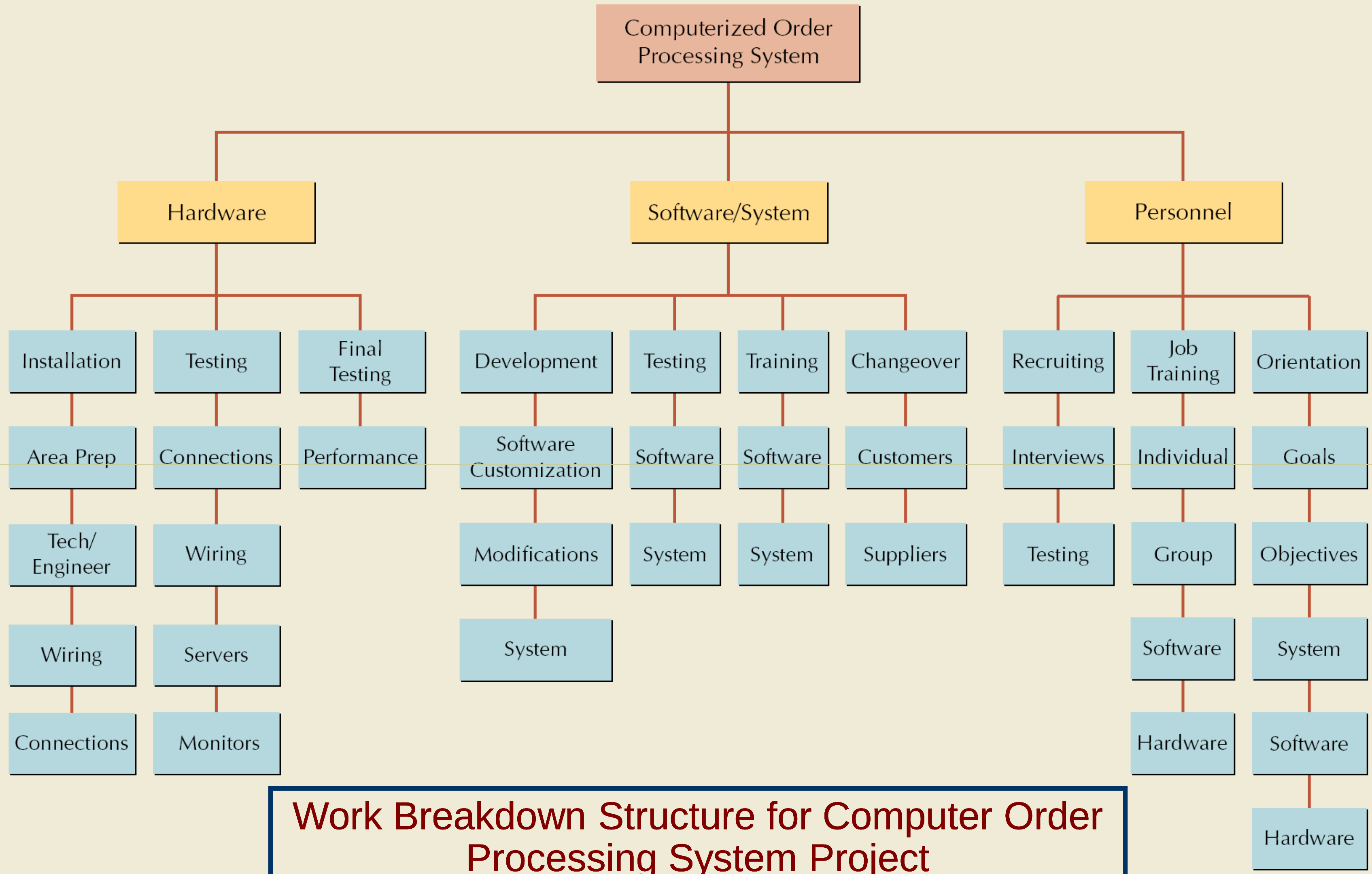
- Objective
- Scope
- Contract requirements
- Schedules
- Resources
- Personnel
- Control
- Risk and problem analysis

# Project Team and Project Manager

- Project team
  - made up of individuals from various areas and departments within a company
- Matrix organization
  - a team structure with members from functional areas, depending on skills required
- Project manager
  - most important member of project team

# Scope Statement and Work Breakdown Structure

- Scope statement
  - a document that provides an understanding, justification, and expected result of a project
- Statement of work
  - written description of objectives of a project
- Work breakdown structure (WBS)
  - breaks down a project into components, subcomponents, activities, and tasks




Work Breakdown Structure for Computer Order Processing System Project

# Responsibility Assignment Matrix

| OBS Units | WBS Activities–Hardware/Installation | | | |
|---|---|---|---|---|
| | 1.1.1 Area Prep | 1.1.2 Tech/Engineer | 1.1.3 Wiring | 1.1.4 Connections |
| Hardware engineering | 3 | 1 | 1 | 1 |
| Systems engineering | | 3 | | 3 |
| Software engineering | | 3 | | |
| Technical support | 1 | 2 | | 2 |
| Electrical staff | 2 | | 2 | 2 |
| Hardware vendor | 3 | 3 | 3 | 3 |
| Quality manager | | | | 3 |
| Customer/supplier liaison | | | | 3 |

Level of responsibility: 1 = overall responsibility
2 = performance responsibility
3 = support

- Organizational Breakdown Structure (OBS)
  - a chart that shows which organizational units are responsible for work items
- Responsibility Assignment Matrix (RAM)
  - shows who is responsible for work in a project

# Global and Diversity Issues in Project Management

- In existing global business environment, project teams are formed from different genders, cultures, ethnicities, etc.
- In global projects diversity among team members can add an extra dimension to project planning
- Cultural research and communication are important elements in planning process

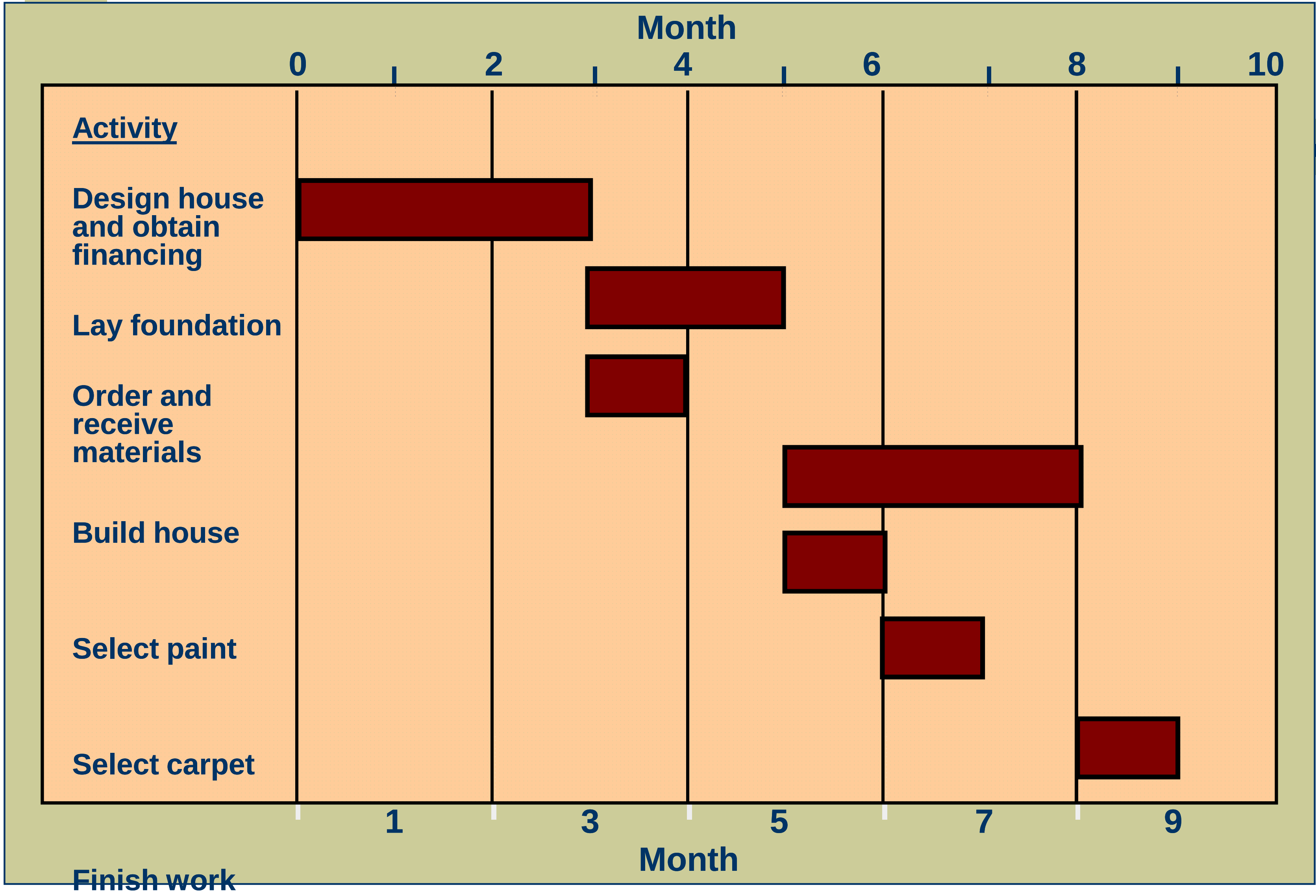
# Project Scheduling

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

# Gantt Chart

- Graph or bar chart with a bar for each project activity that shows passage of time
- Provides visual display of project schedule
- Slack
  - amount of time an activity can be delayed without delaying the project

# Example of Gantt Chart



# Project Control

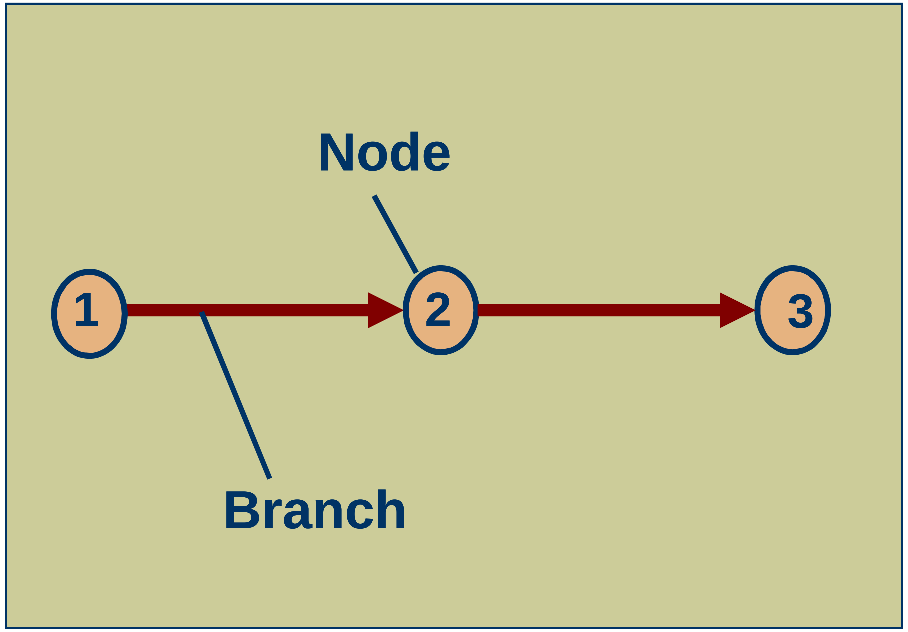
- Time management
- Cost management
- Quality management
- Performance management
  - Earned Value Analysis
    - a standard procedure for numerically measuring a project's progress, forecasting its completion date and cost and measuring schedule and budget variation
- Communication
- Enterprise project management

# CPM/PERT

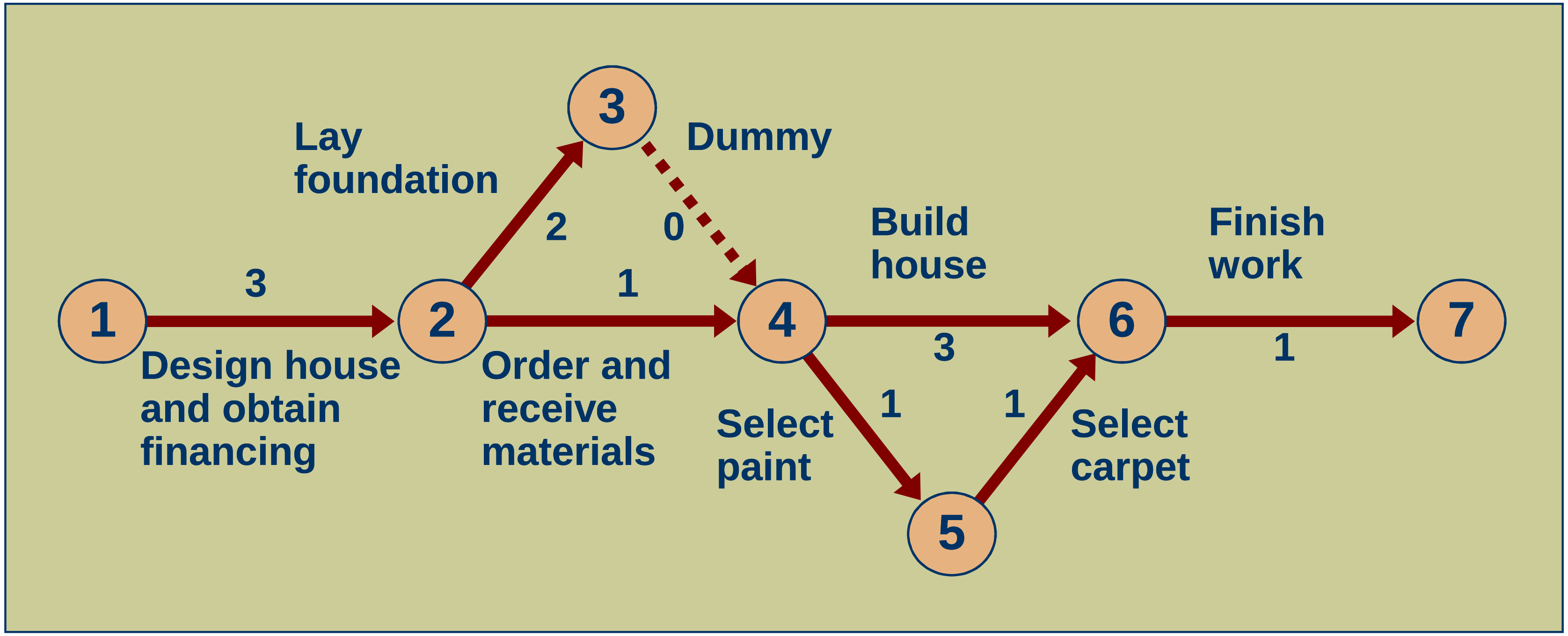
- Critical Path Method (CPM)
  - DuPont & Remington-Rand (1956)
  - Deterministic task times
  - Activity-on-node network construction
- Project Evaluation and Review Technique (PERT)
  - US Navy, Booz, Allen & Hamilton
  - Multiple task time estimates; probabilistic
  - Activity-on-arrow network construction

# Project Network

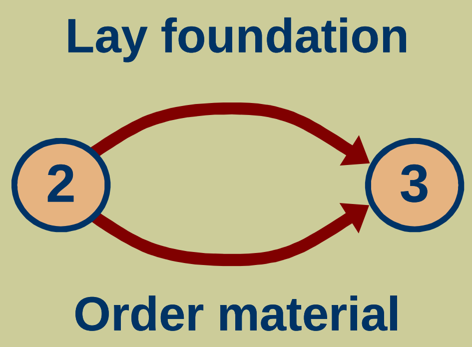
- Activity-on-node (AON)
  - nodes represent activities, and arrows show precedence relationships
- Activity-on-arrow (AOA)
  - arrows represent activities and nodes are events for points in time
- Event
  - completion or beginning of an activity in a project
- Dummy
  - two or more activities cannot share same start and end nodes

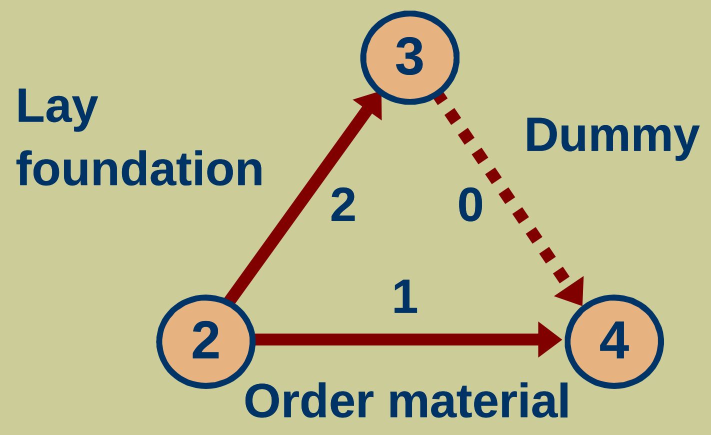


# AOA Project Network for a House



# Concurrent Activities

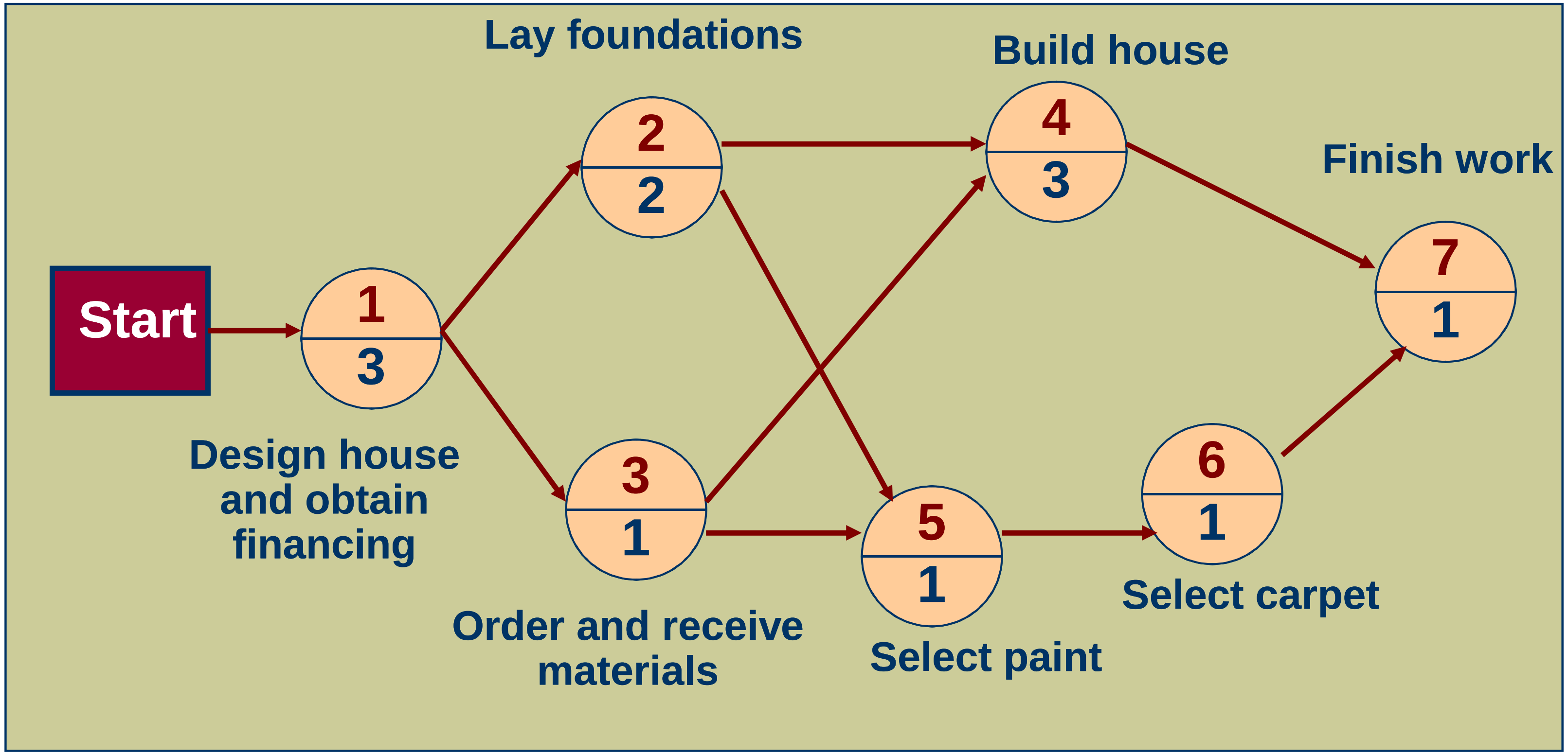


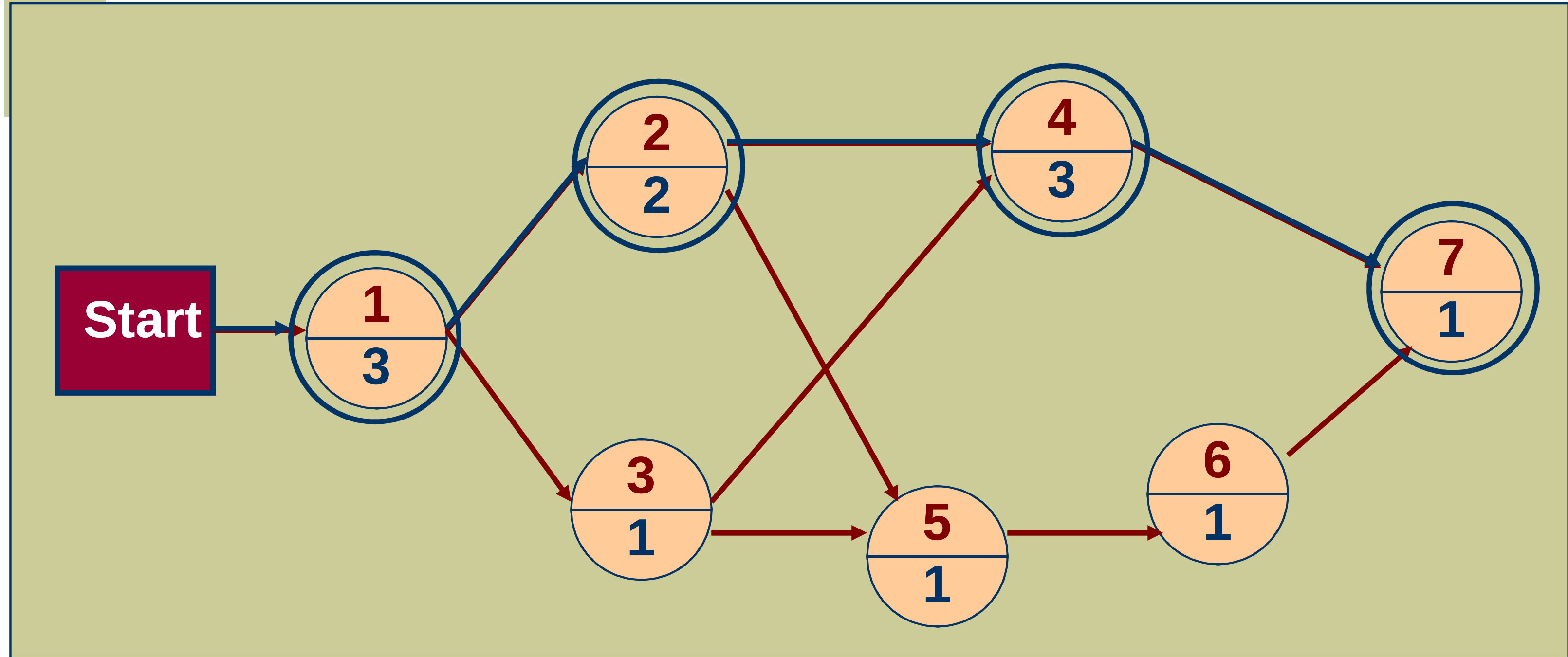

(a) Incorrect precedence relationship

(b) Correct precedence relationship

# AON Network for House Building Project



# Critical Path




A: 1-2-4-7
3 + 2 + 3 + 1 = 9 months

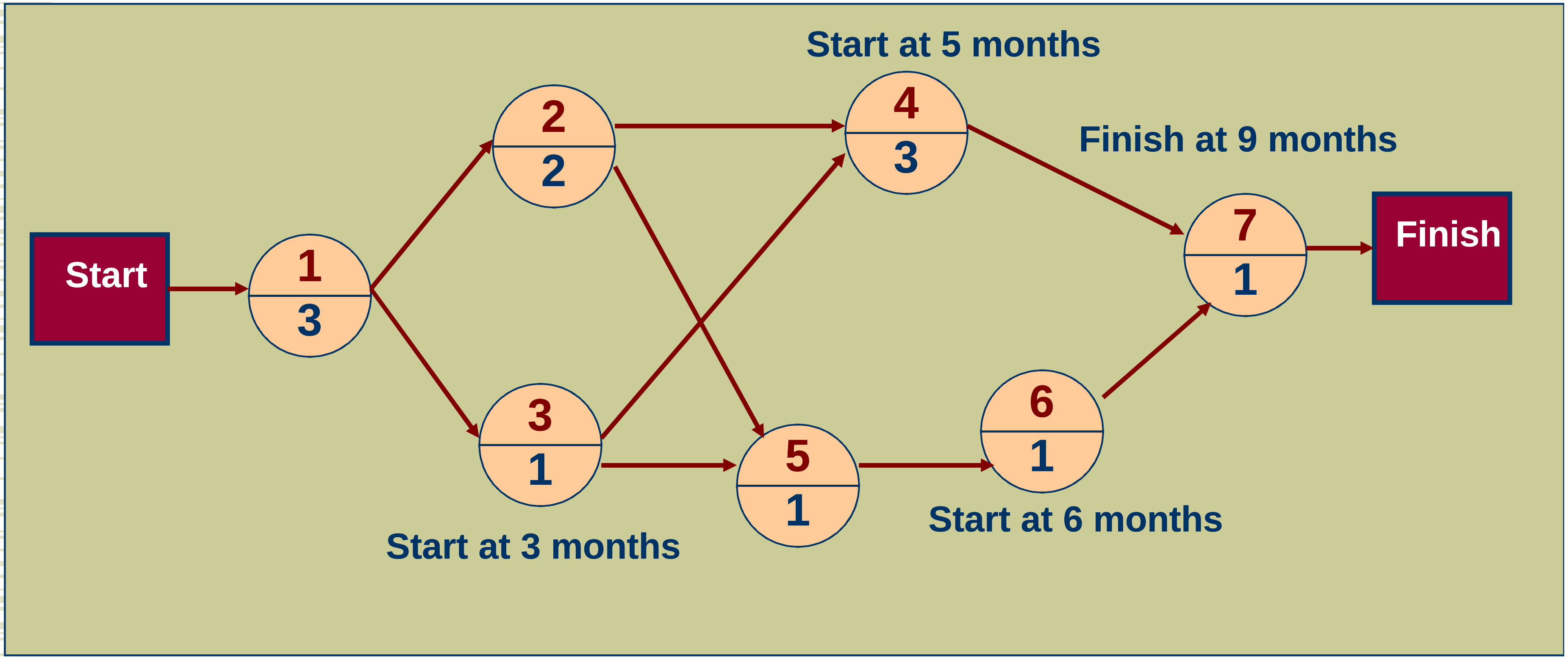
B: 1-2-5-6-7
3 + 2 + 1 + 1 + 1 = 8 months

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

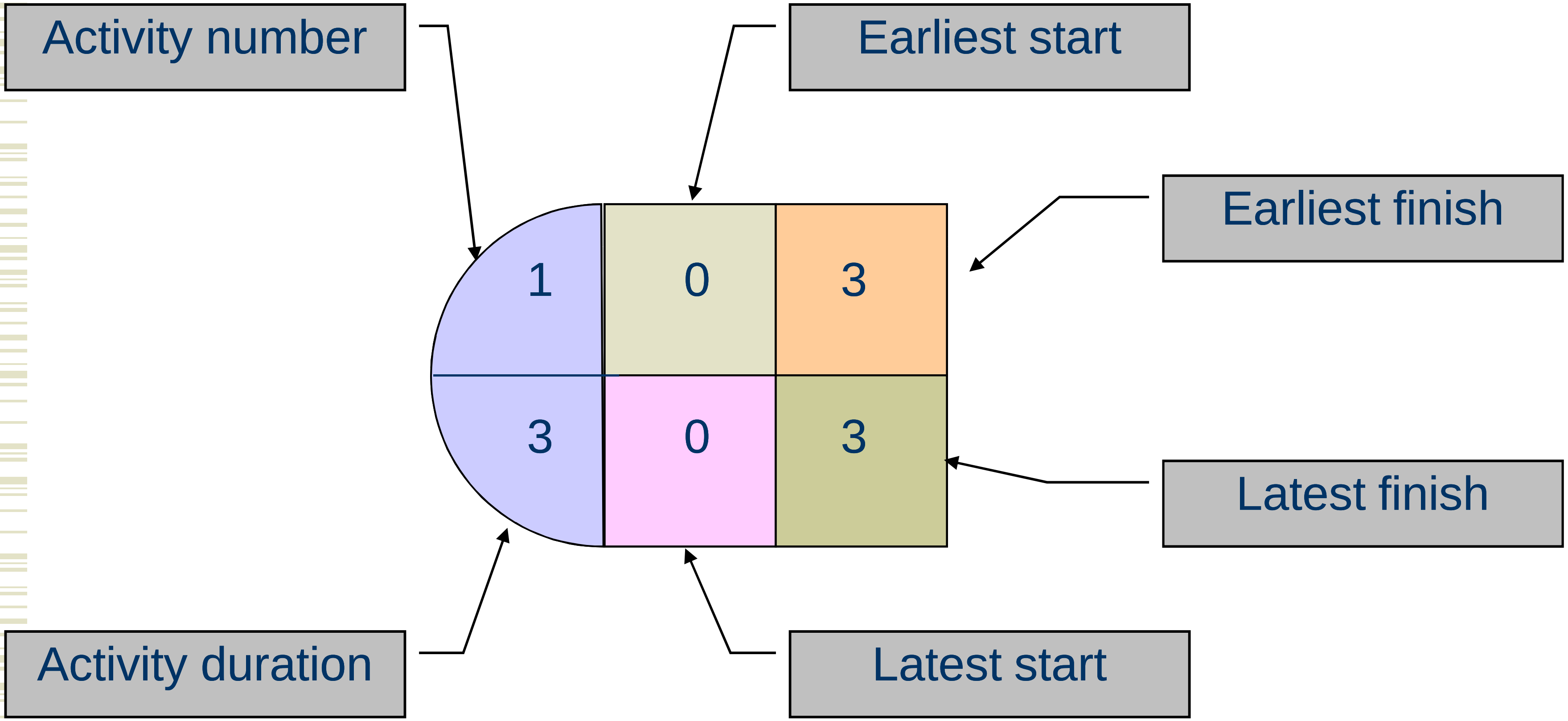
D: 1-3-5-6-7
3 + 1 + 1 + 1 + 1 = 7 months

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

# Activity Start Times



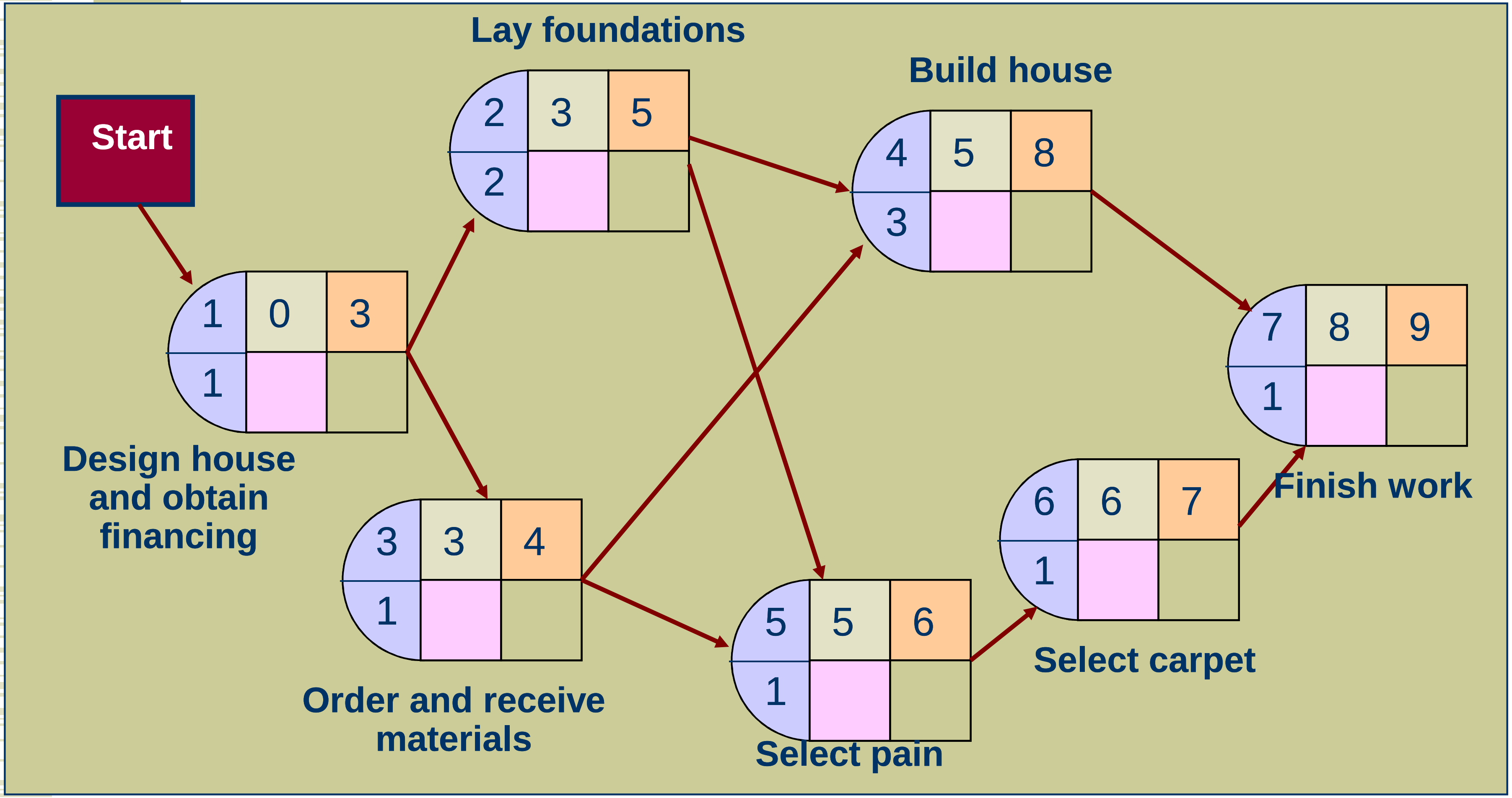
# Node Configuration



# Activity Scheduling

- Earliest start time (ES)
  - earliest time an activity can start
  - ES = maximum EF of immediate predecessors
- Forward pass
  - starts at beginning of CPM/PERT network to determine earliest activity times
- Earliest finish time (EF)
  - earliest time an activity can finish
  - earliest start time plus activity time
  - EF= ES + *t*

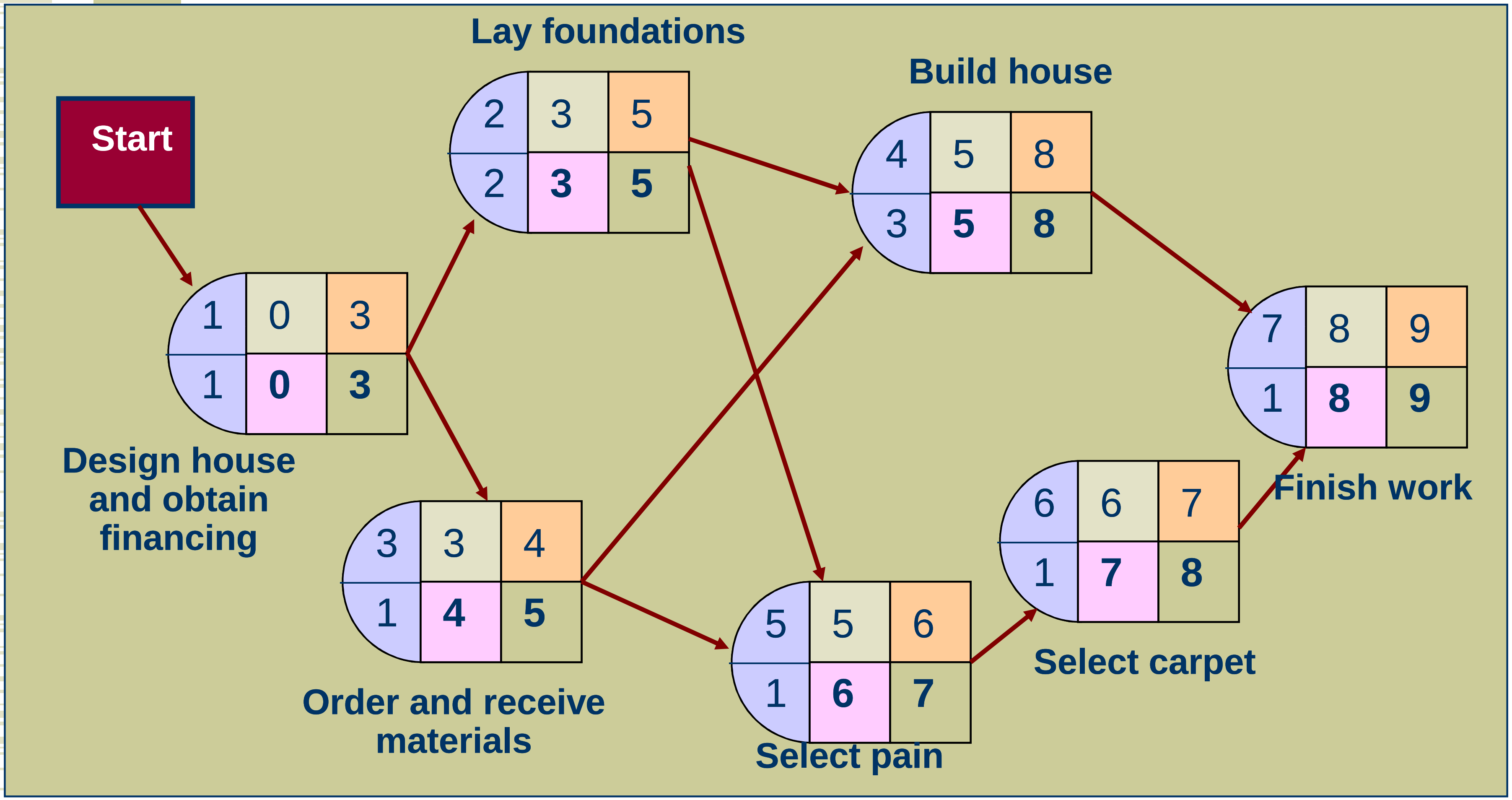
# Earliest Activity Start and Finish Times



# Activity Scheduling (cont.)

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

# 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

# Probabilistic Time Estimates

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

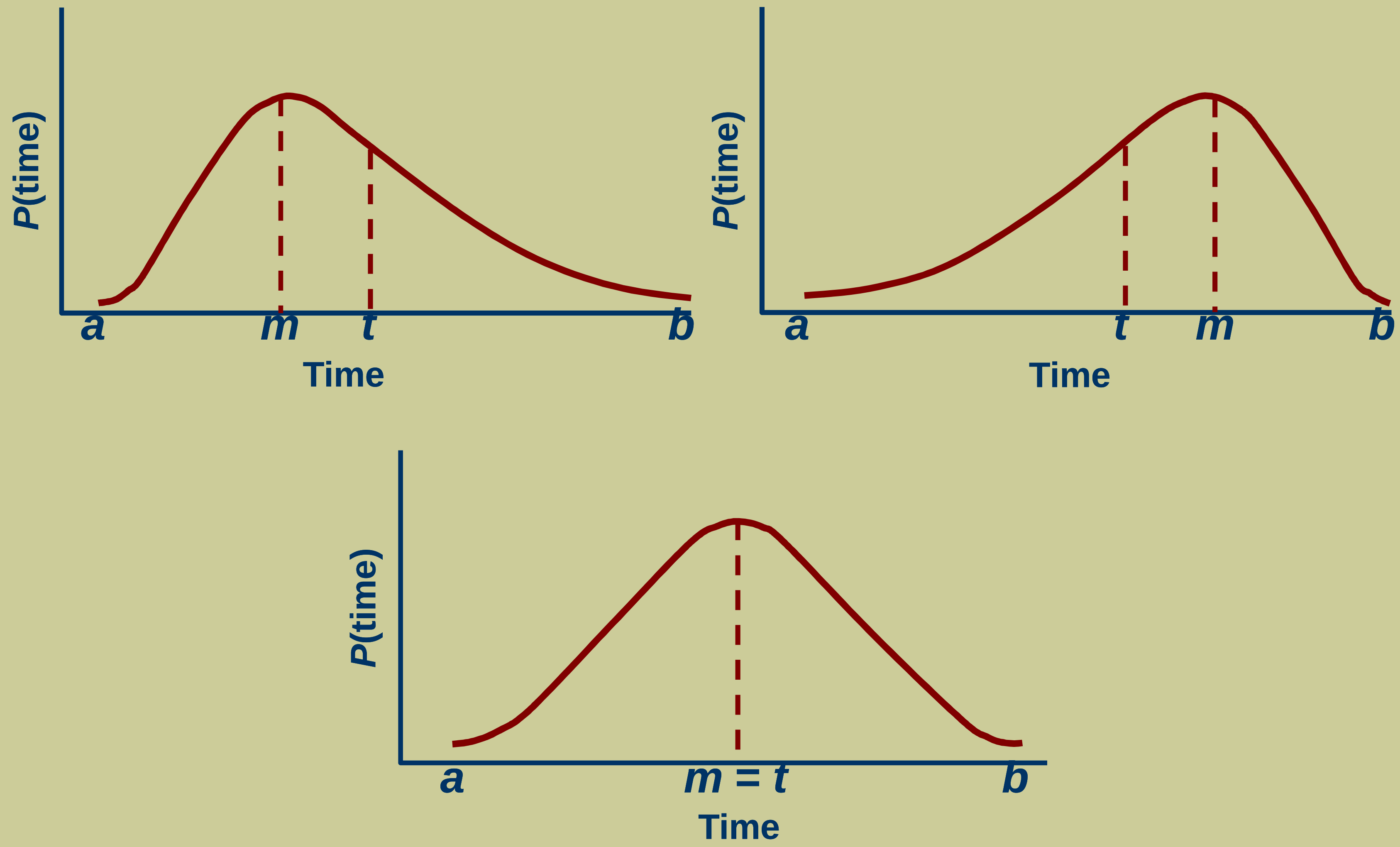
Mean (expected time): $t = \dfrac{a + 4m + b}{6}$

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

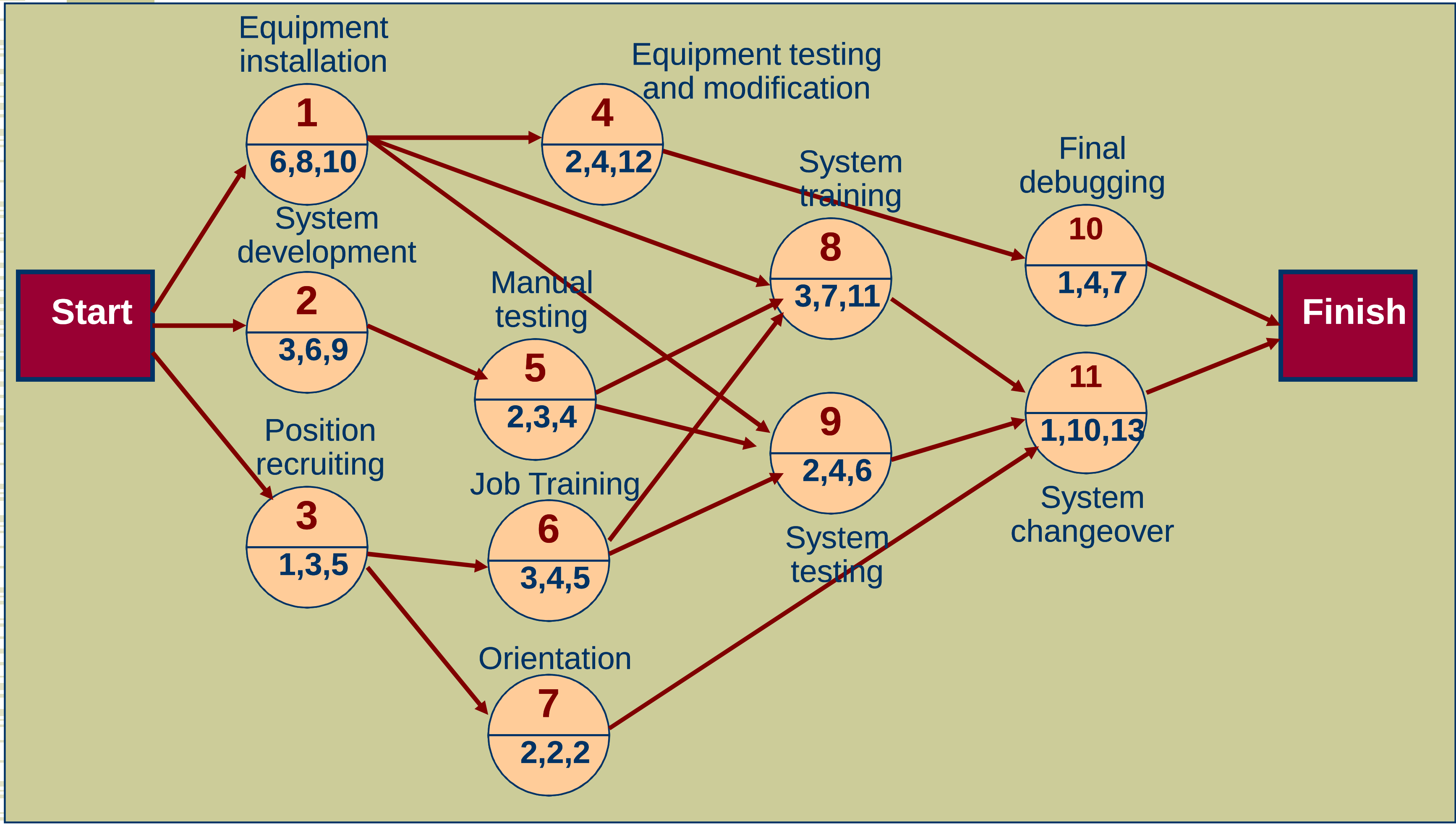
where

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

# Examples of Beta Distributions



# Project Network with Probabilistic Time Estimates: Example



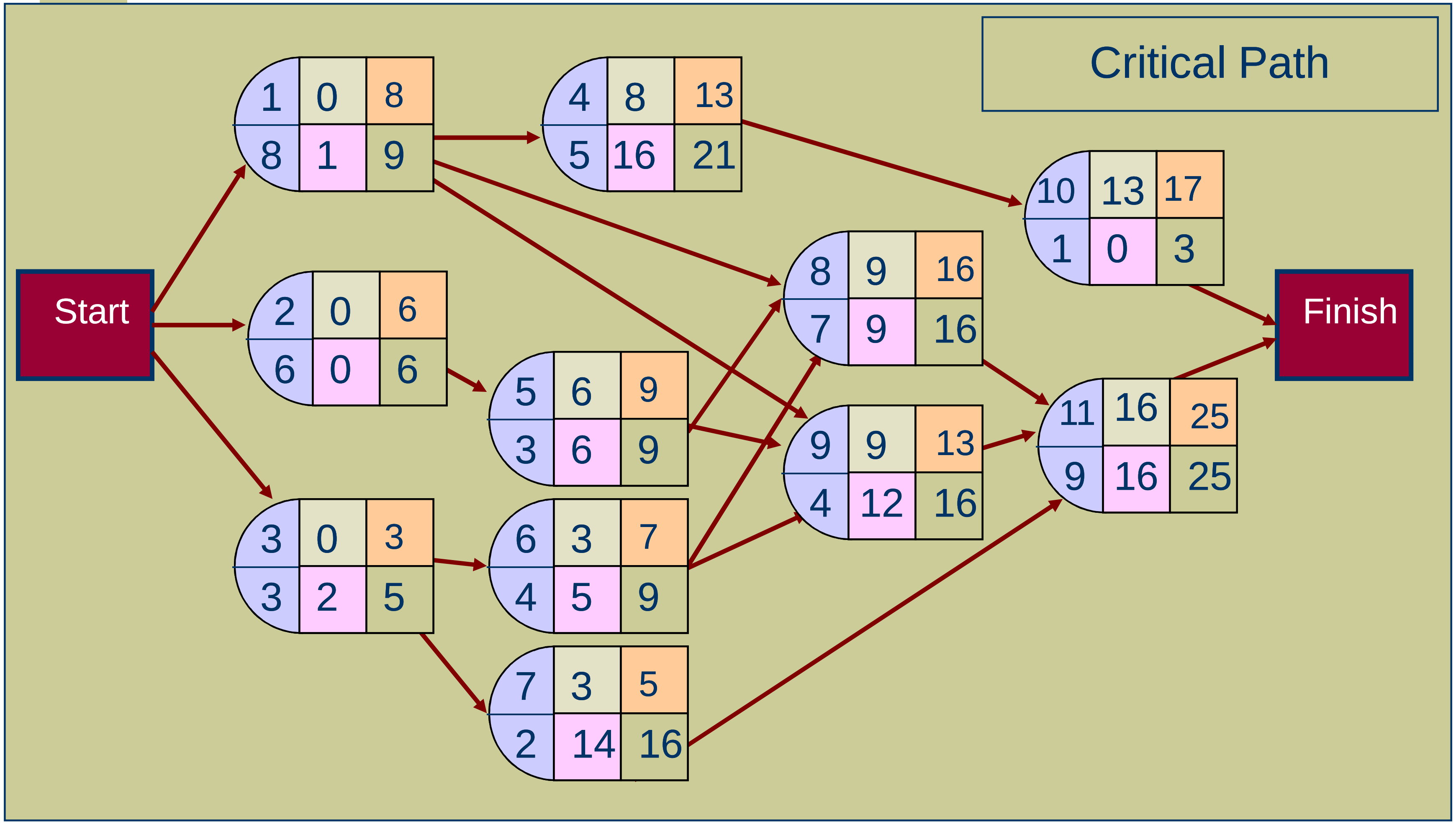
# Activity Time Estimates

| | TIME ESTIMATES (WKS) | | | MEAN TIME | VARIANCE |
|---|---|---|---|---|---|
| ACTIVITY | *a* | *m* | *b* | *t* | $\sigma^2$ |
| 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* | $\sigma^2$ | 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

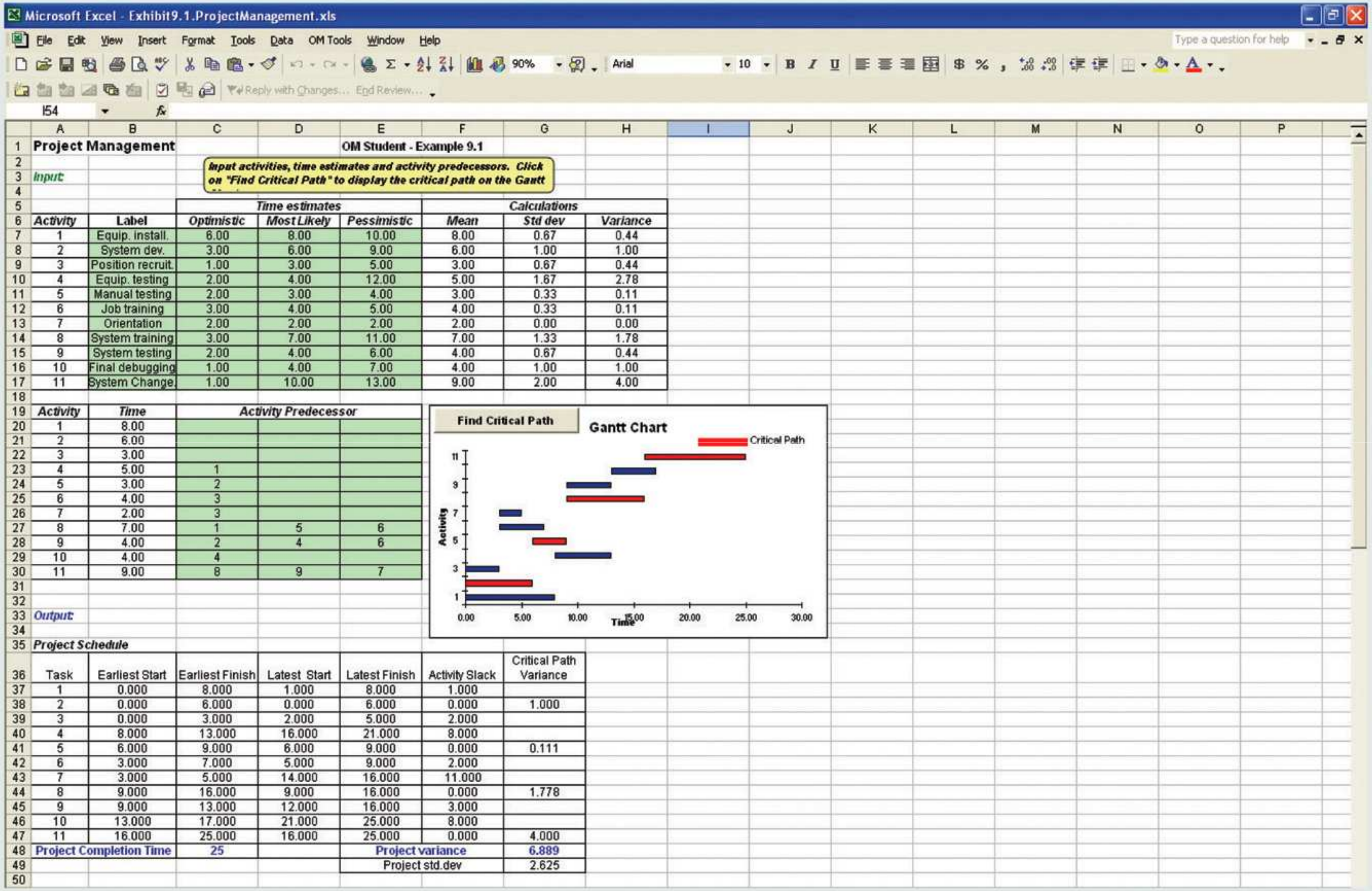


## Total project variance

$\sigma^2 = б_2^{\,2} + б_5^{\,2} + б_8^{\,2} + б_{11}^{\,2}$

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

$= 6.89$ weeks



Microsoft Excel - Exhibit9.1.ProjectManagement.xls

**Project Management** — OM Student - Example 9.1

*Input activities, time estimates and activity predecessors. Click on "Find Critical Path" to display the critical path on the Gantt*

*Input:*

| Activity | Label | Time estimates: Optimistic | Most Likely | Pessimistic | Calculations: Mean | Std dev | Variance |
|---|---|---|---|---|---|---|---|
| 1 | Equip. install. | 6.00 | 8.00 | 10.00 | 8.00 | 0.67 | 0.44 |
| 2 | System dev. | 3.00 | 6.00 | 9.00 | 6.00 | 1.00 | 1.00 |
| 3 | Position recruit. | 1.00 | 3.00 | 5.00 | 3.00 | 0.67 | 0.44 |
| 4 | Equip. testing | 2.00 | 4.00 | 12.00 | 5.00 | 1.67 | 2.78 |
| 5 | Manual testing | 2.00 | 3.00 | 4.00 | 3.00 | 0.33 | 0.11 |
| 6 | Job training | 3.00 | 4.00 | 5.00 | 4.00 | 0.33 | 0.11 |
| 7 | Orientation | 2.00 | 2.00 | 2.00 | 2.00 | 0.00 | 0.00 |
| 8 | System training | 3.00 | 7.00 | 11.00 | 7.00 | 1.33 | 1.78 |
| 9 | System testing | 2.00 | 4.00 | 6.00 | 4.00 | 0.67 | 0.44 |
| 10 | Final debugging | 1.00 | 4.00 | 7.00 | 4.00 | 1.00 | 1.00 |
| 11 | System Change | 1.00 | 10.00 | 13.00 | 9.00 | 2.00 | 4.00 |

| Activity | Time | Activity Predecessor | | |
|---|---|---|---|---|
| 1 | 8.00 | | | |
| 2 | 6.00 | | | |
| 3 | 3.00 | | | |
| 4 | 5.00 | 1 | | |
| 5 | 3.00 | 2 | | |
| 6 | 4.00 | 3 | | |
| 7 | 2.00 | 3 | | |
| 8 | 7.00 | 1 | 5 | 6 |
| 9 | 4.00 | 2 | 4 | 6 |
| 10 | 4.00 | 4 | | |
| 11 | 9.00 | 8 | 9 | 7 |



*Output:*

*Project Schedule*

| Task | Earliest Start | Earliest Finish | Latest Start | Latest Finish | Activity Slack | Critical Path Variance |
|---|---|---|---|---|---|---|
| 1 | 0.000 | 8.000 | 1.000 | 8.000 | 1.000 | |
| 2 | 0.000 | 6.000 | 0.000 | 6.000 | 0.000 | 1.000 |
| 3 | 0.000 | 3.000 | 2.000 | 5.000 | 2.000 | |
| 4 | 8.000 | 13.000 | 16.000 | 21.000 | 8.000 | |
| 5 | 6.000 | 9.000 | 6.000 | 9.000 | 0.000 | 0.111 |
| 6 | 3.000 | 7.000 | 5.000 | 9.000 | 2.000 | |
| 7 | 3.000 | 5.000 | 14.000 | 16.000 | 11.000 | |
| 8 | 9.000 | 16.000 | 9.000 | 16.000 | 0.000 | 1.778 |
| 9 | 9.000 | 13.000 | 12.000 | 16.000 | 3.000 | |
| 10 | 13.000 | 17.000 | 21.000 | 25.000 | 8.000 | |
| 11 | 16.000 | 25.000 | 16.000 | 25.000 | 0.000 | 4.000 |
| Project Completion Time | | 25 | | Project variance | | 6.889 |
| | | | | Project std.dev | | 2.625 |

# Probabilistic Network Analysis

***Determine probability that project is completed within specified time***

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

***where***

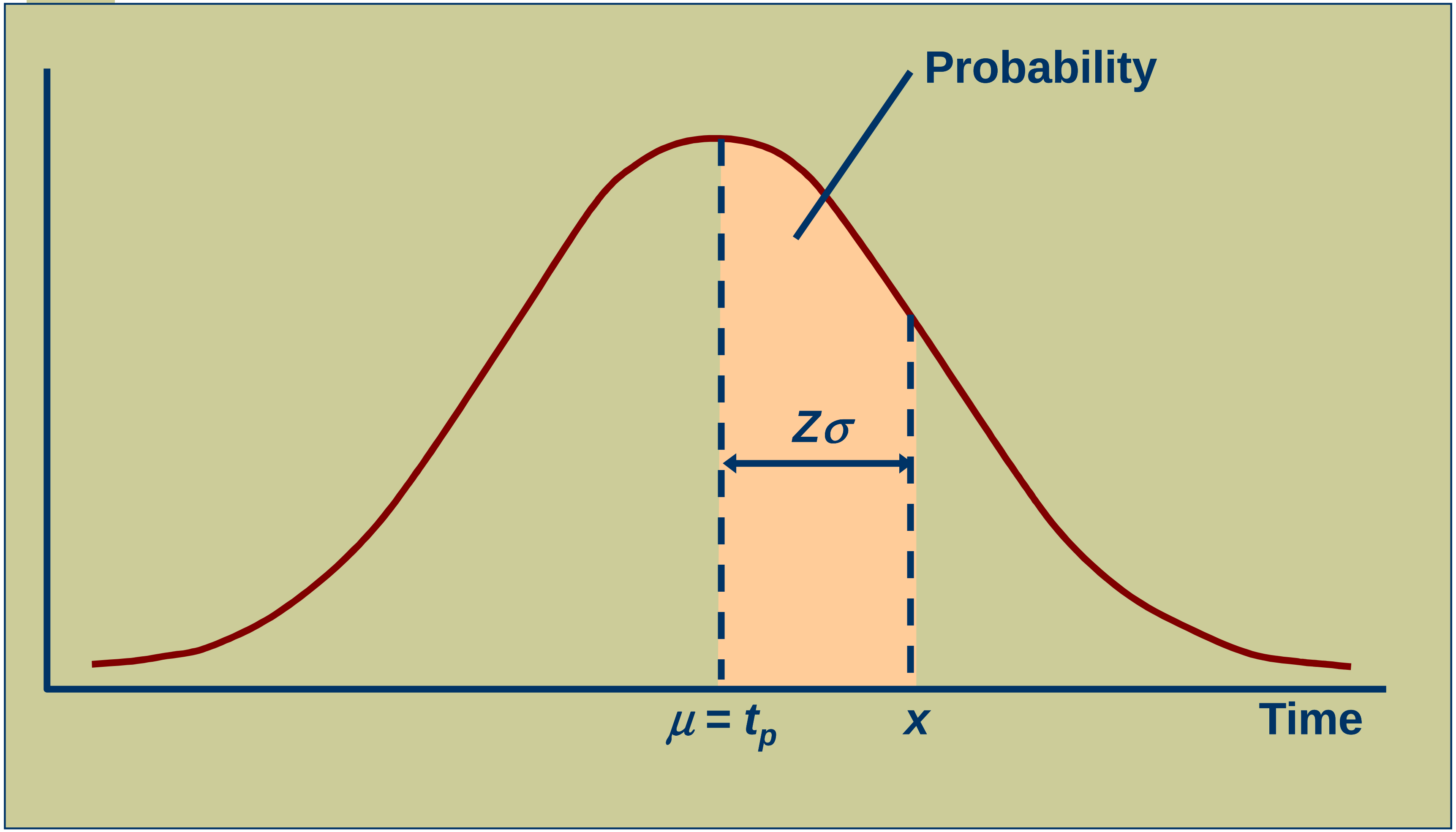
$\mu = t_p$ = ***project mean time***

$\sigma$ = ***project standard deviation***

$x$ = ***proposed project time***

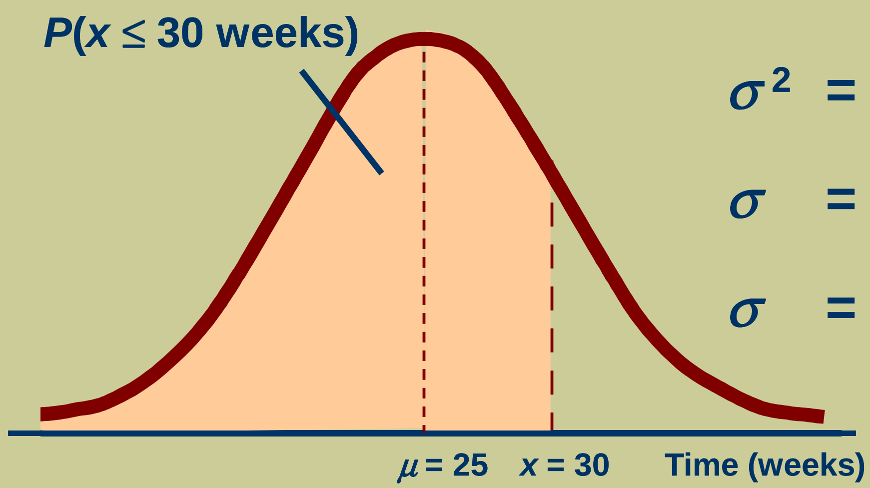
$Z$ = ***number of standard deviations x is from mean***

# Normal Distribution of Project Time



# Southern Textile Example

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




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

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

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

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

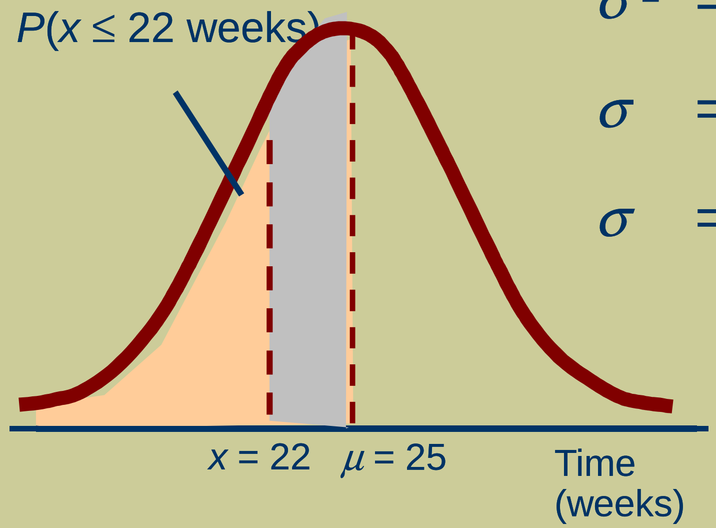
$$= \frac{30 - 25}{2.62}$$

$$= 1.91$$

From Table A.1, (appendix A) a *Z* score of 1.91 corresponds to a probability of 0.4719. Thus *P*(30) = 0.4719 + 0.5000 = 0.9719

# Southern Textile Example

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

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

$= \dfrac{22 - 25}{2.62}$

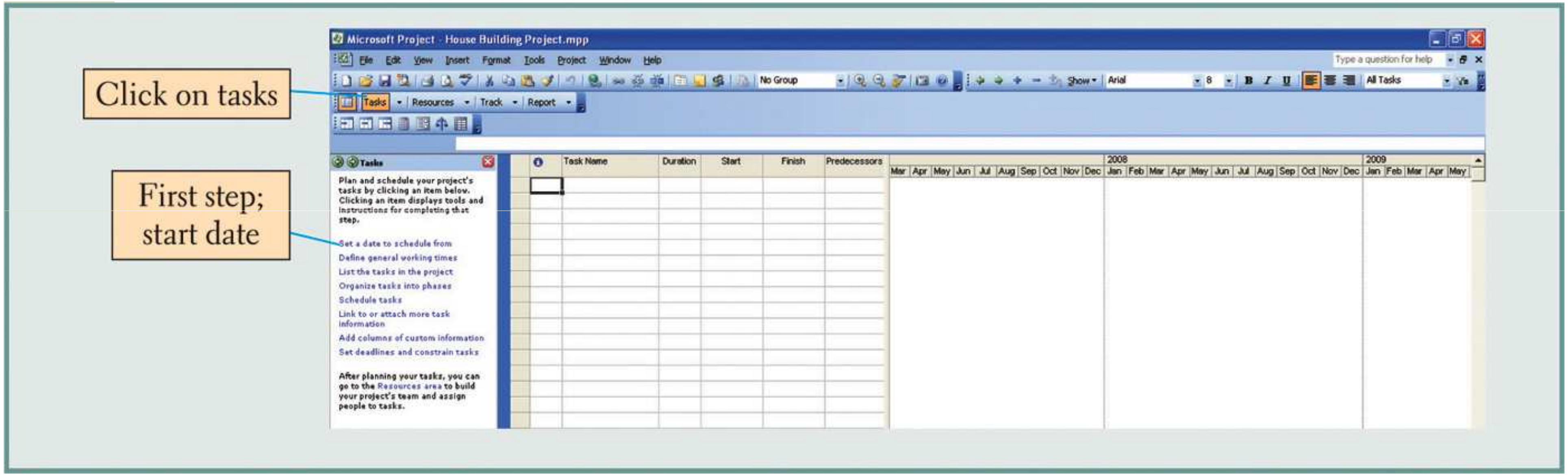
$= -1.14$

From Table A.1 (appendix A) a *Z* score of -1.14 corresponds to a probability of 0.3729. Thus *P*(22) = 0.5000 - 0.3729 = 0.1271

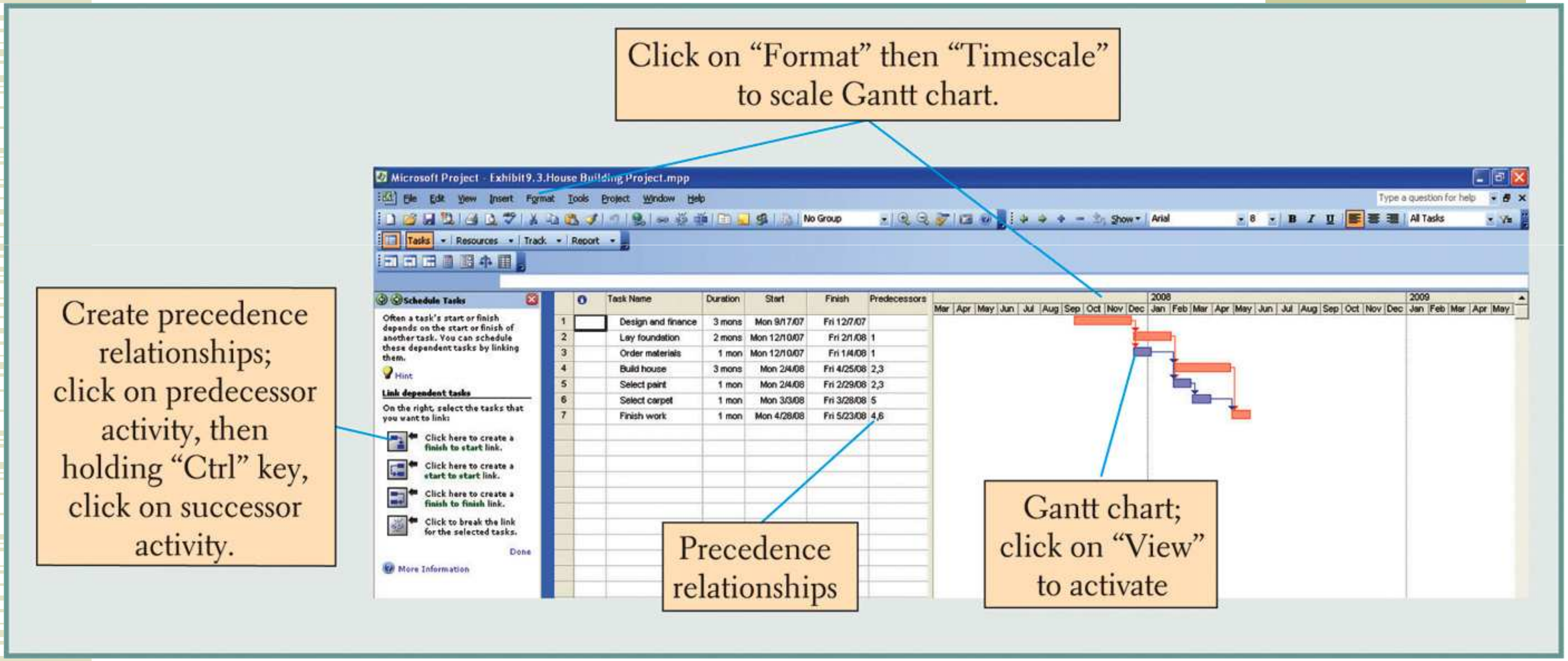
# Microsoft Project

- Popular software package for project management and CPM/PERT analysis
- Relatively easy to use

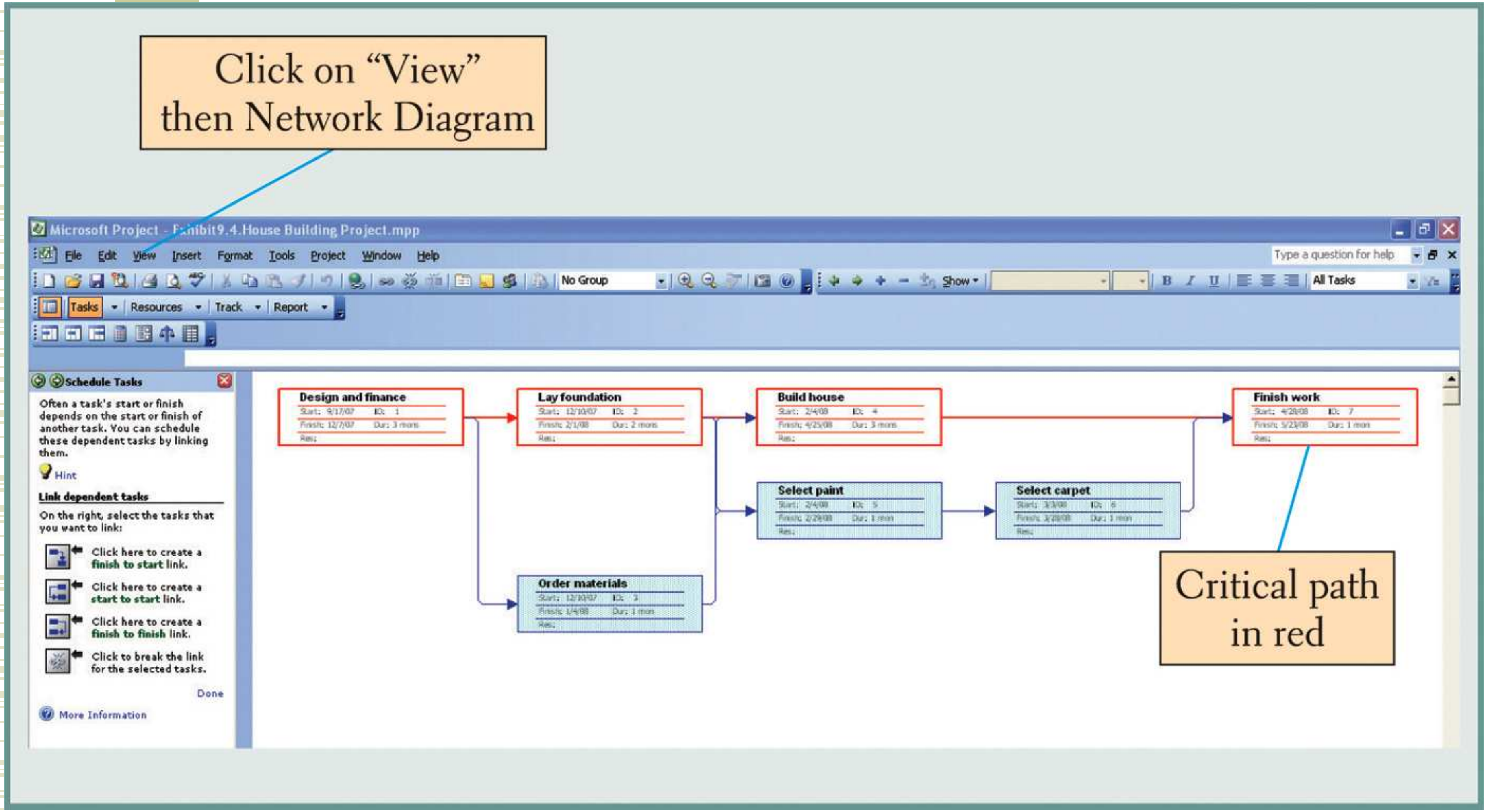
# Microsoft Project (cont.)



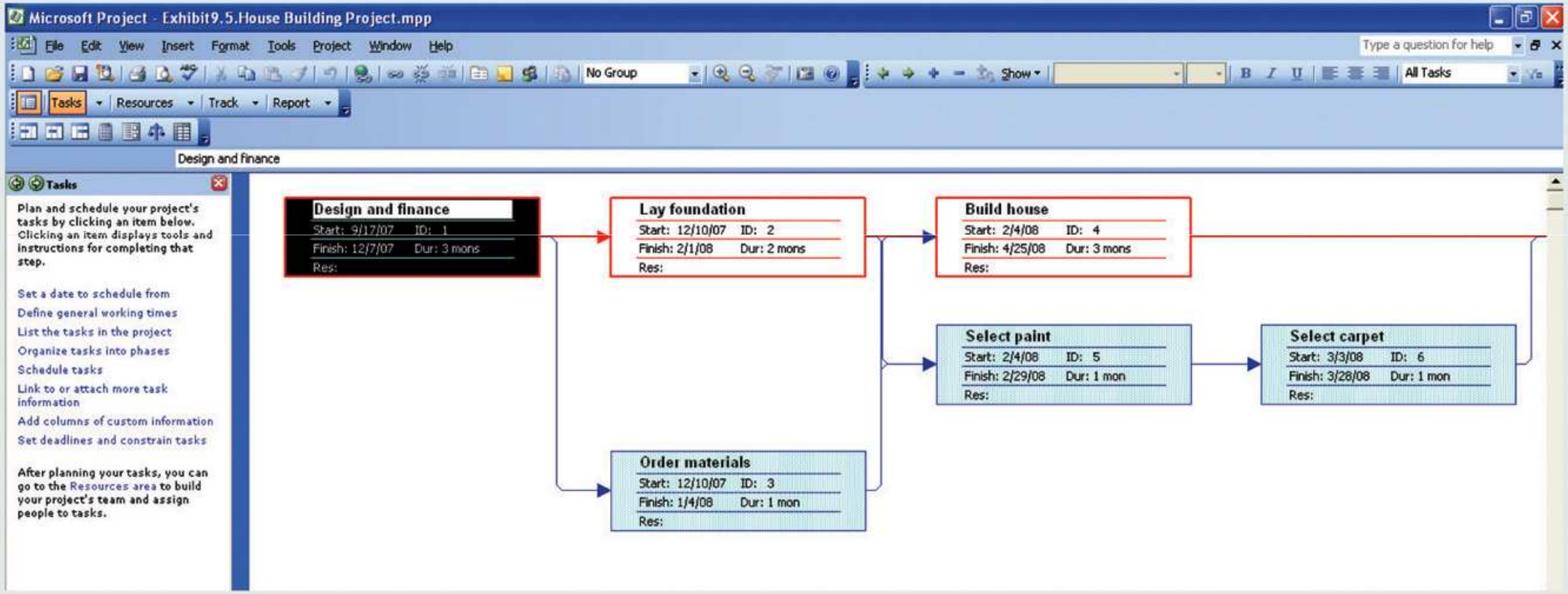
# Microsoft Project (cont.)



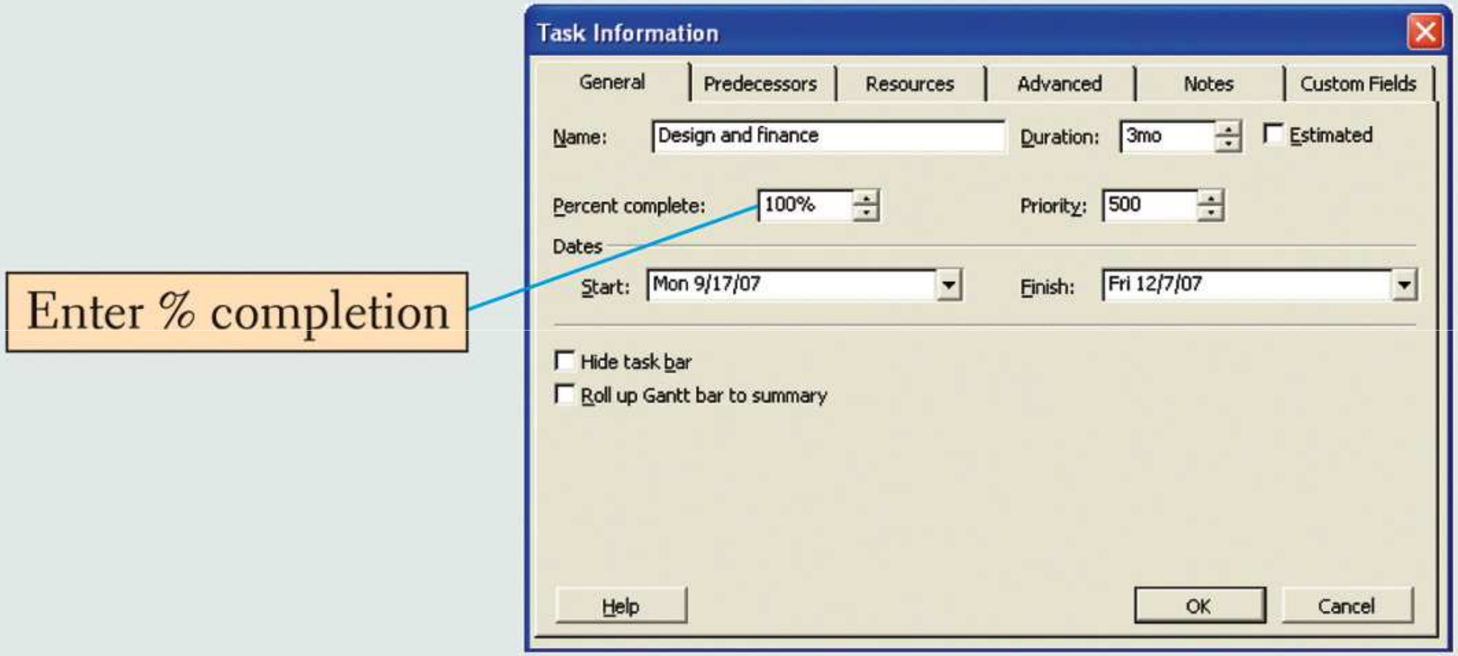
# Microsoft Project (cont.)



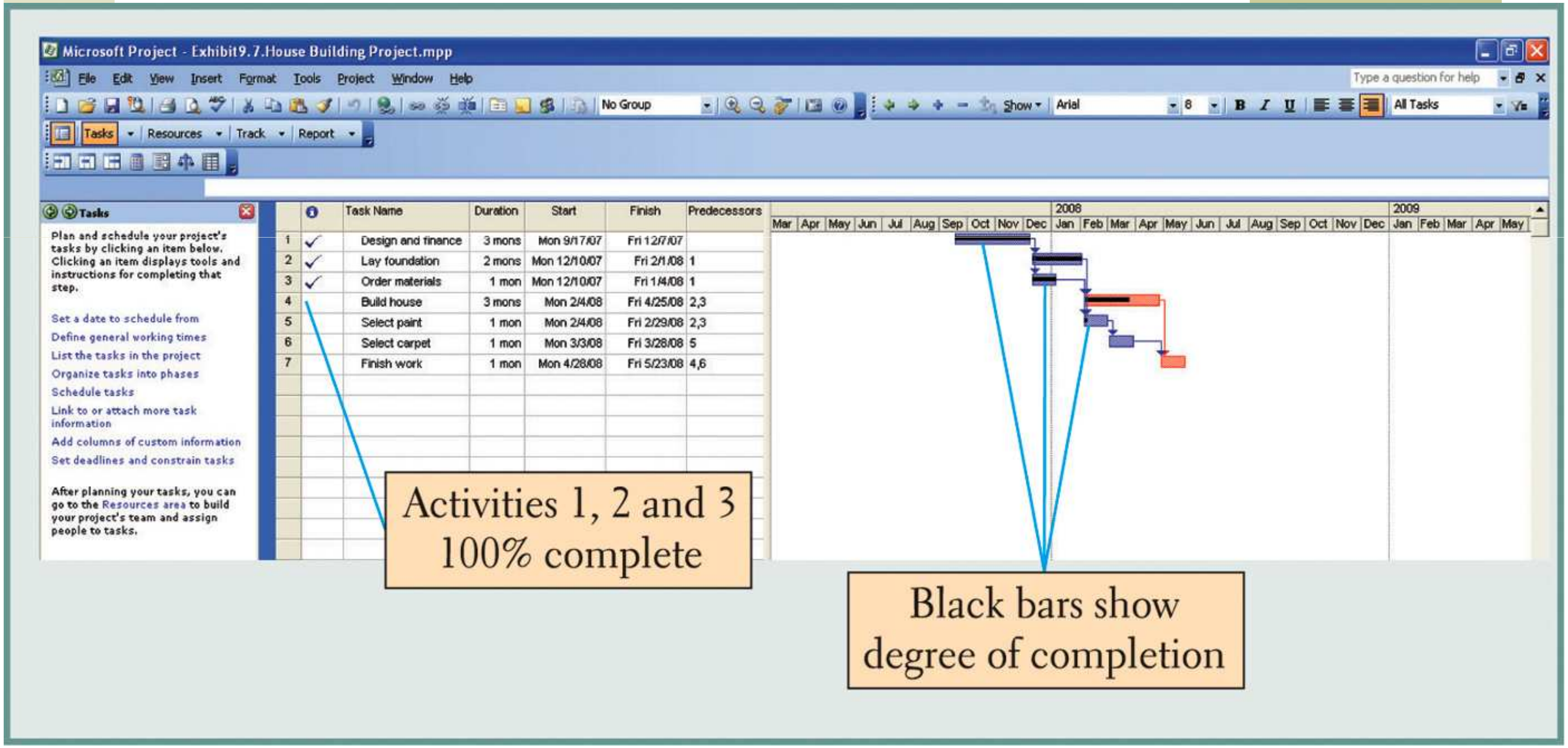
# Microsoft Project (cont.)



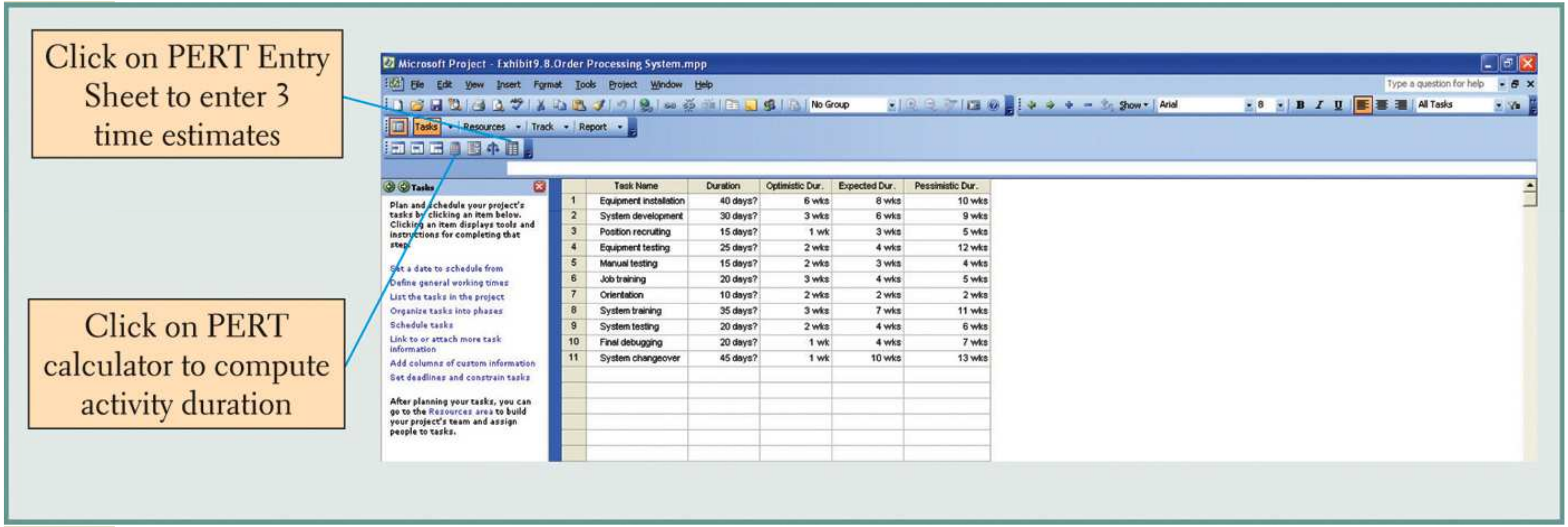
# Microsoft Project (cont.)



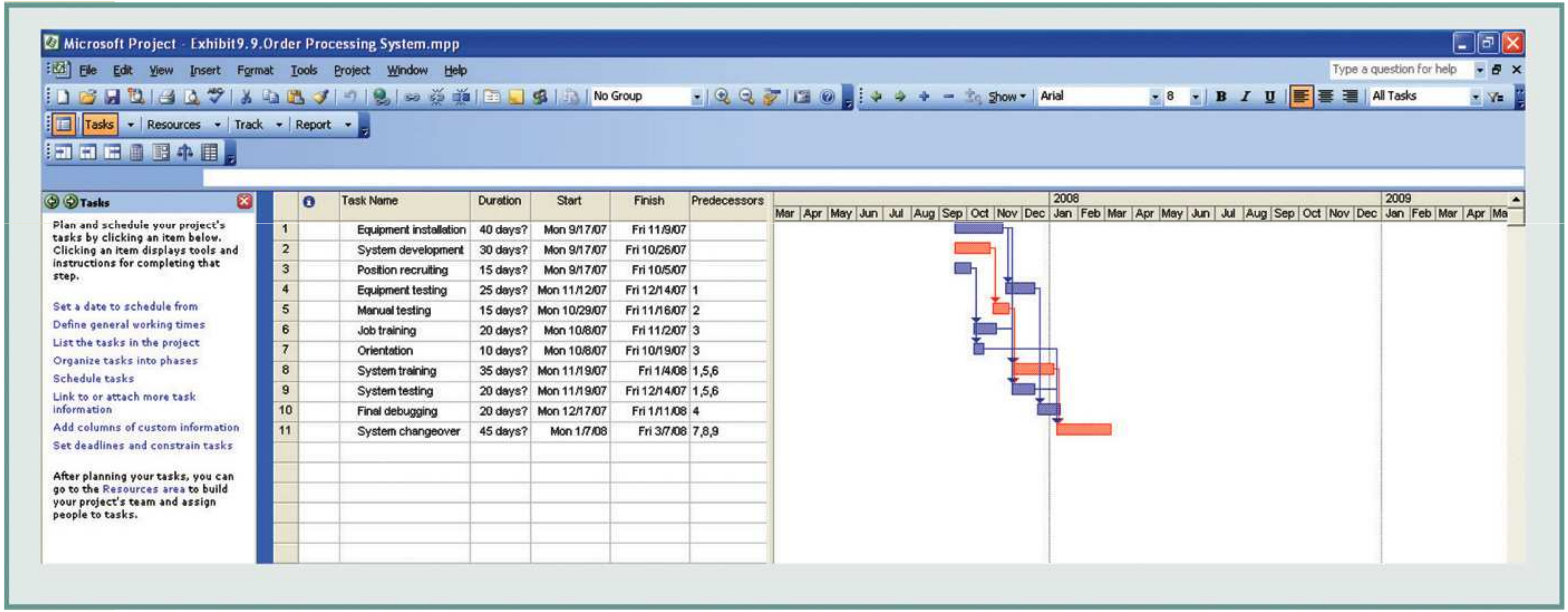
# Microsoft Project (cont.)



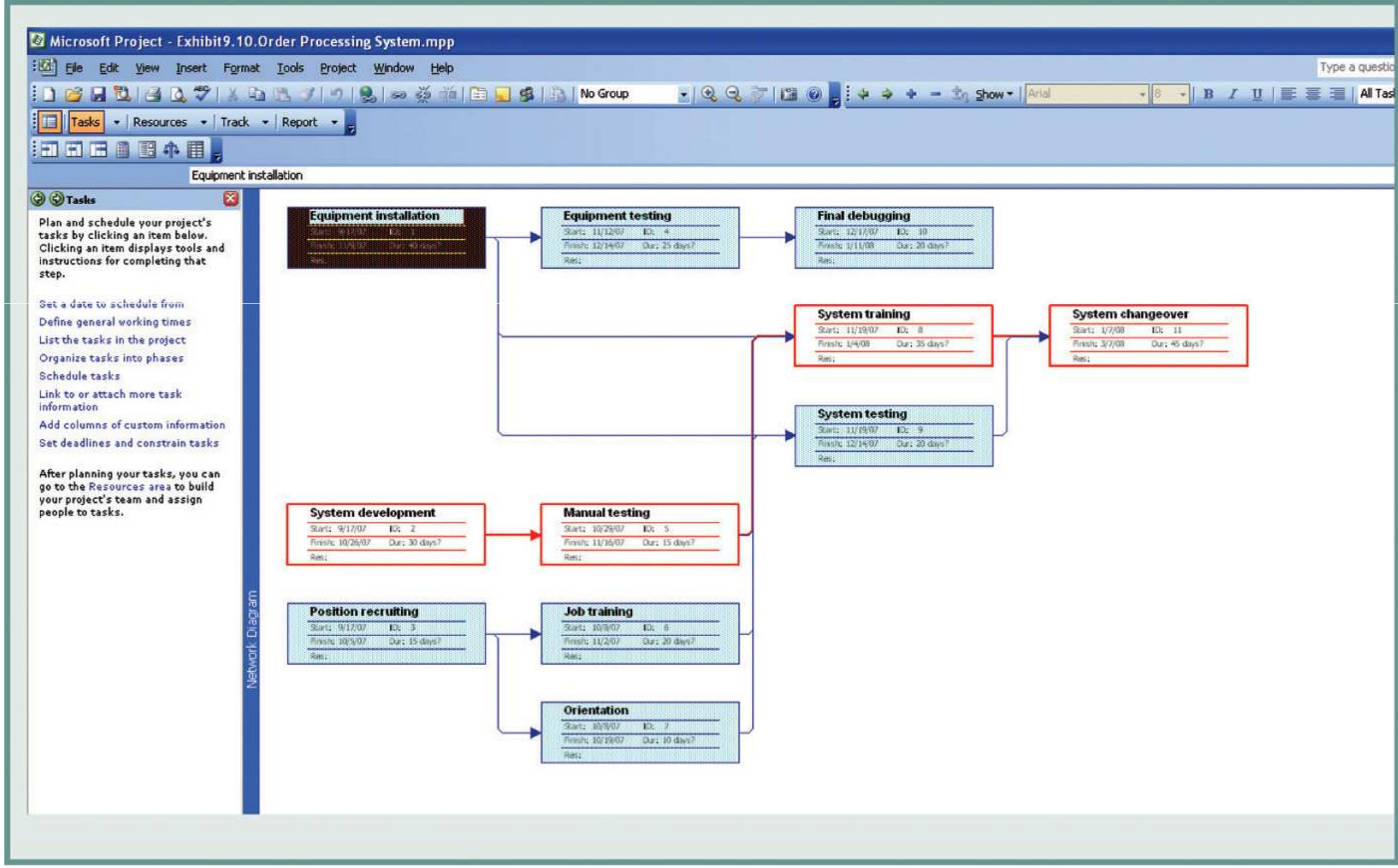
# PERT Analysis with Microsoft Project



# PERT Analysis with Microsoft Project (cont.)



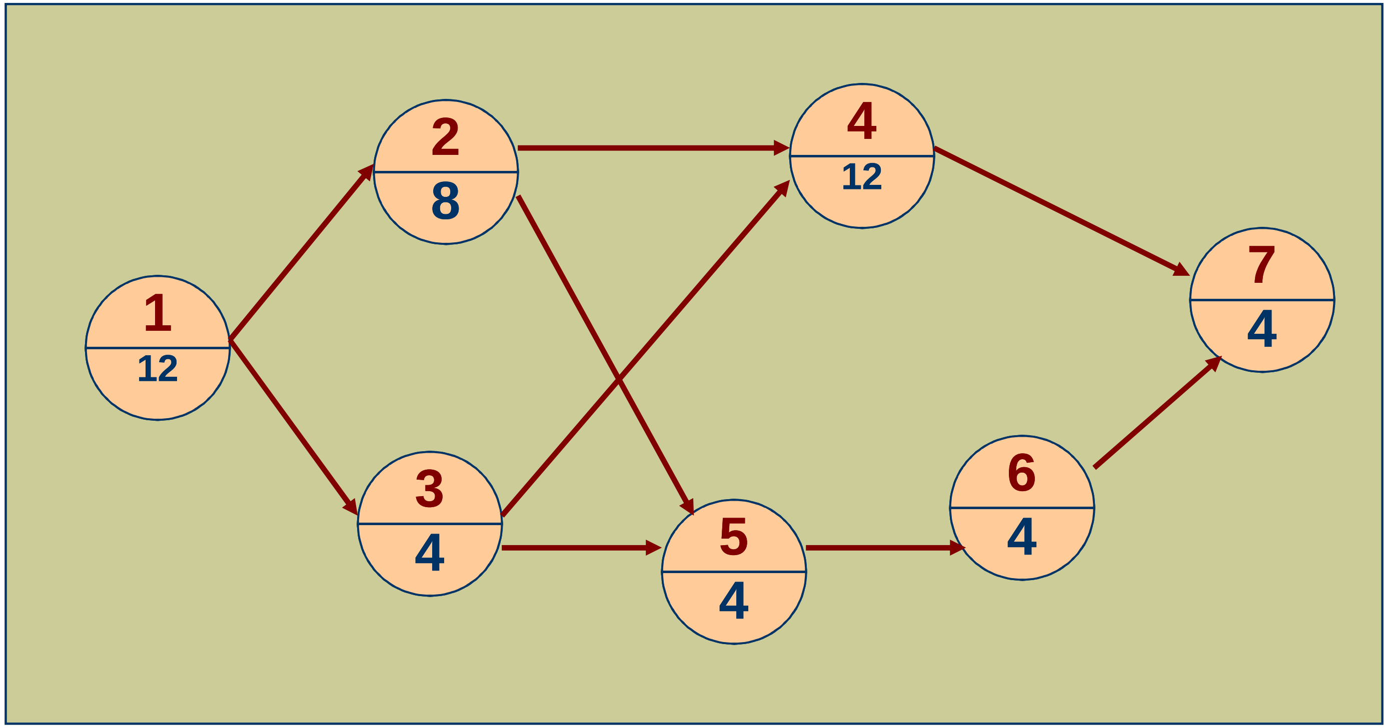
# PERT Analysis with Microsoft Project (cont.)



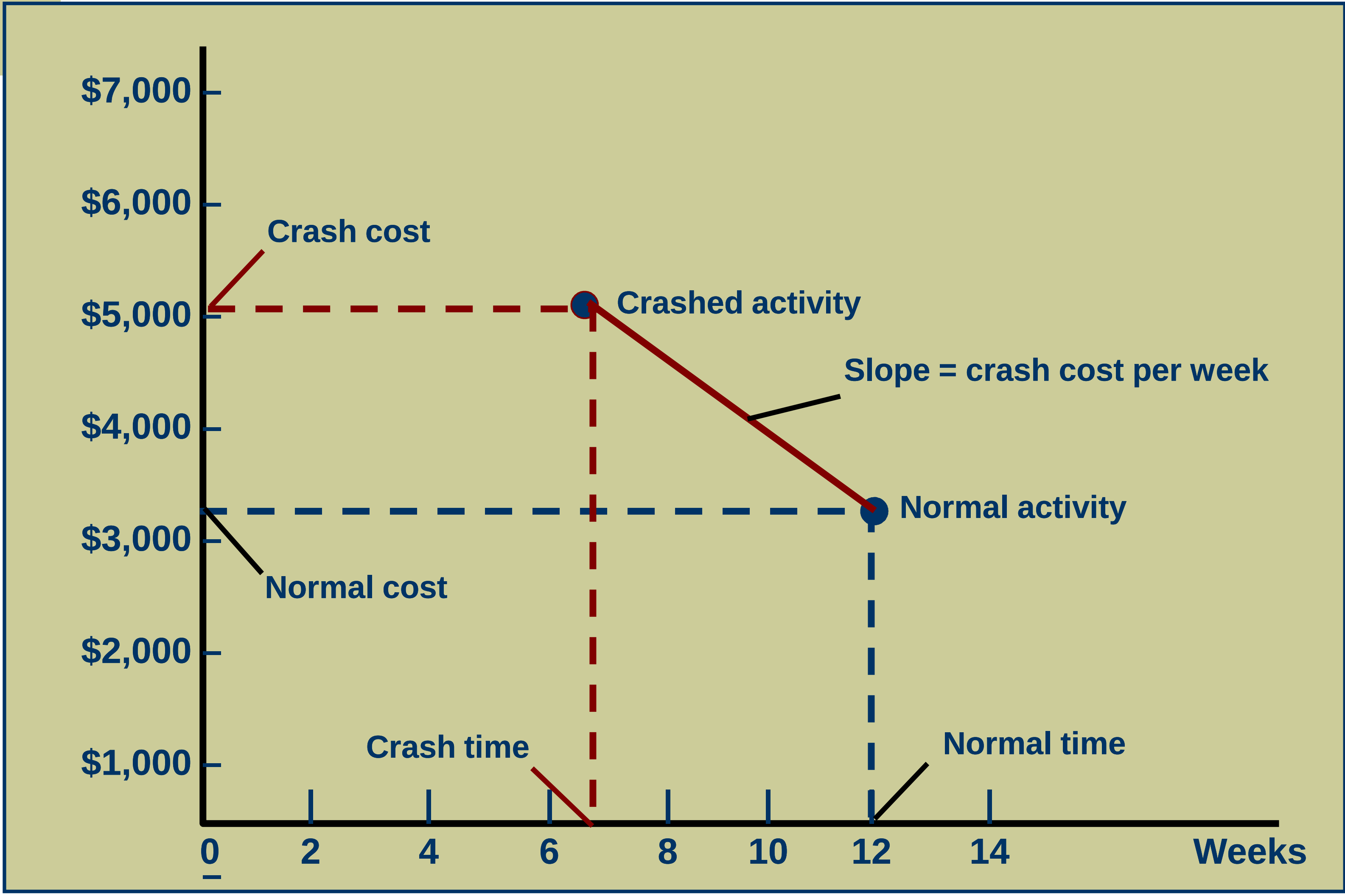
# Project Crashing

- 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 Network for Building a House

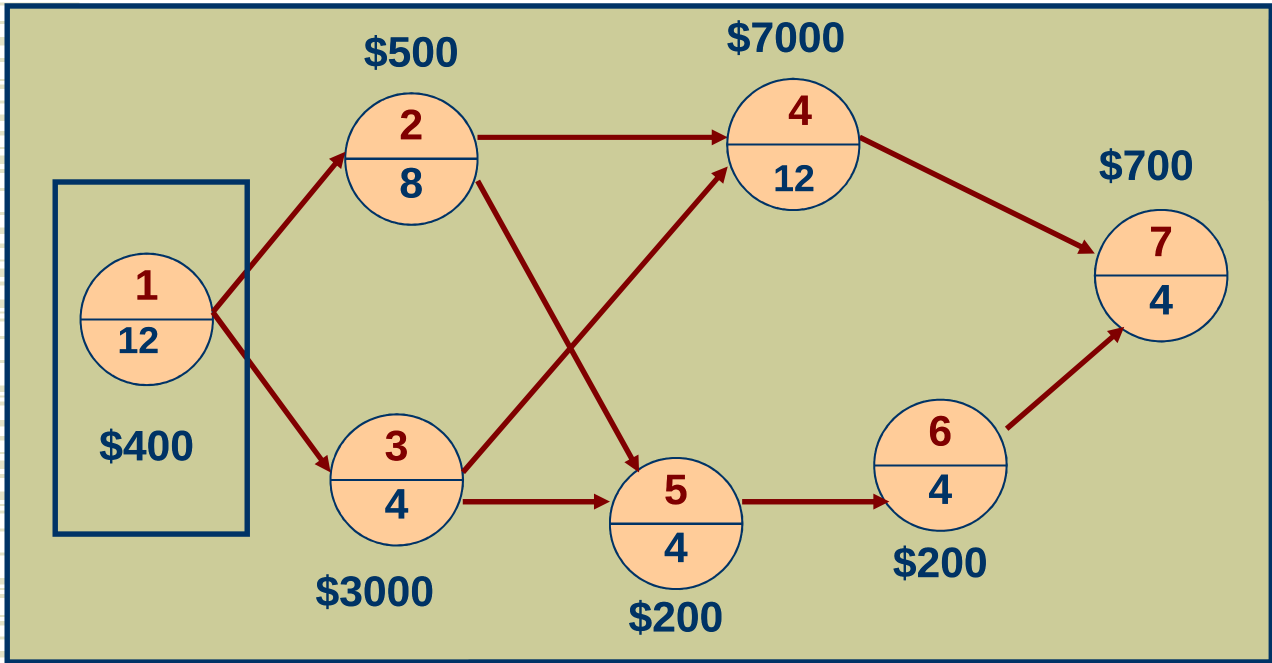


# Normal Time and Cost vs. Crash Time and Cost



# Project Crashing: Example

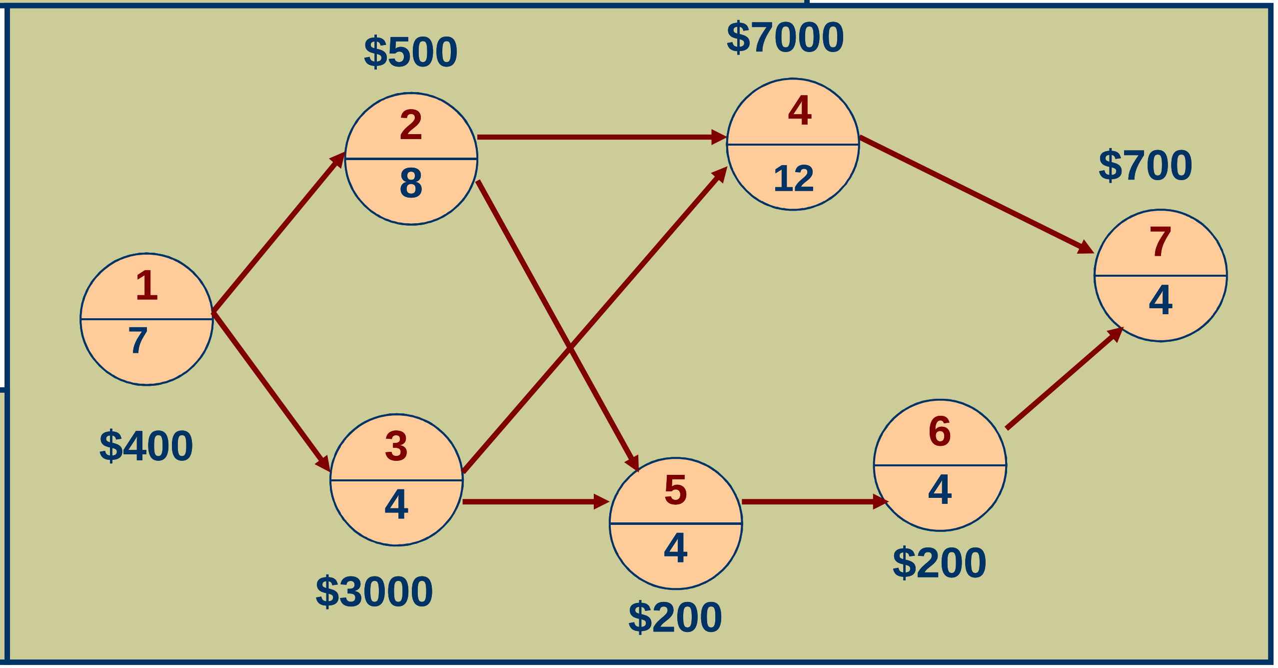
| ACTIVITY | NORMAL TIME (WEEKS) | CRASH TIME (WEEKS) | NORMAL COST | CRASH COST | TOTAL ALLOWABLE CRASH TIME (WEEKS) | CRASH COST PER WEEK |
|---|---|---|---|---|---|---|
| 1 | 12 | 7 | $3,000 | $5,000 | 5 | $400 |
| 2 | 8 | 5 | 2,000 | 3,500 | 3 | 500 |
| 3 | 4 | 3 | 4,000 | 7,000 | 1 | 3,000 |
| 4 | 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…

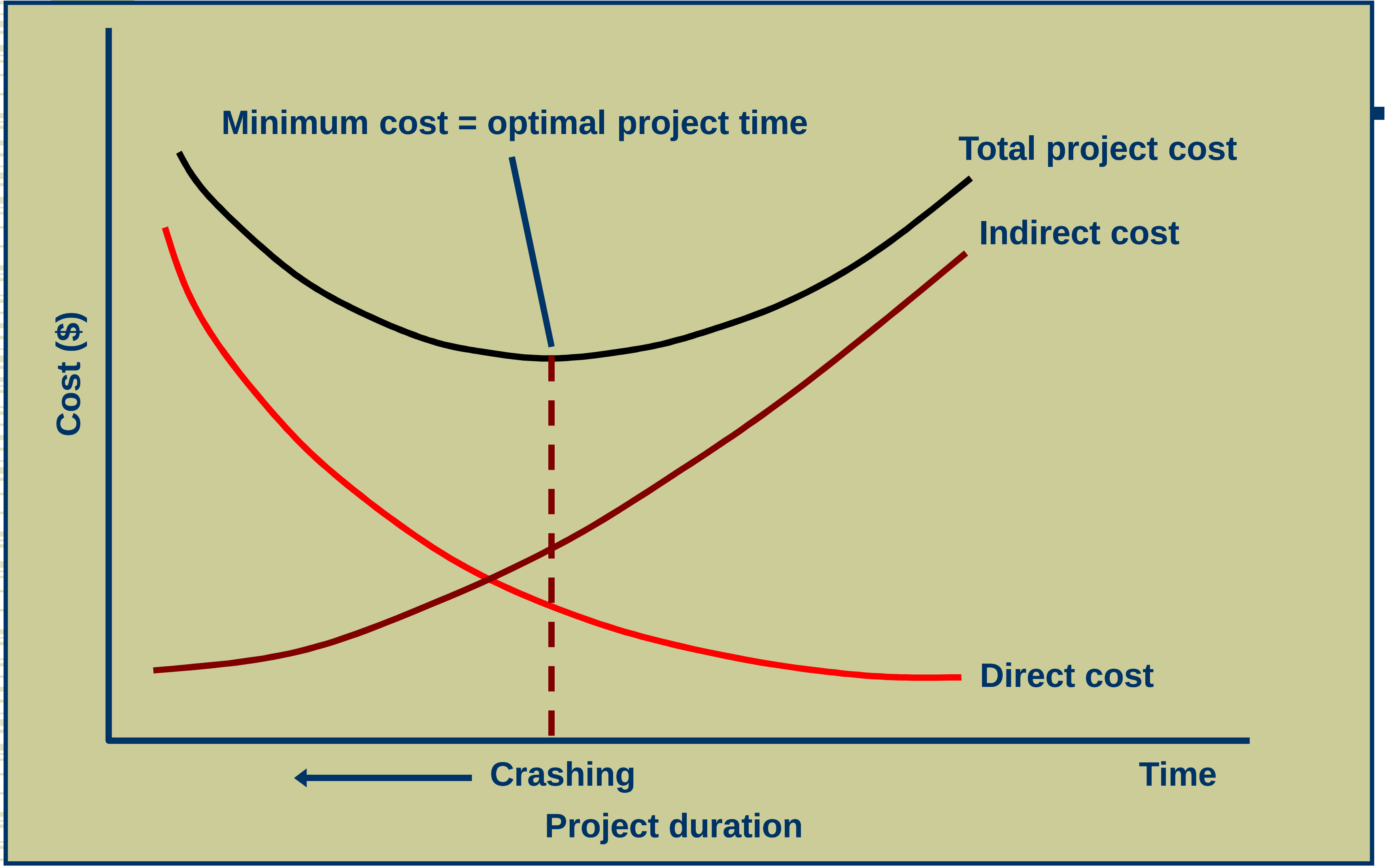


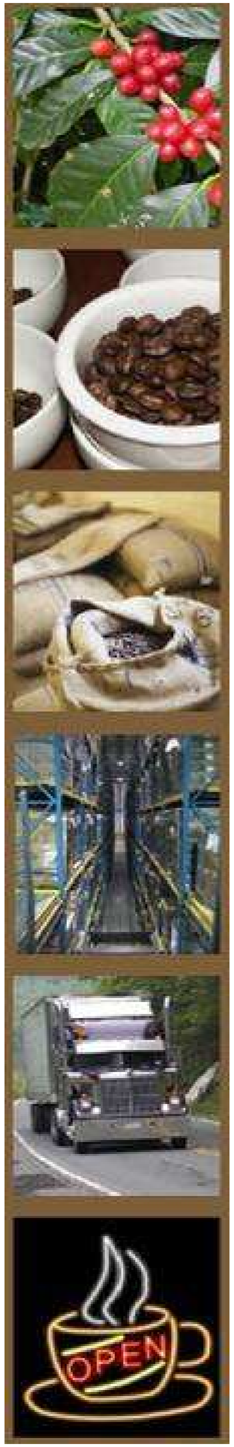

**Project Duration:**
**31 weeks**
**Additional Cost:**
**$2000**

# 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





# Chapter 10

## *Supply Chain Management Strategy and Design*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

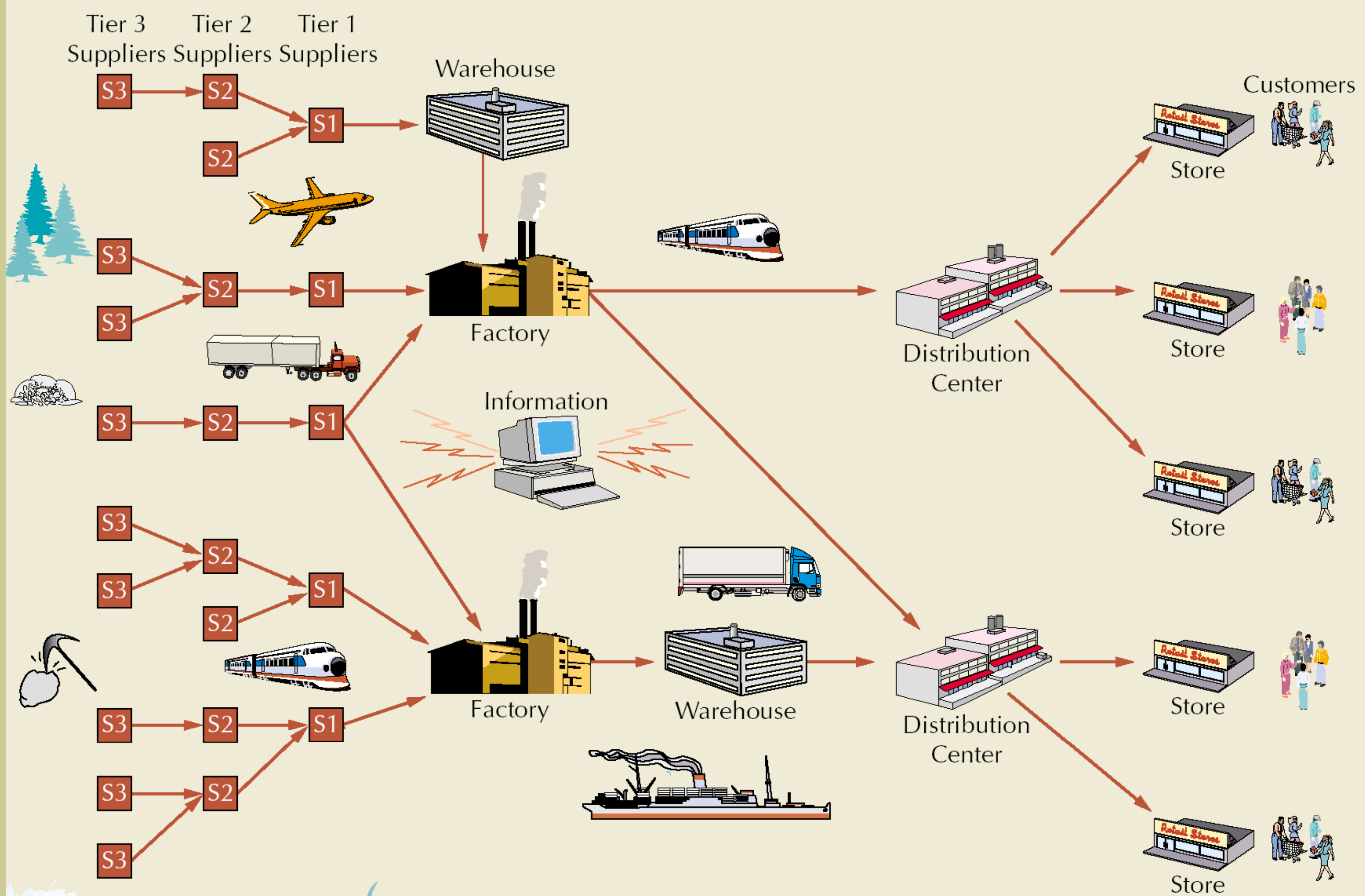
# Lecture Outline

- The Management of Supply Chains
- Information Technology: A Supply Chain Enabler
- Supply Chain Integration
- Supply Chain Management (SCM) Software
- Measuring Supply Chain Performance

# Supply Chains

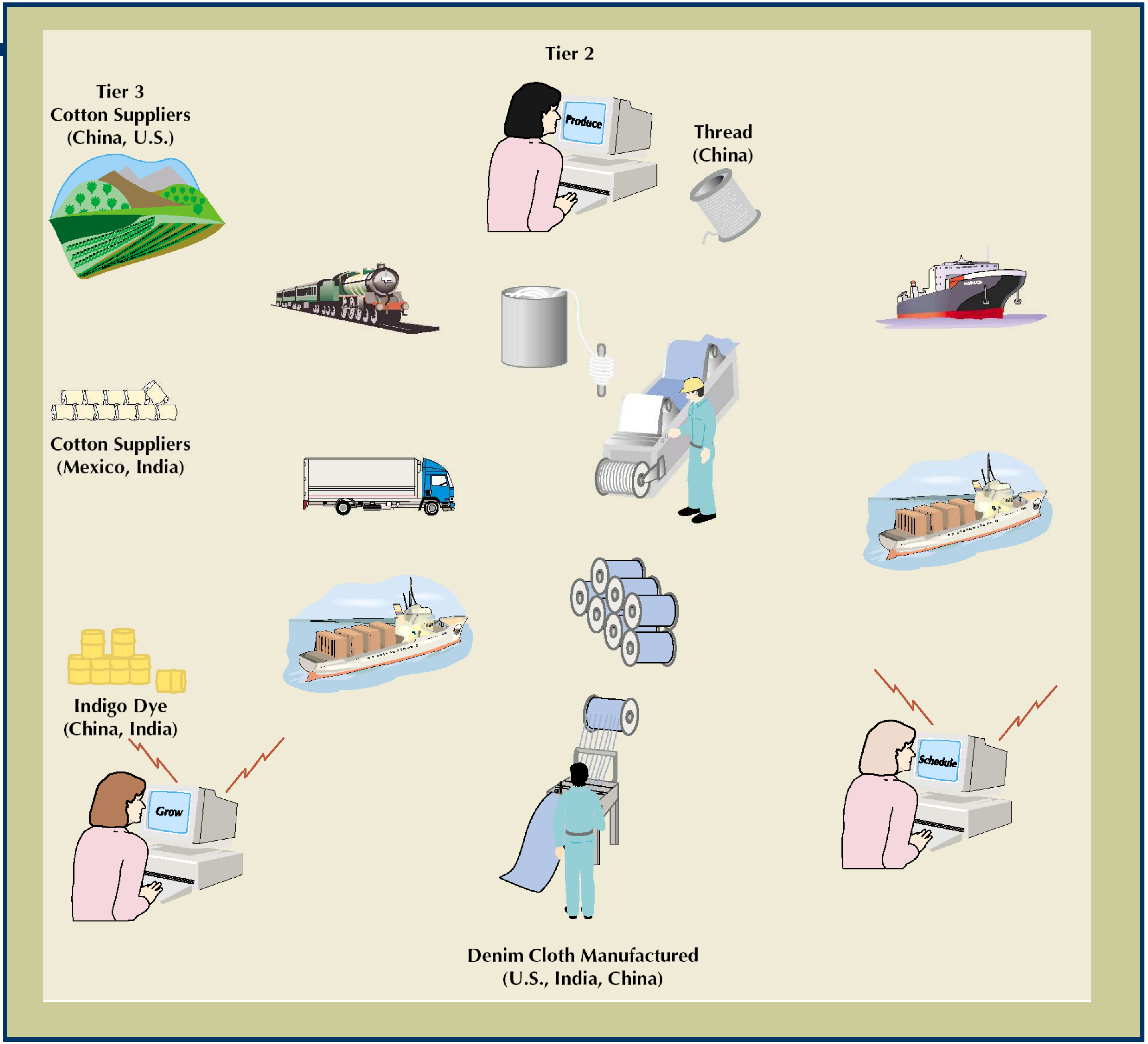
All facilities, functions, and activities associated with flow and transformation of goods and services from raw materials to customer, as well as the associated information flows

An integrated group of processes to “source,” “make,” and “deliver” products

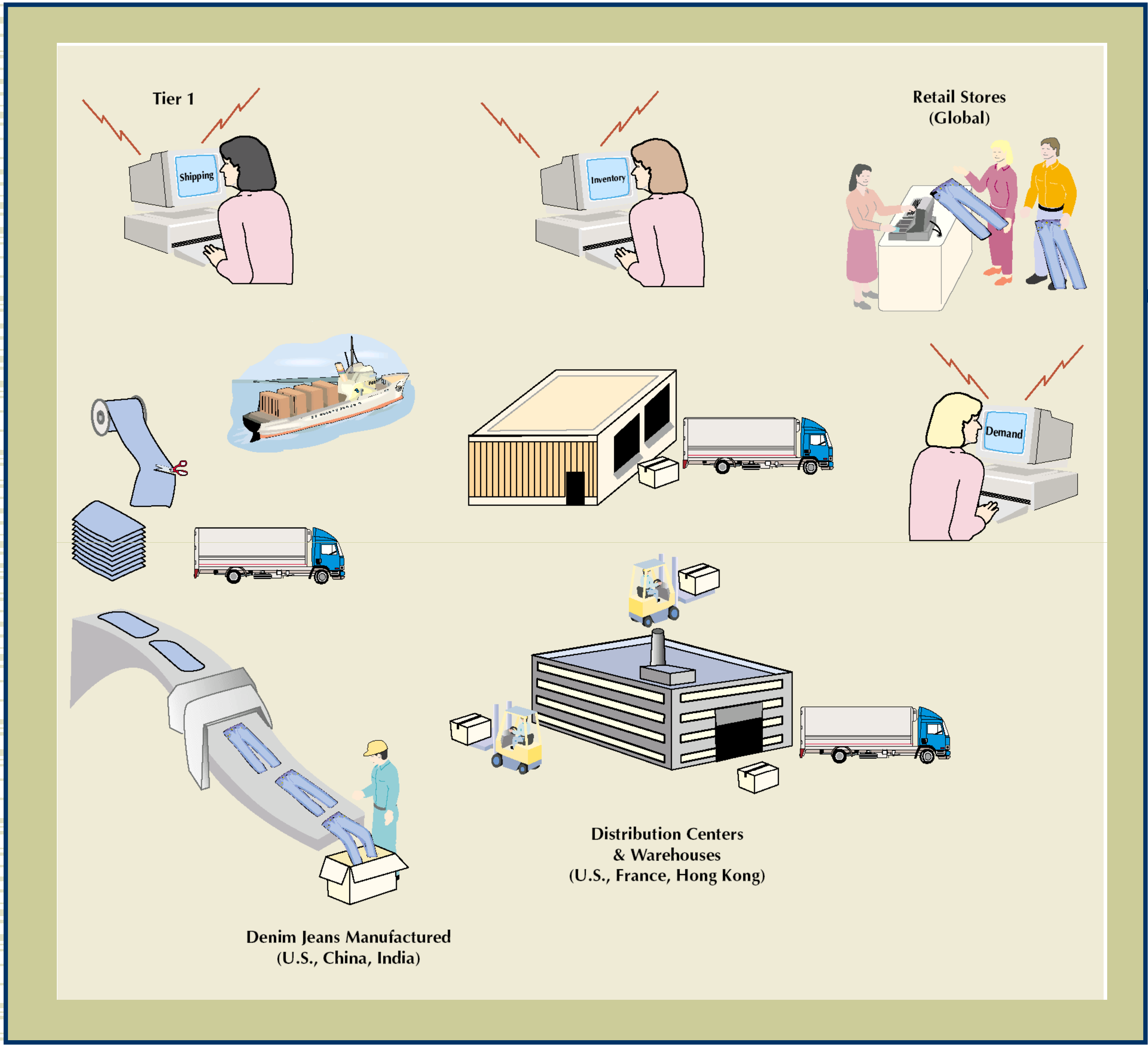



# Supply Chain Illustration

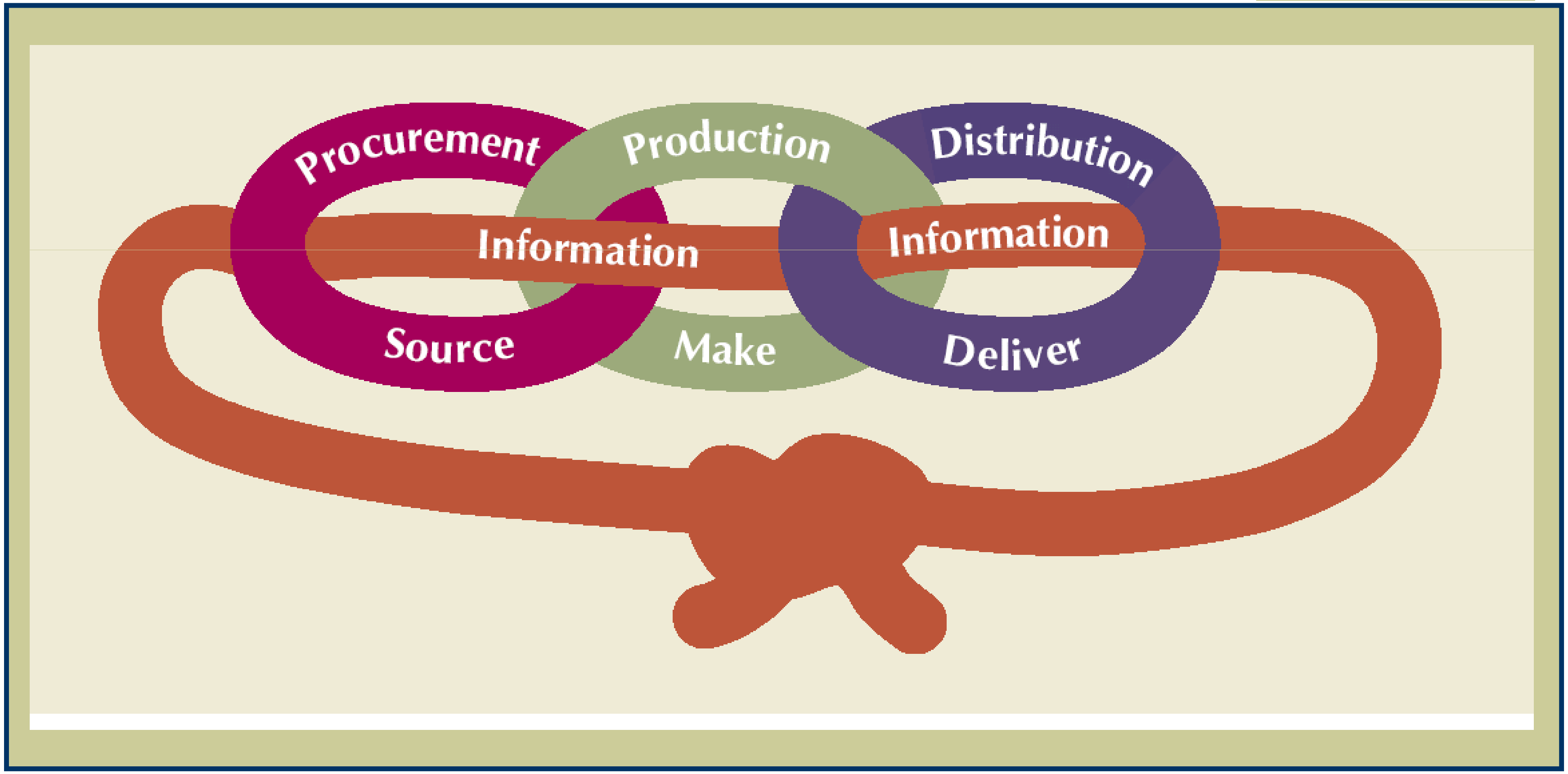
# Supply Chain for Denim Jeans



# Supply Chain for Denim Jeans (cont.)



# Supply Chain Processes



# Supply Chain for Service Providers

- More difficult than manufacturing
- Does not focus on the flow of physical goods
- Focuses on human resources and support services
- More compact and less extended

# Value Chains

- Value chain
  - every step from raw materials to the eventual end user
  - ultimate goal is delivery of maximum value to the end user
- Supply chain
  - activities that get raw materials and subassemblies into manufacturing operation
  - ultimate goal is same as that of value chain
- Demand chain
  - increase value for any part or all of chain
- Terms are used interchangeably
- Value
  - creation of value for customer is important aspect of supply chain management

# Supply Chain Management (SCM)

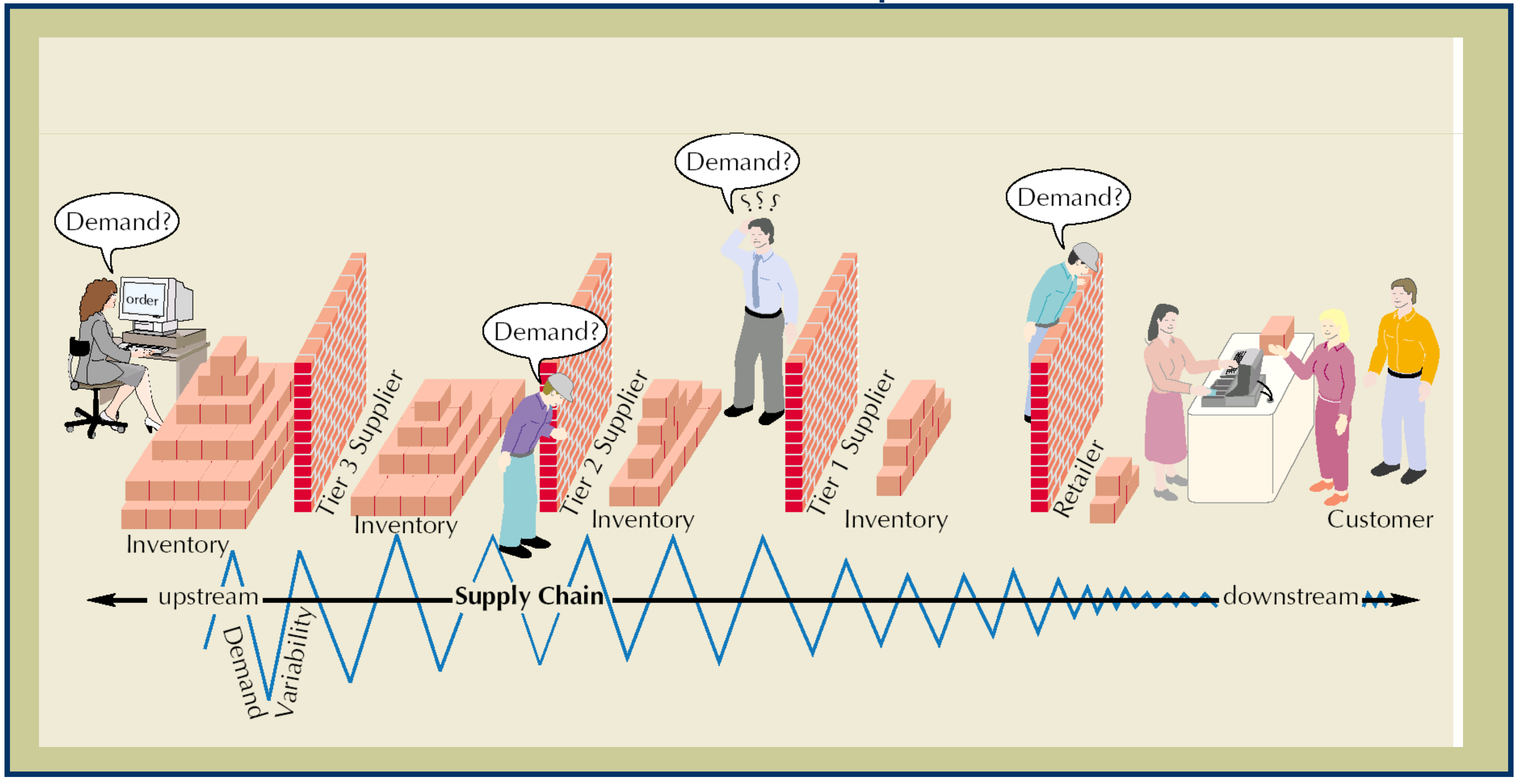
- Managing flow of information through supply chain in order to attain the level of synchronization that will make it more responsive to customer needs while lowering costs
- Keys to effective SCM
  - information
  - communication
  - cooperation
  - trust

# Supply Chain Uncertainty and Inventory

- One goal in SCM:
  - respond to uncertainty in customer demand without creating costly excess inventory
- Negative effects of uncertainty
  - lateness
  - incomplete orders
- Inventory
  - insurance against supply chain uncertainty
- Factors that contribute to uncertainty
  - inaccurate demand forecasting
  - long variable lead times
  - late deliveries
  - incomplete shipments
  - product changes
  - batch ordering
  - price fluctuations and discounts
  - inflated orders

# Bullwhip Effect

Occurs when slight demand variability is magnified as information moves back upstream



# Risk Pooling

- Risks are aggregated to reduce the impact of individual risks
  - Combine inventories from multiple locations into one
  - Reduce parts and product variability, thereby reducing the number of product components
  - Create flexible capacity

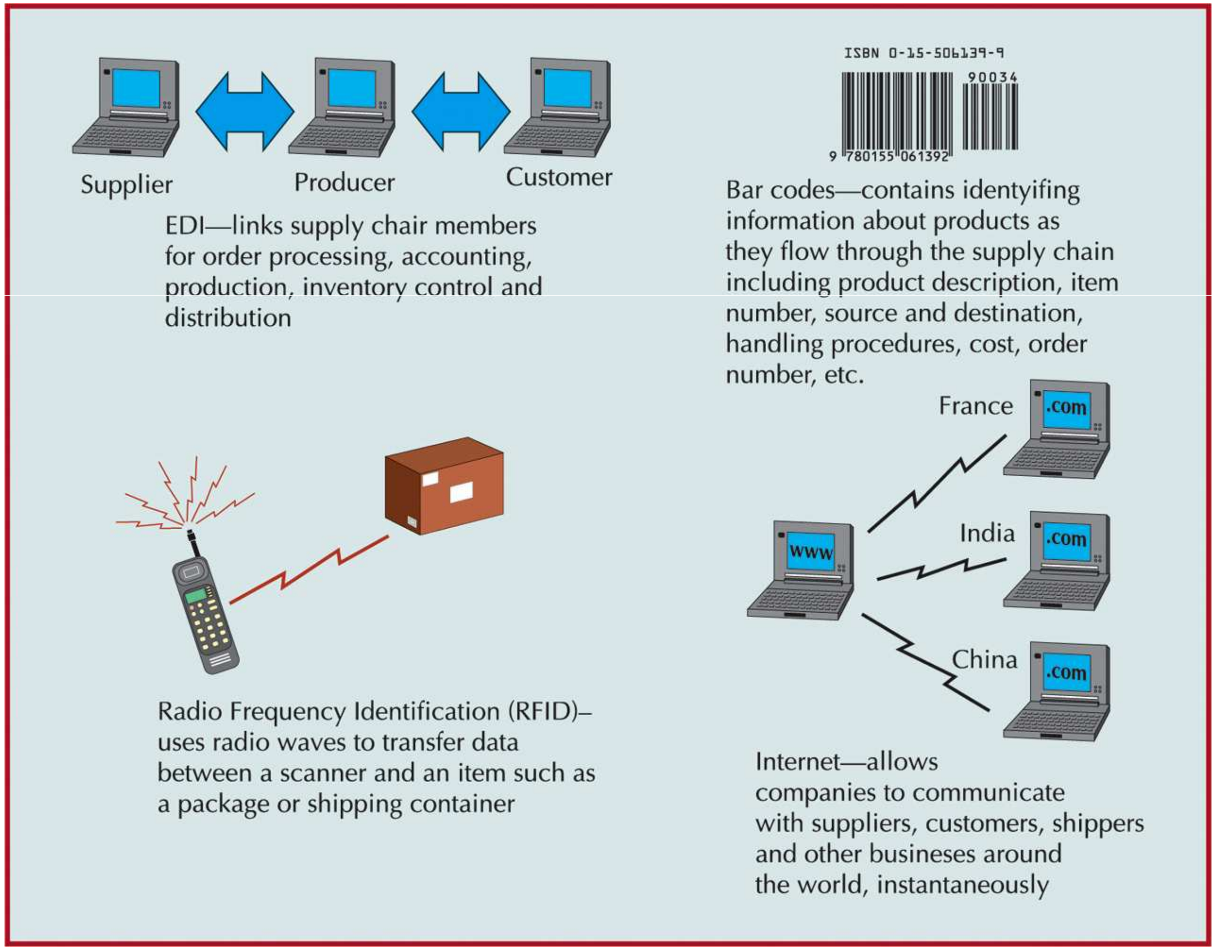
# Information Technology: A Supply Chain Enabler

- Information links all aspects of supply chain
- E-business
  - replacement of physical business processes with electronic ones
- Electronic data interchange (EDI)
  - a computer-to-computer exchange of business documents
- Bar code and point-of-sale
  - data creates an instantaneous computer record of a sale

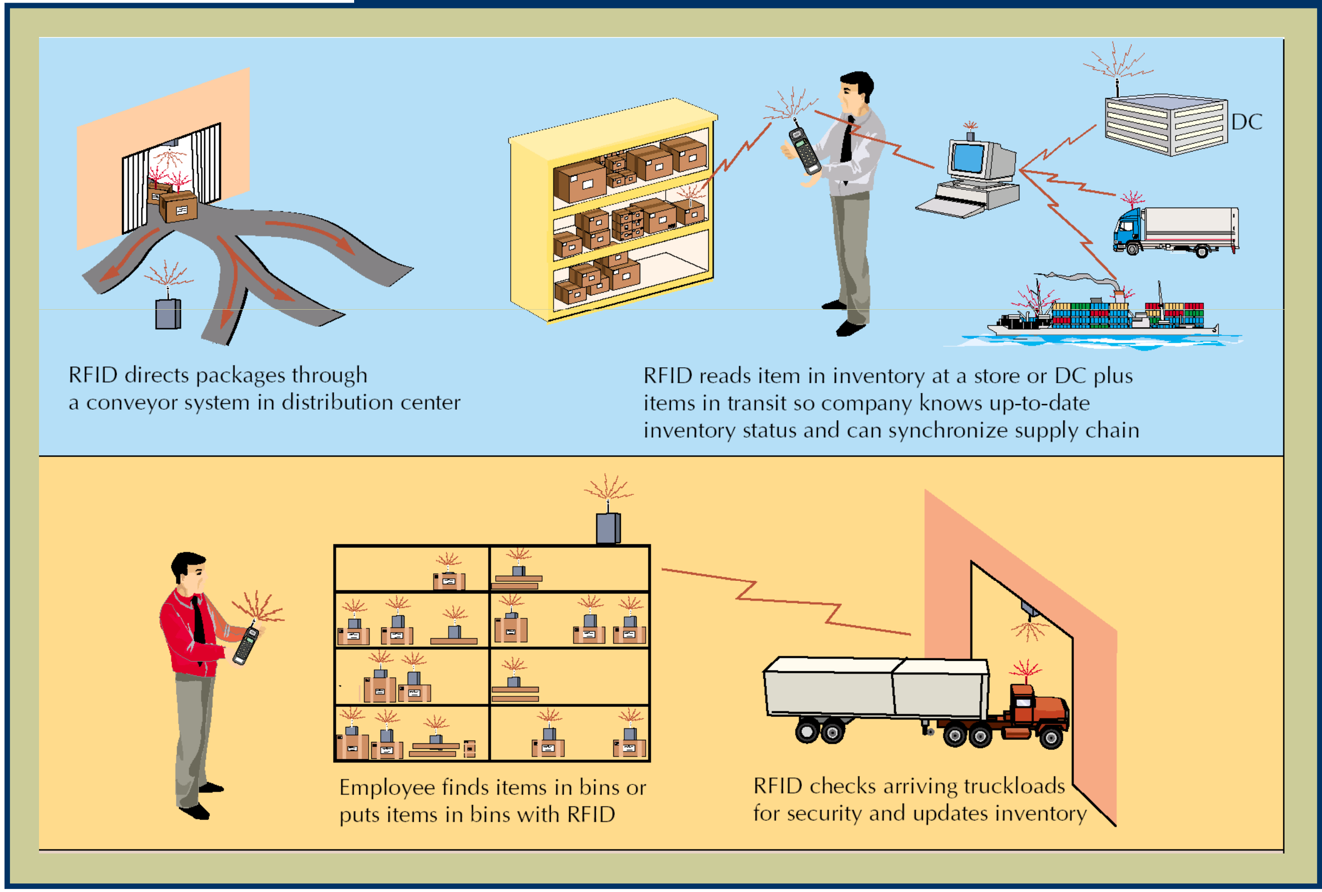
# Information Technology: A Supply Chain Enabler (cont.)

- Radio frequency identification (RFID)
  - technology can send product data from an item to a reader via radio waves
- Internet
  - allows companies to communicate with suppliers, customers, shippers and other businesses around the world instantaneously
- Build-to-order (BTO)
  - direct-sell-to-customers model via the Internet; extensive communication with suppliers and customer

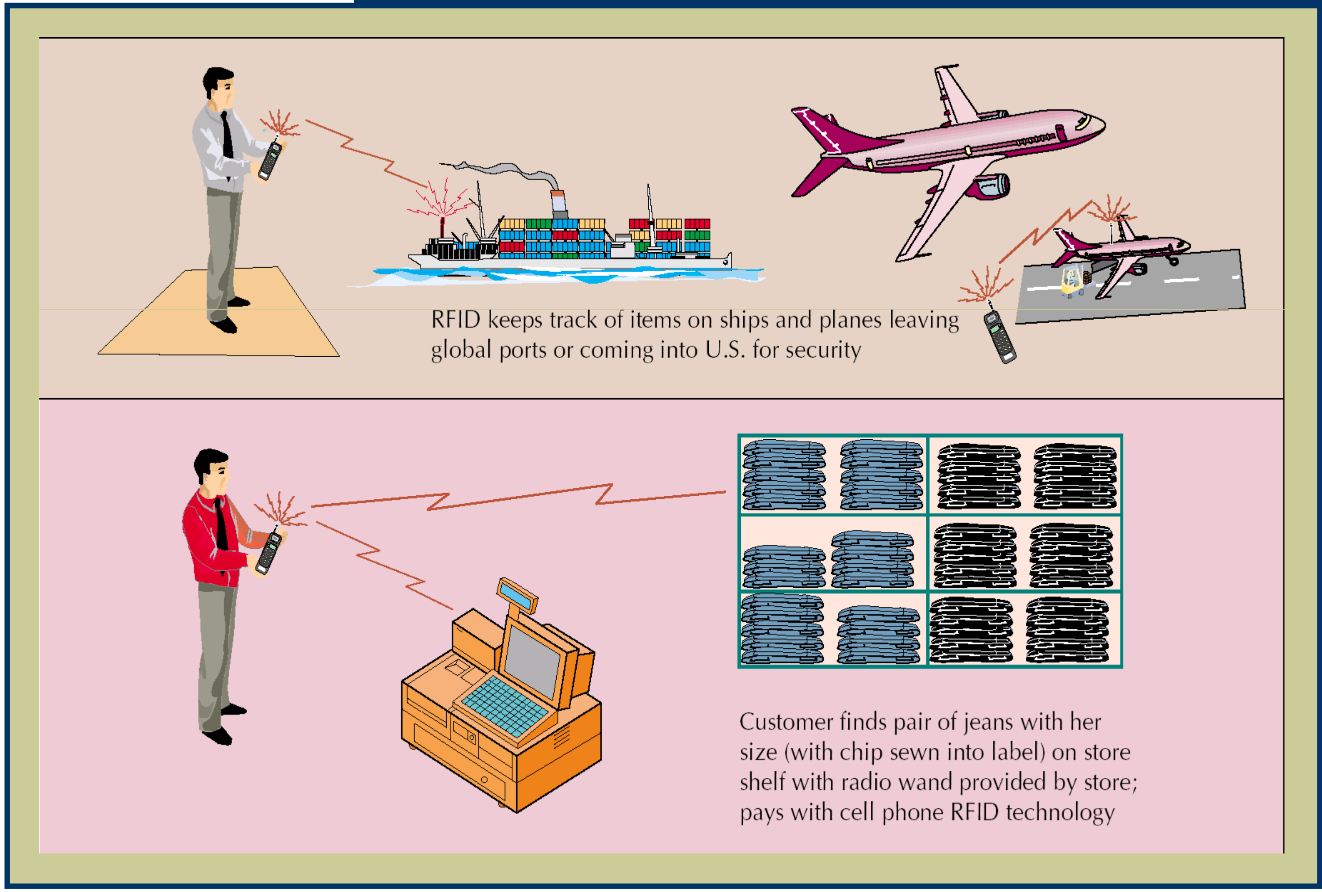
# Supply Chain Enablers



# RFID Capabilities



# RFID Capabilities (cont.)



# Supply Chain Integration

- Information sharing among supply chain members
  - Reduced bullwhip effect
  - Early problem detection
  - Faster response
  - Builds trust and confidence
- Collaborative planning, forecasting, replenishment, and design
  - Reduced bullwhip effect
  - Lower costs (material, logistics, operating, etc.)
  - Higher capacity utilization
  - Improved customer service levels

# Supply Chain Integration (cont.)

- Coordinated workflow, production and operations, procurement
  - Production efficiencies
  - Fast response
  - Improved service
  - Quicker to market
- Adopt new business models and technologies
  - Penetration of new markets
  - Creation of new products
  - Improved efficiency
  - Mass customization

# Collaborative Planning, Forecasting, and Replenishment (CPFR)

- Process for two or more companies in a supply chain to synchronize their demand forecasts into a single plan to meet customer demand
- Parties electronically exchange
  - past sales trends
  - point-of-sale data
  - on-hand inventory
  - scheduled promotions
  - forecasts

# Supply Chain Management (SCM) Software

- Enterprise resource planning (ERP)
  - software that integrates the components of a company by sharing and organizing information and data

# Key Performance Indicators

- Metrics used to measure supply chain performance
  - Inventory turnover

$$\text{Inventory turns} = \frac{\text{Cost of goods sold}}{\text{Average aggregate value of inventory}}$$

  - Total value (at cost) of inventory

$$\text{Average aggregate value of inventory} = \sum (\text{average inventory for item } i) \times (\text{unit value item } i)$$

  - Days of supply

$$\text{Days of supply} = \frac{\text{Average aggregate value of inventory}}{(\text{Cost of goods sold})/(365 \text{ days})}$$

  - Fill rate: fraction of orders filled by a distribution center within a specific time period

# Computing Key Performance Indicators

The Tomahawk Motorcycle Company manufactures motorcycles. Last year the cost of goods sold was $425 million. The company had the following average value of production materials and parts, work-in-process, and finished goods inventory:

| | |
|---|---|
| Production materials and parts | $ 4,629,000 |
| Work-in-process | 17,465,000 |
| Finished goods | 12,322,000 |
| Total average aggregate value of inventory | $34,416,000 |

The company wants to know the number of inventory turns and days of supply being held in inventory.

***Solution***

$$\text{Inventory turns} = \frac{\text{Cost of goods sold}}{\text{Average aggregate value of inventory}}$$

$$= \frac{\$425{,}000{,}000}{34{,}416{,}000}$$

$$\text{Inventory turns} = 12.3$$

$$\text{Days of supply} = \frac{\text{Average aggregate value of inventory}}{(\text{Cost of goods sold})/(365\text{ days})}$$

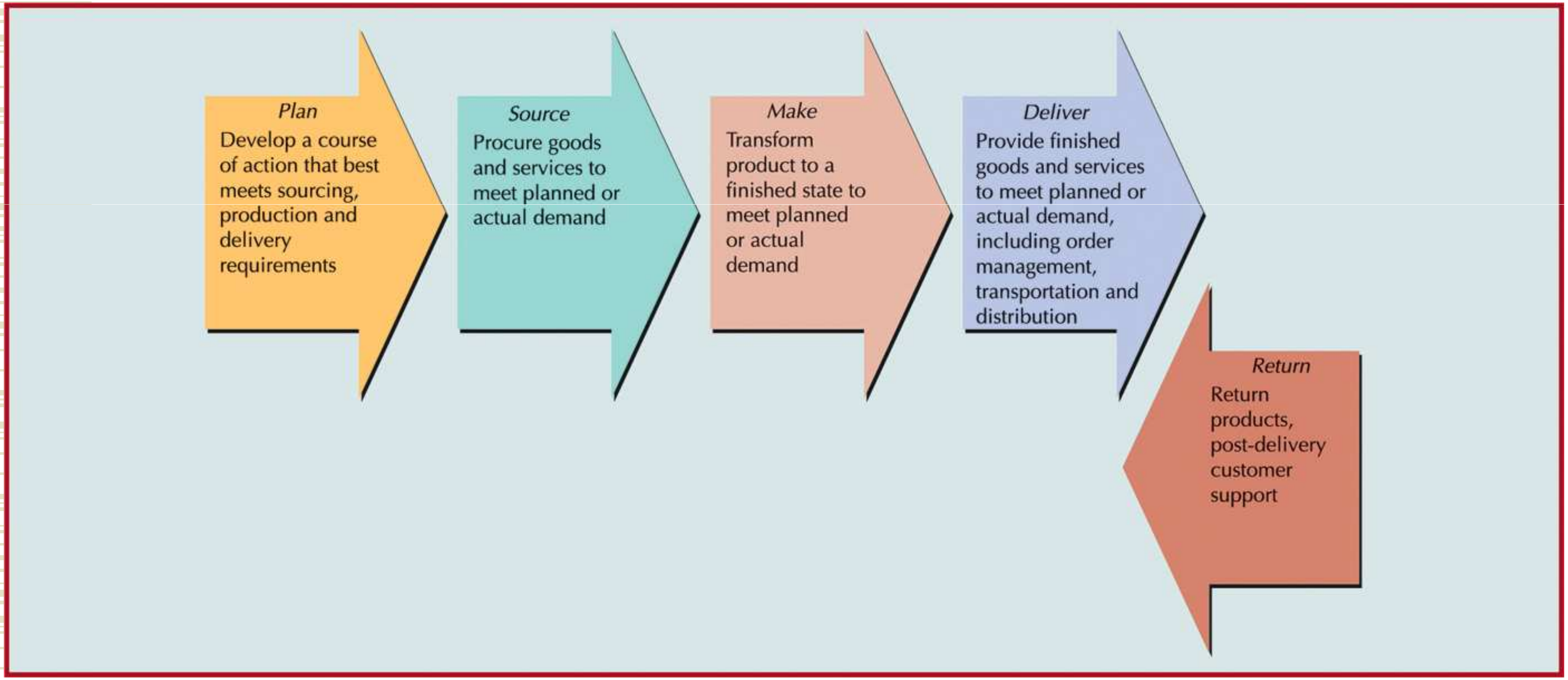
$$= \frac{\$34{,}416{,}000}{(425{,}000{,}000)/(365)}$$

$$\text{Days of supply} = 29.6$$

# Process Control and SCOR

- Process Control
  - not only for manufacturing operations
  - can be used in any processes of supply chain
- Supply Chain Operations Reference (SCOR)
  - a cross industry supply chain diagnostic tool maintained by the Supply Chain Council

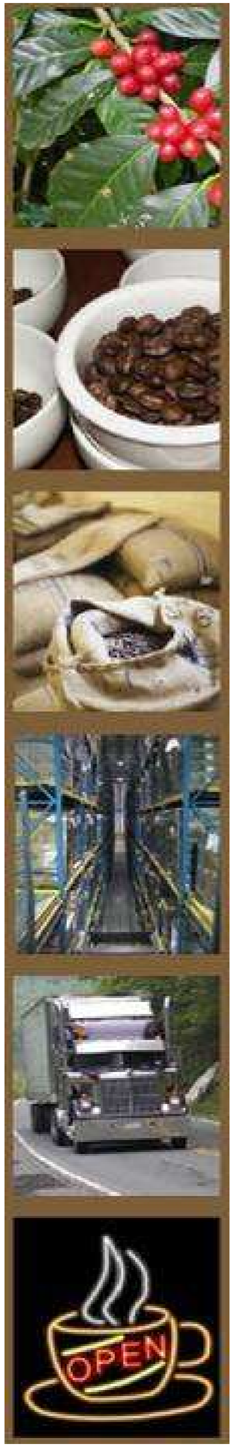
# SCOR



Plan
Develop a course of action that best meets sourcing, production and delivery requirements
Source
Procure goods and services to meet planned or actual demand
Make
Transform product to a finished state to meet planned or actual demand
Deliver
Provide finished goods and services to meet planned or actual demand, including order management, transportation and distribution
Return
Return products, post-delivery customer support

# SCOR (cont.)

| | Performance Attribute | Performance Metric | Definition |
|---|---|---|---|
| Customer Facing | Supply chain delivery reliability | Delivery performance | Percentage of orders delivered on time and in full to the customer |
| | | Fill rate | Percentage of orders shipped within 24 hours of order receipt |
| | | Perfect order fulfillment | Percentage of orders delivered on time and in full, perfectly matched with order with no errors |
| | Supply chain responsiveness | Order fulfillment lead time | Number of days from order receipt to customer delivery |
| | Supply chain flexibility | Supply chain response time | Number of days for the supply chain to respond to an unplanned significant change in demand without a cost penalty |
| | | Production flexibility | Number of days to achieve an unplanned 20% change in orders without a cost penalty |
| Internal Facing | Supply chain cost | Supply chain management cost | The direct and indirect cost to plan, source and deliver products and services |
| | | Cost of goods sold | The direct cost of material and labor to produce a product or service |
| | | Value-added productivity | Direct material cost subtracted from revenue and divided by the number of employees, similar to sales per employee |
| | | Warranty/returns processing cost | Direct and indirect costs associated with returns including defective, planned maintenance and excess inventory |
| | Supply Chain Asset Management Efficiency | Cash-to-cash cycle time | The number of days that cash is tied up as working capital |
| | | Inventory days of supply | The number of days that cash is tied up as inventory |
| | | Asset turns | Revenue divided by total assets including working capital and fixed assets |



# Chapter 11

## *Global Supply Chain Procurement and Distribution*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Procurement
- E-Procurement
- Distribution
- Transportation
- The Global Supply Chain

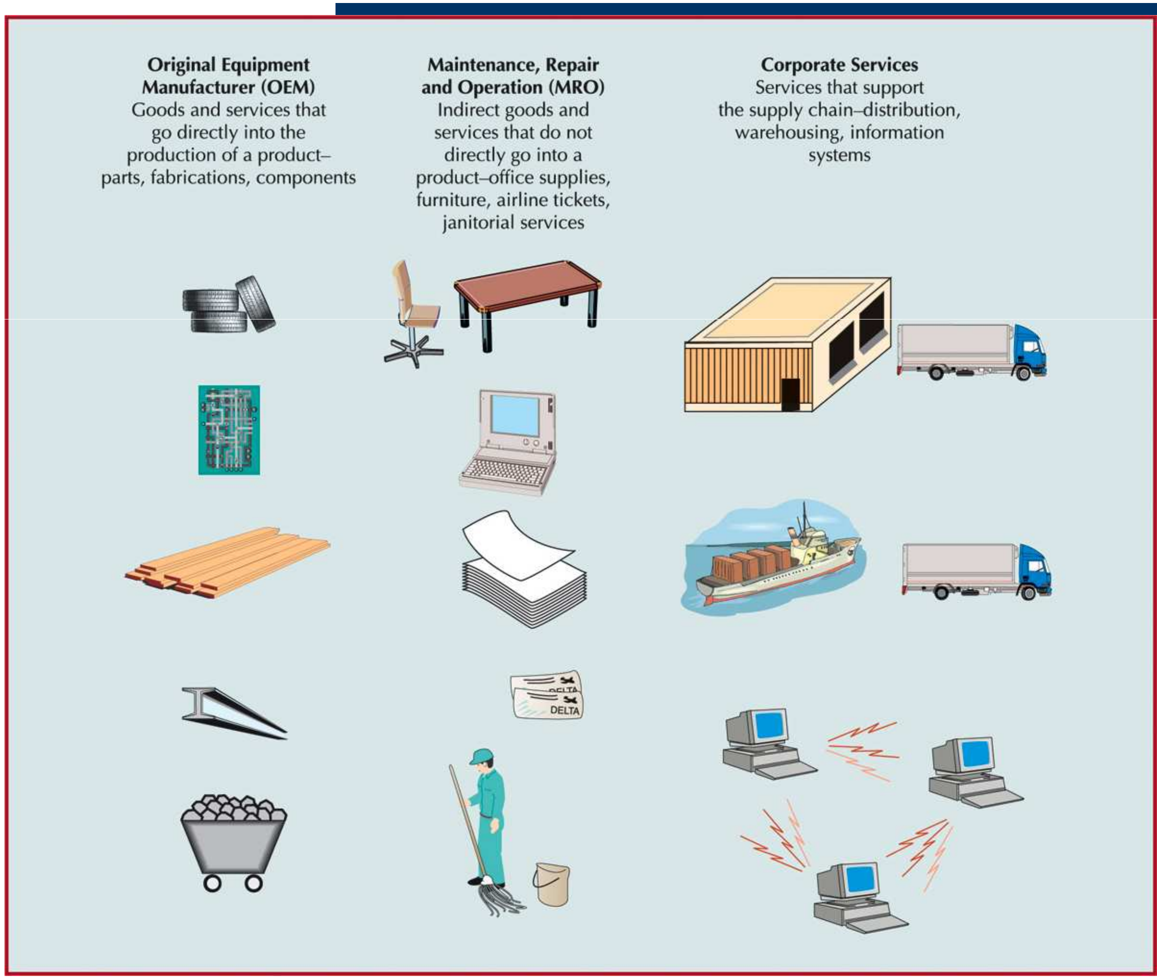
# Procurement

- The purchase of goods and services from suppliers
- Cross enterprise teams
  - coordinate processes between a company and its supplier
- On-demand (direct-response) delivery
  - requires the supplier to deliver goods when demanded by the customer
- Continuous replenishment
  - supplying orders in a short period of time according to a predetermined schedule

# Outsourcing

- Sourcing
  - selection of suppliers
- Outsourcing
  - purchase of goods and services from an outside supplier
- Core competencies
  - what a company does best
- Single sourcing
  - a company purchases goods and services from only a few (or one) suppliers

# Categories of Goods and Services...



# E-Procurement

- Direct purchase from suppliers over the Internet, by using software packages or through e-marketplaces, e-hubs, and trading exchanges
- Can streamline and speed up the purchase order and transaction process

# E-Procurement (cont.)

- What can companies buy over the Internet?
  - Manufacturing inputs
    - the raw materials and components that go directly into the production process of the product
  - Operating inputs
    - maintenance, repair, and operation goods and services

# E-Procurement (cont.)

- E-marketplaces (e-hubs)
  - Websites where companies and suppliers conduct business-to-business activities
- Reverse auction
  - process used by e-marketplaces for buyers to purchase items; company posts orders on the internet for suppliers to bid on

# Distribution

Encompasses all channels, processes, and functions, including warehousing and transportation, that a product passes on its way to final customer

Order fulfillment

process of ensuring on-time delivery of an order

Logistics

transportation and distribution of goods and services

Driving force today is speed

Particularly important for Internet dot-coms

# Distribution Centers (DC) and Warehousing

DCs are some of the largest business facilities in the United States

Trend is for more frequent orders in smaller quantities

Flow-through facilities and automated material handling

Postponement

final assembly and product configuration may be done at the DC

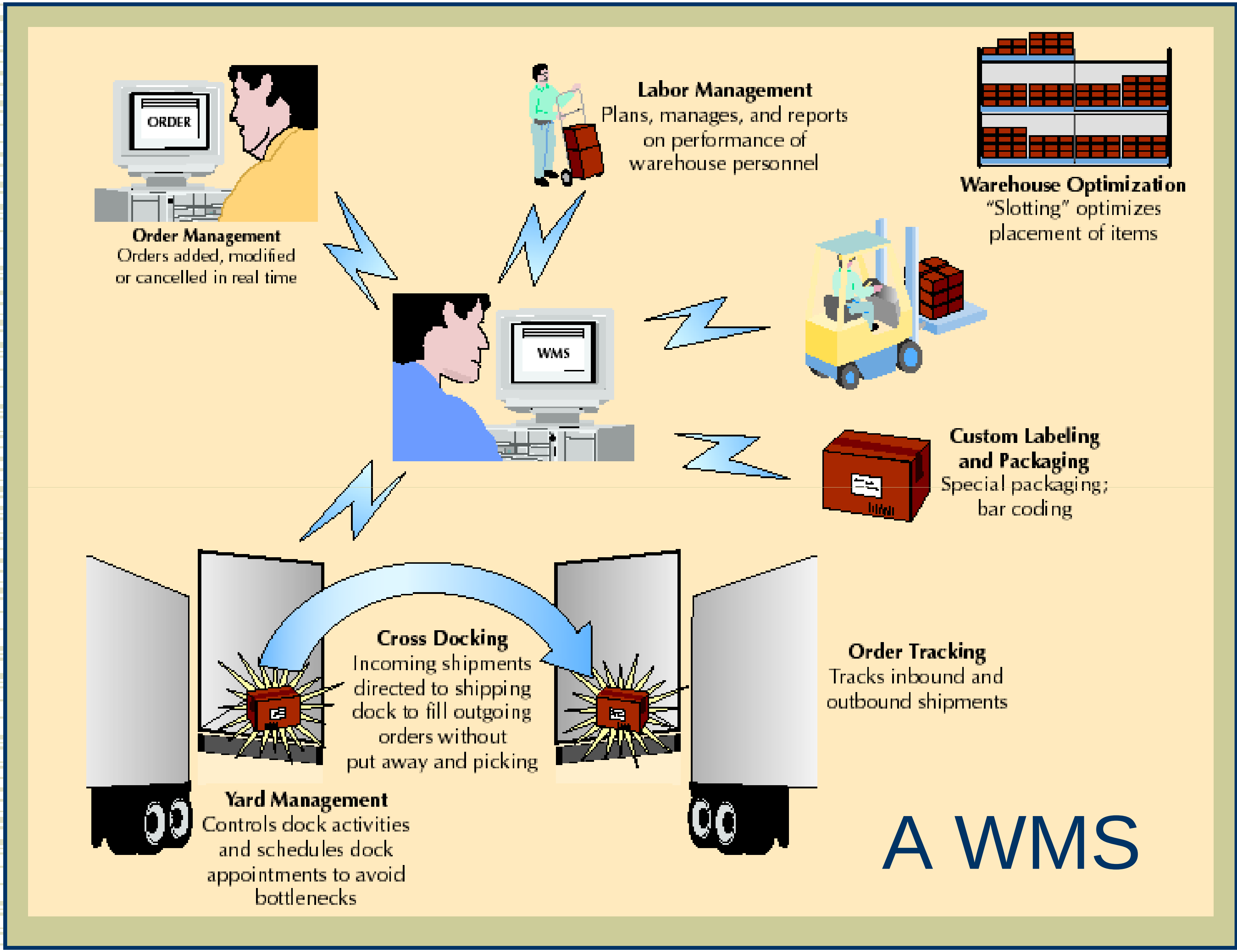
# Warehouse Management Systems

Highly automated system that runs day-to-day operations of a DC

Controls item putaway, picking, packing, and shipping

Features

- transportation management
- order management
- yard management
- labor management
- warehouse optimization


ORDER
Order Management
Orders added, modified or cancelled in real time
Labor Management
Plans, manages, and reports on performance of warehouse personnel
Warehouse Optimization
"Slotting" optimizes placement of items
WMS
Custom Labeling and Packaging
Special packaging; bar coding
Cross Docking
Incoming shipments directed to shipping dock to fill outgoing orders without put away and picking
Order Tracking
Tracks inbound and outbound shipments
Yard Management
Controls dock activities and schedules dock appointments to avoid bottlenecks
A WMS

# Vendor-Managed Inventory

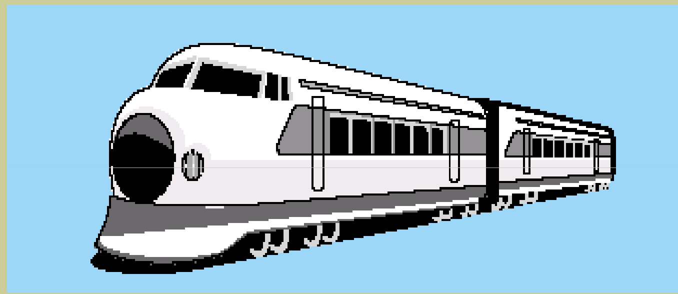
Manufacturers generate orders, not distributors or retailers
Stocking information is accessed using EDI
A first step towards supply chain collaboration
Increased speed, reduced errors, and improved service

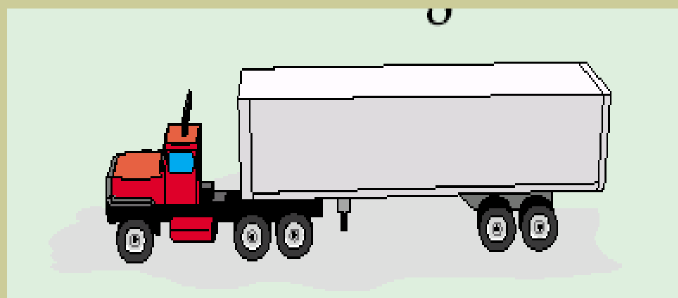
# Collaborative Logistics and Distribution Outsourcing

- Collaborative planning, forecasting, and replenishment create greater economies of scale
- Internet-based exchange of data and information
- Significant decrease in inventory levels and costs and more efficient logistics
- Companies focus on core competencies

# Transportation

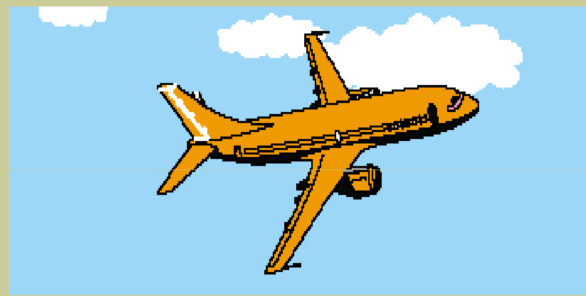
- **Rail**
  - low-value, high-density, bulk products, raw materials, intermodal containers
  - not as economical for small loads, slower, less flexible than trucking
- **Trucking**
  - main mode of freight transport in U.S.
  - small loads, point-to-point service, flexible
  - More reliable, less damage than rails; more expensive than rails for long distance

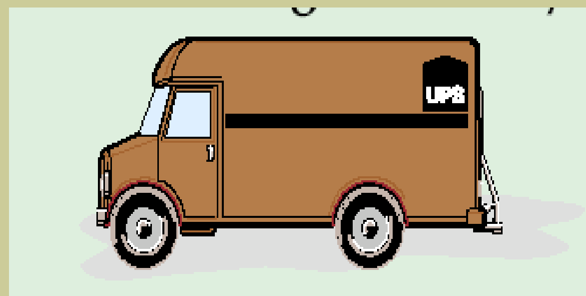




# Transportation (cont.)

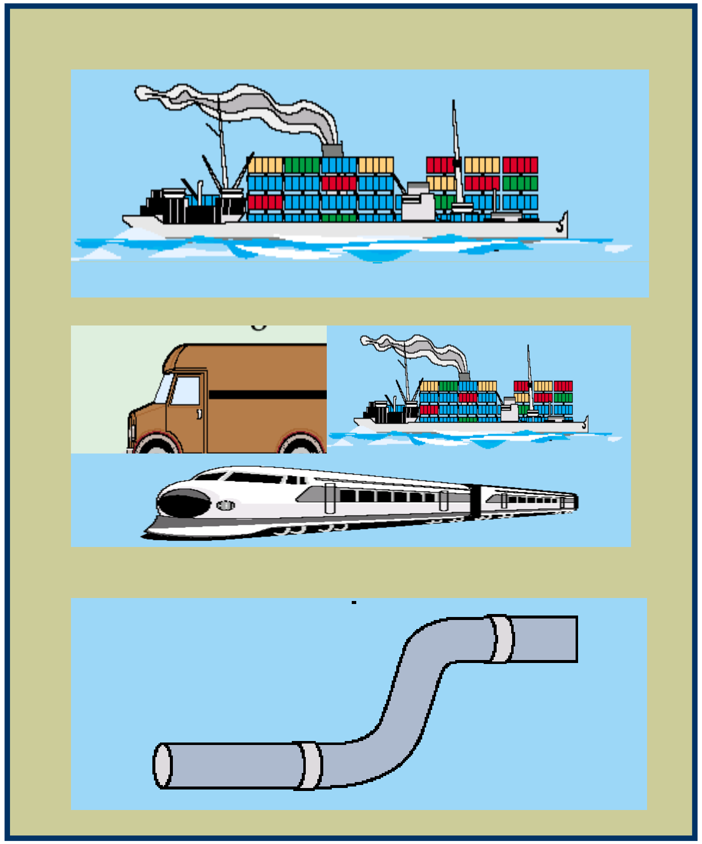
- Air
  - most expensive and fastest, mode of freight transport
  - lightweight, small packages <500 lbs
  - high-value, perishable and critical goods
  - less theft
- Package Delivery
  - small packages
  - fast and reliable
  - increased with e-Business
  - primary shipping mode for Internet companies





# Transportation (cont.)

- Water
  - low-cost shipping mode
  - primary means of international shipping
  - U.S. waterways
  - slowest shipping mode
- Intermodal
  - combines several modes of shipping-truck, water and rail
  - key component is containers
- Pipeline
  - transport oil and products in liquid form
  - high capital cost, economical use
  - long life and low operating cost



# Internet Transportation Exchanges

Bring together shippers and carriers
Initial contact, negotiations, auctions
Examples
www.nte.com
www.freightquote.com

# Global Supply Chain

International trade barriers have fallen

New trade agreements

To compete globally requires an effective supply chain

Information technology is an “enabler” of global trade

# Obstacles to Global Chain Transactions

- Increased documentation for invoices, cargo insurance, letters of credit, ocean bills of lading or air waybills, and inspections
- Ever changing regulations that vary from country to country that govern the import and export of goods
- Trade groups, tariffs, duties, and landing costs
- Limited shipping modes
- Differences in communication technology and availability

# Obstacles to Global Chain Transactions (cont.)

- Different business practices as well as language barriers
- Government codes and reporting requirements that vary from country to country
- Numerous players, including forwarding agents, custom house brokers, financial institutions, insurance providers, multiple transportation carriers, and government agencies
- Since 9/11, numerous security regulations and requirements

# Duties and Tariffs

Proliferation of trade agreements

Nations form trading groups

no tariffs or duties within group

charge uniform tariffs to nonmembers

Member nations have a competitive advantage within the group

Trade specialists

include freight forwarders, customs house brokers, export packers, and export management and trading companies

# Duties and Tariffs (cont.)

# Landed Cost

- Total cost of producing, storing, and transporting a product to the site of consumption or another port
- Value added tax (VAT)
  - an indirect tax assessed on the increase in value of a good at any stage of production process from raw material to final product
- Clicker shock
  - occurs when an ordered is placed with a company that does not have the capability to calculate landed cost

# Web-based International Trade Logistic Systems

- International trade logistics web-based software systems reduce obstacles to global trade
  - convert language and currency
  - provide information on tariffs, duties, and customs processes
  - attach appropriate weights, measurements, and unit prices to individual products ordered over the Web
  - incorporate transportation costs and conversion rates
  - calculate shipping costs online while a company enters an order
  - track global shipments

# Recent Trends in Globalization for U.S. Companies

- Two significant changes
  - passage of NAFTA
  - admission of China in WTO
- Mexico
  - cheap labor and relatively short shipping time
- China
  - cheaper labor and longer work week, but lengthy shipping time
  - Major supply chains have moved to China

# China's Increasing Role in the Global Supply Chain

- World's premier sources of supply
- Abundance of low-wage labor
- World's fastest growing market
- Regulatory changes have liberalized its market
- Increased exporting of higher technology products

# Models in Doing Business in China

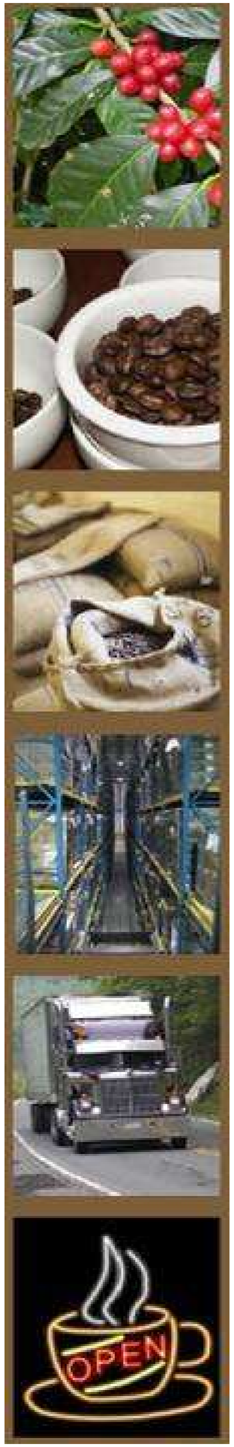
- Employ local third-party trading agents
- Wholly-owned foreign enterprise
- Develop your own international procurement offices

# Challenges Sourcing from China

- Getting reliable information in more difficult than in the U.S.
- Information technology is much less advanced and sophisticated than in the U.S.
- Work turnover rates among low-skilled workers is extremely high

# Effects of 9/11 on Global Chains

- Increase security measures
  - added time to supply chain schedules
  - Increased supply chain costs
- 24 hours rules for “risk screening”
  - extended documentation
  - extend time by 3-4 days
- Inventory levels have increased 5%
- Other costs include:
  - new people, technologies, equipment, surveillance, communication, and security systems, and training necessary for screening at airports and seaports around the world



# Chapter 11 Supplement

## *Transportation and Transshipment Models*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Transportation Model
- Transshipment Model

# Transportation Model

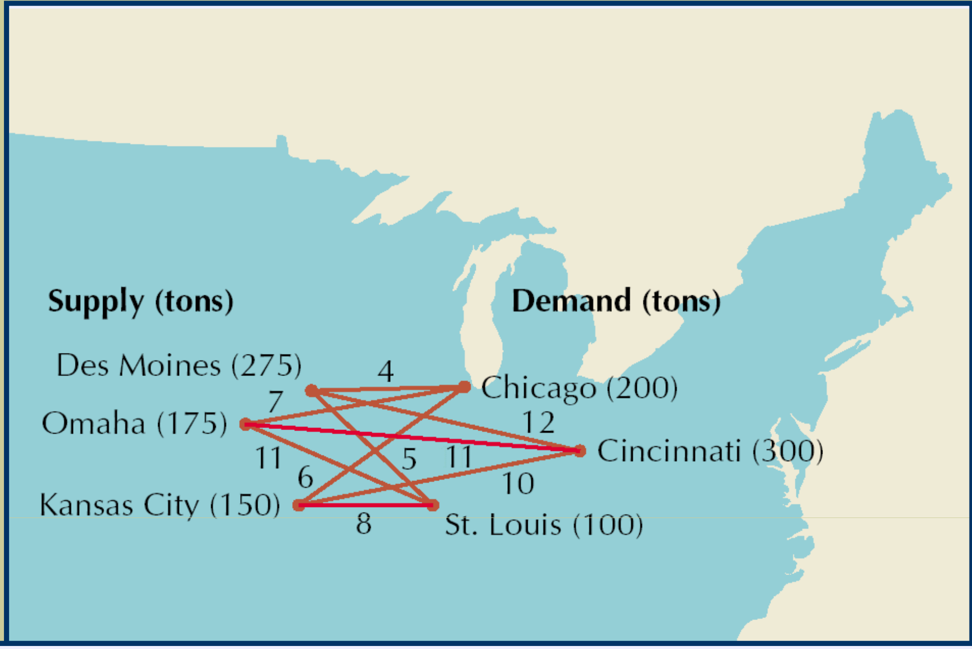
- A transportation model is formulated for a class of problems with the following characteristics
  - a product is transported from a number of sources to a number of destinations at the minimum possible cost
  - each source is able to supply a fixed number of units of product
  - each destination has a fixed demand for product
- Solution Methods
  - stepping-stone
  - modified distribution
  - Excel’s Solver

# Transportation Method: Example

| Distribution Center | Supply |
|---|---|
| 1. Kansas City | 150 |
| 2. Omaha | 175 |
| 3. Des Moines | 275 |
| | 600 tons |

| Plant | Demand |
|---|---|
| A. Chicago | 200 |
| B. St. Louis | 100 |
| C. Cincinnati | 300 |
| | 600 tons |

# Transportation Method: Example




| | Plant | | |
|---|---|---|---|
| **Distribution Center** | *Chicago* *A* | *St. Louis* *B* | *Cincinnati* *C* |
| Kansas City | $6 | $8 | $10 |
| Omaha | 7 | 11 | 11 |
| Des Moines | 4 | 5 | 12 |

# Problem Formulation Using Excel

**Total Cost Formula**

Microsoft Excel - Book1

B10 $f_x$ =B5*6+B6*7+B7*4+C5*8+C6*11+C7*5+D5*10+D6*11+D7*12

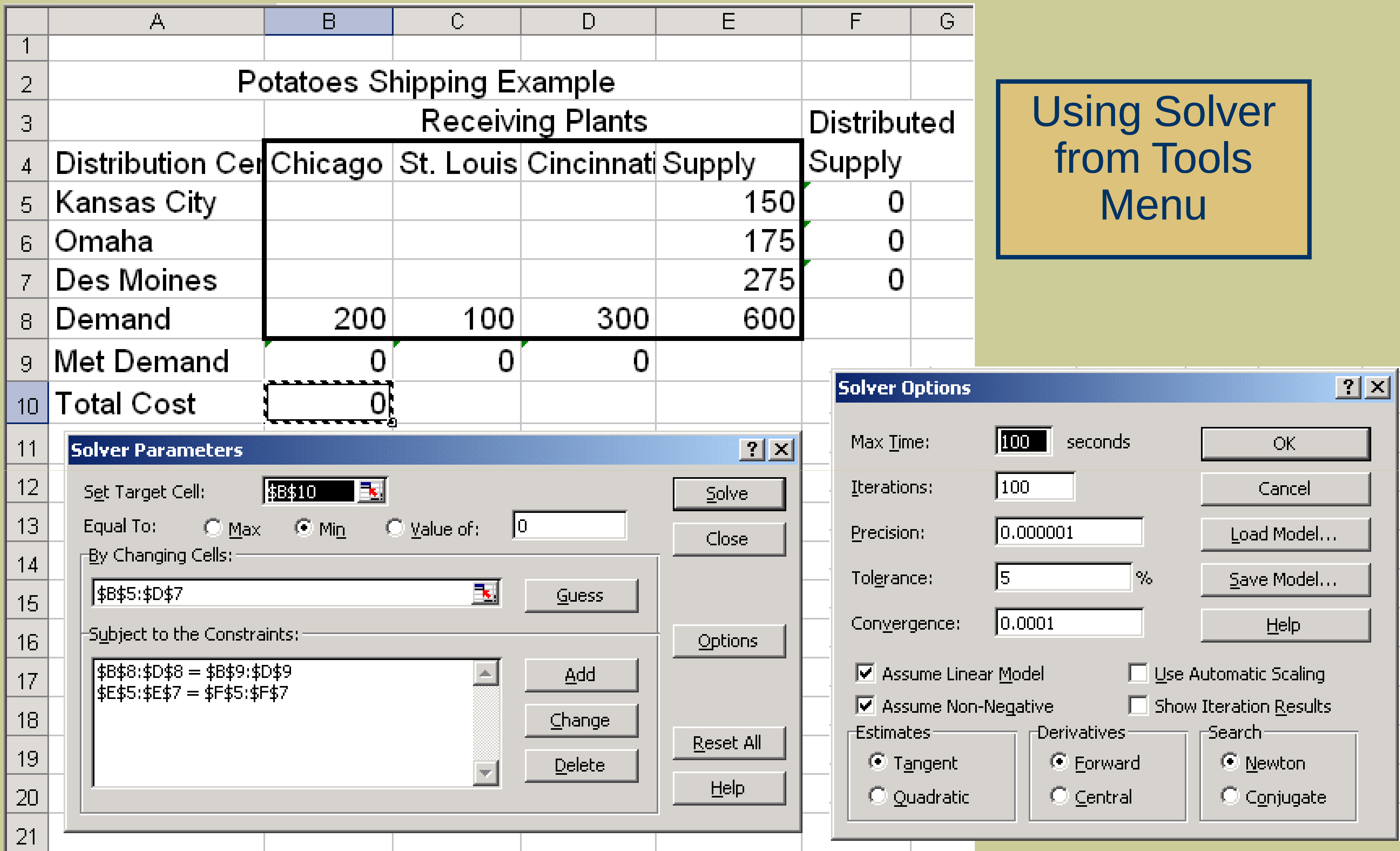
| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | Potatoes Shipping Example | | | | |
| 3 | | Receiving Plants | | | | Distributed |
| 4 | Distribution Centers | Chicago | St. Louis | Cincinnati | Supply | Supply |
| 5 | Kansas City | | | | 150 | 0 |
| 6 | Omaha | | | | 175 | 0 |
| 7 | Des Moines | | | | 275 | 0 |
| 8 | Demand | 200 | 100 | 300 | 600 | |
| 9 | Met Demand | 0 | 0 | 0 | | |
| 10 | Total Cost | 0 | | | | |

Microsoft Excel - Book1

B10 $f_x$ =B5*6+B6*7+B7*4+C5*8+C6*11+C7*5+D5*10+D6*11+D7*12

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | | | Potatoes Shipping Example | | | |
| 3 | | | Receiving Plants | | | |
| 4 | Distribution | Chicago | St. Louis | Cincinnati | Supply | Distributed Sup |
| 5 | Kansas City | | | | 150 | =SUM(B5:D5) |
| 6 | Omaha | | | | 175 | =SUM(B6:D6) |
| 7 | Des Moines | | | | 275 | =SUM(B7:D7) |
| 8 | Demand | 200 | 100 | 300 | =SUM(E5:E7) | |
| 9 | Met Demand | =SUM(B5:B7) | =SUM(C5:C7) | =SUM(D5:D7) | | |
| 10 | Total Cost | =B5*6+B6*7+ | | | | |
| 11 | | | | | | |

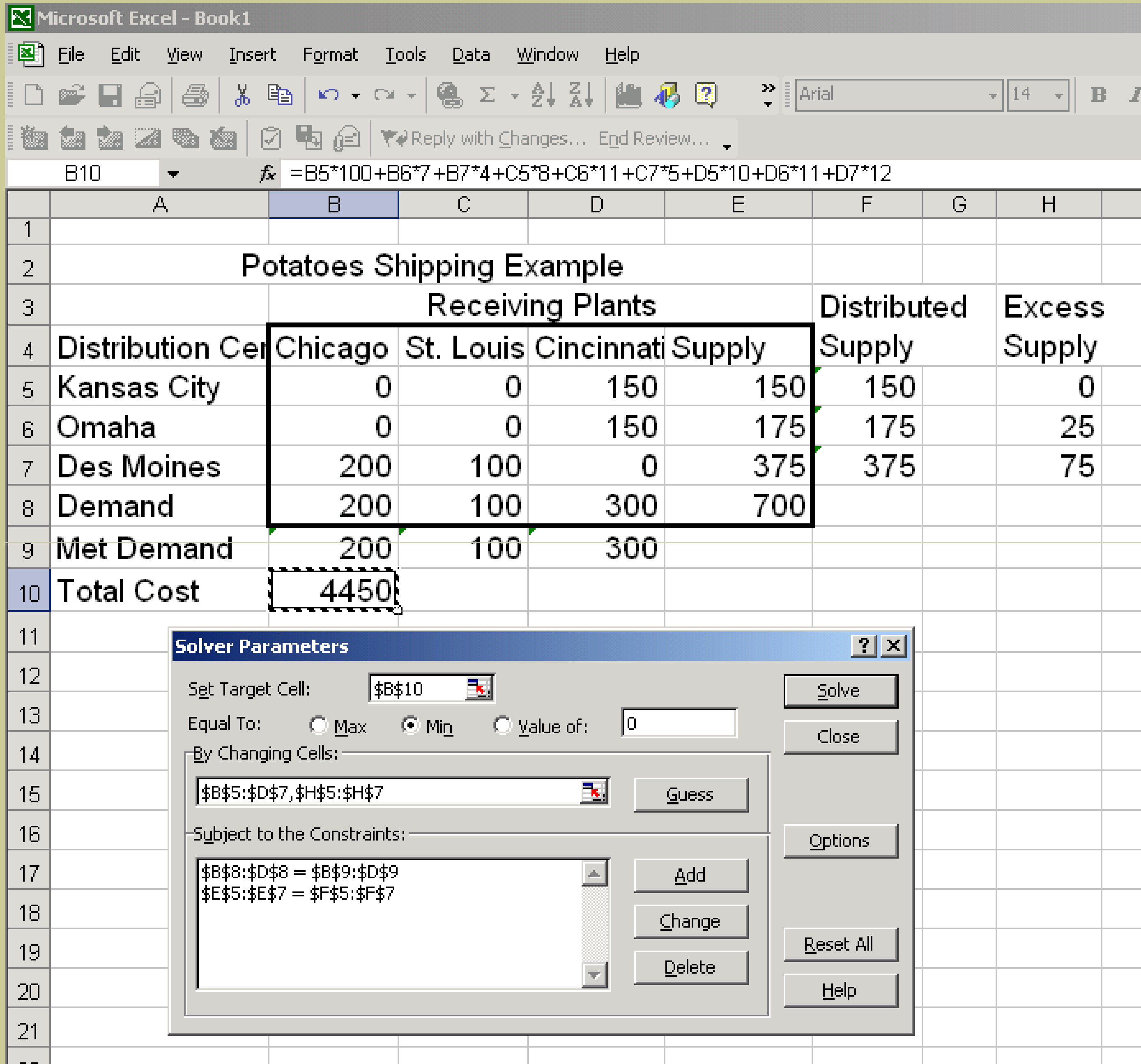
# Using Solver from Tools Menu



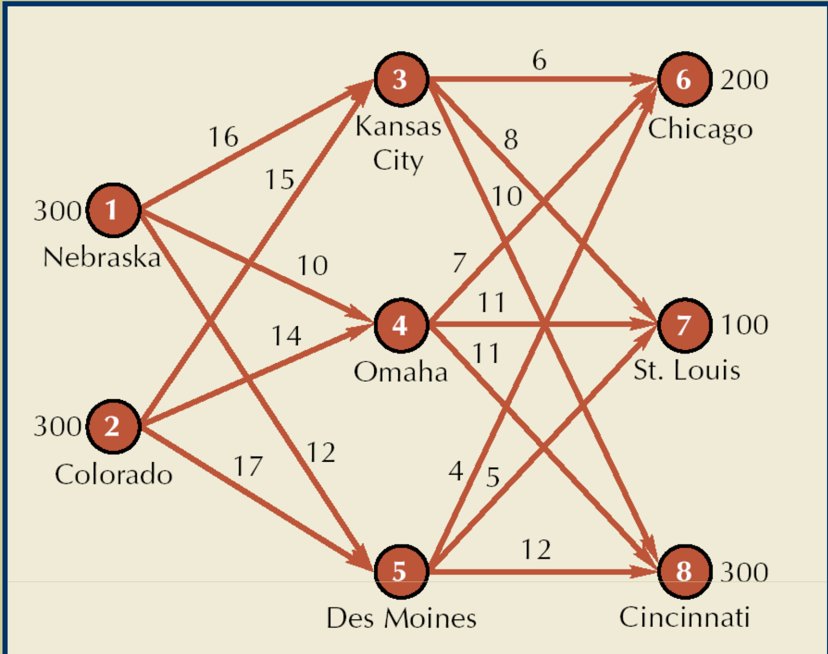
# Solution

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | | | | | | |
| 2 | Potatoes Shipping Example | | | | | |
| 3 | | Receiving Plants | | | | Distributed |
| 4 | Distribution Cer | Chicago | St. Louis | Cincinnati | Supply | Supply |
| 5 | Kansas City | 0 | 0 | 150 | 150 | 150 |
| 6 | Omaha | 25 | 0 | 150 | 175 | 175 |
| 7 | Des Moines | 175 | 100 | 0 | 275 | 275 |
| 8 | Demand | 200 | 100 | 300 | 600 | |
| 9 | Met Demand | 200 | 100 | 300 | | |
| 10 | Total Cost | 4525 | | | | |
| 11 | | | | | | |

# Modified Problem Solution



# Transshipment Model




| | Distribution Centers | | |
|---|---|---|---|
| Farm | 3. Kansas City | 4. Omaha | 5. Des Moines |
| 1. Nebraska | $16 | 10 | 12 |
| 2. Colorado | 15 | 14 | 17 |

# Transshipment Model: Solution

K11 | =SUM(K3:K4,K6:K8)

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 2 | From | Kansas City | Omaha | Des Moi | Supply | |
| 3 | Nebraska | 0 | 0 | 300 | 300 | 300 |
| 4 | Colorado | 0 | 300 | 0 | 300 | 300 |
| 5 | Total | 0 | 300 | 300 | 600 | |
| 6 | | | | | | |
| 7 | Unit Cost Table | | | | | |
| 8 | From | KC | Omaha | Des Moines | | |
| 9 | Nebraska | 16 | 10 | 12 | | |
| 10 | Colorado | 15 | 14 | 17 | | |
| 11 | | | | | | |
| 12 | | To | | | | |
| 13 | From | Chicago | St. Louis | Cincinna | Supply | |
| 14 | Kansas City | 0 | 0 | 0 | 0 | |
| 15 | Omaha | 0 | 0 | 300 | 300 | |
| 16 | Des Moines | 200 | 100 | 0 | 300 | |
| 17 | Demand | 200 | 100 | 300 | 600 | |
| 18 | Met Demand | 200 | 100 | 300 | | |
| 19 | | | | | | |
| 20 | Unit Cost Table | | | | | |
| 21 | From | Chicago | St. Louis | Cincinnati | | |
| 22 | Kansas City | 6 | 8 | 10 | | |
| 23 | Omaha | 7 | 11 | 11 | | |
| 24 | Des Moines | 4 | 5 | 12 | | |
| 25 | | | | | | |

| | H | I | J | K |
|---|---|---|---|---|
| 3 | 0 | 0 | 3600 | 3600 |
| 4 | 0 | 4200 | 0 | 4200 |
| 5 | | | | |
| 6 | 0 | 0 | 0 | 0 |
| 7 | 0 | 0 | 3300 | 3300 |
| 8 | 800 | 500 | 0 | 1300 |
| 11 | | TOTAL COST | | 12400 |

**Solver Parameters**

Set Target Cell: $K$11

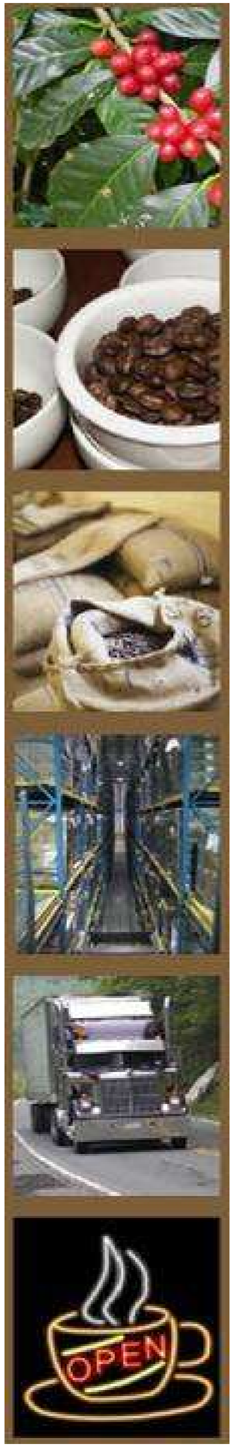
Equal To: Max / (•) Min / Value of: 0

By Changing Cells: $B$14:$D$16,$B$3:$D$4

Subject to the Constraints:

$B$17:$D$17 = $B$18:$D$18
$B$5:$D$5 = $E$14:$E$16
$E$3:$E$4 = $F$3:$F$4

Solve | Close | Guess | Options | Add | Change | Delete | Reset All | Help



# Chapter 12

## *Forecasting*

***Operations Management***

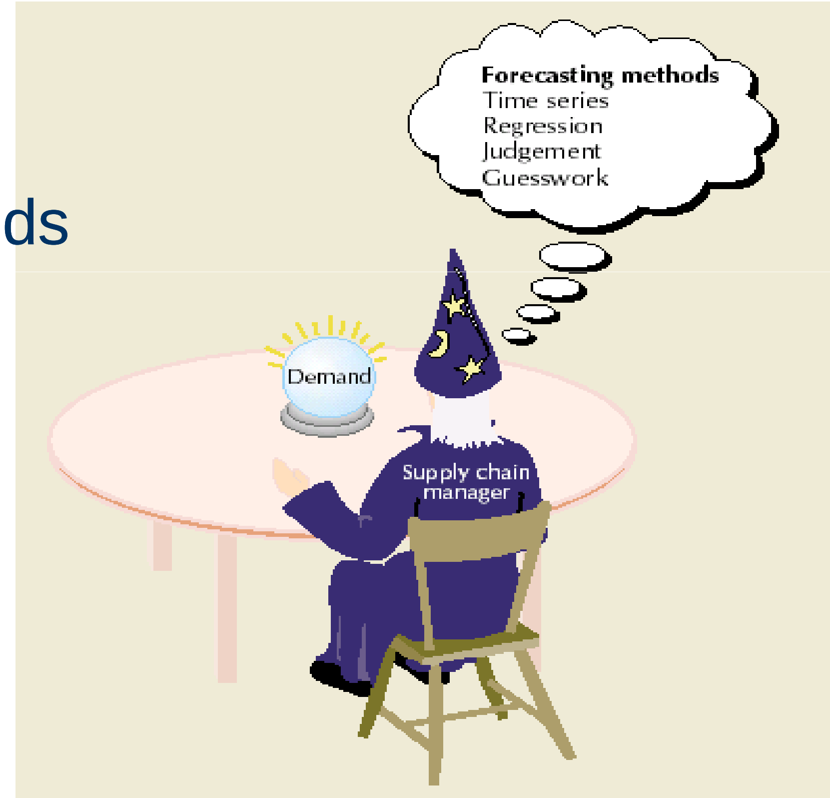
**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Strategic Role of Forecasting in Supply Chain Management
- Components of Forecasting Demand
- Time Series Methods
- Forecast Accuracy
- Time Series Forecasting Using Excel
- Regression Methods

# Forecasting

- Predicting the future
- Qualitative forecast methods
  - subjective
- Quantitative forecast methods
  - based on mathematical formulas



# Forecasting and Supply Chain Management

- Accurate forecasting determines how much inventory a company must keep at various points along its supply chain
- Continuous replenishment
  - supplier and customer share continuously updated data
  - typically managed by the supplier
  - reduces inventory for the company
  - speeds customer delivery
- Variations of continuous replenishment
  - quick response
  - JIT (just-in-time)
  - VMI (vendor-managed inventory)
  - stockless inventory

# Forecasting

- Quality Management
  - Accurately forecasting customer demand is a key to providing good quality service
- Strategic Planning
  - Successful strategic planning requires accurate forecasts of future products and markets

# Types of Forecasting Methods

- Depend on
  - time frame
  - demand behavior
  - causes of behavior

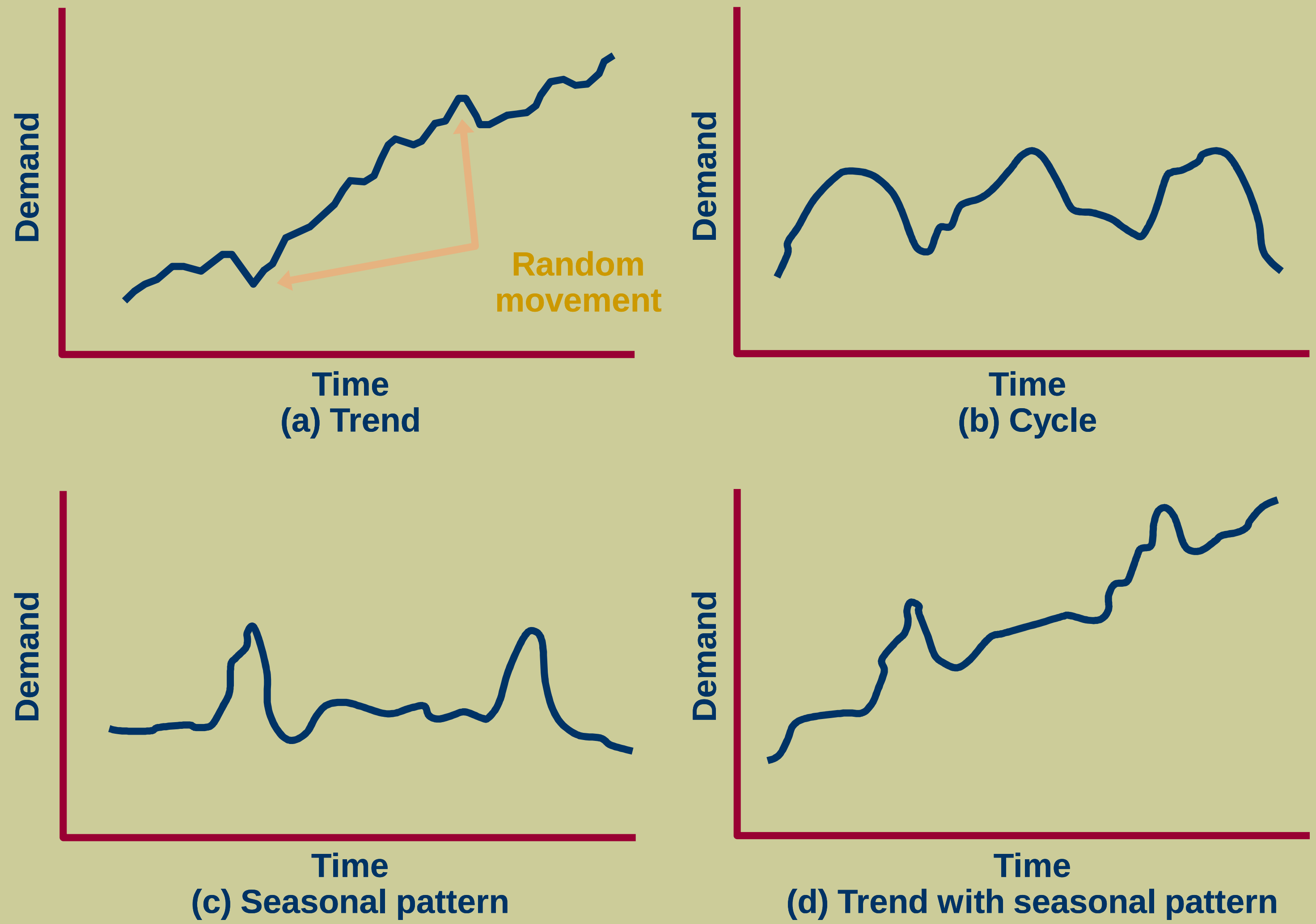
# Time Frame

- Indicates how far into the future is forecast
  - Short- to mid-range forecast
    - typically encompasses the immediate future
    - daily up to two years
  - Long-range forecast
    - usually encompasses a period of time longer than two years

# Demand Behavior

- Trend
  - a gradual, long-term up or down movement of demand
- Random variations
  - movements in demand that do not follow a pattern
- Cycle
  - an up-and-down repetitive movement in demand
- Seasonal pattern
  - an up-and-down repetitive movement in demand occurring periodically

# Forms of Forecast Movement



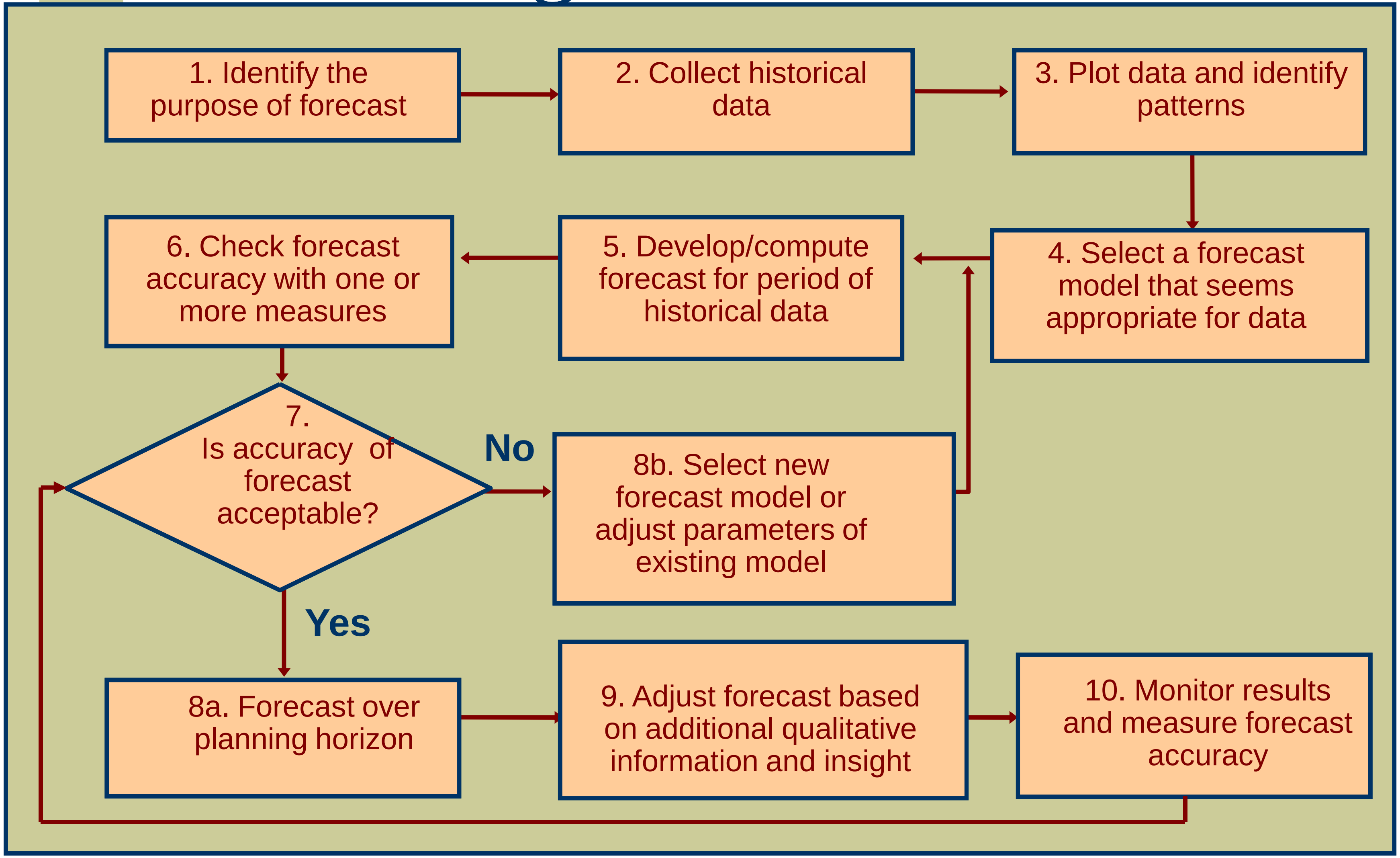
# Forecasting Methods

- Time series
  - statistical techniques that use historical demand data to predict future demand
- Regression methods
  - attempt to develop a mathematical relationship between demand and factors that cause its behavior
- Qualitative
  - use management judgment, expertise, and opinion to predict future demand

# Qualitative Methods

- Management, marketing, purchasing, and engineering are sources for internal qualitative forecasts
- Delphi method
  - involves soliciting forecasts about technological advances from experts

# Forecasting Process



# Time Series

- Assume that what has occurred in the past will continue to occur in the future
- Relate the forecast to only one factor - time
- Include
  - moving average
  - exponential smoothing
  - linear trend line

# Moving Average

- *Naive* forecast
  - demand in current period is used as next period's forecast
- Simple moving average
  - uses average demand for a fixed sequence of periods
  - stable demand with no pronounced behavioral patterns
- Weighted moving average
  - weights are assigned to most recent data

# Moving Average: Naïve Approach

| MONTH | ORDERS PER MONTH | FORECAST |
|---|---|---|
| Jan | 120 | - |
| Feb | 90 | 120 |
| Mar | 100 | 90 |
| Apr | 75 | 100 |
| May | 110 | 75 |
| June | 50 | 110 |
| July | 75 | 50 |
| Aug | 130 | 75 |
| Sept | 110 | 130 |
| Oct | 90 | 110 |
| Nov | - | 90 |

# Simple Moving Average

$$MA_n = \frac{\sum_{i=1}^{n} D_i}{n}$$

where

$n$ = number of periods in the moving average

$D_i$ = demand in period $i$

# 3-month Simple Moving Average

| MONTH | ORDERS PER MONTH | MOVING AVERAGE |
|---|---|---|
| Jan | 120 | – |
| Feb | 90 | – |
| Mar | 100 | – |
| Apr | 75 | 103.3 |
| May | 110 | 88.3 |
| June | 50 | 95.0 |
| July | 75 | 78.3 |
| Aug | 130 | 78.3 |
| Sept | 110 | 85.0 |
| Oct | 90 | 105.0 |
| Nov | - | 110.0 |

$$MA_3 = \frac{\sum_{i=1}^{3} D_i}{3}$$

$$= \frac{90 + 110 + 130}{3}$$

= 110 orders for Nov

# 5-month Simple Moving Average

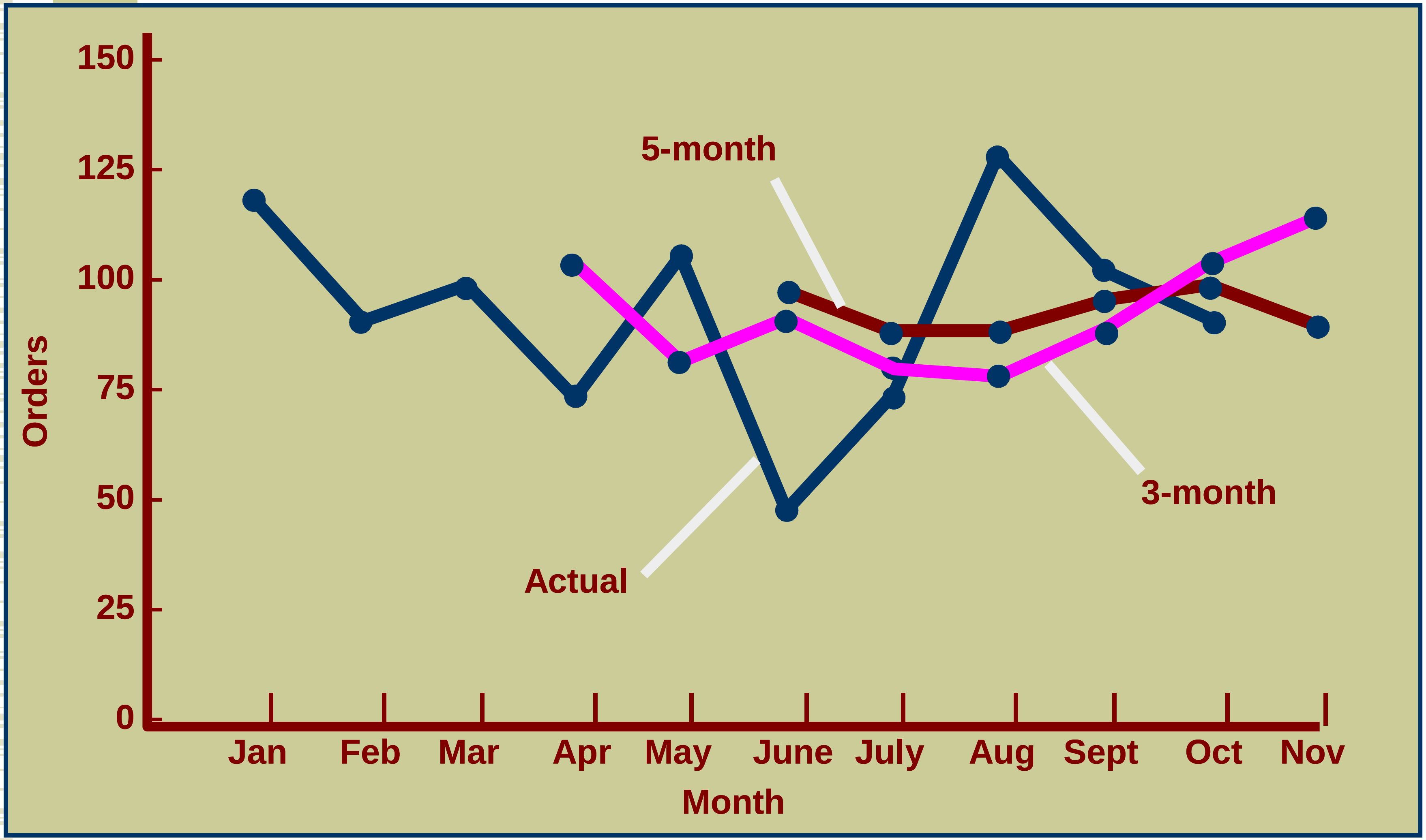
| MONTH | ORDERS PER MONTH | MOVING AVERAGE |
|---|---|---|
| Jan | 120 | – |
| Feb | 90 | – |
| Mar | 100 | – |
| Apr | 75 | – |
| May | 110 | – |
| June | 50 | 99.0 |
| July | 75 | 85.0 |
| Aug | 130 | 82.0 |
| Sept | 110 | 88.0 |
| Oct | 90 | 95.0 |
| Nov | - | 91.0 |

$$MA_5 = \frac{\sum_{i=1}^{5} D_i}{5}$$

$$= \frac{90 + 110 + 130+75+50}{5}$$

= 91 orders for Nov

# Smoothing Effects



# Weighted Moving Average

Adjusts moving average method to more closely reflect data fluctuations

$$WMA_n = \sum_{i=1}^{n} W_i D_i$$

where

$W_i$ = the weight for period $i$, between 0 and 100 percent

$$\sum W_i = 1.00$$

# Weighted Moving Average Example

| MONTH | WEIGHT | DATA |
|---|---|---|
| *August* | 17% | 130 |
| *September* | 33% | 110 |
| *October* | 50% | 90 |

November Forecast $WMA_3 = \sum_{i=1}^{3} W_i D_i$

$= (0.50)(90) + (0.33)(110) + (0.17)(130)$

$= 103.4$ orders

# Exponential Smoothing

Averaging method

Weights most recent data more strongly

Reacts more to recent changes

Widely used, accurate method

# Exponential Smoothing (cont.)

$$F_{t+1} = \alpha D_t + (1 - \alpha)F_t$$

where:

$F_{t+1}$ = forecast for next period

$D_t$ = actual demand for present period

$F_t$ = previously determined forecast for present period

$\alpha$ = weighting factor, smoothing constant

# Effect of Smoothing Constant

$0.0 \leq \alpha \leq 1.0$

If $\alpha = 0.20$, then $F_{t+1} = 0.20\, D_t + 0.80\, F_t$

If $\alpha = 0$, then $F_{t+1} = 0\, D_t + 1\, F_t = F_t$

*Forecast does not reflect recent data*

If $\alpha = 1$, then $F_{t+1} = 1\, D_t + 0\, F_t = D_t$

*Forecast based only on most recent data*

# Exponential Smoothing ($\alpha$=0.30)

| PERIOD | MONTH | DEMAND |
|---|---|---|
| 1 | Jan | 37 |
| 2 | Feb | 40 |
| 3 | Mar | 41 |
| 4 | Apr | 37 |
| 5 | May | 45 |
| 6 | Jun | 50 |
| 7 | Jul | 43 |
| 8 | Aug | 47 |
| 9 | Sep | 56 |
| 10 | Oct | 52 |
| 11 | Nov | 55 |
| 12 | Dec | 54 |

$$F_2 = \alpha D_1 + (1 - \alpha)F_1$$
$$= (0.30)(37) + (0.70)(37)$$
$$= 37$$

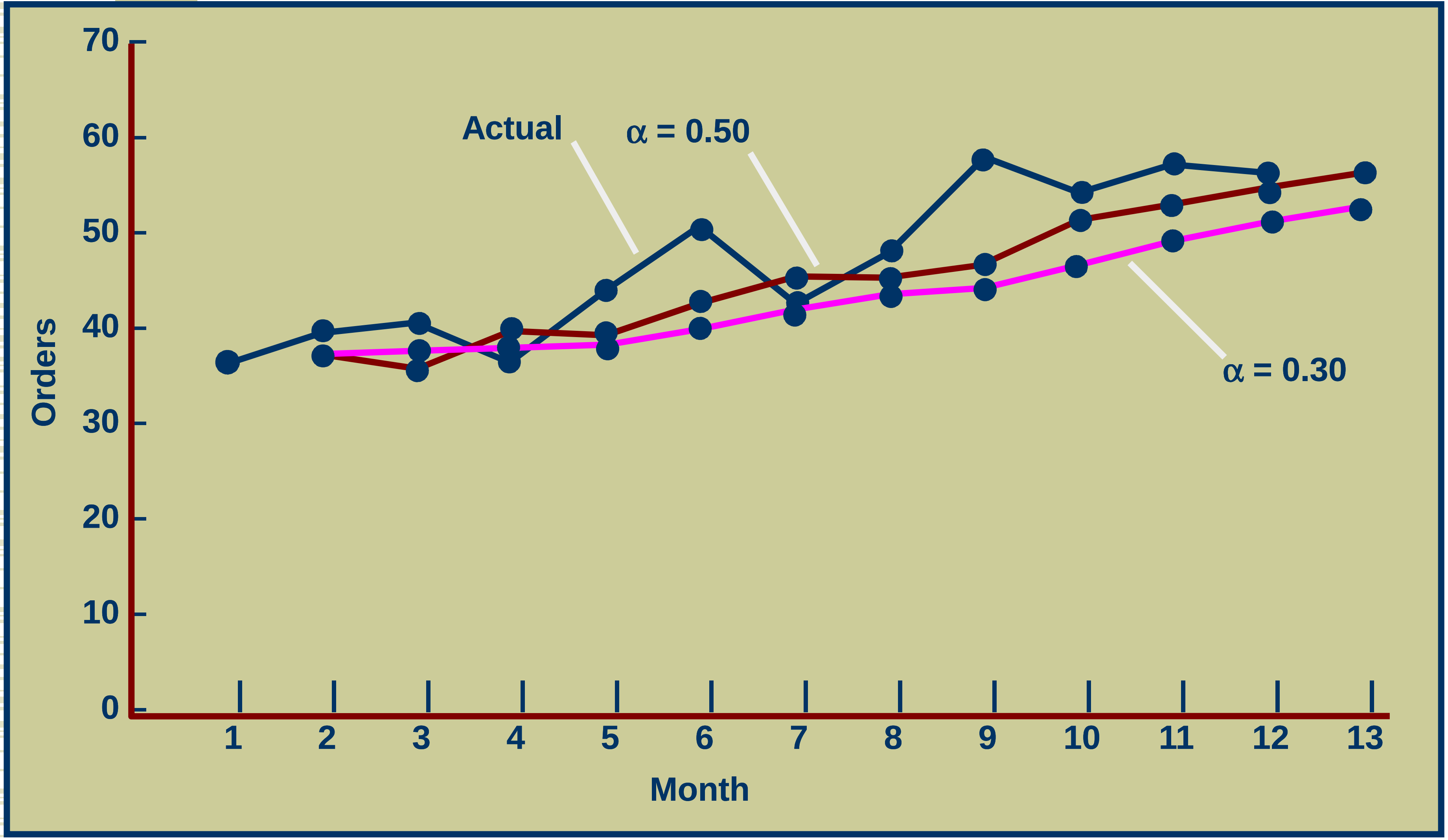
$$F_3 = \alpha D_2 + (1 - \alpha)F_2$$
$$= (0.30)(40) + (0.70)(37)$$
$$= 37.9$$

$$F_{13} = \alpha D_{12} + (1 - \alpha)F_{12}$$
$$= (0.30)(54) + (0.70)(50.84)$$
$$= 51.79$$

# Exponential Smoothing (cont.)

| PERIOD | MONTH | DEMAND | FORECAST, $F_{t+1}$ ($\alpha = 0.3$) | ($\alpha = 0.5$) |
|---|---|---|---|---|
| 1 | Jan | 37 | – | – |
| 2 | Feb | 40 | 37.00 | 37.00 |
| 3 | Mar | 41 | 37.90 | 38.50 |
| 4 | Apr | 37 | 38.83 | 39.75 |
| 5 | May | 45 | 38.28 | 38.37 |
| 6 | Jun | 50 | 40.29 | 41.68 |
| 7 | Jul | 43 | 43.20 | 45.84 |
| 8 | Aug | 47 | 43.14 | 44.42 |
| 9 | Sep | 56 | 44.30 | 45.71 |
| 10 | Oct | 52 | 47.81 | 50.85 |
| 11 | Nov | 55 | 49.06 | 51.42 |
| 12 | Dec | 54 | 50.84 | 53.21 |
| 13 | Jan | – | 51.79 | 53.61 |

# Exponential Smoothing (cont.)



# Adjusted Exponential Smoothing

$$AF_{t+1} = F_{t+1} + T_{t+1}$$

where

$T$ = an exponentially smoothed trend factor

$$T_{t+1} = \beta(F_{t+1} - F_t) + (1 - \beta)\, T_t$$

where

$T_t$ = the last period trend factor

$\beta$ = a smoothing constant for trend

# Adjusted Exponential Smoothing ($\beta$=0.30)

| PERIOD | MONTH | DEMAND |
|---|---|---|
| 1 | Jan | 37 |
| 2 | Feb | 40 |
| 3 | Mar | 41 |
| 4 | Apr | 37 |
| 5 | May | 45 |
| 6 | Jun | 50 |
| 7 | Jul | 43 |
| 8 | Aug | 47 |
| 9 | Sep | 56 |
| 10 | Oct | 52 |
| 11 | Nov | 55 |
| 12 | Dec | 54 |

$$T_3 = \beta(F_3 - F_2) + (1 - \beta)\, T_2$$
$$= (0.30)(38.5 - 37.0) + (0.70)(0)$$
$$= 0.45$$

$$AF_3 = F_3 + T_3 = 38.5 + 0.45$$
$$= 38.95$$

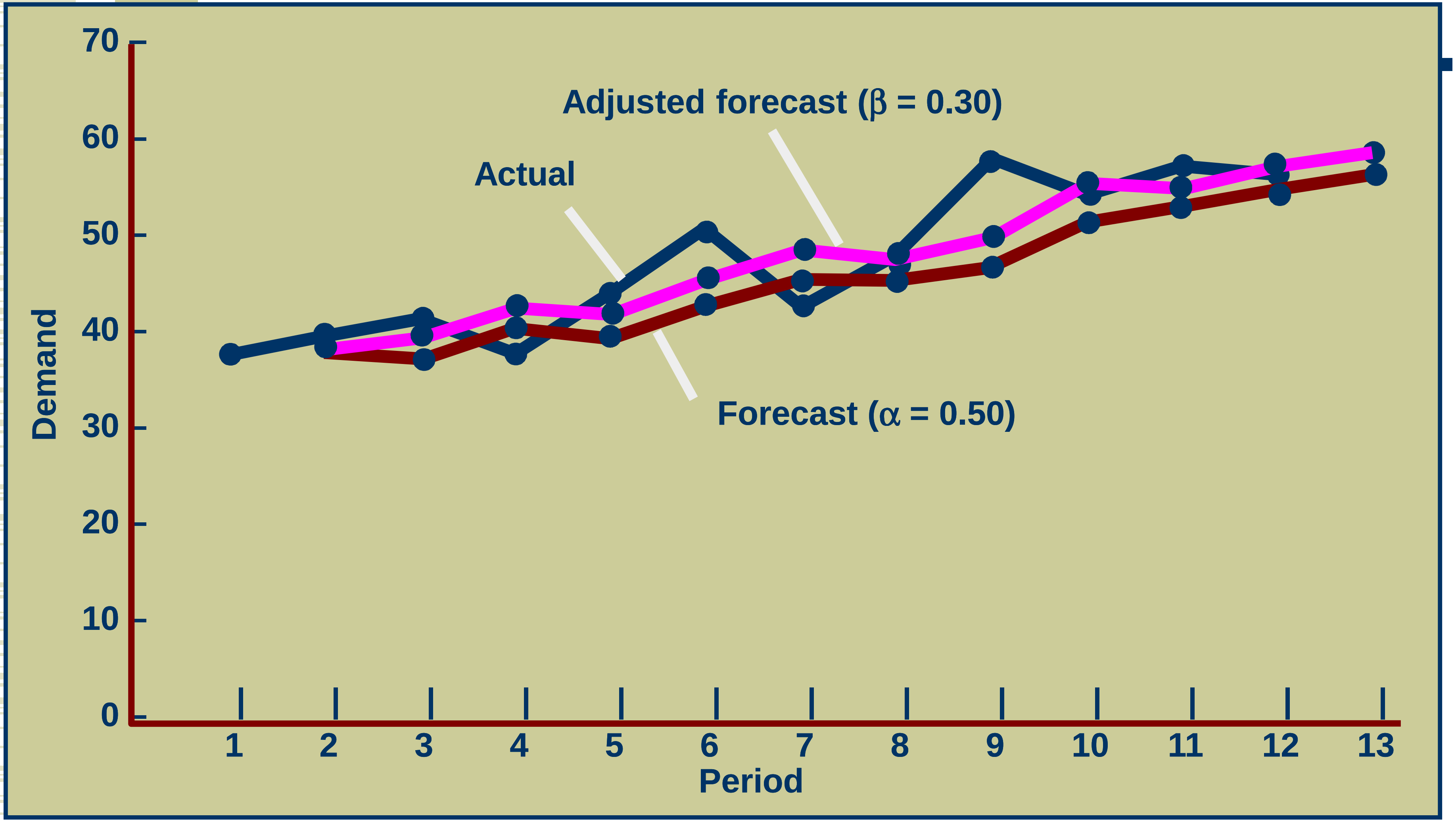
$$T_{13} = \beta(F_{13} - F_{12}) + (1 - \beta)\, T_{12}$$
$$= (0.30)(53.61 - 53.21) + (0.70)(1.77)$$
$$= 1.36$$

$$AF_{13} = F_{13} + T_{13} = 53.61 + 1.36 = 54.97$$

# Adjusted Exponential Smoothing: Example

| PERIOD | MONTH | DEMAND | FORECAST $F_{t+1}$ | TREND $T_{t+1}$ | ADJUSTED FORECAST $AF_{t+1}$ |
|---|---|---|---|---|---|
| 1 | Jan | 37 | 37.00 | – | – |
| 2 | Feb | 40 | 37.00 | 0.00 | 37.00 |
| 3 | Mar | 41 | 38.50 | 0.45 | 38.95 |
| 4 | Apr | 37 | 39.75 | 0.69 | 40.44 |
| 5 | May | 45 | 38.37 | 0.07 | 38.44 |
| 6 | Jun | 50 | 38.37 | 0.07 | 38.44 |
| 7 | Jul | 43 | 45.84 | 1.97 | 47.82 |
| 8 | Aug | 47 | 44.42 | 0.95 | 45.37 |
| 9 | Sep | 56 | 45.71 | 1.05 | 46.76 |
| 10 | Oct | 52 | 50.85 | 2.28 | 58.13 |
| 11 | Nov | 55 | 51.42 | 1.76 | 53.19 |
| 12 | Dec | 54 | 53.21 | 1.77 | 54.98 |
| 13 | Jan | – | 53.61 | 1.36 | 54.96 |

# Adjusted Exponential Smoothing Forecasts



# Linear Trend Line

$y = a + bx$

where
$a$ = intercept
$b$ = slope of the line
$x$ = time period
$y$ = forecast for demand for period $x$

$$b = \frac{\Sigma xy - n\bar{x}\bar{y}}{\Sigma x^2 - n\bar{x}^2}$$

$$a = \bar{y} - b\bar{x}$$

where
$n$ = number of periods

$\bar{x} = \frac{\Sigma x}{n}$ = mean of the $x$ values

$\bar{y} = \frac{\Sigma y}{n}$ = mean of the $y$ values

# Least Squares Example

| $x$(PERIOD) | $y$(DEMAND) | $xy$ | $x^2$ |
|---|---|---|---|
| 1 | 73 | 37 | 1 |
| 2 | 40 | 80 | 4 |
| 3 | 41 | 123 | 9 |
| 4 | 37 | 148 | 16 |
| 5 | 45 | 225 | 25 |
| 6 | 50 | 300 | 36 |
| 7 | 43 | 301 | 49 |
| 8 | 47 | 376 | 64 |
| 9 | 56 | 504 | 81 |
| 10 | 52 | 520 | 100 |
| 11 | 55 | 605 | 121 |
| 12 | 54 | 648 | 144 |
| 78 | 557 | 3867 | 650 |

# Least Squares Example (cont.)

$$\bar{x} = \frac{78}{12} = 6.5$$

$$\bar{y} = \frac{557}{12} = 46.42$$

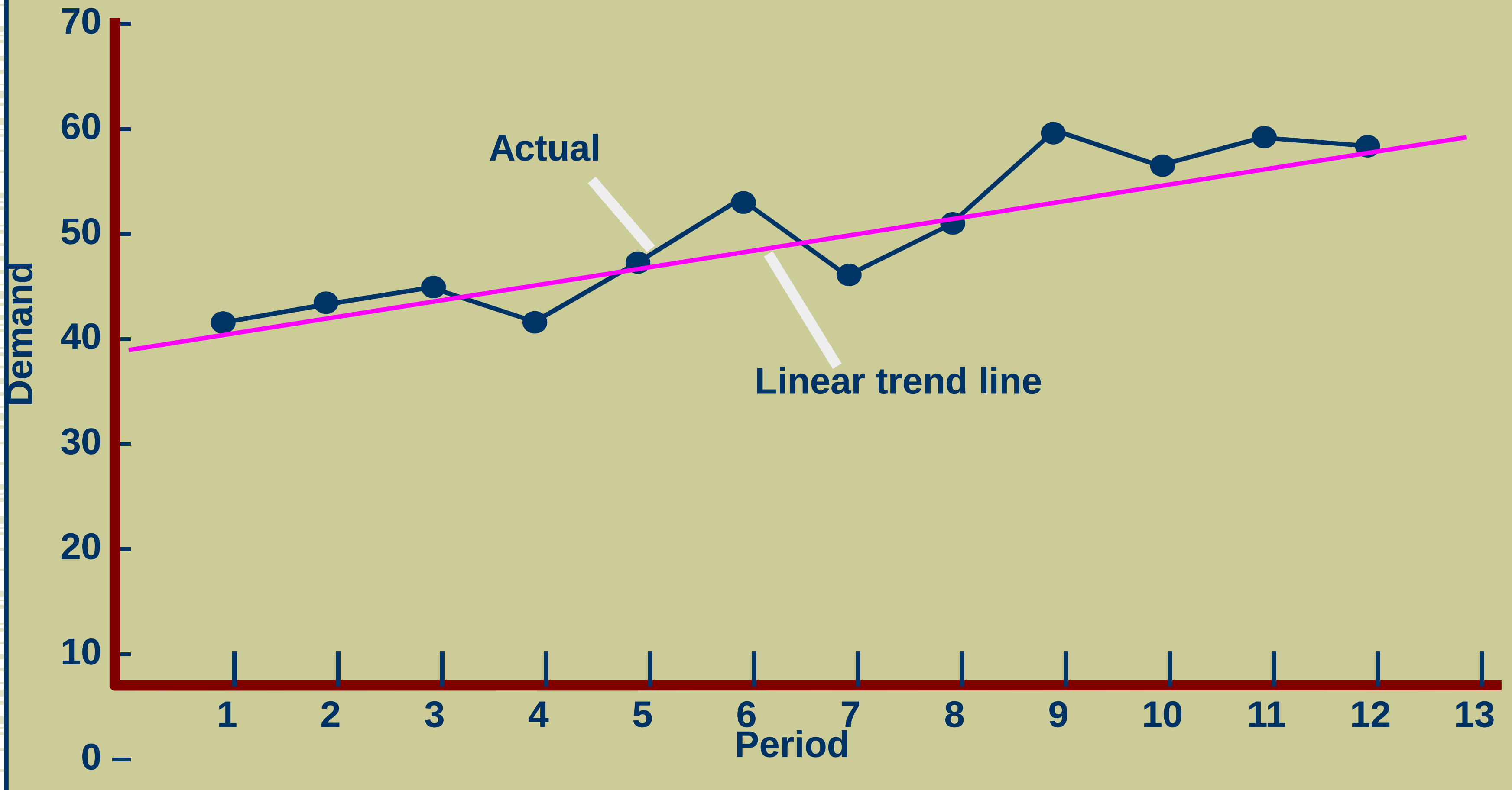
$$b = \frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2} = \frac{3867 - (12)(6.5)(46.42)}{650 - 12(6.5)^2} = 1.72$$

$$a = \bar{y} - b\bar{x}$$

$$= 46.42 - (1.72)(6.5) = 35.2$$

Linear trend line $y = 35.2 + 1.72x$

Forecast for period 13 $y = 35.2 + 1.72(13) = 57.56$ units



# Seasonal Adjustments

Repetitive increase/ decrease in demand

Use seasonal factor to adjust forecast

$$\text{Seasonal factor} = S_i = \frac{D_i}{\sum D}$$

# Seasonal Adjustment (cont.)

| | DEMAND (1000'S PER QUARTER) | | | | |
|---|---|---|---|---|---|
| YEAR | *1* | *2* | *3* | *4* | *Total* |
| 2002 | 12.6 | 8.6 | 6.3 | 17.5 | 45.0 |
| 2003 | 14.1 | 10.3 | 7.5 | 18.2 | 50.1 |
| 2004 | 15.3 | 10.6 | 8.1 | 19.6 | 53.6 |
| Total | 42.0 | 29.5 | 21.9 | 55.3 | 148.7 |

$$S_1 = \frac{D_1}{\sum D} = \frac{42.0}{148.7} = 0.28$$

$$S_3 = \frac{D_3}{\sum D} = \frac{21.9}{148.7} = 0.15$$

$$S_2 = \frac{D_2}{\sum D} = \frac{29.5}{148.7} = 0.20$$

$$S_4 = \frac{D_4}{\sum D} = \frac{55.3}{148.7} = 0.37$$

# Seasonal Adjustment (cont.)

**For 2005**

$$y = 40.97 + 4.30x = 40.97 + 4.30(4) = 58.17$$

$$SF_1 = (S_1)\ (F_5) = (0.28)(58.17) = 16.28$$
$$SF_2 = (S_2)\ (F_5) = (0.20)(58.17) = 11.63$$
$$SF_3 = (S_3)\ (F_5) = (0.15)(58.17) = 8.73$$
$$SF_4 = (S_4)\ (F_5) = (0.37)(58.17) = 21.53$$

# Forecast Accuracy

- Forecast error
  - difference between forecast and actual demand
  - MAD
    - mean absolute deviation
  - MAPD
    - mean absolute percent deviation
  - Cumulative error
  - Average error or bias

# Mean Absolute Deviation (MAD)

$$\text{MAD} = \frac{\Sigma | D_t - F_t |}{n}$$

where

$t$ = period number

$D_t$ = demand in period $t$

$F_t$ = forecast for period $t$

$n$ = total number of periods

$|\ |$ = absolute value

# MAD Example

| PERIOD | DEMAND, $D_t$ | $F_t$ ($\alpha$ =0.3) | ($D_t$ - $F_t$) | $\lvert D_t$ - $F_t\rvert$ |
|---|---|---|---|---|
| 1 | 37 | 37.00 | – | – |
| | | | | 3.00 |
| | | | | 3.10 |
| | | | | 1.83 |
| | | | | 6.72 |
| | | | | 9.69 |
| | | | | 0.20 |
| | | | | 3.86 |
| | | | | 11.70 |
| | | | | 4.19 |
| | | | | 5.94 |
| 12 | 54 | 50.84 | 3.15 | 3.15 |
| | 557 | | 49.31 | 53.39 |

$$\text{MAD} = \frac{\Sigma\lvert D_t - F_t\rvert}{n}$$

$$= \frac{53.39}{11}$$

$$= 4.85$$

# Other Accuracy Measures

*Mean absolute percent deviation (MAPD)*

$$MAPD = \frac{\sum |D_t - F_t|}{\sum D_t}$$

*Cumulative error*

$$E = \sum e_t$$

*Average error*

$$E = \frac{\sum e_t}{n}$$

# Comparison of Forecasts

| FORECAST | MAD | MAPD | *E* | (*E*) |
|---|---|---|---|---|
| Exponential smoothing ($\alpha = 0.30$) | 4.85 | 9.6% | 49.31 | 4.48 |
| Exponential smoothing ($\alpha = 0.50$) | 4.04 | 8.5% | 33.21 | 3.02 |
| Adjusted exponential smoothing ($\alpha = 0.50$, $\beta = 0.30$) | 3.81 | 7.5% | 21.14 | 1.92 |
| Linear trend line | 2.29 | 4.9% | – | – |

# Forecast Control

- Tracking signal
  - monitors the forecast to see if it is biased high or low

$$\text{Tracking signal} = \frac{\sum(D_t - F_t)}{MAD} = \frac{E}{MAD}$$

  - 1 MAD ≈ 0.8 б
  - Control limits of 2 to 5 MADs are used most frequently

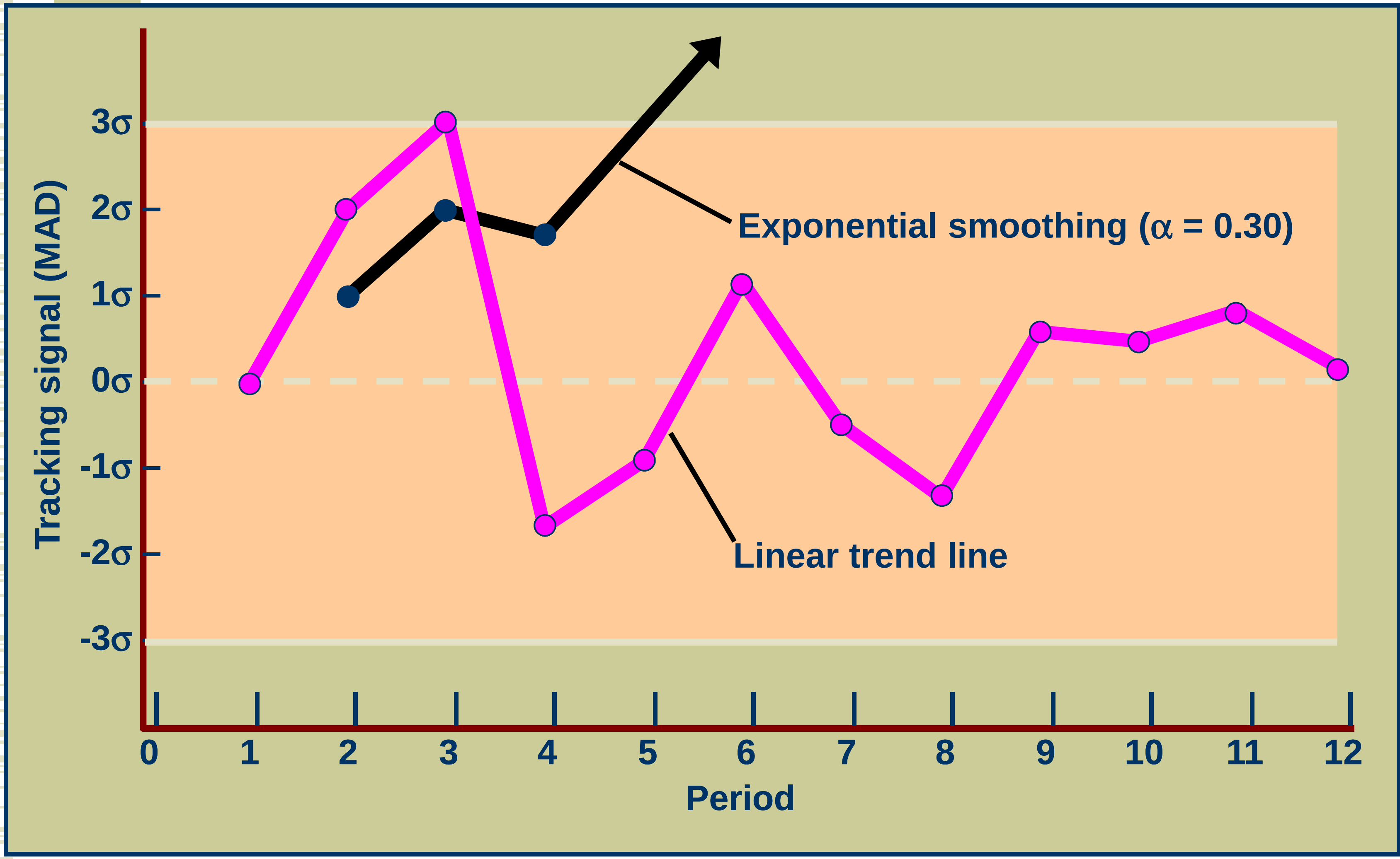
# Tracking Signal Values

| PERIOD | DEMAND $D_t$ | FORECAST, $F_t$ | ERROR $D_t - F_t$ | $\sum E = \sum(D_t - F_t)$ | MAD | TRACKING SIGNAL |
|---|---|---|---|---|---|---|
| 1 | 37 | 37.00 | – | – | – | – |
| 2 | 40 | 37.00 | 3.00 | 3.00 | 3.00 | 1.00 |
| 3 | 41 | 37.90 | 3.10 | 6.10 | 3.05 | 2.00 |
| 4 | 37 | [illegible] | [illegible] | [illegible] | 2.64 | 1.62 |
| 5 | 45 | [illegible] | [illegible] | [illegible] | 3.66 | 3.00 |
| 6 | 50 | [illegible] | [illegible] | [illegible] | 4.87 | 4.25 |
| 7 | 43 | [illegible] | [illegible] | [illegible] | 4.09 | 5.01 |
| 8 | 47 | [illegible] | [illegible] | [illegible] | 4.06 | 6.00 |
| 9 | 56 | [illegible] | [illegible] | [illegible] | 5.01 | 7.19 |
| 10 | 52 | [illegible] | [illegible] | [illegible] | 4.92 | 8.18 |
| 11 | 55 | 49.06 | 5.94 | 46.17 | 5.02 | 9.20 |
| 12 | 54 | 50.84 | 3.15 | 49.32 | 4.85 | 10.17 |

**Tracking signal for period 3**

$$TS_3 = \frac{6.10}{3.05} = 2.00$$

# Tracking Signal Plot



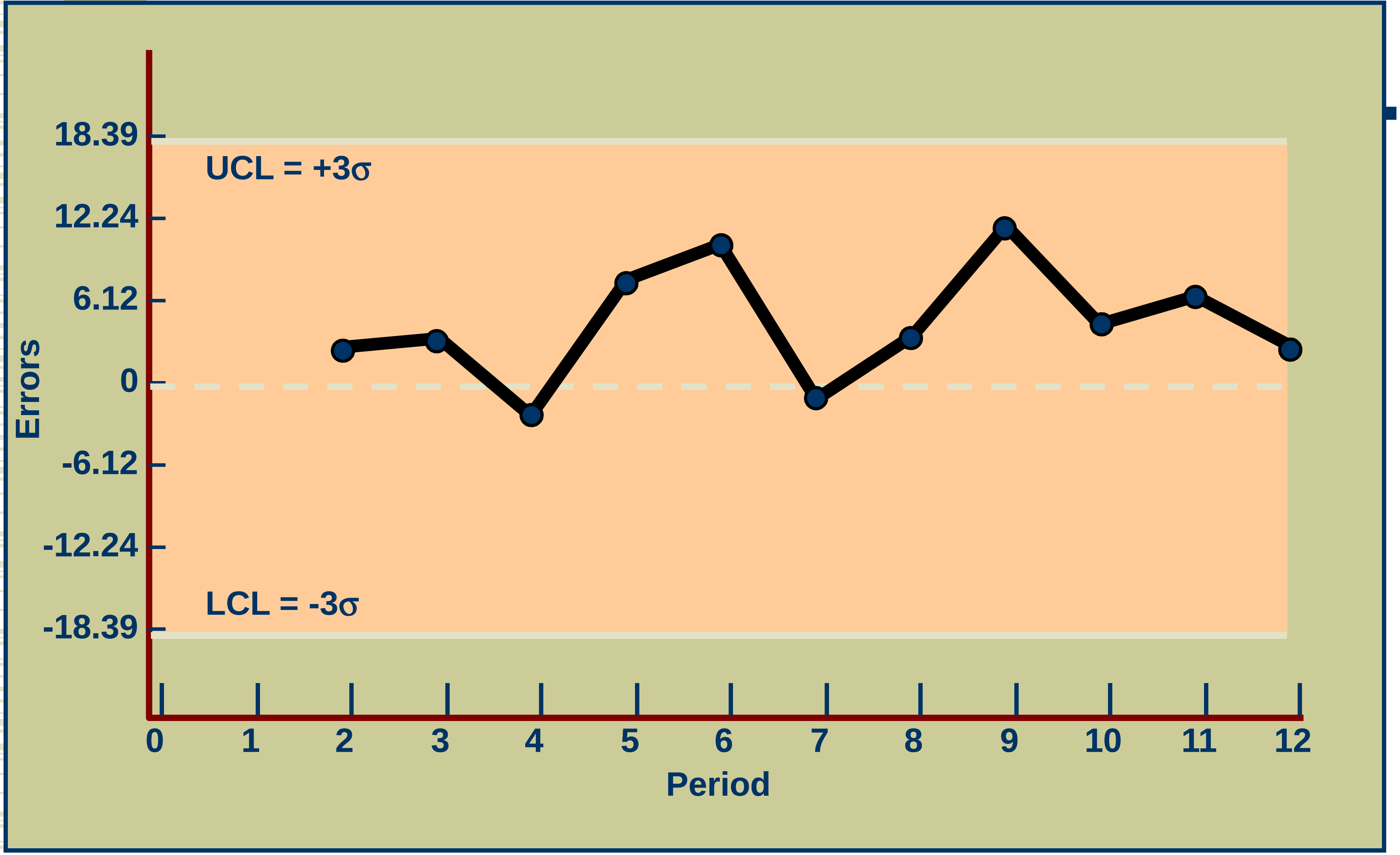
# Statistical Control Charts

$$\sigma = \sqrt{\frac{\sum(D_t - F_t)^2}{n - 1}}$$

Using $\sigma$ we can calculate statistical control limits for the forecast error

Control limits are typically set at $\pm 3\sigma$

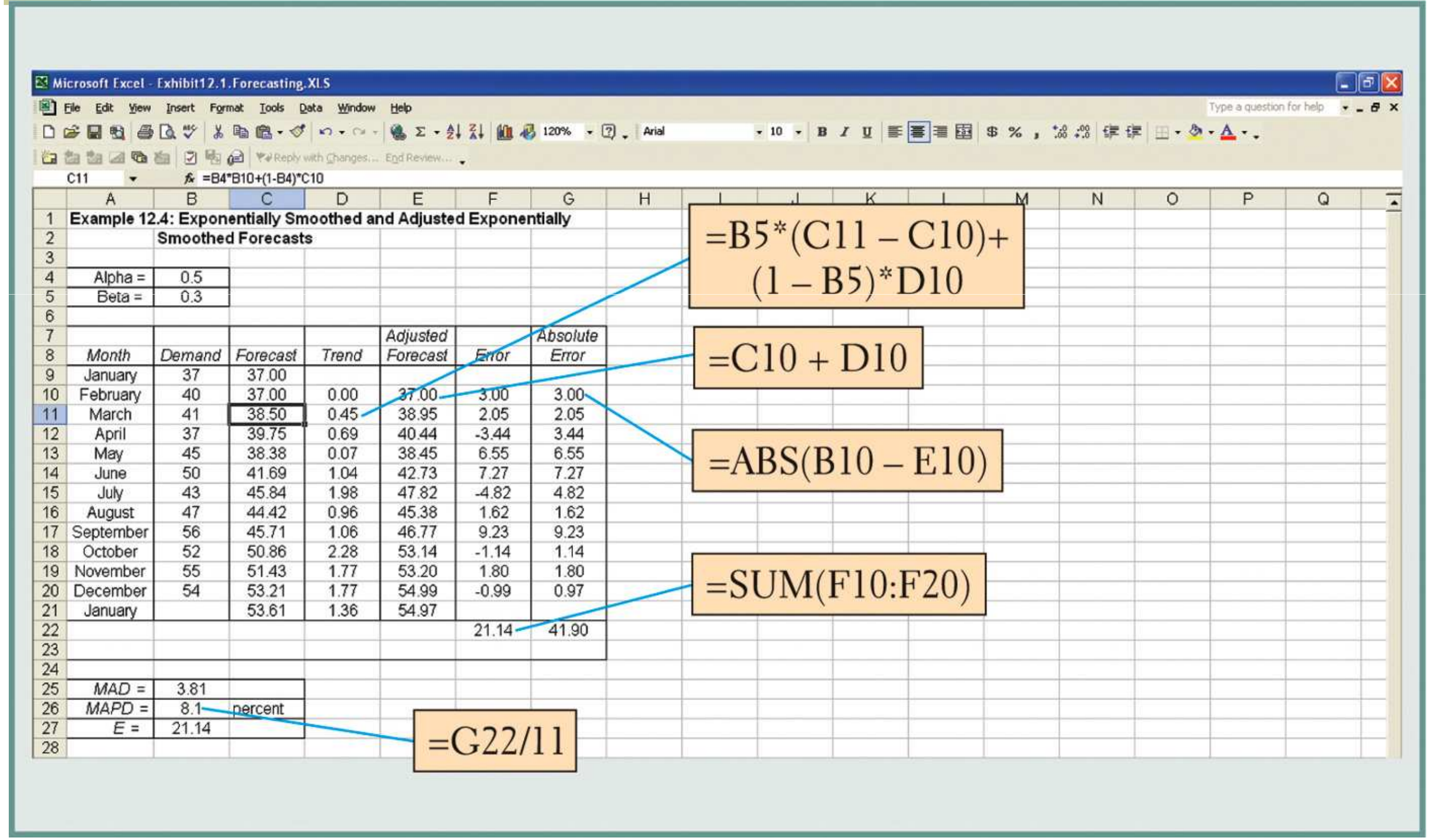
# Statistical Control Charts



# Time Series Forecasting using Excel

- Excel can be used to develop forecasts:
  - Moving average
  - Exponential smoothing
  - Adjusted exponential smoothing
  - Linear trend line

# Exponentially Smoothed and Adjusted Exponentially Smoothed Forecasts



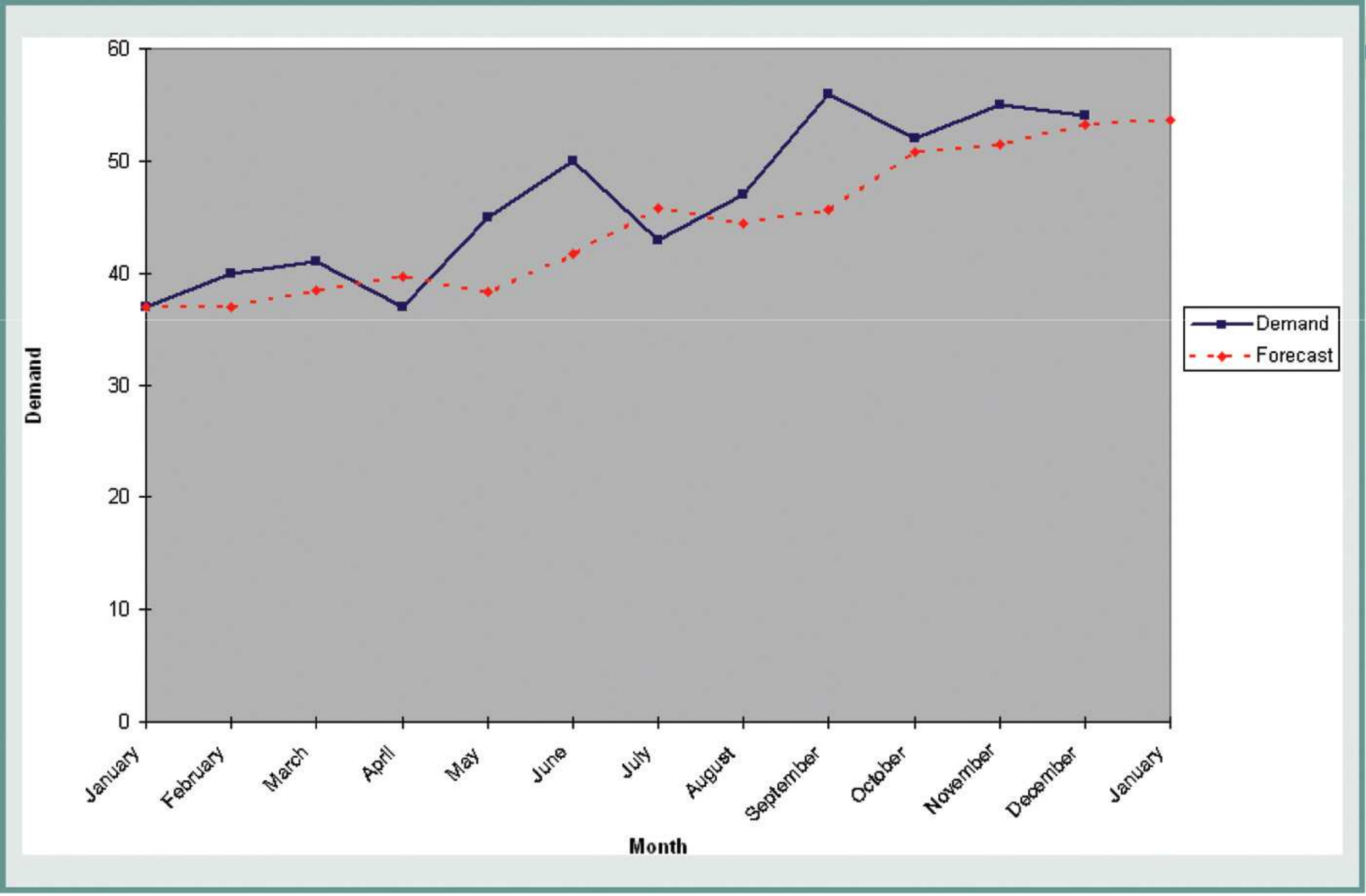

Example 12.4: Exponentially Smoothed and Adjusted Exponentially Smoothed Forecasts

| | |
|---|---|
| Alpha = | 0.5 |
| Beta = | 0.3 |

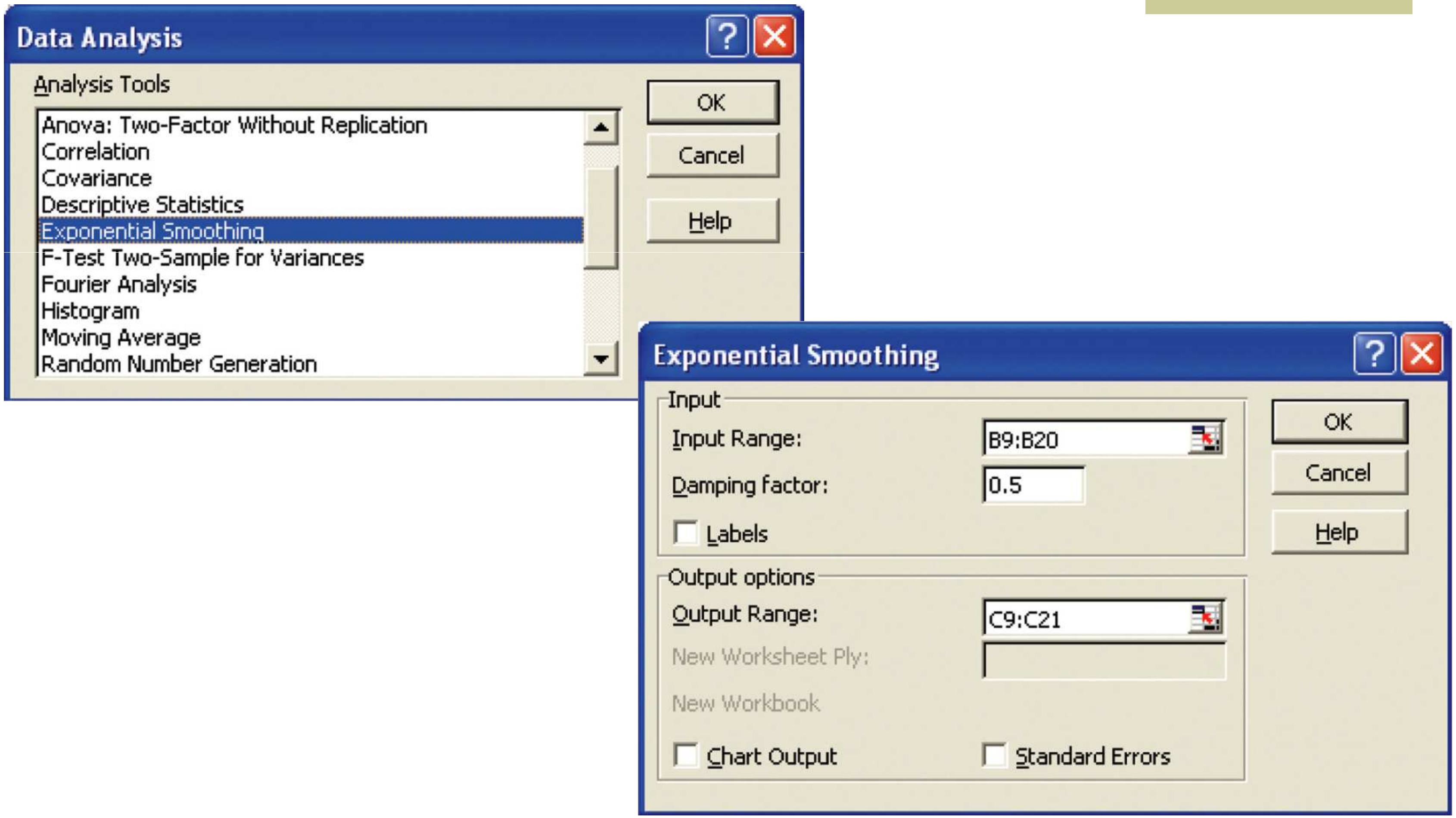
| Month | Demand | Forecast | Trend | Adjusted Forecast | Error | Absolute Error |
|---|---|---|---|---|---|---|
| January | 37 | 37.00 | | | | |
| February | 40 | 37.00 | 0.00 | 37.00 | 3.00 | 3.00 |
| March | 41 | 38.50 | 0.45 | 38.95 | 2.05 | 2.05 |
| April | 37 | 39.75 | 0.69 | 40.44 | -3.44 | 3.44 |
| May | 45 | 38.38 | 0.07 | 38.45 | 6.55 | 6.55 |
| June | 50 | 41.69 | 1.04 | 42.73 | 7.27 | 7.27 |
| July | 43 | 45.84 | 1.98 | 47.82 | -4.82 | 4.82 |
| August | 47 | 44.42 | 0.96 | 45.38 | 1.62 | 1.62 |
| September | 56 | 45.71 | 1.06 | 46.77 | 9.23 | 9.23 |
| October | 52 | 50.86 | 2.28 | 53.14 | -1.14 | 1.14 |
| November | 55 | 51.43 | 1.77 | 53.20 | 1.80 | 1.80 |
| December | 54 | 53.21 | 1.77 | 54.99 | -0.99 | 0.97 |
| January | | 53.61 | 1.36 | 54.97 | | |
| | | | | | 21.14 | 41.90 |

| | | |
|---|---|---|
| MAD = | 3.81 | |
| MAPD = | 8.1 | percent |
| E = | 21.14 | |

# Demand and exponentially smoothed forecast



# Data Analysis option



# Computing a Forecast with Seasonal Adjustment

Microsoft Excel - Exhibit12.5.Forecasting.XLS

B12 =(B8/F8)*E10

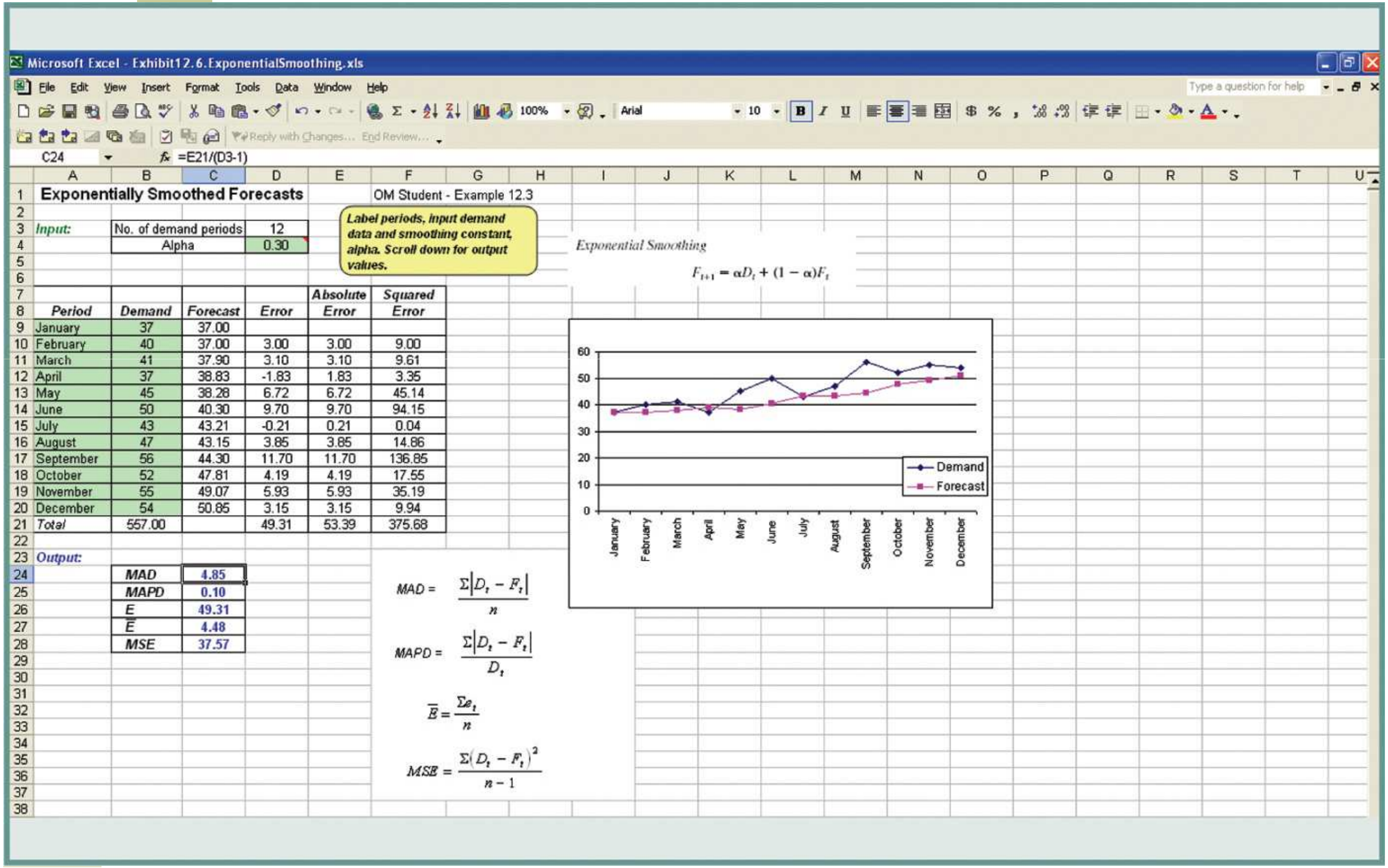
**Example 12.6: Computing a Forecast with Seasonal Adjustments**

| | *Demand (1,000s) per Quarter* | | | | |
|---|---|---|---|---|---|
| ***Year*** | *1* | *2* | *3* | *4* | ***Total*** |
| 2002 | 12.6 | 8.6 | 6.3 | 17.5 | 45.0 |
| 2003 | 14.1 | 10.3 | 7.5 | 18.2 | 50.1 |
| 2004 | 15.3 | 10.6 | 8.1 | 19.6 | 53.6 |
| ***Total*** | 42.0 | 29.5 | 21.9 | 55.3 | 148.7 |

Linear trend line forecast for 2005 = 58.17

| | |
|---|---|
| *SF1* = | 16.43 |
| *SF2* = | 11.54 |
| *SF3* = | 8.57 |
| *SF4* = | 21.63 |

# OM Tools



Microsoft Excel - Exhibit12.6.ExponentialSmoothing.xls

C24 =E21/(D3-1)

**Exponentially Smoothed Forecasts** — OM Student - Example 12.3

*Input:*

| | |
|---|---|
| No. of demand periods | 12 |
| Alpha | 0.30 |

*Label periods, input demand data and smoothing constant, alpha. Scroll down for output values.*

| Period | Demand | Forecast | Error | Absolute Error | Squared Error |
|---|---|---|---|---|---|
| January | 37 | 37.00 | | | |
| February | 40 | 37.00 | 3.00 | 3.00 | 9.00 |
| March | 41 | 37.90 | 3.10 | 3.10 | 9.61 |
| April | 37 | 38.83 | -1.83 | 1.83 | 3.35 |
| May | 45 | 38.28 | 6.72 | 6.72 | 45.14 |
| June | 50 | 40.30 | 9.70 | 9.70 | 94.15 |
| July | 43 | 43.21 | -0.21 | 0.21 | 0.04 |
| August | 47 | 43.15 | 3.85 | 3.85 | 14.86 |
| September | 56 | 44.30 | 11.70 | 11.70 | 136.85 |
| October | 52 | 47.81 | 4.19 | 4.19 | 17.55 |
| November | 55 | 49.07 | 5.93 | 5.93 | 35.19 |
| December | 54 | 50.85 | 3.15 | 3.15 | 9.94 |
| *Total* | 557.00 | | 49.31 | 53.39 | 375.68 |

*Output:*

| | |
|---|---|
| MAD | 4.85 |
| MAPD | 0.10 |
| E | 49.31 |
| $\bar{E}$ | 4.48 |
| MSE | 37.57 |

*Exponential Smoothing*

$$F_{t+1} = \alpha D_t + (1-\alpha)F_t$$

$$MAD = \frac{\Sigma|D_t - F_t|}{n}$$

$$MAPD = \frac{\Sigma|D_t - F_t|}{D_t}$$

$$\bar{E} = \frac{\Sigma e_t}{n}$$

$$MSE = \frac{\Sigma(D_t - F_t)^2}{n-1}$$

# Regression Methods

- Linear regression
  - a mathematical technique that relates a dependent variable to an independent variable in the form of a linear equation
- Correlation
  - a measure of the strength of the relationship between independent and dependent variables

# Linear Regression

$y = a + bx$

$$a = \bar{y} - b\,\bar{x}$$

$$b = \frac{\Sigma xy - n\bar{x}\bar{y}}{\Sigma x^2 - n\bar{x}^2}$$

where

$a$ = intercept

$b$ = slope of the line

$\bar{x} = \frac{\Sigma x}{n}$ = mean of the $x$ data

$\bar{y} = \frac{\Sigma y}{n}$ = mean of the $y$ data

# Linear Regression Example

| (WINS) | $x$ (ATTENDANCE) | $y$ $xy$ | $x^2$ |
|---|---|---|---|
| 4 | 36.3 | 145.2 | 16 |
| 6 | 40.1 | 240.6 | 36 |
| 6 | 41.2 | 247.2 | 36 |
| 8 | 53.0 | 424.0 | 64 |
| 6 | 44.0 | 264.0 | 36 |
| 7 | 45.6 | 319.2 | 49 |
| 5 | 39.0 | 195.0 | 25 |
| 7 | 47.5 | 332.5 | 49 |
| 49 | 346.7 | 2167.7 | 311 |

# Linear Regression Example (cont.)

$$\bar{x} = \frac{49}{8} = 6.125$$

$$\bar{y} = \frac{346.9}{8} = 43.36$$

$$b = \frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2}$$

$$= \frac{(2{,}167.7) - (8)(6.125)(43.36)}{(311) - (8)(6.125)^2} = 4.06$$

$$a = \bar{y} - b\bar{x}$$

$$= 43.36 - (4.06)(6.125)$$

$$= 18.46$$

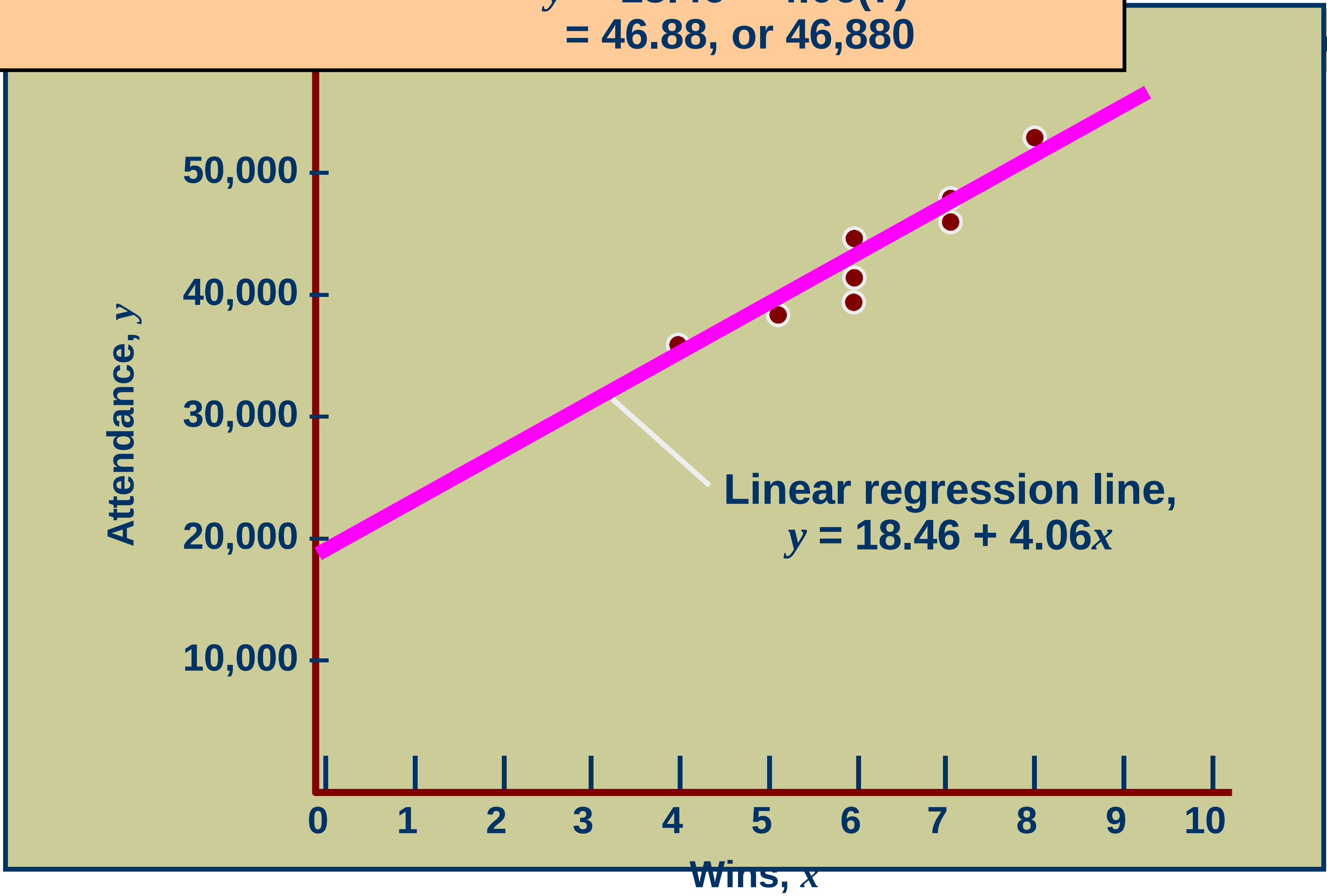
# Linear Regression Example (cont.)

**Regression equation**

$y = 18.46 + 4.06x$

**Attendance forecast for 7 wins**

$y = 18.46 + 4.06(7)$
$= 46.88$, or 46,880



# Correlation and Coefficient of Determination

Correlation, $r$

Measure of strength of relationship

Varies between -1.00 and +1.00

Coefficient of determination, $r^2$

Percentage of variation in dependent variable resulting from changes in the independent variable

# Computing Correlation

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2]\,[n\sum y^2 - (\sum y)^2]}}$$

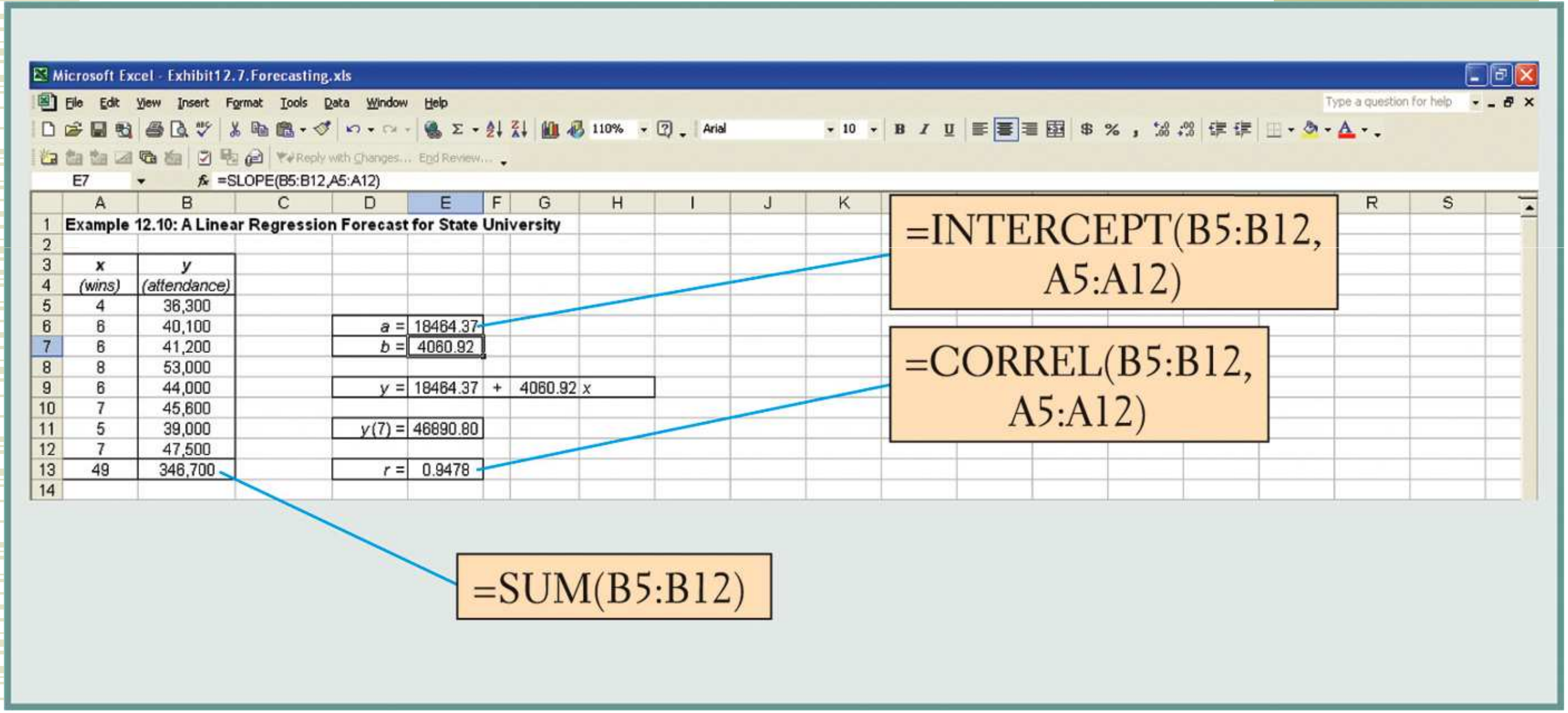
$$r = \frac{(8)(2,167.7) - (49)(346.9)}{\sqrt{[(8)(311) - (49)^2]\,[(8)(15,224.7) - (346.9)^2]}}$$

$$r = 0.947$$

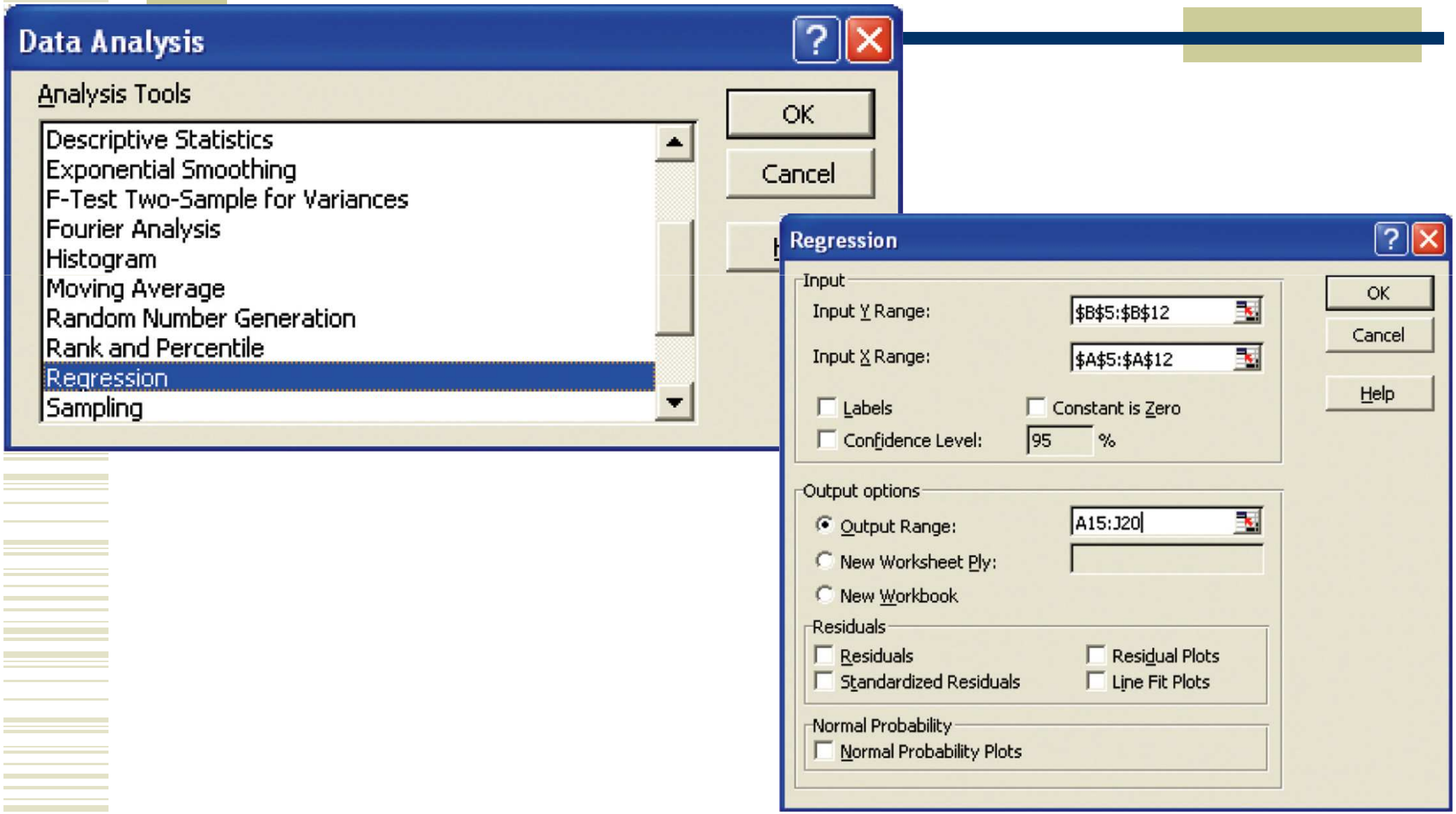
Coefficient of determination

$$r^2 = (0.947)^2 = 0.897$$

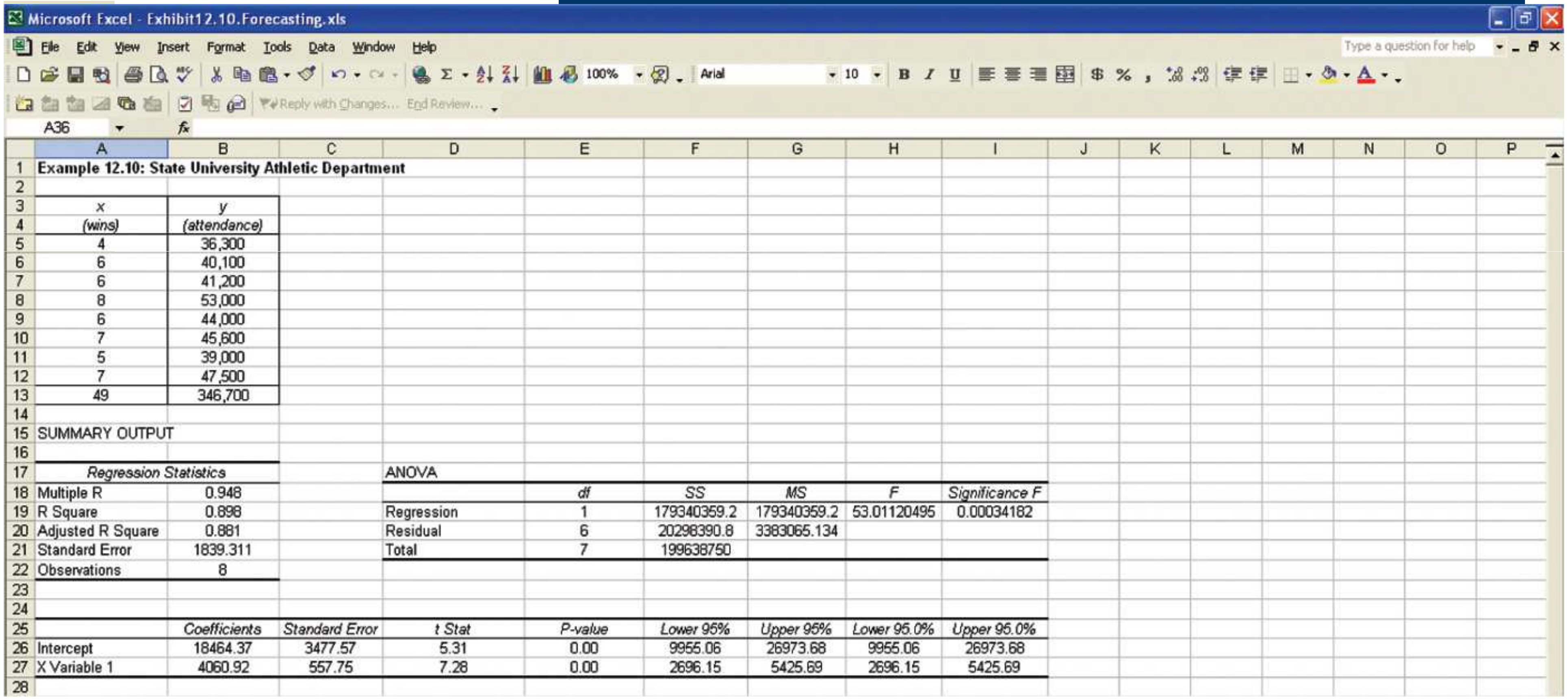
# Regression Analysis with Excel



# Regression Analysis with Excel (cont.)



# Regression Analysis with Excel (cont.)



Microsoft Excel - Exhibit12.10.Forecasting.xls

**Example 12.10: State University Athletic Department**

| x (wins) | y (attendance) |
|---|---|
| 4 | 36,300 |
| 6 | 40,100 |
| 6 | 41,200 |
| 8 | 53,000 |
| 6 | 44,000 |
| 7 | 45,600 |
| 5 | 39,000 |
| 7 | 47,500 |
| 49 | 346,700 |

SUMMARY OUTPUT

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.948 |
| R Square | 0.898 |
| Adjusted R Square | 0.881 |
| Standard Error | 1839.311 |
| Observations | 8 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 1 | 179340359.2 | 179340359.2 | 53.01120495 | 0.00034182 |
| Residual | 6 | 20298390.8 | 3383065.134 | | |
| Total | 7 | 199638750 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | 18464.37 | 3477.57 | 5.31 | 0.00 | 9955.06 | 26973.68 | 9955.06 | 26973.68 |
| X Variable 1 | 4060.92 | 557.75 | 7.28 | 0.00 | 2696.15 | 5425.69 | 2696.15 | 5425.69 |

# Multiple Regression

Study the relationship of demand to two or more independent variables

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \ldots + \beta_k x_k$$

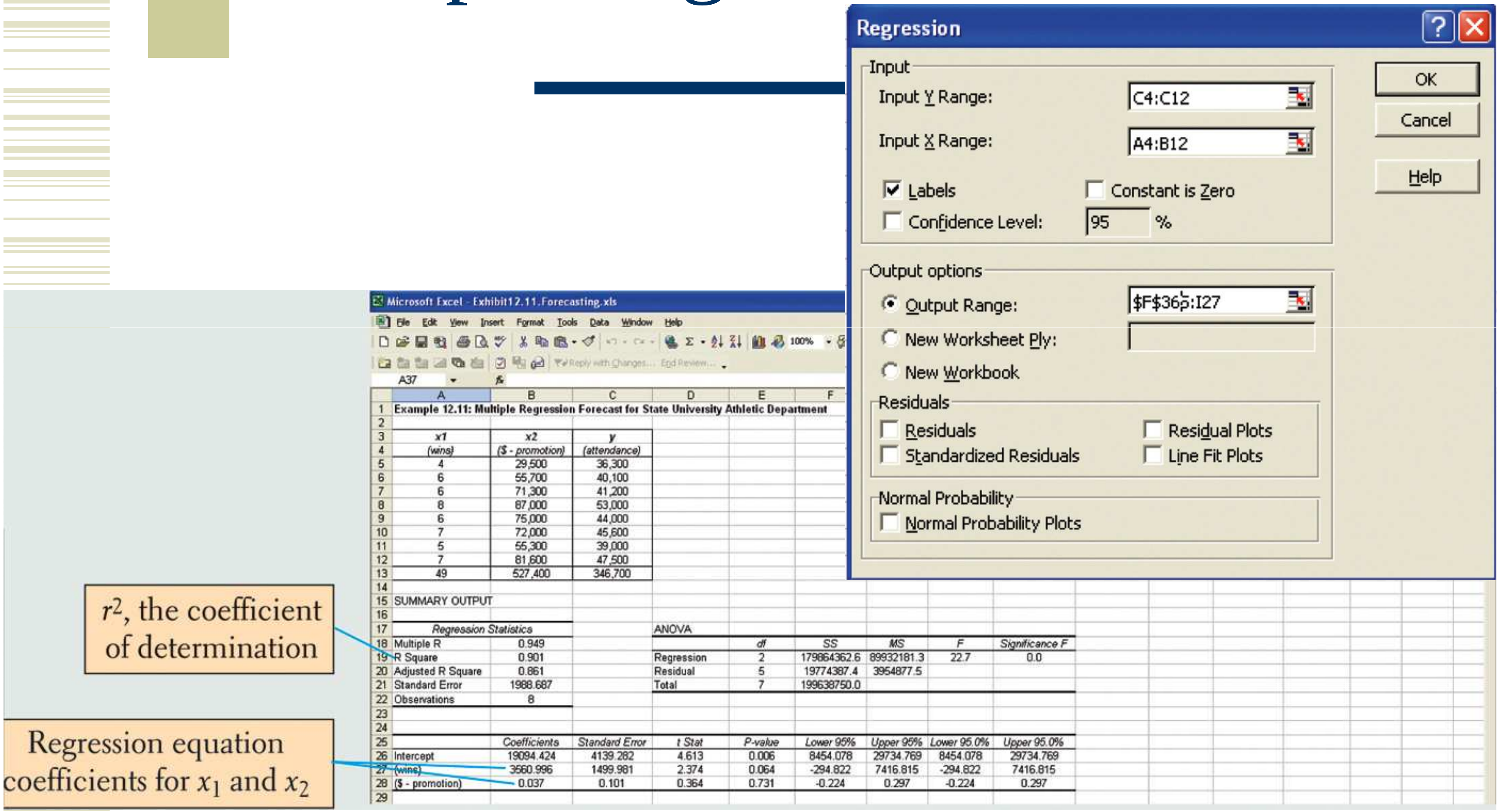
where

$\beta_0$ = the intercept

$\beta_1, \ldots, \beta_k$ = parameters for the independent variables

$x_1, \ldots, x_k$ = independent variables

# Multiple Regression with Excel




Example 12.11: Multiple Regression Forecast for State University Athletic Department

| x1 (wins) | x2 ($ - promotion) | y (attendance) |
|---|---|---|
| 4 | 29,500 | 36,300 |
| 6 | 55,700 | 40,100 |
| 6 | 71,300 | 41,200 |
| 8 | 87,000 | 53,000 |
| 6 | 75,000 | 44,000 |
| 7 | 72,000 | 45,600 |
| 5 | 55,300 | 39,000 |
| 7 | 81,600 | 47,500 |
| 49 | 527,400 | 346,700 |

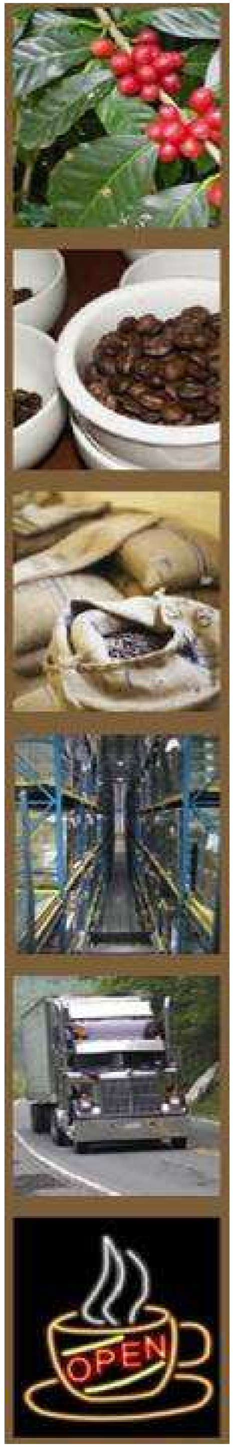
SUMMARY OUTPUT

| Regression Statistics | |
|---|---|
| Multiple R | 0.949 |
| R Square | 0.901 |
| Adjusted R Square | 0.861 |
| Standard Error | 1988.687 |
| Observations | 8 |

ANOVA

| | df | SS | MS | F | Significance F |
|---|---|---|---|---|---|
| Regression | 2 | 179864362.6 | 89932181.3 | 22.7 | 0.0 |
| Residual | 5 | 19774387.4 | 3954877.5 | | |
| Total | 7 | 199638750.0 | | | |

| | Coefficients | Standard Error | t Stat | P-value | Lower 95% | Upper 95% | Lower 95.0% | Upper 95.0% |
|---|---|---|---|---|---|---|---|---|
| Intercept | 19094.424 | 4139.282 | 4.613 | 0.006 | 8454.078 | 29734.769 | 8454.078 | 29734.769 |
| (wins) | 3560.996 | 1499.981 | 2.374 | 0.064 | -294.822 | 7416.815 | -294.822 | 7416.815 |
| ($ - promotion) | 0.037 | 0.101 | 0.364 | 0.731 | -0.224 | 0.297 | -0.224 | 0.297 |



# Chapter 13

## *Inventory Management*

***Operations Management - 6th Edition***

**Roberta Russell & Bernard W. Taylor, III**


Beni Asllani
University of Tennessee at Chattanooga

# Lecture Outline

- Elements of Inventory Management
- Inventory Control Systems
- Economic Order Quantity Models
- Quantity Discounts
- Reorder Point
- Order Quantity for a Periodic Inventory System

# What Is Inventory?

- Stock of items kept to meet future demand
- Purpose of inventory management
  - how many units to order
  - when to order

# Inventory and Supply Chain Management

- Bullwhip effect
  - demand information is distorted as it moves away from the end-use customer
  - higher safety stock inventories to are stored to compensate
- Seasonal or cyclical demand
- Inventory provides independence from vendors
- Take advantage of price discounts
- Inventory provides independence between stages and avoids work stoppages

# Inventory and Quality Management in the Supply Chain

- Customers usually perceive quality service as availability of goods they want when they want them
- Inventory must be sufficient to provide high-quality customer service in QM

# Types of Inventory

- Raw materials
- Purchased parts and supplies
- Work-in-process (partially completed) products (WIP)
- Items being transported
- Tools and equipment

# Two Forms of Demand

## Dependent

Demand for items used to produce final products

Tires stored at a Goodyear plant are an example of a dependent demand item

## Independent

Demand for items used by external customers

Cars, appliances, computers, and houses are examples of independent demand inventory

# Inventory Costs

Carrying cost

cost of holding an item in inventory

Ordering cost

cost of replenishing inventory

Shortage cost

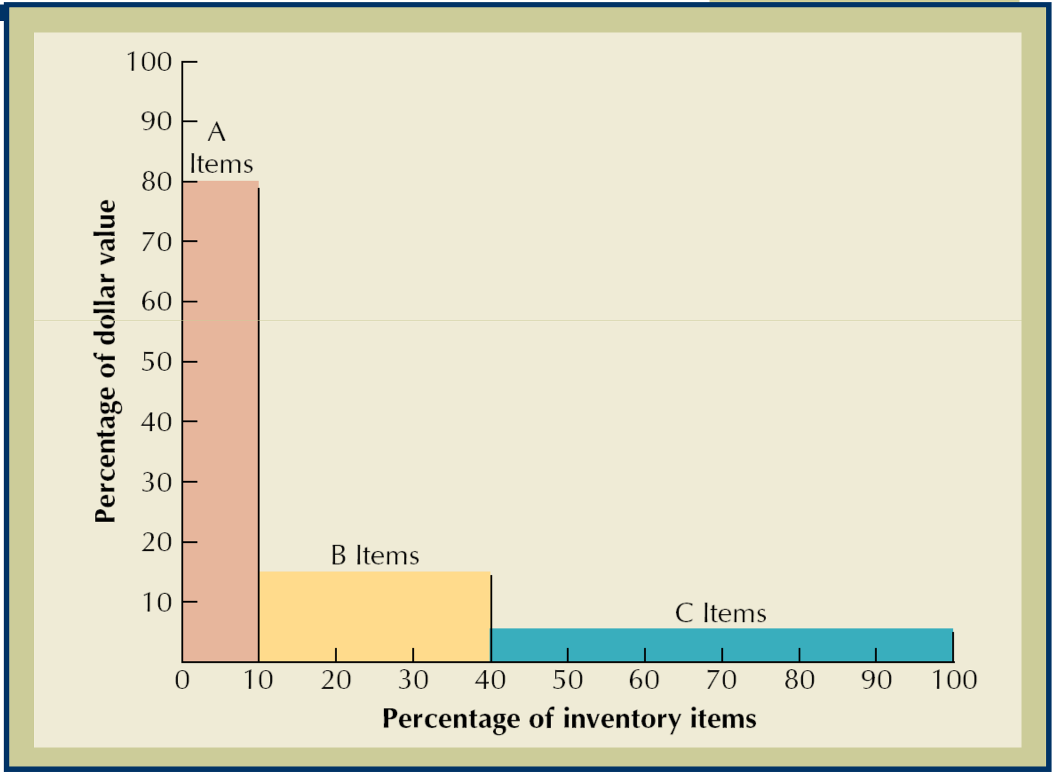
temporary or permanent loss of sales when demand cannot be met

# Inventory Control Systems

- Continuous system (fixed-order-quantity)
  - constant amount ordered when inventory declines to predetermined level
- Periodic system (fixed-time-period)
  - order placed for variable amount after fixed passage of time

# ABC Classification

- Class A
  - 5 – 15 % of units
  - 70 – 80 % of value
- Class B
  - 30 % of units
  - 15 % of value
- Class C
  - 50 – 60 % of units
  - 5 – 10 % of value



# ABC Classification: Example

| PART | UNIT COST | ANNUAL USAGE |
|---|---|---|
| 1 | $ 60 | 90 |
| 2 | 350 | 40 |
| 3 | 30 | 130 |
| 4 | 80 | 60 |
| 5 | 30 | 100 |
| 6 | 20 | 180 |
| 7 | 10 | 170 |
| 8 | 320 | 50 |
| 9 | 510 | 60 |
| 10 | 20 | 120 |

# ABC Classification: Example (cont.)

| PART | VALUE | TOTAL VALUE | % OF TOTAL QUANTITY | % OF TOTAL | % CUMMULATIVE |
|---|---|---|---|---|---|
| 9 | $30,600 | 35.9 | 6.0 | | 6.0 |
| 8 | 16,000 | 18.7 | 5.0 | A | 11.0 |
| 2 | 14,000 | 16.4 | 4.0 | | 15.0 |
| 1 | 5,400 | 6.3 | 9.0 | | 24.0 |
| 4 | 4,800 | 5.6 | 6.0 | B | 30.0 |

| CLASS | ITEMS | % OF TOTAL VALUE | % OF TOTAL QUANTITY |
|---|---|---|---|
| A | 9, 8, 2 | 71.0 | 15.0 |
| B | 1, 4, 3 | 16.5 | 25.0 |
| C | 6, 5, 10, 7 | 12.5 | 60.0 |

# Economic Order Quantity (EOQ) Models

- EOQ
  - optimal order quantity that will minimize total inventory costs
- Basic EOQ model
- Production quantity model

# Assumptions of Basic EOQ Model

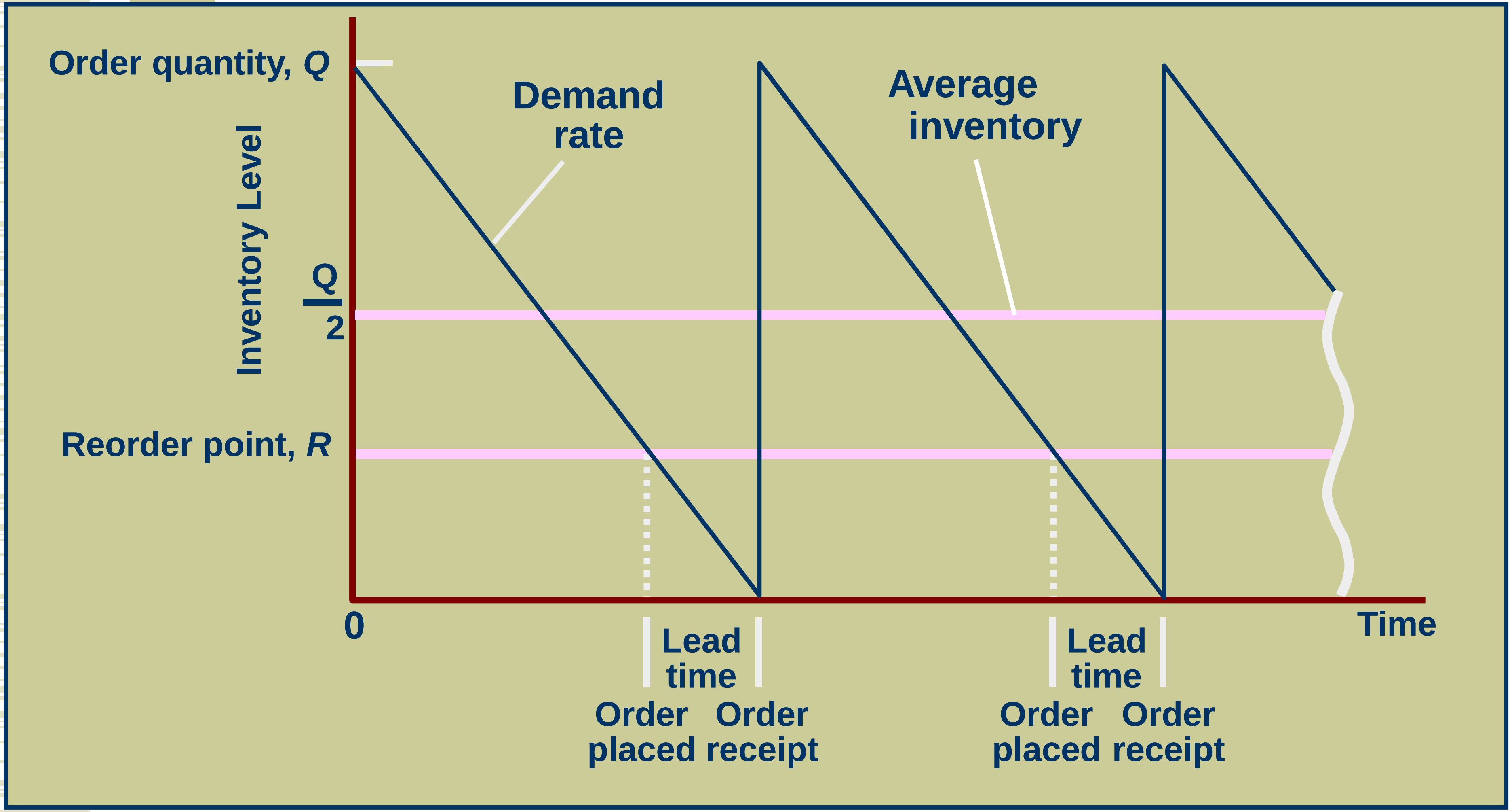
Demand is known with certainty and is constant over time

No shortages are allowed

Lead time for the receipt of orders is constant

Order quantity is received all at once

# Inventory Order Cycle



# EOQ Cost Model

$C_o$ - cost of placing order

$C_c$ - annual per-unit carrying cost

$D$ - annual demand

$Q$ - order quantity

Annual ordering cost = $\dfrac{C_o D}{Q}$

Annual carrying cost = $\dfrac{C_c Q}{2}$

Total cost = $\dfrac{C_o D}{Q} + \dfrac{C_c Q}{2}$

# EOQ Cost Model

**Deriving $Q_{opt}$**

$$TC = \frac{C_o D}{Q} + \frac{C_c Q}{2}$$

$$\frac{\partial TC}{\partial Q} = -\frac{C_o D}{Q^2} + \frac{C_c}{2}$$

$$0 = -\frac{C_0 D}{Q^2} + \frac{C_c}{2}$$

$$Q_{opt} = \sqrt{\frac{2C_o D}{C_c}}$$

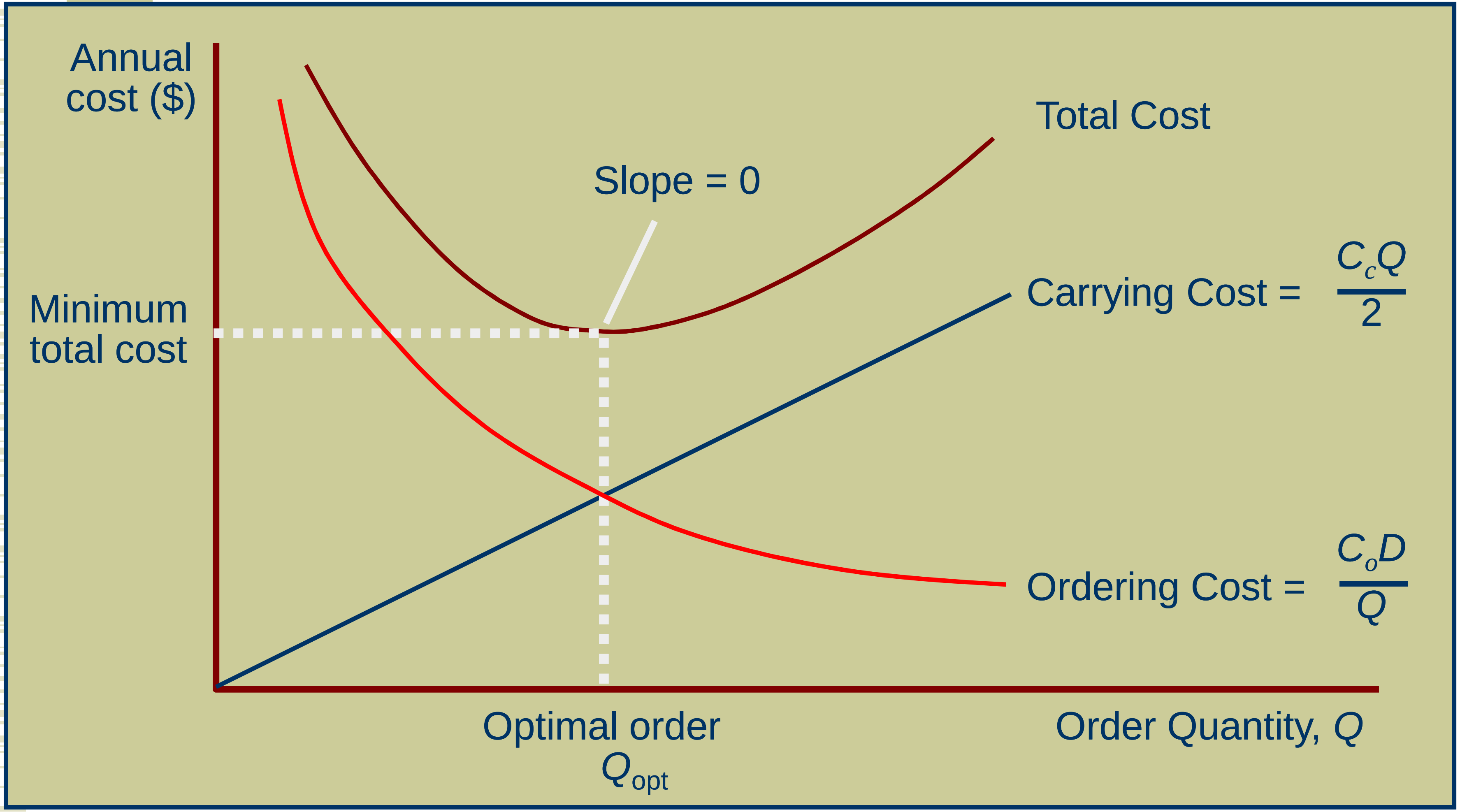
**Proving equality of costs at optimal point**

$$\frac{C_o D}{Q} = \frac{C_c Q}{2}$$

$$Q^2 = \frac{2C_o D}{C_c}$$

$$Q_{opt} = \sqrt{\frac{2C_o D}{C_c}}$$

# EOQ Cost Model (cont.)



# EOQ Example

$C_c$ = \$0.75 per gallon  $C_o$ = \$150  $D$ = 10,000 gallons

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c}} \qquad TC_{min} = \frac{C_oD}{Q} + \frac{C_cQ}{2}$$

$$Q_{opt} = \sqrt{\frac{2(150)(10,000)}{(0.75)}} \qquad TC_{min} = \frac{(150)(10,000)}{2,000} + \frac{(0.75)(2,000)}{2}$$

$Q_{opt}$ = 2,000 gallons  $TC_{min}$ = \$750 + \$750 = \$1,500

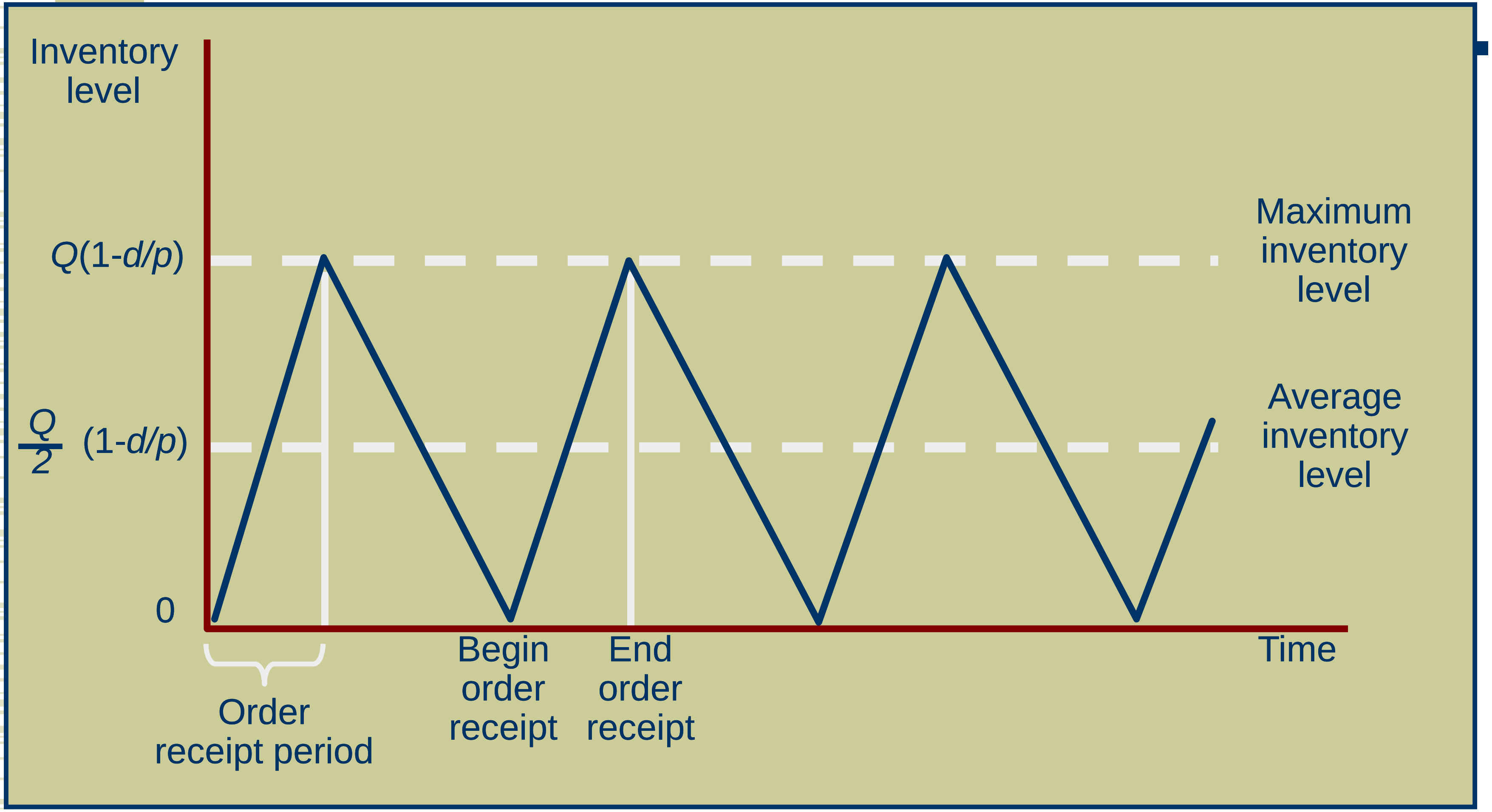
Orders per year = $D/Q_{opt}$
= 10,000/2,000
= 5 orders/year

Order cycle time = 311 days/($D/Q_{opt}$)
= 311/5
= 62.2 store days

# Production Quantity Model

- An inventory system in which an order is received gradually, as inventory is simultaneously being depleted
  - AKA non-instantaneous receipt model
  - assumption that *Q* is received all at once is relaxed
- *p* - daily rate at which an order is received over time, a.k.a. *production rate*
- *d* - daily rate at which inventory is demanded

# Production Quantity Model (cont.)



# Production Quantity Model (cont.)

*p* = production rate    *d* = demand rate

$$\text{Maximum inventory level} = Q - \frac{Q}{p}d = Q\left(1 - \frac{d}{p}\right)$$

$$\text{Average inventory level} = \frac{Q}{2}\left(1 - \frac{d}{p}\right)$$

$$TC = \frac{C_o D}{Q} + \frac{C_c Q}{2}\left(1 - \frac{d}{p}\right)$$

$$Q_{opt} = \sqrt{\frac{2C_o D}{C_c\left(1 - \frac{d}{p}\right)}}$$

# Production Quantity Model: Example

$C_c$ = \$0.75 per gallon   $C_o$ = \$150   $D$ = 10,000 gallons
$d$ = 10,000/311 = 32.2 gallons per day   $p$ = 150 gallons per day

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c\left(1 - \frac{d}{p}\right)}} = \sqrt{\frac{2(150)(10{,}000)}{0.75\left(1 - \frac{32.2}{150}\right)}} = 2{,}256.8 \text{ gallons}$$

$$TC = \frac{C_oD}{Q} + \frac{C_cQ}{2}\left(1 - \frac{d}{p}\right) = \$1{,}329$$

$$\text{Production run} = \frac{Q}{p} = \frac{2{,}256.8}{150} = 15.05 \text{ days per order}$$

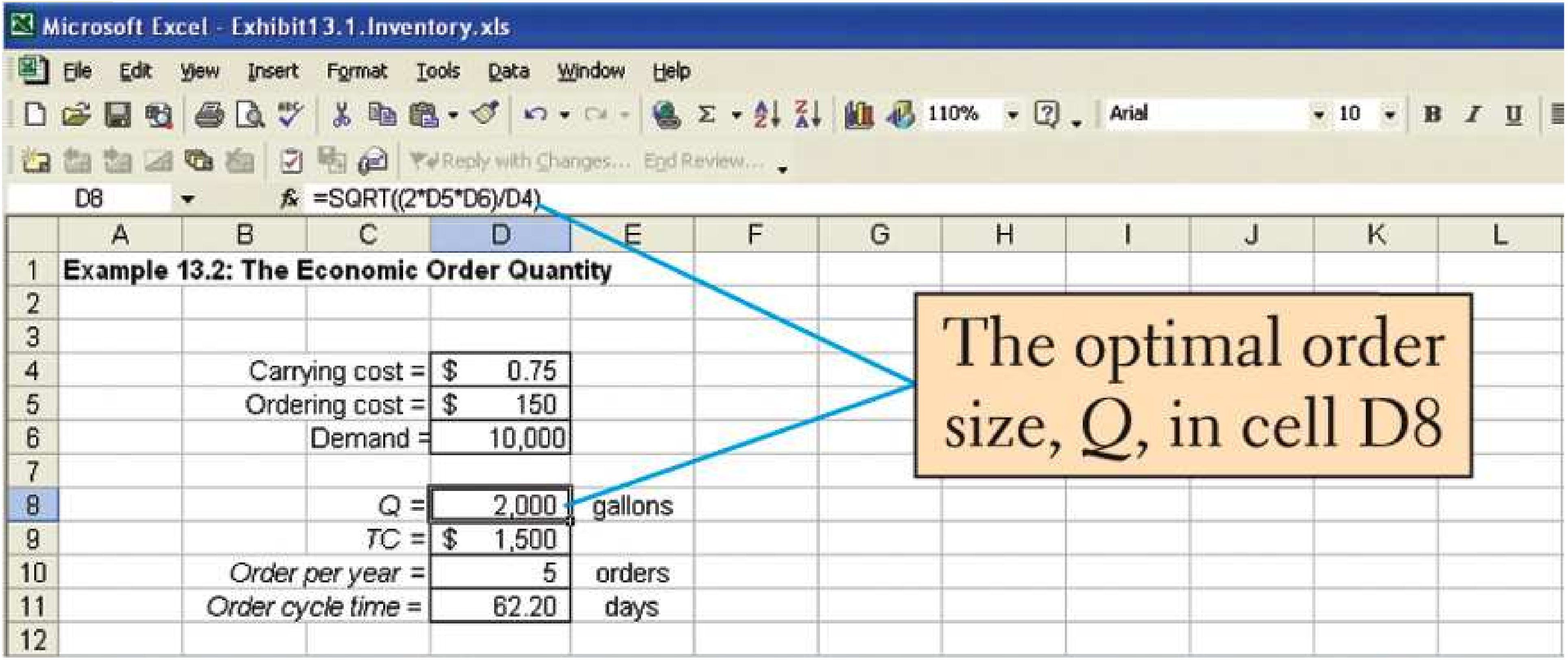
# Production Quantity Model: Example (cont.)

$$\text{Number of production runs} = \frac{D}{Q} = \frac{10{,}000}{2{,}256.8} = 4.43 \text{ runs/year}$$

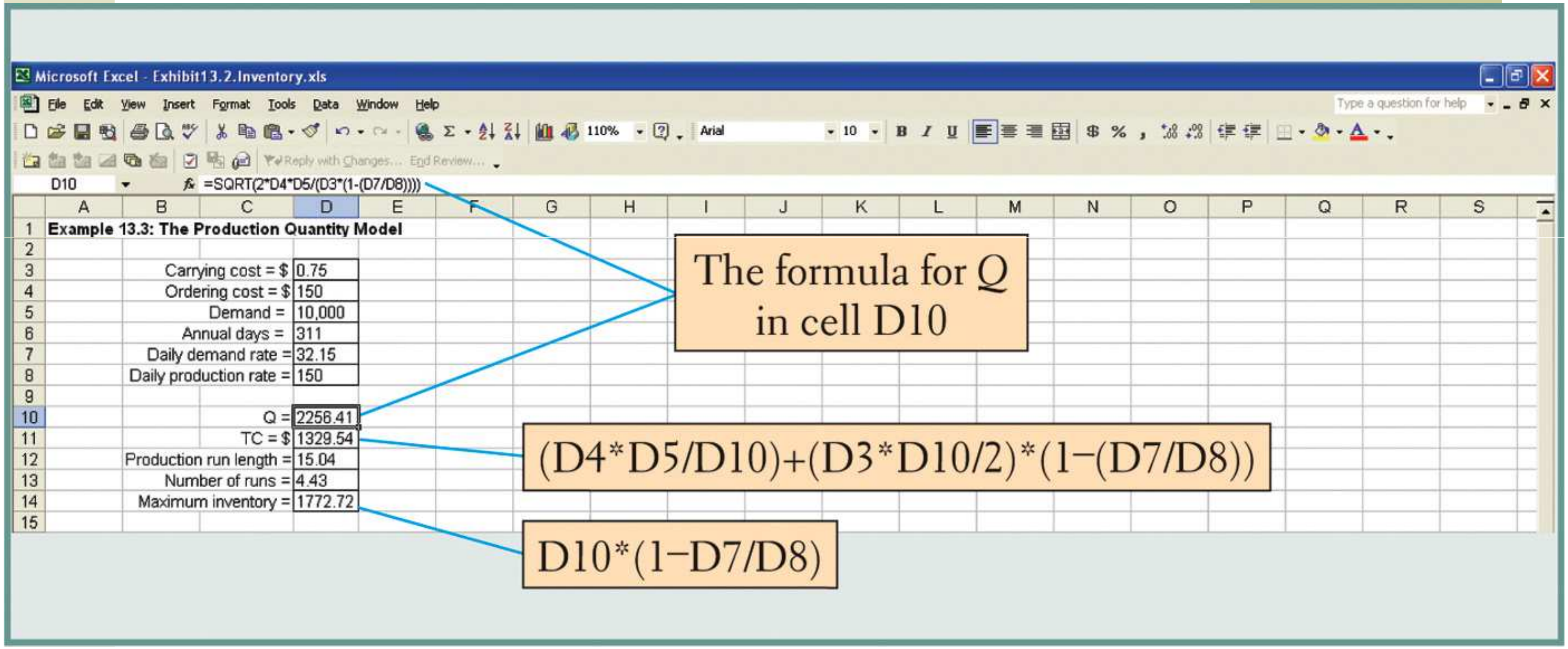
$$\text{Maximum inventory level} = Q\left(1 - \frac{d}{p}\right) = 2{,}256.8\left(1 - \frac{32.2}{150}\right)$$

$$= 1{,}772 \text{ gallons}$$

# Solution of EOQ Models with Excel



# Solution of EOQ Models with Excel (Con't)



# Solution of EOQ Models with OM Tools

Microsoft Excel - Exhibit13.3.xls

File Edit View Insert Format Tools Data Window Help

D10 $f_x$ =SQRT((2*D5*D6)/D4)

**The Economic Order Quantity Model**

*Input:*

| | |
|---|---|
| Carrying cost, Cc = | $0.75 |
| Ordering cost, Co = | $150.00 |
| Demand = | 10,000 |
| Days per year = | 311 |

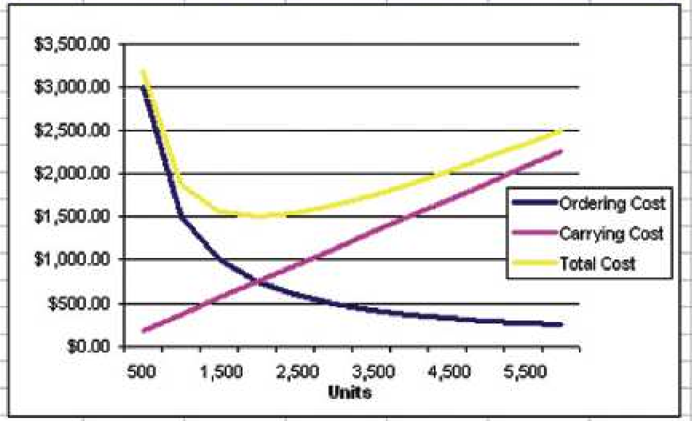
*Output:*

| | | |
|---|---|---|
| Qopt = | 2,000 | |
| Total Cost, TC = | $1,500.00 | |
| Orders per year = | 5 | |
| Order cycle time = | 62.20 | days |

*Graph:*

| Q | Co * D/Q | Cc *Q/2 | TC |
|---|---|---|---|
| 500 | $3,000.00 | $187.50 | $3,187.50 |
| 1,000 | $1,500.00 | $375.00 | $1,875.00 |
| 1,500 | $1,000.00 | $562.50 | $1,562.50 |
| 2,000 | $750.00 | $750.00 | $1,500.00 |
| 2,500 | $600.00 | $937.50 | $1,537.50 |
| 3,000 | $500.00 | $1,125.00 | $1,625.00 |
| 3,500 | $428.57 | $1,312.50 | $1,741.07 |
| 4,000 | $375.00 | $1,500.00 | $1,875.00 |
| 4,500 | $333.33 | $1,687.50 | $2,020.83 |
| 5,000 | $300.00 | $1,875.00 | $2,175.00 |
| 5,500 | $272.73 | $2,062.50 | $2,335.23 |
| 6,000 | $250.00 | $2,250.00 | $2,500.00 |

*Input costs, demand and days per year. Excel will calculate the optimal order quantity, total cost, the number of orders per year, and the order cycle time. Costs are graphed for various quantities ordered.*




$$TC = \frac{C_o D}{Q} + \frac{C_c Q}{2}$$

$$Q_{opt} = \sqrt{\frac{2 C_o D}{C_c}}$$

# Quantity Discounts

Price per unit decreases as order quantity increases

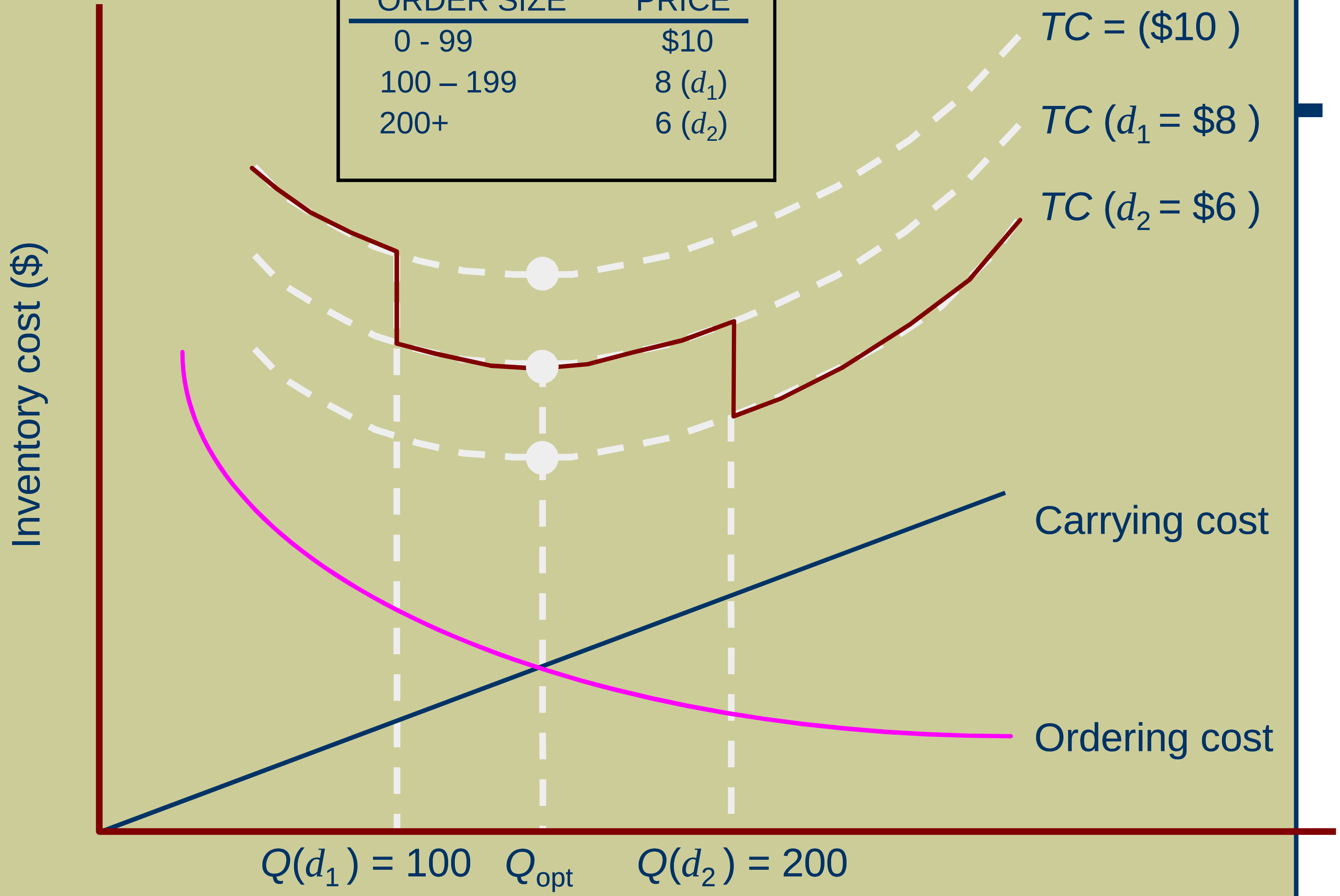
$$TC = \frac{C_o D}{Q} + \frac{C_c Q}{2} + PD$$

where

$P$ = per unit price of the item
$D$ = annual demand

# Quantity Discount Model (cont.)

| ORDER SIZE | PRICE |
|---|---|
| 0 - 99 | $10 |
| 100 – 199 | 8 ($d_1$) |
| 200+ | 6 ($d_2$) |



# Quantity Discount: Example

| QUANTITY | PRICE |
|---|---|
| 1 - 49 | $1,400 |
| 50 - 89 | 1,100 |
| 90+ | 900 |

$C_o$ = $2,500
$C_c$ = $190 per TV
$D$ = 200 TVs per year

$$Q_{opt} = \sqrt{\frac{2C_oD}{C_c}} = \sqrt{\frac{2(2500)(200)}{190}} = 72.5 \text{ TVs}$$

For $Q$ = 72.5

$$TC = \frac{C_oD}{Q_{opt}} + \frac{C_cQ_{opt}}{2} + PD = \$233{,}784$$

For $Q$ = 90

$$TC = \frac{C_oD}{Q} + \frac{C_cQ}{2} + PD = \$194{,}105$$

# Quantity-Discount Model Solution with Excel

Microsoft Excel - Exhibit13.4.Inventory.xls

E8 =IF(D8>=B8,D8,B8)

**Example 13.4: A Quantity Discount Model with Constant Carrying Cost**

| | |
|---|---|
| Carrying cost = | $ 190 |
| Ordering cost = | $ 2,500 |
| Demand = | 200 |

| Quantity | Price | Q | Discount Q | Total Cost | |
|---|---|---|---|---|---|
| 1 | 1,400 | 72.55 | 72.55 | $ 293,784.05 | |
| 50 | 1,100 | 72.55 | 72.55 | $ 233,784.05 | |
| 90 | 900 | 72.55 | 90.00 | $ 194,105.56 | *Optimal* |

=(D4*D5/E10)+(D3*E10/2)+C10*D5

=IF(D10>B10,D10,B10)

# Reorder Point

*Level of inventory at which a new order is placed*

$$R = dL$$

where

$d$ = demand rate per period
$L$ = lead time

# Reorder Point: Example

Demand = 10,000 gallons/year

Store open 311 days/year

Daily demand = 10,000 / 311 = 32.154 gallons/day

Lead time = L = 10 days

R = dL = (32.154)(10) = 321.54 gallons

# Safety Stocks

## Safety stock

buffer added to on hand inventory during lead time

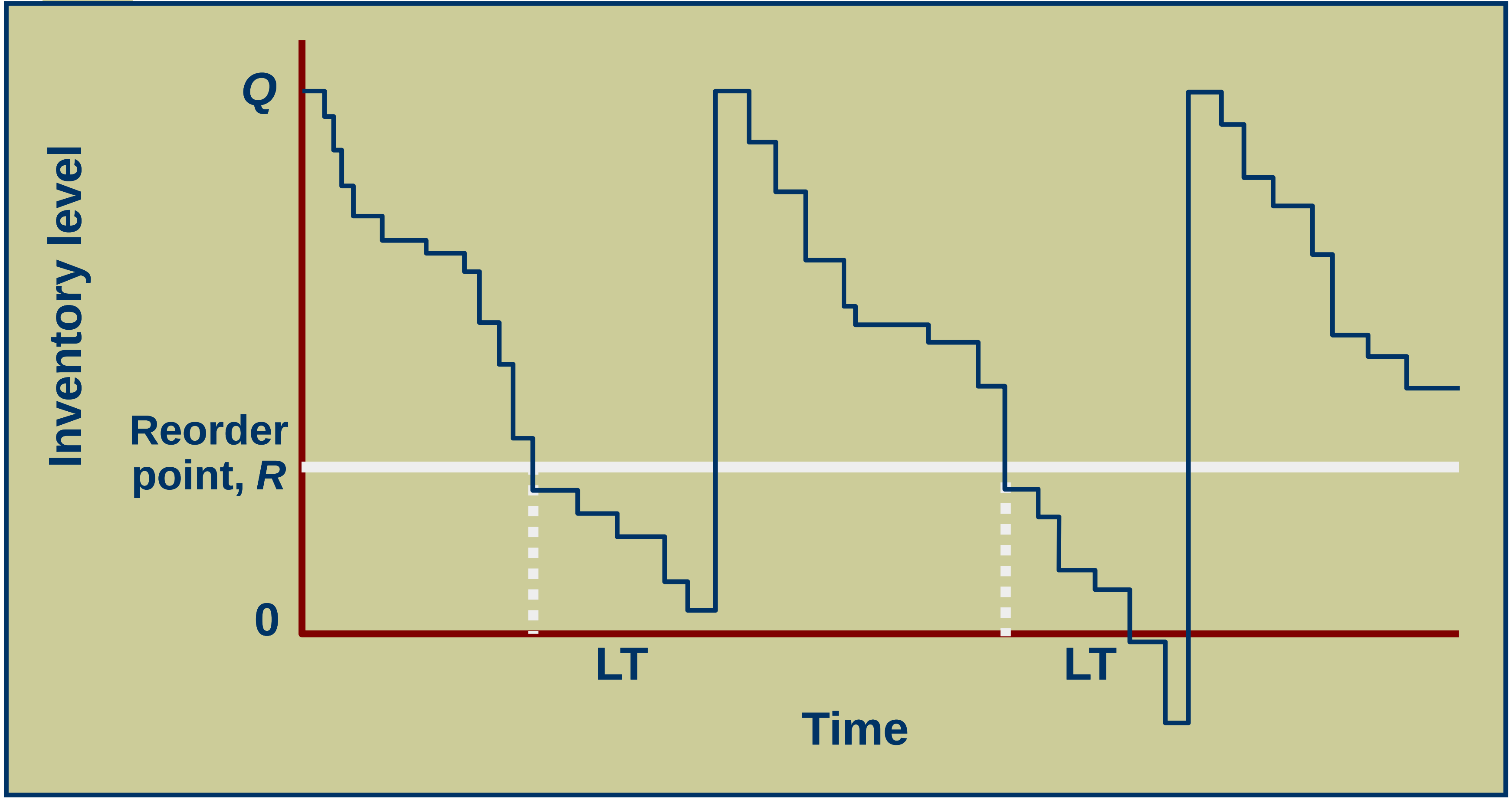
## Stockout

an inventory shortage

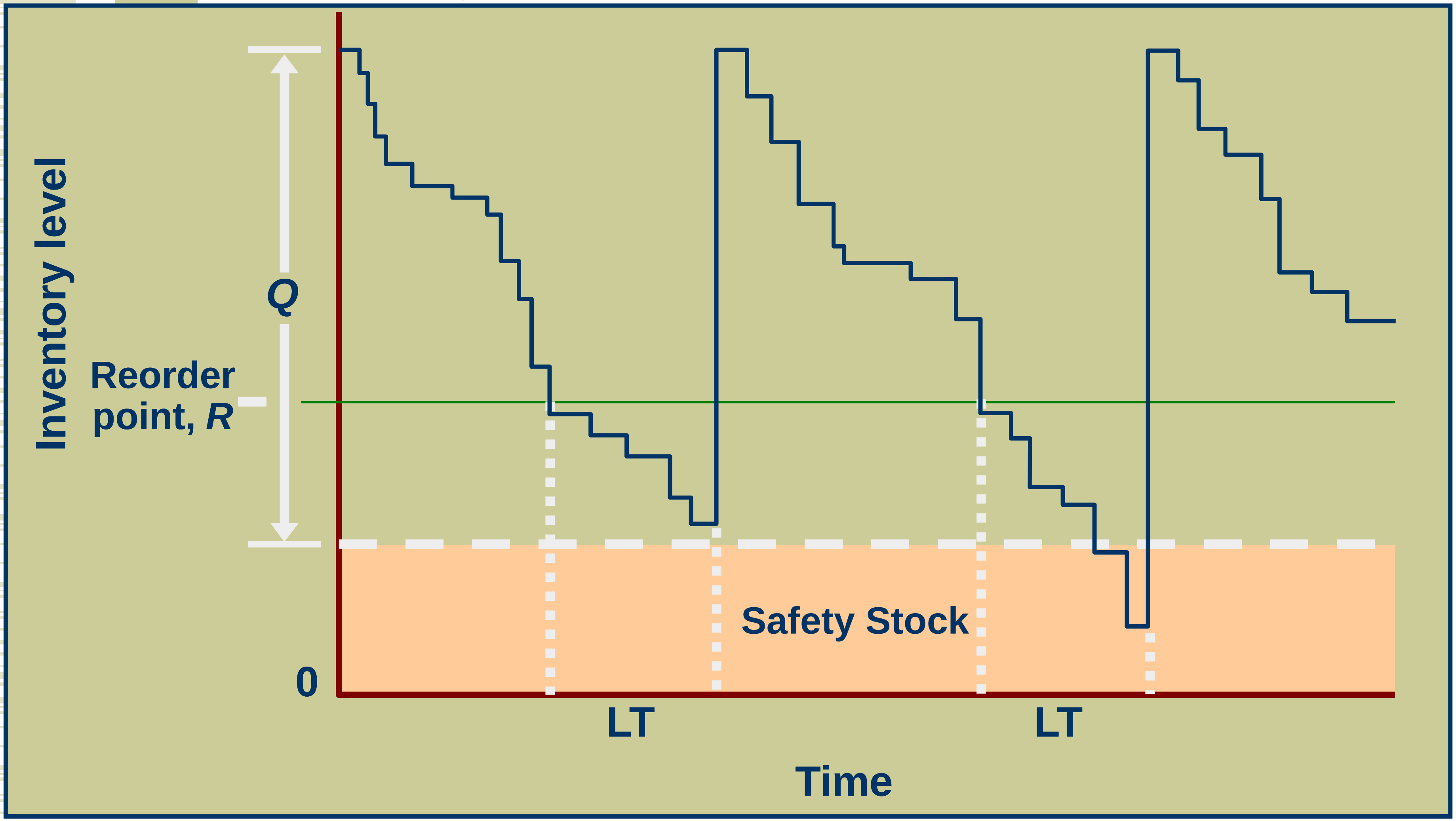
## Service level

probability that the inventory available during lead time will meet demand

# Variable Demand with a Reorder Point



# Reorder Point with a Safety Stock



# Reorder Point With Variable Demand

$$R = \bar{d}L + z\sigma_d \sqrt{L}$$

where

$\bar{d}$ = average daily demand

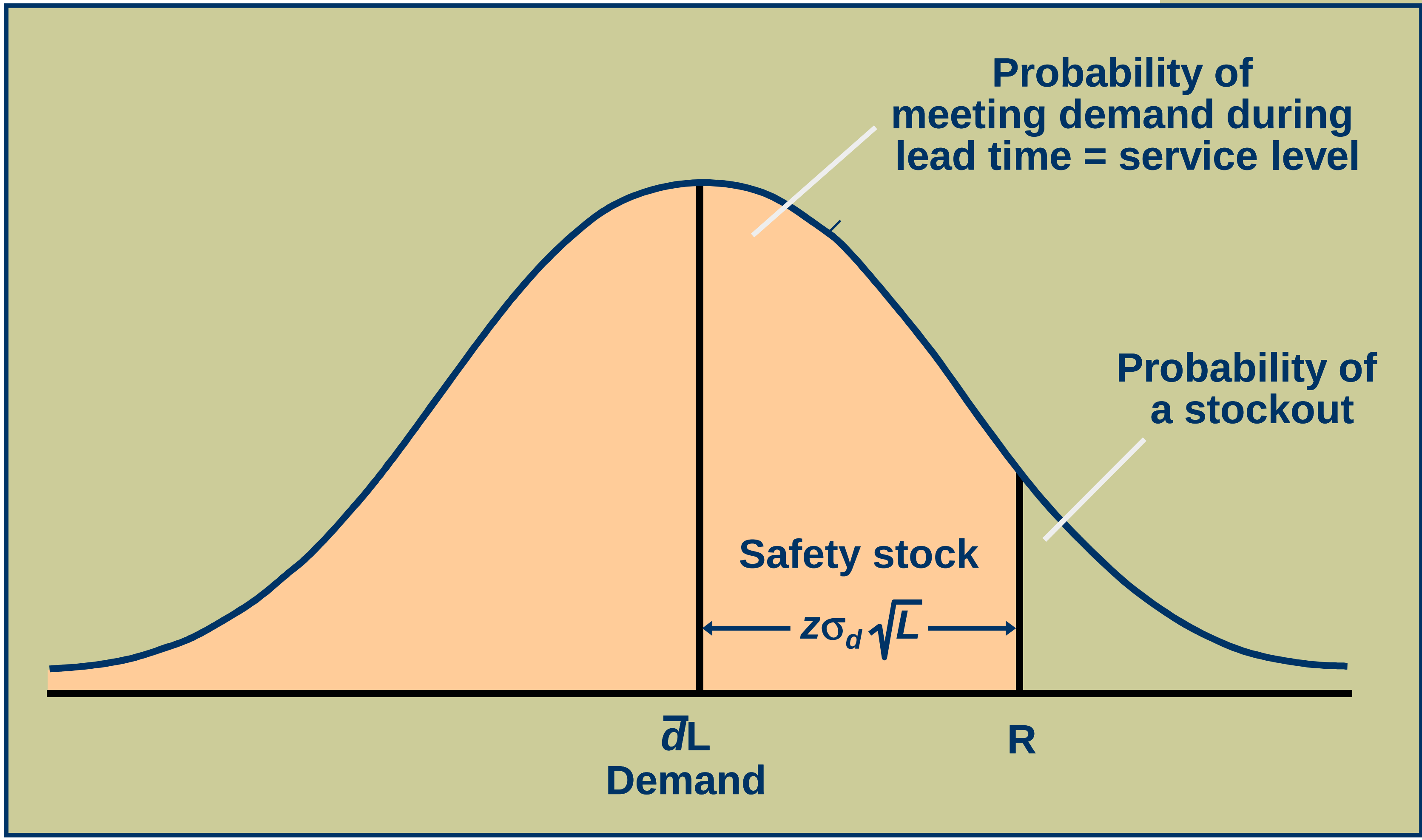
$L$ = lead time

$\sigma_d$ = the standard deviation of daily demand

$z$ = number of standard deviations corresponding to the service level probability

$z\sigma_d \sqrt{L}$ = safety stock

# Reorder Point for a Service Level



# Reorder Point for Variable Demand

The paint store wants a reorder point with a 95% service level and a 5% stockout probability

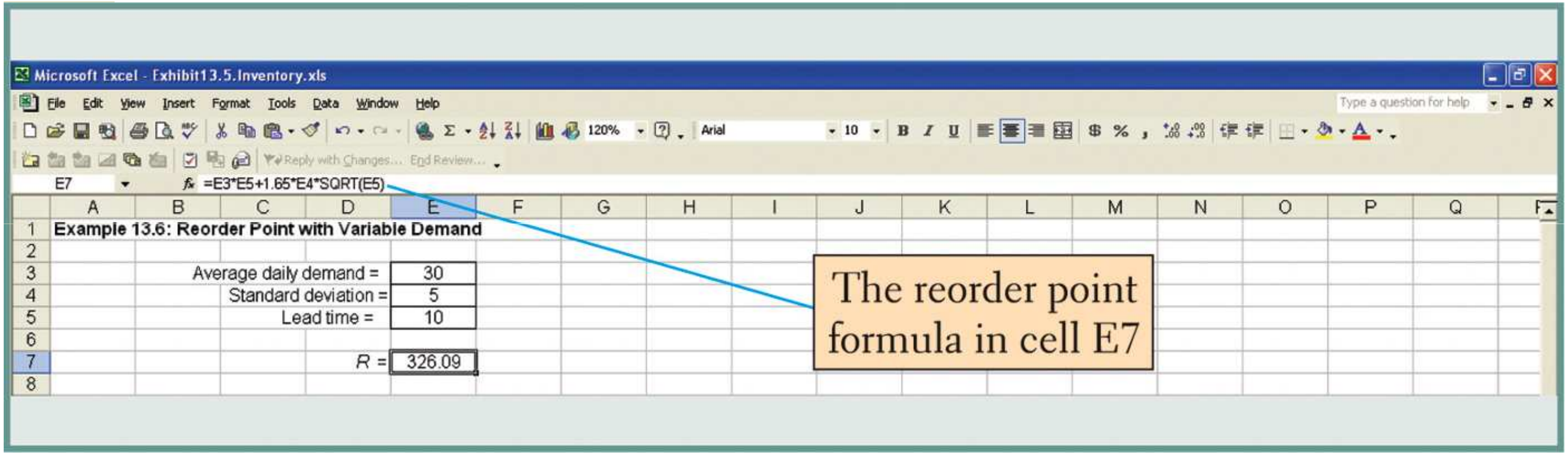
$\bar{d}$ = 30 gallons per day
$L$ = 10 days
$\sigma_d$ = 5 gallons per day

For a 95% service level, $z$ = 1.65

$$R = \bar{d}L + z\sigma_d\sqrt{L}$$
$$= 30(10) + (1.65)(5)(\sqrt{10})$$
$$= 326.1 \text{ gallons}$$

$$\text{Safety stock} = z\sigma_d\sqrt{L}$$
$$= (1.65)(5)(\sqrt{10})$$
$$= 26.1 \text{ gallons}$$

# Determining Reorder Point with Excel



# Order Quantity for a Periodic Inventory System

$$Q = \bar{d}(t_b + L) + z\sigma_d \sqrt{t_b + L} - I$$

where

$d$ = average demand rate

$t_b$ = the fixed time between orders

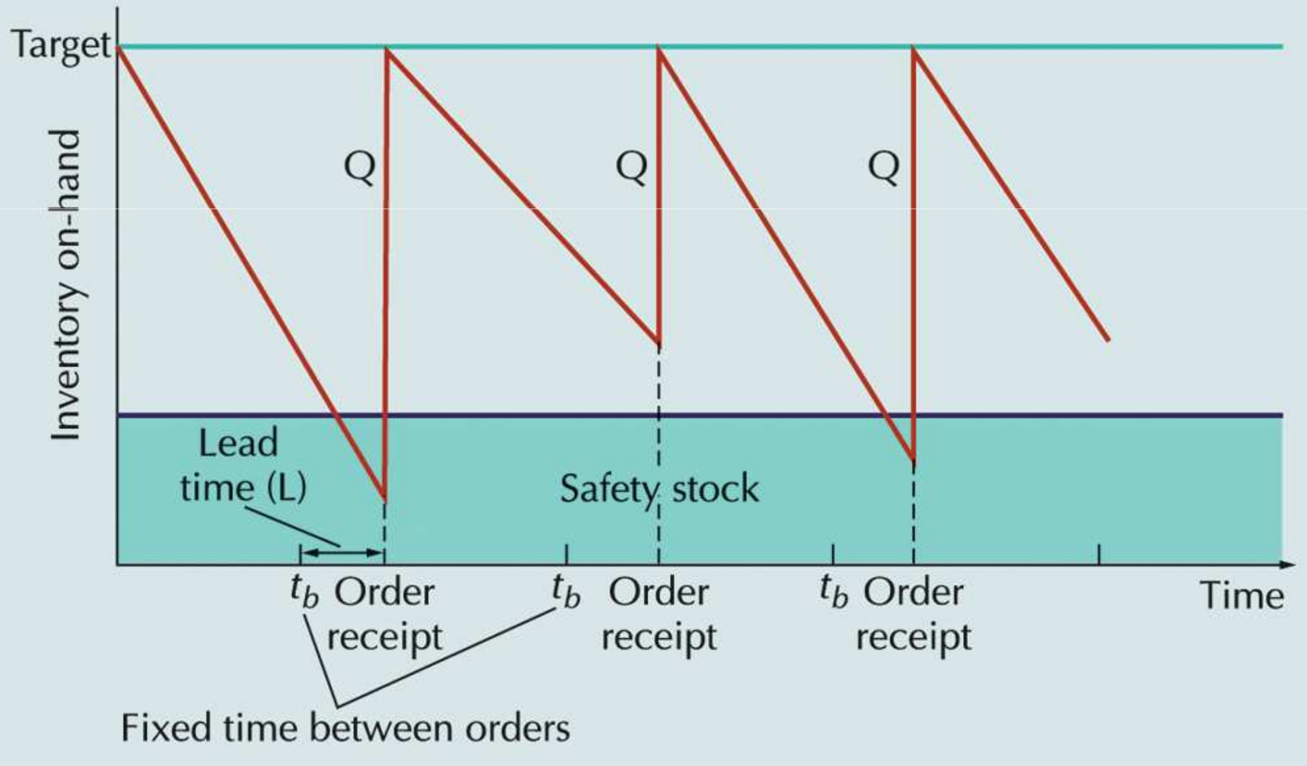
$L$ = lead time

$\sigma_d$ = standard deviation of demand

$z\sigma_d \sqrt{t_b + L}$ = safety stock

$I$ = inventory level

# Periodic Inventory System



# Fixed-Period Model with Variable Demand

$d$ = 6 packages per day

$\sigma_d$ = 1.2 packages

$t_b$ = 60 days

$L$ = 5 days

$I$ = 8 packages

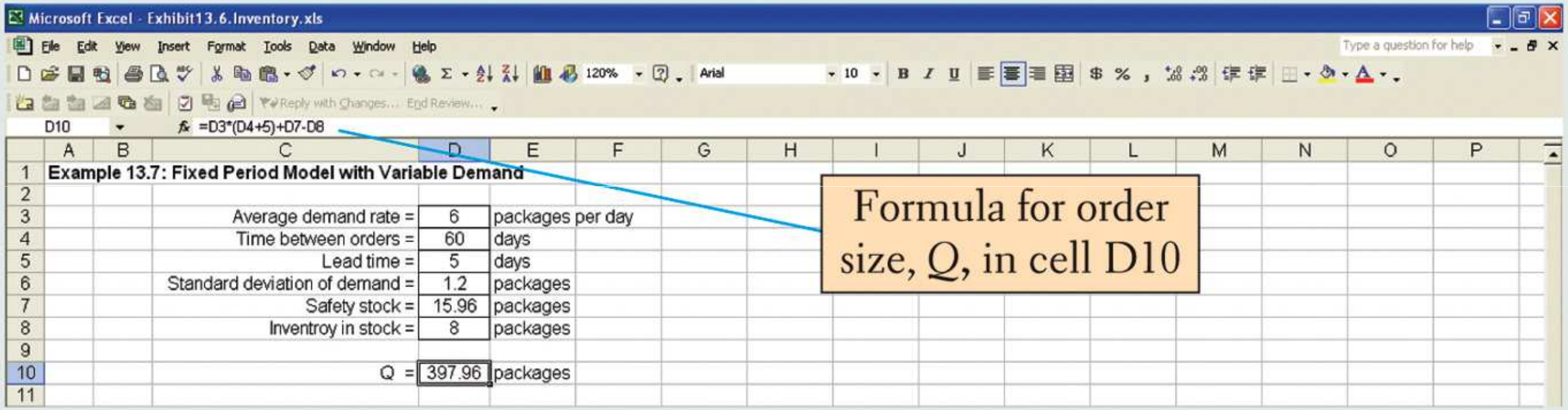
$z$ = 1.65 (for a 95% service level)

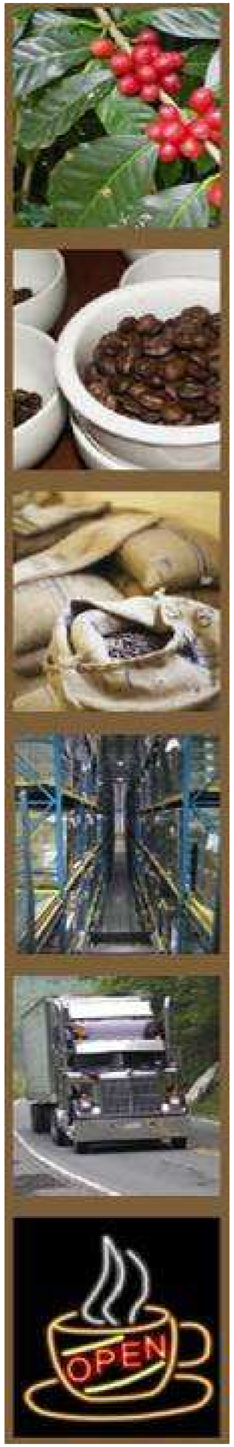
$$Q = \bar{d}(t_b + L) + z\sigma_d\sqrt{t_b + L} - I$$

$$= (6)(60 + 5) + (1.65)(1.2)\sqrt{60 + 5} - 8$$

$$= 397.96 \text{ packages}$$

# Fixed-Period Model with Excel





# Chapter 13 Supplement

## *Simulation*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Monte Carlo Simulation
- Computer Simulation with Excel
- Areas of Simulation Application

# Simulation

- Mathematical and computer modeling technique for replicating real-world problem situations
- Modeling approach primarily used to analyze probabilistic problems
  - It does not normally provide a solution; instead it provides information that is used to make a decision
- Physical simulation
  - Space flights, wind tunnels, treadmills for tires
- Mathematical-computerized simulation
  - Computer-based replicated models

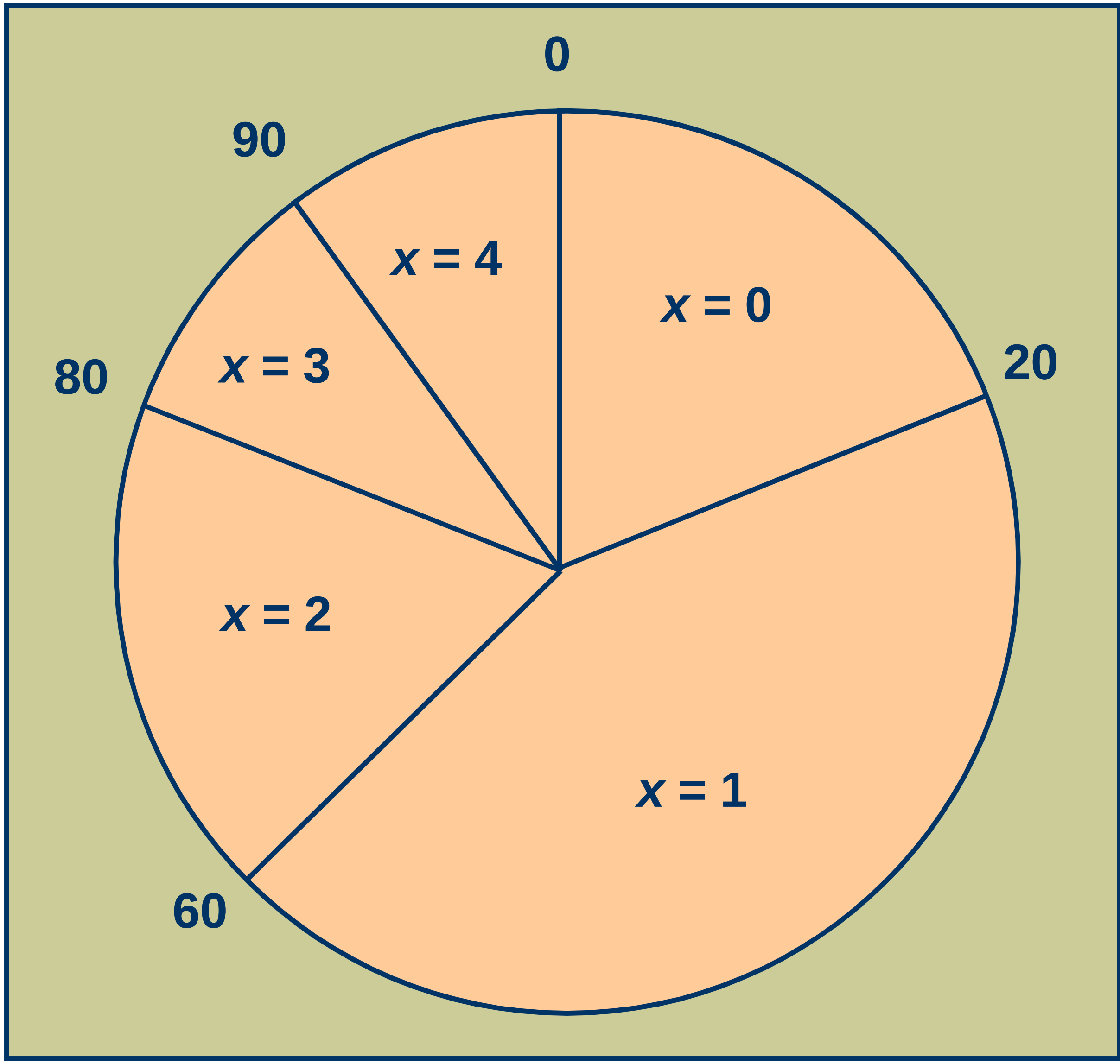
# Monte Carlo Simulation

- Select numbers randomly from a probability distribution
- Use these values to observe how a model performs over time
- Random numbers each have an equal likelihood of being selected at random

# Distribution of Demand

| LAPTOPS DEMANDED PER WEEK, $x$ | FREQUENCY OF DEMAND | PROBABILITY OF DEMAND, $P(x)$ |
|---|---|---|
| 0 | 20 | 0.20 |
| 1 | 40 | 0.40 |
| 2 | 20 | 0.20 |
| 3 | 10 | 0.10 |
| 4 | 10 | 0.10 |
| | 100 | 1.00 |

# Roulette Wheel of Demand



# Generating Demand from Random Numbers

| DEMAND, $x$ | RANGES OF RANDOM NUMBERS, $r$ | |
|---|---|---|
| 0 | 0-19 | |
| 1 | 20-59 | $r$ = 39 |
| 2 | 60-79 | |
| 3 | 80-89 | |
| 4 | 90-99 | |

# Random Number Table

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 39 | 65 | 76 | 45 | 45 | 19 | 90 | 69 | 64 | 61 |
| 73 | 71 | 23 | 70 | 90 | 65 | 97 | 60 | 12 | 11 |
| 72 | 18 | 47 | 33 | 84 | 51 | 67 | 47 | 97 | 19 |
| 75 | 12 | 25 | 69 | 17 | 17 | 95 | 21 | 78 | 58 |
| 37 | 17 | 79 | 88 | 74 | 63 | 52 | 06 | 34 | 30 |

# 15 Weeks of Demand

| WEEK | *r* | DEMAND (*x*) | REVENUE (S) |
|---|---|---|---|
| 1 | 39 | 1 | 4,300 |
| 2 | 73 | 2 | 8,600 |
| 3 | 72 | 2 | 8,600 |
| 4 | 75 | 2 | 8,600 |
| 5 | 37 | 1 | 4,300 |
| 6 | 02 | 0 | 0 |
| 7 | 87 | 3 | 12,900 |
| 8 | 98 | 4 | 17,200 |
| 9 | 10 | 0 | 0 |
| 10 | 47 | 1 | 4,300 |
| 11 | 93 | 4 | 17,200 |
| 12 | 21 | 1 | 4,300 |
| 13 | 95 | 4 | 17,200 |
| 14 | 97 | 4 | 17,200 |
| 15 | 69 | 2 | 8,600 |
| | | $\Sigma = 31$ | $133,300 |

Average demand
= 31/15
= 2.07 laptops/week

# Computing Expected Demand

$$E(x) = (0.20)(0) + (0.40)(1) + (0.20)(2) + (0.10)(3) + (0.10)(4) = 1.5 \text{ laptops per week}$$

- Difference between 1.5 and 2.07 is due to small number of periods analyzed (only 15 weeks)
- Steady-state result
  - an average result that remains constant after enough trials

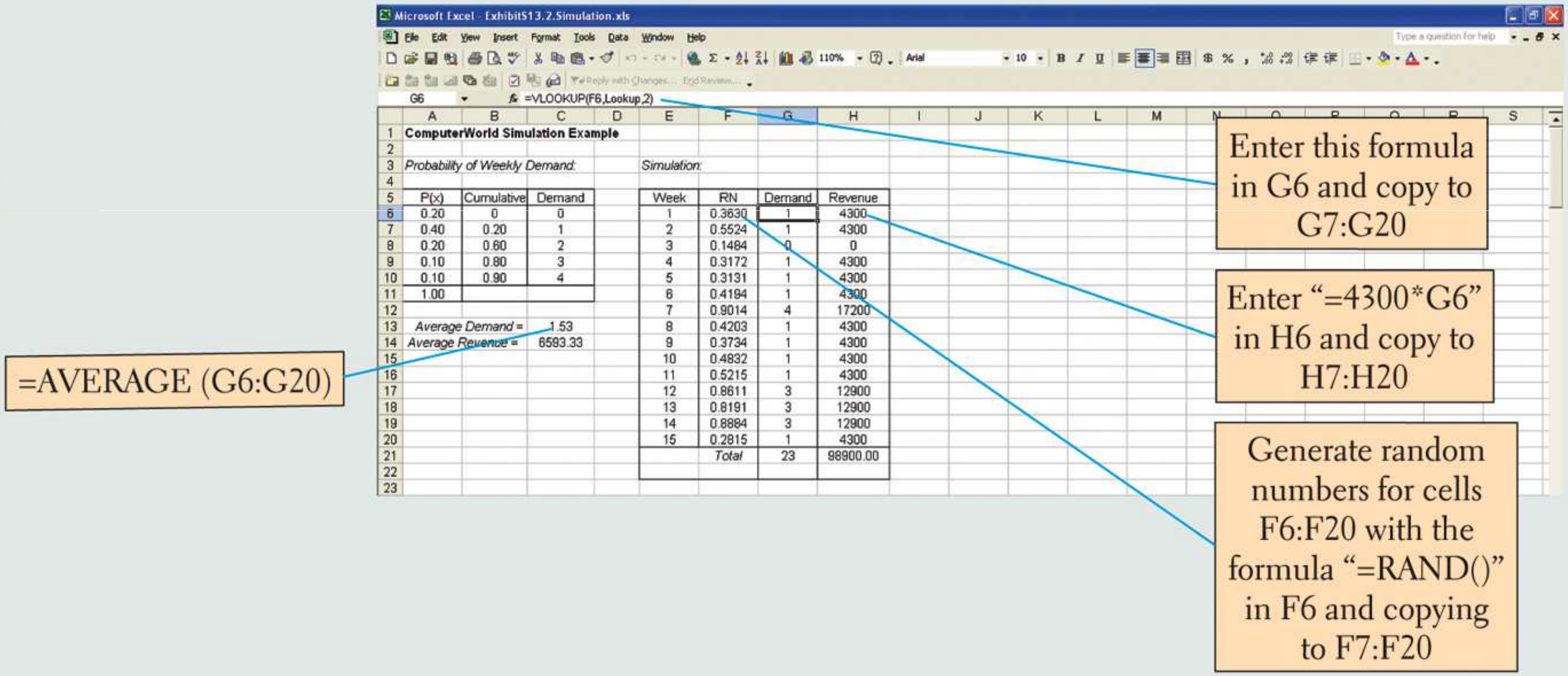
# Random Numbers in Excel

Microsoft Excel - ExhibitS13.1.Simulation.xls

A3 | 0.629923723538247

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 100 Random Numbers Generated Using RAND() | | | | | | | | | | |
| 2 | | | | | | | | | | | |
| 3 | 0.6299 | 0.6922 | 0.4634 | 0.0433 | 0.0755 | 0.0641 | 0.3189 | 0.2599 | 0.2288 | 0.7371 | |
| 4 | 0.4191 | 0.7927 | 0.6893 | 0.9192 | 0.8019 | 0.4114 | 0.3443 | 0.5397 | 0.8936 | 0.6944 | |
| 5 | 0.7306 | 0.4968 | 0.5271 | 0.2341 | 0.3518 | 0.1129 | 0.7664 | 0.5752 | 0.7673 | 0.7338 | |
| 6 | 0.8712 | 0.5170 | 0.8834 | 0.9357 | 0.6817 | 0.6175 | 0.9635 | 0.0216 | 0.9409 | 0.3832 | |
| 7 | 0.8718 | 0.2347 | 0.3095 | 0.8006 | 0.7955 | 0.0621 | 0.3317 | 0.4863 | 0.4599 | 0.3011 | |
| 8 | 0.0935 | 0.0287 | 0.1110 | 0.6009 | 0.1023 | 0.3886 | 0.3424 | 0.2876 | 0.1904 | 0.1980 | |
| 9 | 0.2892 | 0.0149 | 0.5325 | 0.4057 | 0.0385 | 0.4983 | 0.8286 | 0.1043 | 0.3955 | 0.1855 | |
| 10 | 0.4016 | 0.8078 | 0.0656 | 0.2995 | 0.5729 | 0.5776 | 0.8871 | 0.4656 | 0.9582 | 0.6215 | |
| 11 | 0.4508 | 0.3710 | 0.1533 | 0.9799 | 0.4267 | 0.7611 | 0.2242 | 0.8883 | 0.7665 | 0.5268 | |
| 12 | 0.6573 | 0.4849 | 0.6997 | 0.4905 | 0.8855 | 0.9194 | 0.5891 | 0.0643 | 0.2703 | 0.9780 | |
| 13 | | | | | | | | | | | |

# Simulation in Excel



# Simulation in Excel (cont.)

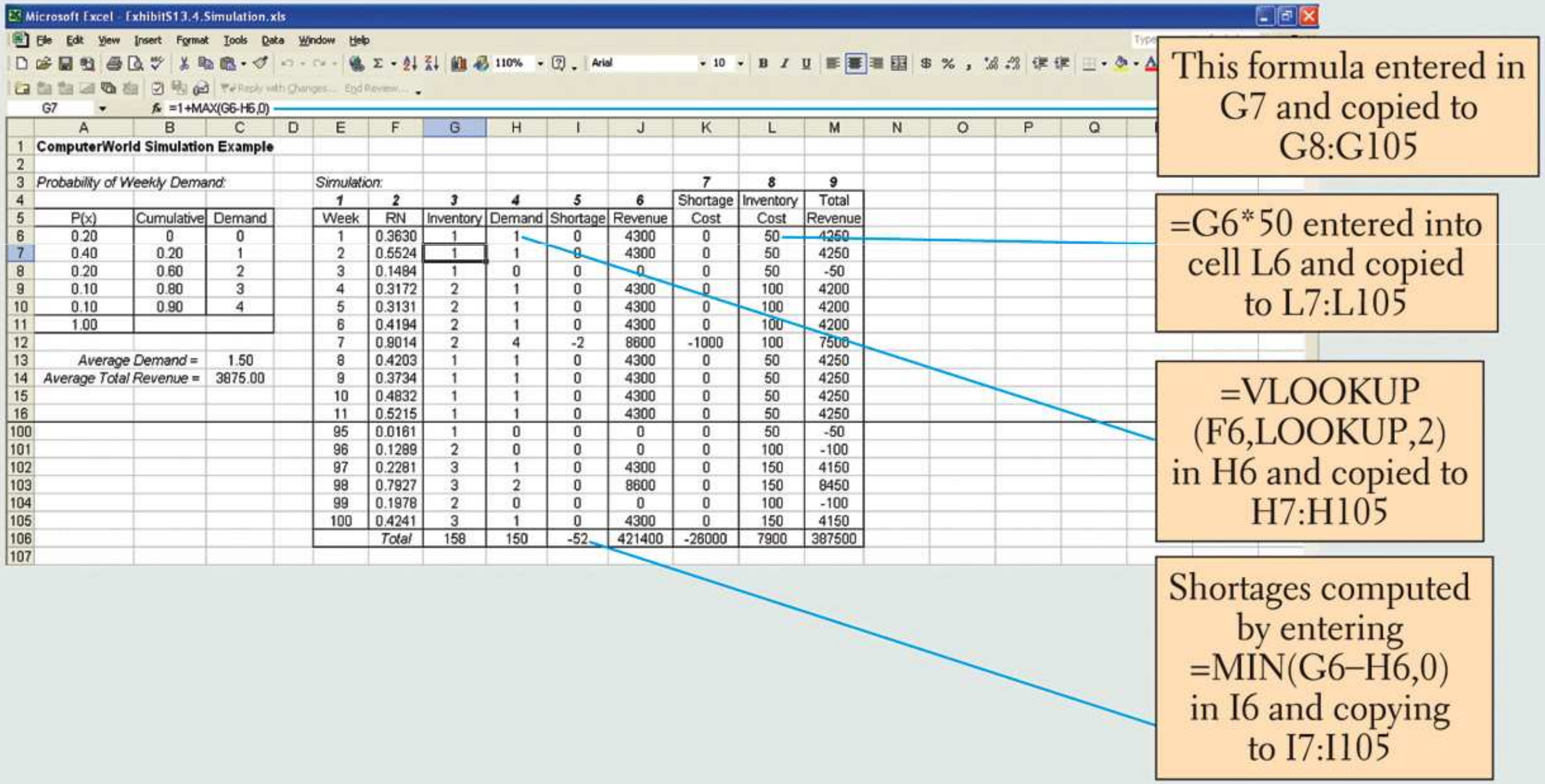
Microsoft Excel - ExhibitS13.3.Simulation.xls

G6 =VLOOKUP(F6,Lookup,2)

| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | **ComputerWorld Simulation Example (100 Weeks)** | | | | | | | |
| 2 | | | | | | | | |
| 3 | *Probability of Weekly Demand:* | | | | *Simulation:* | | | |
| 4 | | | | | | | | |
| 5 | P(x) | Cumulative | Demand | | Week | RN | Demand | Revenue |
| 6 | 0.20 | 0 | 0 | | 1 | 0.3630 | 1 | 4300 |
| 7 | 0.40 | 0.20 | 1 | | 2 | 0.5524 | 1 | 4300 |
| 8 | 0.20 | 0.60 | 2 | | 3 | 0.1484 | 0 | 0 |
| 9 | 0.10 | 0.80 | 3 | | 4 | 0.3172 | 1 | 4300 |
| 10 | 0.10 | 0.90 | 4 | | 5 | 0.3131 | 1 | 4300 |
| 11 | 1.00 | | | | 6 | 0.4194 | 1 | 4300 |
| 12 | | | | | 7 | 0.9014 | 4 | 17200 |
| 13 | *Average Demand =* | | 1.49 | | 8 | 0.4203 | 1 | 4300 |
| 14 | *Average Revenue =* | | 6407.00 | | 9 | 0.3734 | 1 | 4300 |
| 15 | | | | | 10 | 0.4832 | 1 | 4300 |
| 100 | | | | | 95 | 0.2370 | 1 | 4300 |
| 101 | | | | | 96 | 0.1215 | 2 | 8600 |
| 102 | | | | | 97 | 0.0809 | 2 | 8600 |
| 103 | | | | | 98 | 0.8202 | 0 | 0 |
| 104 | | | | | 99 | 0.9290 | 0 | 0 |
| 105 | | | | | 100 | 0.3653 | 2 | 8600 |
| 106 | | | | | | *Total* | 149 | 640700 |
| 107 | | | | | | | | |

Spreadsheet "frozen" at row 16 to show first 10 weeks and last 6

# Decision Making with Simulation



Microsoft Excel - ExhibitS13.4.Simulation.xls

G7 =1+MAX(G6-H6,0)

| | A | B | C | E | F | G | H | I | J | K | L | M |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **ComputerWorld Simulation Example** | | | | | | | | | | | |
| 2 | | | | | | | | | | | | |
| 3 | *Probability of Weekly Demand:* | | | *Simulation:* | | | | | | *7* | *8* | *9* |
| 4 | | | | *1* | *2* | *3* | *4* | *5* | *6* | Shortage | Inventory | Total |
| 5 | P(x) | Cumulative | Demand | Week | RN | Inventory | Demand | Shortage | Revenue | Cost | Cost | Revenue |
| 6 | 0.20 | 0 | 0 | 1 | 0.3630 | 1 | 1 | 0 | 4300 | 0 | 50 | 4250 |
| 7 | 0.40 | 0.20 | 1 | 2 | 0.5524 | 1 | 1 | 0 | 4300 | 0 | 50 | 4250 |
| 8 | 0.20 | 0.60 | 2 | 3 | 0.1484 | 1 | 0 | 0 | 0 | 0 | 50 | -50 |
| 9 | 0.10 | 0.80 | 3 | 4 | 0.3172 | 2 | 1 | 0 | 4300 | 0 | 100 | 4200 |
| 10 | 0.10 | 0.90 | 4 | 5 | 0.3131 | 2 | 1 | 0 | 4300 | 0 | 100 | 4200 |
| 11 | 1.00 | | | 6 | 0.4194 | 2 | 1 | 0 | 4300 | 0 | 100 | 4200 |
| 12 | | | | 7 | 0.9014 | 2 | 4 | -2 | 8600 | -1000 | 100 | 7500 |
| 13 | *Average Demand =* | | 1.50 | 8 | 0.4203 | 1 | 1 | 0 | 4300 | 0 | 50 | 4250 |
| 14 | *Average Total Revenue =* | | 3875.00 | 9 | 0.3734 | 1 | 1 | 0 | 4300 | 0 | 50 | 4250 |
| 15 | | | | 10 | 0.4832 | 1 | 1 | 0 | 4300 | 0 | 50 | 4250 |
| 16 | | | | 11 | 0.5215 | 1 | 1 | 0 | 4300 | 0 | 50 | 4250 |
| 100 | | | | 95 | 0.0161 | 1 | 0 | 0 | 0 | 0 | 50 | -50 |
| 101 | | | | 96 | 0.1289 | 2 | 0 | 0 | 0 | 0 | 100 | -100 |
| 102 | | | | 97 | 0.2281 | 3 | 1 | 0 | 4300 | 0 | 150 | 4150 |
| 103 | | | | 98 | 0.7927 | 3 | 2 | 0 | 8600 | 0 | 150 | 8450 |
| 104 | | | | 99 | 0.1978 | 2 | 0 | 0 | 0 | 0 | 100 | -100 |
| 105 | | | | 100 | 0.4241 | 3 | 1 | 0 | 4300 | 0 | 150 | 4150 |
| 106 | | | | | *Total* | 158 | 150 | -52 | 421400 | -26000 | 7900 | 387500 |
| 107 | | | | | | | | | | | | |

# Decision Making with Simulation (cont.)

Microsoft Excel - ExhibitS13.5.Simulation.xls

G7 =2+MAX(G6-H6,0)

**ComputerWorld Simulation Example**

*Probability of Weekly Demand:*

| P(x) | Cumulative | Demand |
|---|---|---|
| 0.20 | 0 | 0 |
| 0.40 | 0.20 | 1 |
| 0.20 | 0.60 | 2 |
| 0.10 | 0.80 | 3 |
| 0.10 | 0.90 | 4 |
| 1.00 | | |

*Average Demand =* 1.52

*Average Total Revenue =* 5107.50

*Simulation:*

| 1 Week | 2 RN | 3 Inventory | 4 Demand | 5 Shortage | 6 Revenue | 7 Shortage Cost | 8 Inventory Cost | 9 Total Revenue |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.3630 | 2 | 1 | 0 | 4300 | 0 | 100 | 4200 |
| 2 | 0.5524 | 3 | 1 | 0 | 4300 | 0 | 150 | 4150 |
| 3 | 0.1484 | 4 | 0 | 0 | 0 | 0 | 200 | -200 |
| 4 | 0.3172 | 6 | 1 | 0 | 4300 | 0 | 300 | 4000 |
| 5 | 0.3131 | 7 | 1 | 0 | 4300 | 0 | 350 | 3950 |
| 6 | 0.4194 | 8 | 3 | 0 | 12900 | 0 | 400 | 12500 |
| 7 | 0.9014 | 7 | 4 | 0 | 17200 | 0 | 350 | 16850 |
| 8 | 0.4203 | 5 | 1 | 0 | 4300 | 0 | 250 | 4050 |
| 9 | 0.3734 | 6 | 1 | 0 | 4300 | 0 | 300 | 4000 |
| 10 | 0.4832 | 7 | 1 | 0 | 4300 | 0 | 350 | 3950 |
| 11 | 0.5215 | 8 | 1 | 0 | 4300 | 0 | 400 | 3900 |
| 95 | 0.0161 | 42 | 0 | 0 | 0 | 0 | 2100 | -2100 |
| 96 | 0.1289 | 44 | 0 | 0 | 0 | 0 | 2200 | -2200 |
| 97 | 0.2281 | 46 | 1 | 0 | 4300 | 0 | 2300 | 2000 |
| 98 | 0.7927 | 47 | 2 | 0 | 8600 | 0 | 2350 | 6250 |
| 99 | 0.1978 | 47 | 0 | 0 | 0 | 0 | 2350 | -2350 |
| 100 | 0.4241 | 49 | 1 | 0 | 4300 | 0 | 2450 | 1850 |
| | *Total* | 2857 | 152 | 0 | 653600 | 0 | 142850 | 510750 |

New formula for two laptops ordered per week.

# Areas of Simulation Application

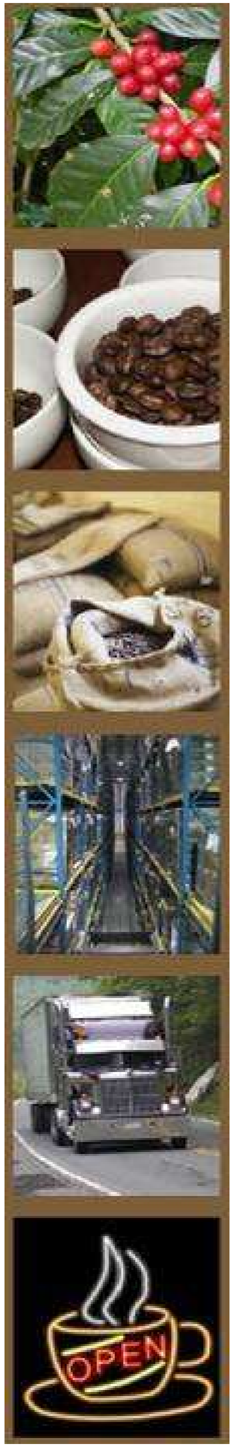
- Waiting Lines/Service
  - Complex systems for which it is difficult to develop analytical formulas
  - Determine how many registers and servers are needed to meet customer demand
- Inventory Management
  - Traditional models make the assumption that customer demand is certain
  - Simulation is widely used to analyze JIT without having to implement it physically

# Areas of Simulation Application (cont.)

- Production and Manufacturing Systems
  - Examples: production scheduling, production sequencing, assembly line balancing, plant layout, and plant location analysis
  - Machine breakdowns typically occur according to some probability distributions
- Capital Investment and Budgeting
  - Capital budgeting problems require estimates of cash flows, often resulting from many random variables
  - Simulation has been used to generate values of cash flows, market size, selling price, growth rate, and market share

# Areas of Simulation Application (cont.)

- Logistics
  - Typically include numerous random variables, such as distance, different modes of transport, shipping rates, and schedules to analyze different distribution channels
- Service Operations
  - Examples: police departments, fire departments, post offices, hospitals, court systems, airports
  - Complex operations that no technique except simulation can be employed
- Environmental and Resource Analysis
  - Examples: impact of manufacturing plants, waste-disposal facilities, nuclear power plants, waste and population conditions, feasibility of alternative energy sources



# Chapter 14

## *Sales and Operations Planning*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

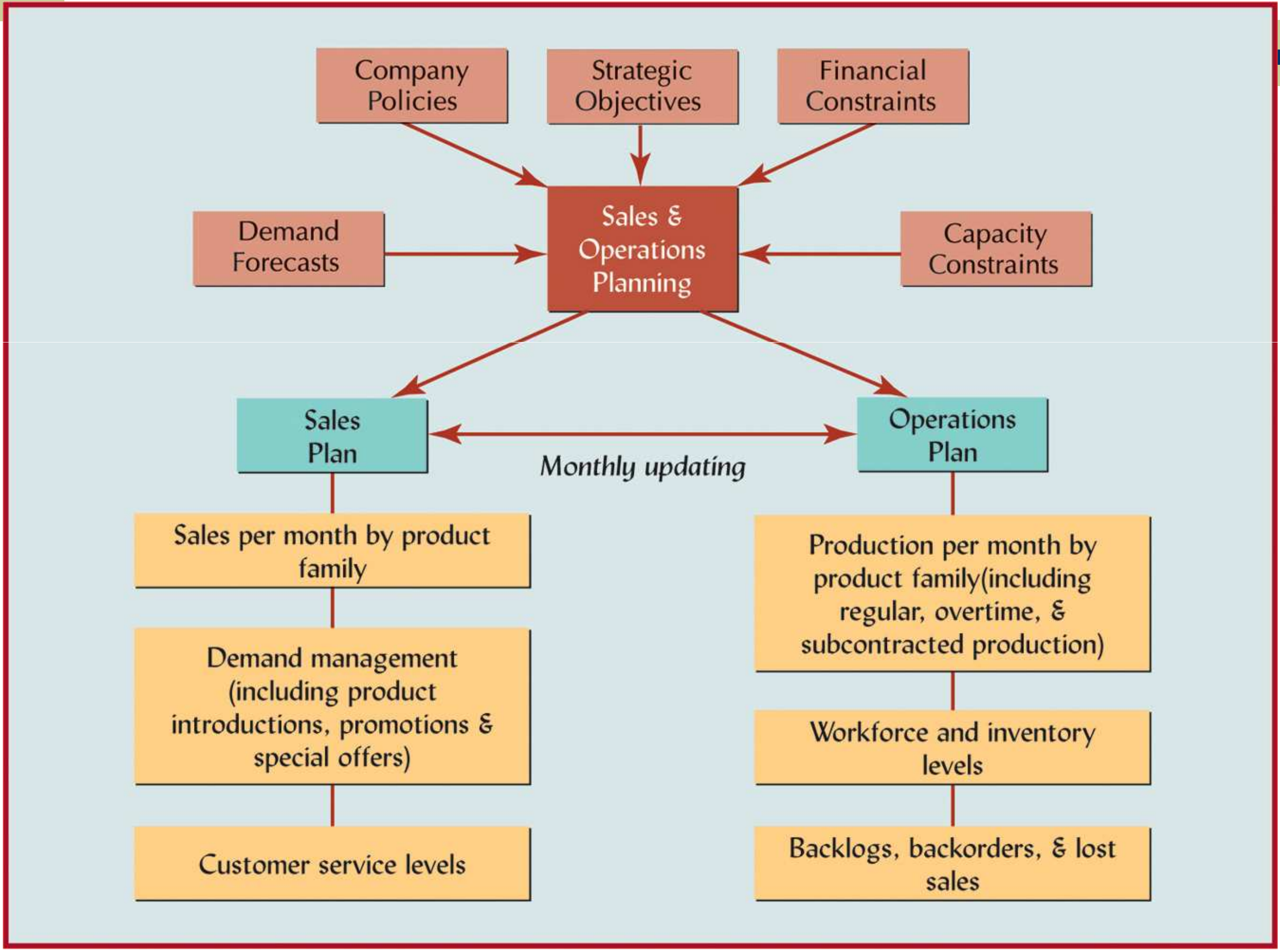
# Lecture Outline

- The Sales and Operations Planning Process
- Strategies for Adjusting Capacity
- Strategies for Managing Demand
- Quantitative Techniques for Aggregate Planning
- Hierarchical Nature of Planning
- Aggregate Planning for Services

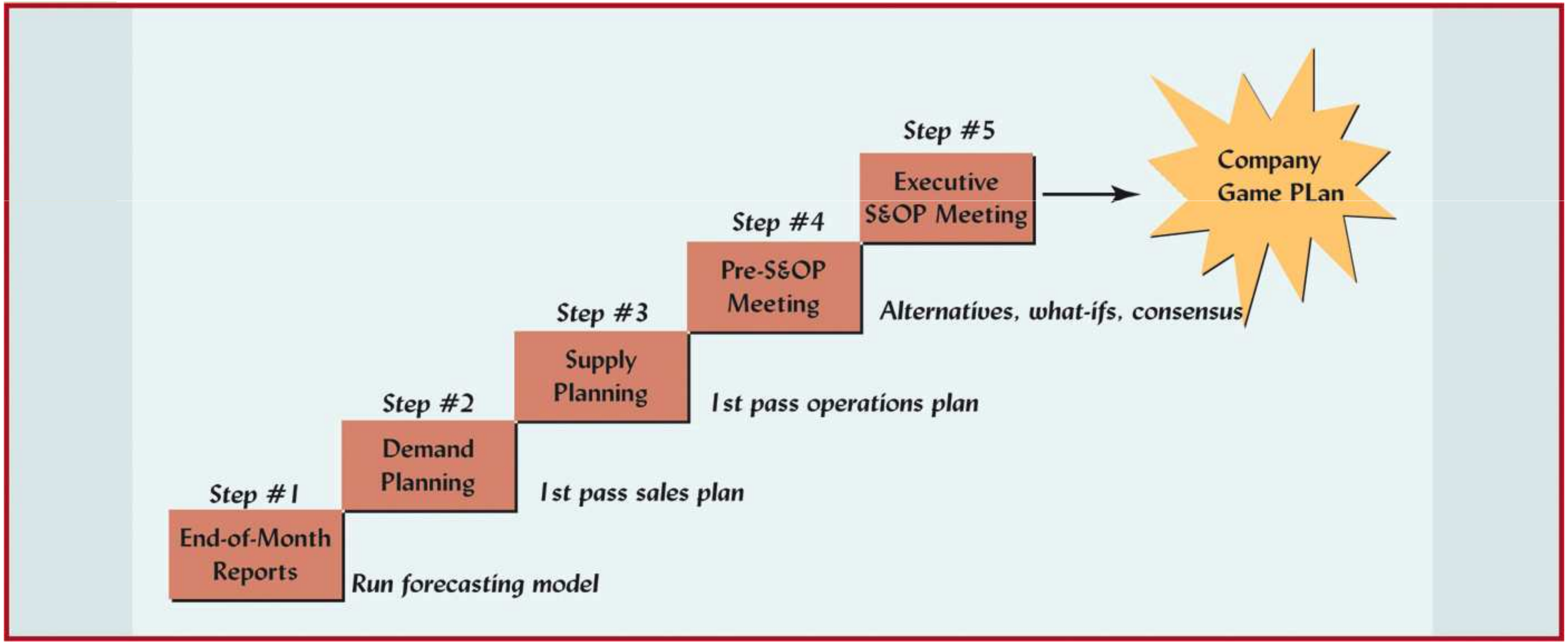
# Sales and Operations Planning

- Determines the resource capacity needed to meet demand over an intermediate time horizon
  - *Aggregate* refers to sales and operations planning for product lines or families
  - *Sales and Operations planning (S&OP)* matches supply and demand
- Objectives
  - Establish a company wide game plan for allocating resources
  - Develop an economic strategy for meeting demand

# Sales and Operations Planning Process



# The Monthly S&OP Planning Process



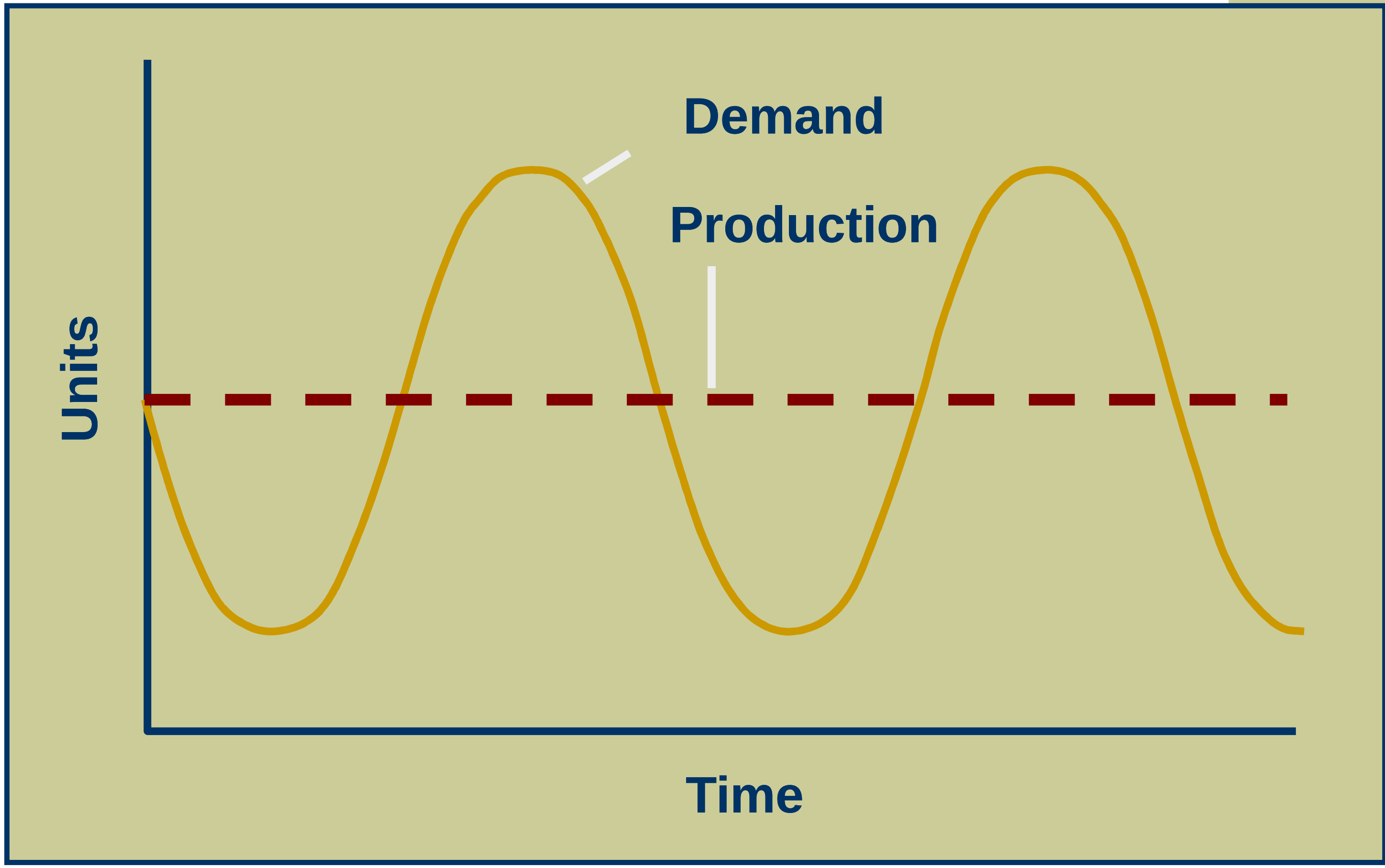
# Meeting Demand Strategies

- Adjusting capacity
  - Resources necessary to meet demand are acquired and maintained over the time horizon of the plan
  - Minor variations in demand are handled with overtime or under-time
- Managing demand
  - Proactive demand management

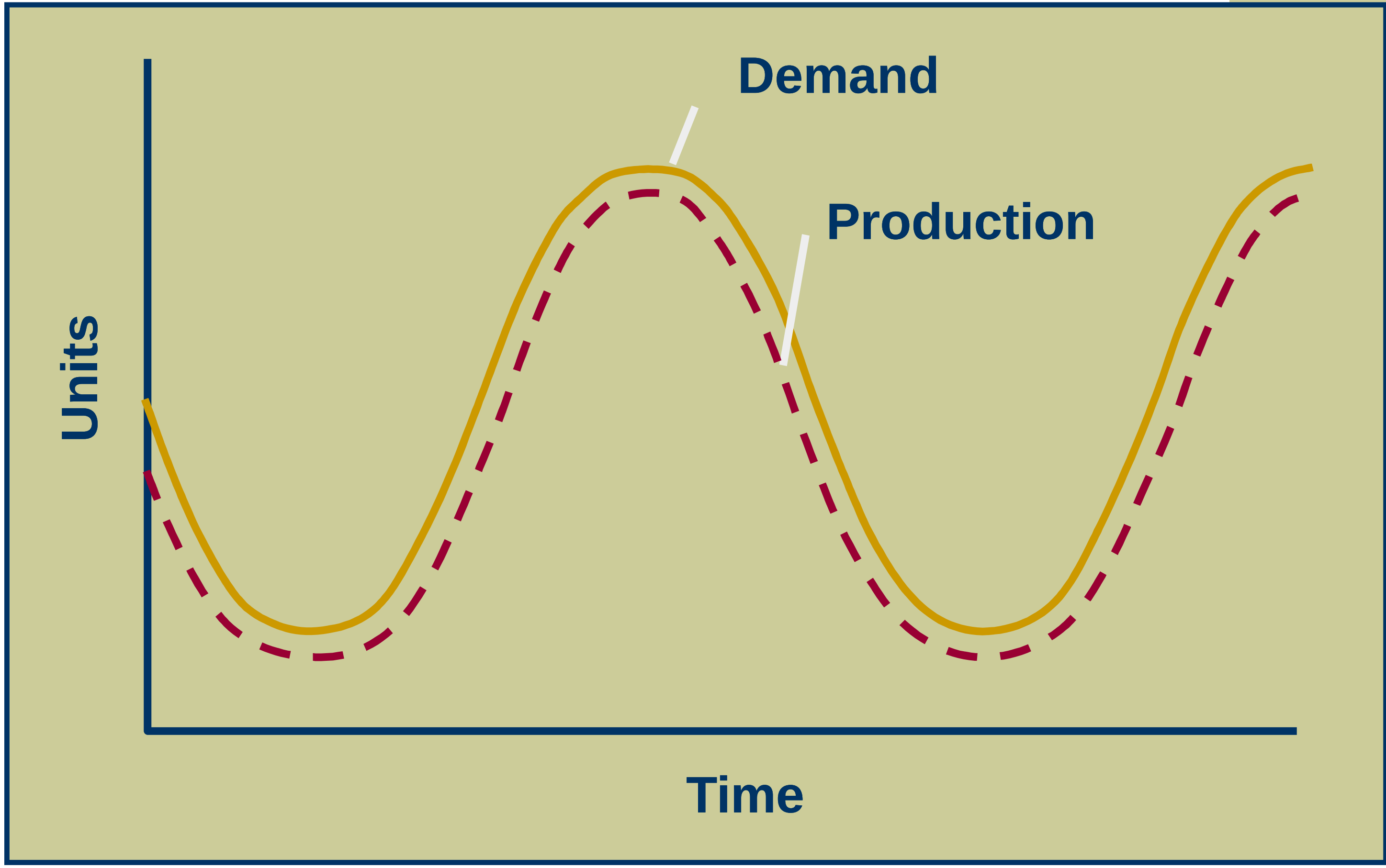
# Strategies for Adjusting Capacity

- Level production
  - Producing at a constant rate and using inventory to absorb fluctuations in demand
- Chase demand
  - Hiring and firing workers to match demand
- Peak demand
  - Maintaining resources for high-demand levels
- Overtime and under-time
  - Increasing or decreasing working hours
- Subcontracting
  - Let outside companies complete the work
- Part-time workers
  - Hiring part time workers to complete the work
- Backordering
  - Providing the service or product at a later time period

# Level Production



# Chase Demand



# Strategies for Managing Demand

- Shifting demand into other time periods
  - Incentives
  - Sales promotions
  - Advertising campaigns
- Offering products or services with counter-cyclical demand patterns
- Partnering with suppliers to reduce information distortion along the supply chain

# Quantitative Techniques For AP

- Pure Strategies
- Mixed Strategies
- Linear Programming
- Transportation Method
- Other Quantitative Techniques

# Pure Strategies

Example:

| QUARTER | SALES FORECAST (LB) |
|---|---|
| Spring | 80,000 |
| Summer | 50,000 |
| Fall | 120,000 |
| Winter | 150,000 |

Hiring cost = $100 per worker
Firing cost = $500 per worker
Inventory carrying cost = $0.50 pound per quarter
Regular production cost per pound = $2.00
Production per employee = 1,000 pounds per quarter
Beginning work force = 100 workers

# Level Production Strategy

Level production

$$\frac{(50{,}000 + 120{,}000 + 150{,}000 + 80{,}000)}{4} = 100{,}000 \text{ pounds}$$

| QUARTER | SALES FORECAST | PRODUCTION PLAN | INVENTORY |
|---|---|---|---|
| Spring | 80,000 | 100,000 | 20,000 |
| Summer | 50,000 | 100,000 | 70,000 |
| Fall | 120,000 | 100,000 | 50,000 |
| Winter | 150,000 | 100,000 | 0 |
| | | 400,000 | 140,000 |

**Cost of Level Production Strategy**

**(400,000 X $2.00) + (140,00 X $.50) = $870,000**

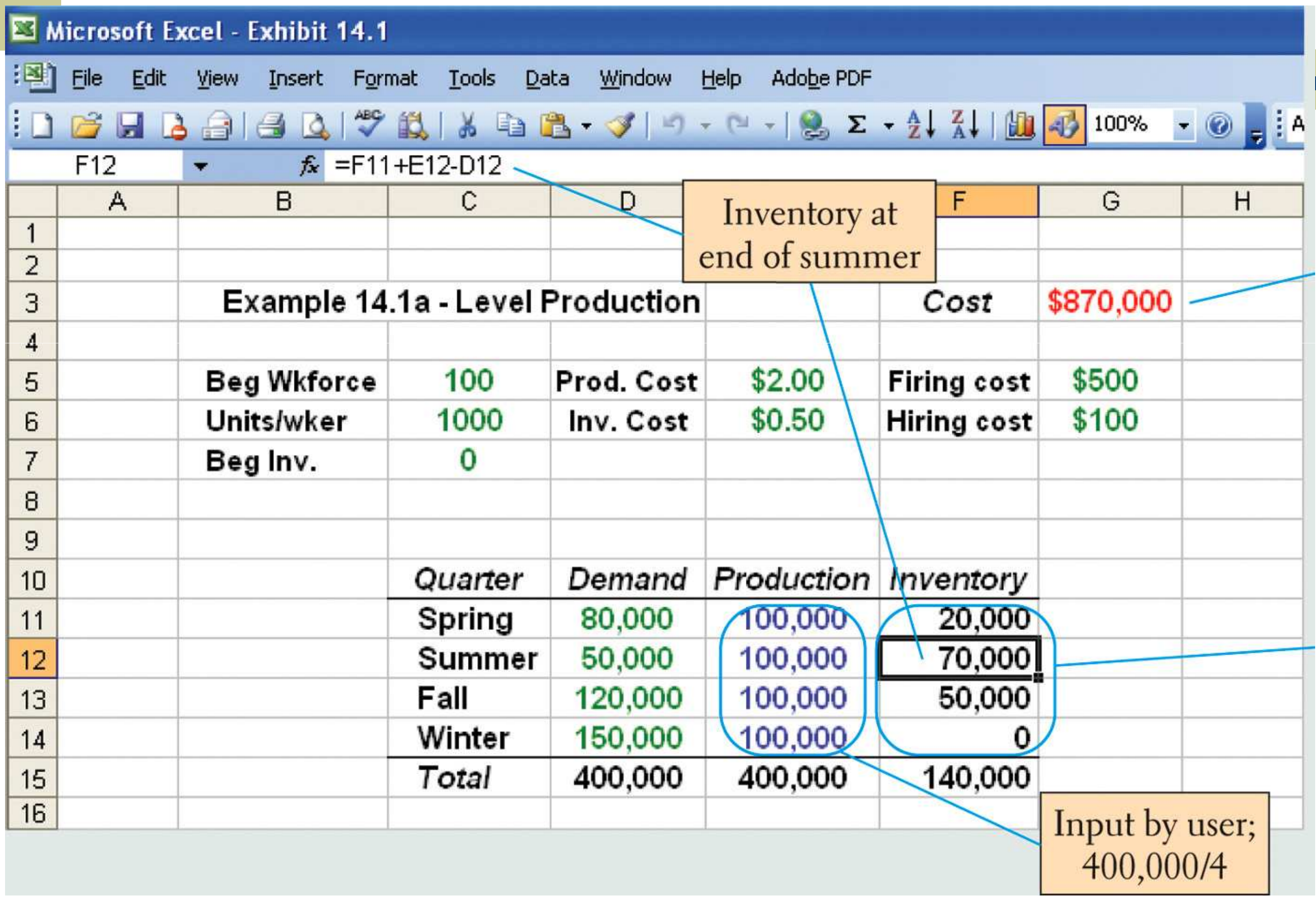
# Chase Demand Strategy

| QUARTER | SALES FORECAST | PRODUCTION PLAN | WORKERS NEEDED | WORKERS HIRED | WORKERS FIRED |
|---|---|---|---|---|---|
| Spring | 80,000 | 80,000 | 80 | 0 | 20 |
| Summer | 50,000 | 50,000 | 50 | 0 | 30 |
| Fall | 120,000 | 120,000 | 120 | 70 | 0 |
| Winter | 150,000 | 150,000 | 150 | 30 | 0 |
| | | | | 100 | 50 |

Cost of Chase Demand Strategy

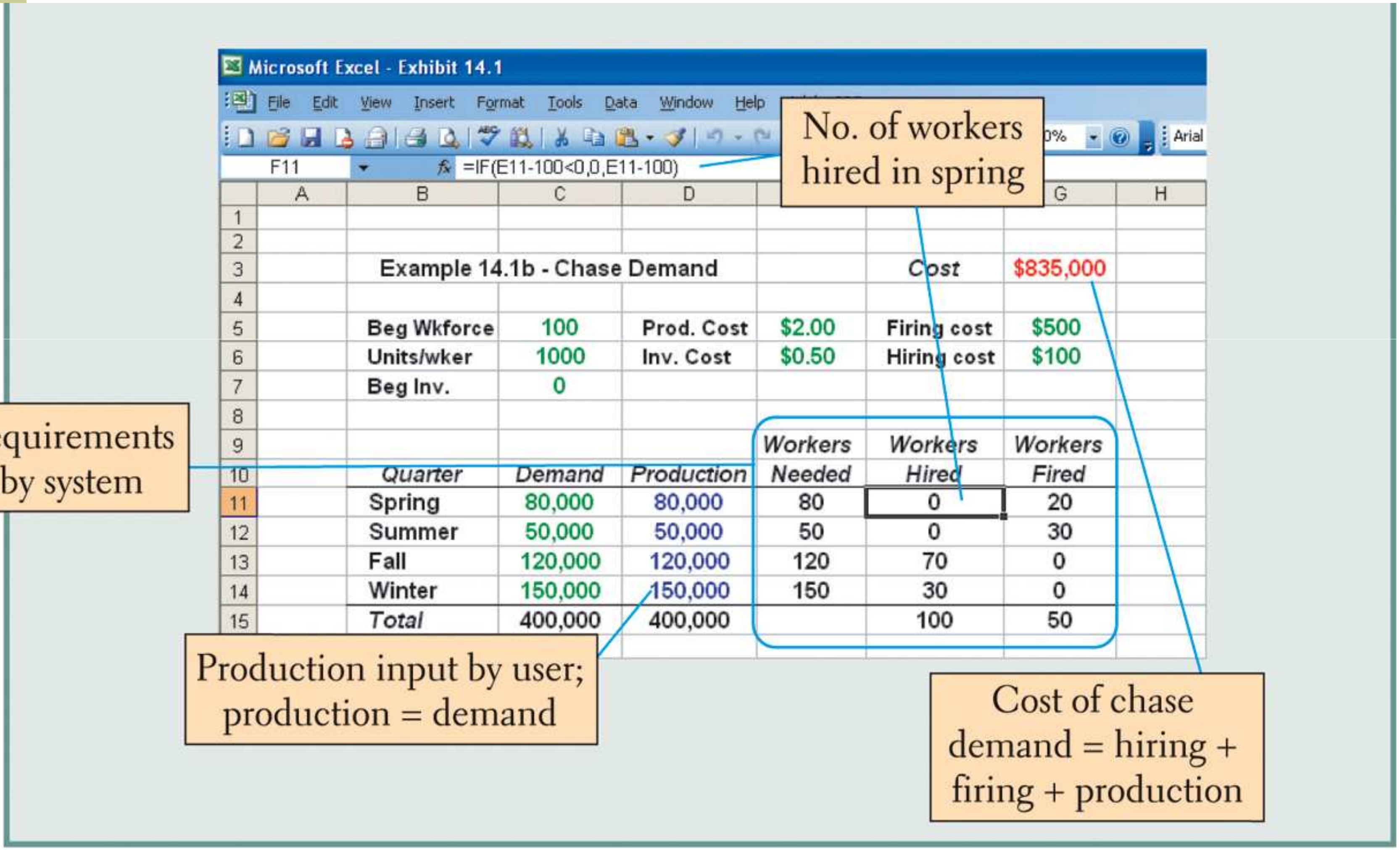
(400,000 X $2.00) + (100 x $100) + (50 x $500) = $835,000

# Level Production with Excel



| | B | C | D | E | F | G |
|---|---|---|---|---|---|---|
| 3 | | Example 14.1a - Level Production | | | Cost | $870,000 |
| 5 | Beg Wkforce | 100 | Prod. Cost | $2.00 | Firing cost | $500 |
| 6 | Units/wker | 1000 | Inv. Cost | $0.50 | Hiring cost | $100 |
| 7 | Beg Inv. | 0 | | | | |
| 10 | | *Quarter* | *Demand* | *Production* | *Inventory* | |
| 11 | | Spring | 80,000 | 100,000 | 20,000 | |
| 12 | | Summer | 50,000 | 100,000 | 70,000 | |
| 13 | | Fall | 120,000 | 100,000 | 50,000 | |
| 14 | | Winter | 150,000 | 100,000 | 0 | |
| 15 | | *Total* | 400,000 | 400,000 | 140,000 | |

# Chase Demand with Excel



Microsoft Excel - Exhibit 14.1

F11 =IF(E11-100<0,0,E11-100)

| | | | | | |
|---|---|---|---|---|---|
| Example 14.1b - Chase Demand | | | | Cost | $835,000 |
| Beg Wkforce | 100 | Prod. Cost | $2.00 | Firing cost | $500 |
| Units/wker | 1000 | Inv. Cost | $0.50 | Hiring cost | $100 |
| Beg Inv. | 0 | | | | |
| Quarter | Demand | Production | Workers Needed | Workers Hired | Workers Fired |
| Spring | 80,000 | 80,000 | 80 | 0 | 20 |
| Summer | 50,000 | 50,000 | 50 | 0 | 30 |
| Fall | 120,000 | 120,000 | 120 | 70 | 0 |
| Winter | 150,000 | 150,000 | 150 | 30 | 0 |
| Total | 400,000 | 400,000 | | 100 | 50 |

# Mixed Strategy

- Combination of Level Production and Chase Demand strategies
- Examples of management policies
  - no more than *x*% of the workforce can be laid off in one quarter
  - inventory levels cannot exceed *x* dollars
- Many industries may simply shut down manufacturing during the low demand season and schedule employee vacations during that time

# Mixed Strategies with Excel

Microsoft Excel - Exhibit 14.2

G9 =MAX(G8+D9+E9+F9-C9,0)

| | A | B | C | D | E | F | G | H | I | J | K |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | Example 14.2 (a) - Level Production | | | | | | |
| 2 | | | | | | | | | | | |
| 3 | | *Input:* | Beg. Wkrs | 10 | Regular | $10 | Hiring | $1,000 | | | |
| 4 | | | Units/wkr | 100 | Overtime | $15 | Firing | $500 | | *Cost:* | $146,000 |
| 5 | | | Beg. Inv. | 0 | Subk | $25 | Inventory | $1 | | | |
| 6 | | | | | | | | | | | |
| 7 | | *Month* | *Demand* | *Reg* | *OT* | *Subk* | *Inv* | *#Wkrs* | *#Hired* | *#Fired* | |
| 8 | | Jan | 1000 | 1,000 | 0 | 0 | 0 | 10 | 0 | 0 | |
| 9 | | Feb | 400 | 1,000 | 0 | 0 | 600 | 10 | 0 | 0 | |
| 10 | | Mar | 400 | 1,000 | 0 | 0 | 1,200 | 10 | 0 | 0 | |
| 11 | | Apr | 400 | 1,000 | 0 | 0 | 1,800 | 10 | 0 | 0 | |
| 12 | | May | 400 | 1,000 | 0 | 0 | 2,400 | 10 | 0 | 0 | |
| 13 | | Jun | 400 | 1,000 | 0 | 0 | 3,000 | 10 | 0 | 0 | |
| 14 | | July | 500 | 1,000 | 0 | 0 | 3,500 | 10 | 0 | 0 | |
| 15 | | Aug | 500 | 1,000 | 0 | 0 | 4,000 | 10 | 0 | 0 | |
| 16 | | Sept | 1000 | 1,000 | 0 | 0 | 4,000 | 10 | 0 | 0 | |
| 17 | | Oct | 1500 | 1,000 | 0 | 0 | 3,500 | 10 | 0 | 0 | |
| 18 | | Nov | 2500 | 1,000 | 0 | 0 | 2,000 | 10 | 0 | 0 | |
| 19 | | Dec | 3000 | 1,000 | 0 | 0 | 0 | 10 | 0 | 0 | |
| 20 | | Total | 12,000 | 12,000 | 0 | 0 | 26,000 | | 0 | 0 | |
| 21 | | | | | | | | | | | |

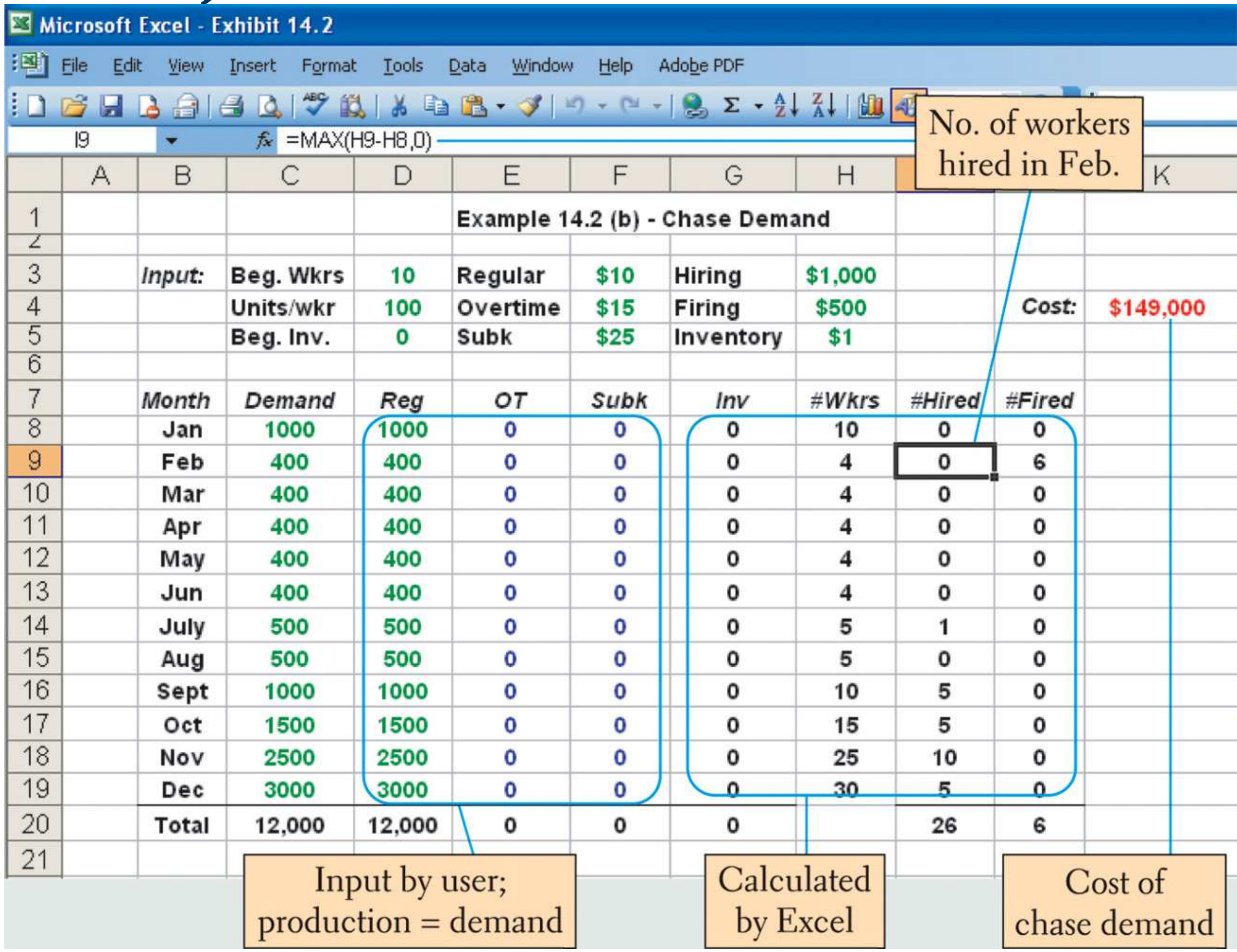
Feb's ending inventory

Cost of level production

Excel calculates these

Production input by user; 12,000/12 = 1,000

# Mixed Strategies with Excel (cont.)




Example 14.2 (b) - Chase Demand

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Input:* | Beg. Wkrs | 10 | Regular | $10 | Hiring | $1,000 | | | |
| | Units/wkr | 100 | Overtime | $15 | Firing | $500 | | Cost: | $149,000 |
| | Beg. Inv. | 0 | Subk | $25 | Inventory | $1 | | | |

| *Month* | *Demand* | *Reg* | *OT* | *Subk* | *Inv* | *#Wkrs* | *#Hired* | *#Fired* |
|---|---|---|---|---|---|---|---|---|
| Jan | 1000 | 1000 | 0 | 0 | 0 | 10 | 0 | 0 |
| Feb | 400 | 400 | 0 | 0 | 0 | 4 | 0 | 6 |
| Mar | 400 | 400 | 0 | 0 | 0 | 4 | 0 | 0 |
| Apr | 400 | 400 | 0 | 0 | 0 | 4 | 0 | 0 |
| May | 400 | 400 | 0 | 0 | 0 | 4 | 0 | 0 |
| Jun | 400 | 400 | 0 | 0 | 0 | 4 | 0 | 0 |
| July | 500 | 500 | 0 | 0 | 0 | 5 | 1 | 0 |
| Aug | 500 | 500 | 0 | 0 | 0 | 5 | 0 | 0 |
| Sept | 1000 | 1000 | 0 | 0 | 0 | 10 | 5 | 0 |
| Oct | 1500 | 1500 | 0 | 0 | 0 | 15 | 5 | 0 |
| Nov | 2500 | 2500 | 0 | 0 | 0 | 25 | 10 | 0 |
| Dec | 3000 | 3000 | 0 | 0 | 0 | 30 | 5 | 0 |
| Total | 12,000 | 12,000 | 0 | 0 | 0 | | 26 | 6 |

# General Linear Programming (LP) Model

- LP gives an optimal solution, but demand and costs must be linear
- *Let*
  - $W_t$ = workforce size for period $t$
  - $P_t$ =units produced in period $t$
  - $I_t$ =units in inventory at the end of period $t$
  - $F_t$ =number of workers fired for period $t$
  - $H_t$ = number of workers hired for period $t$

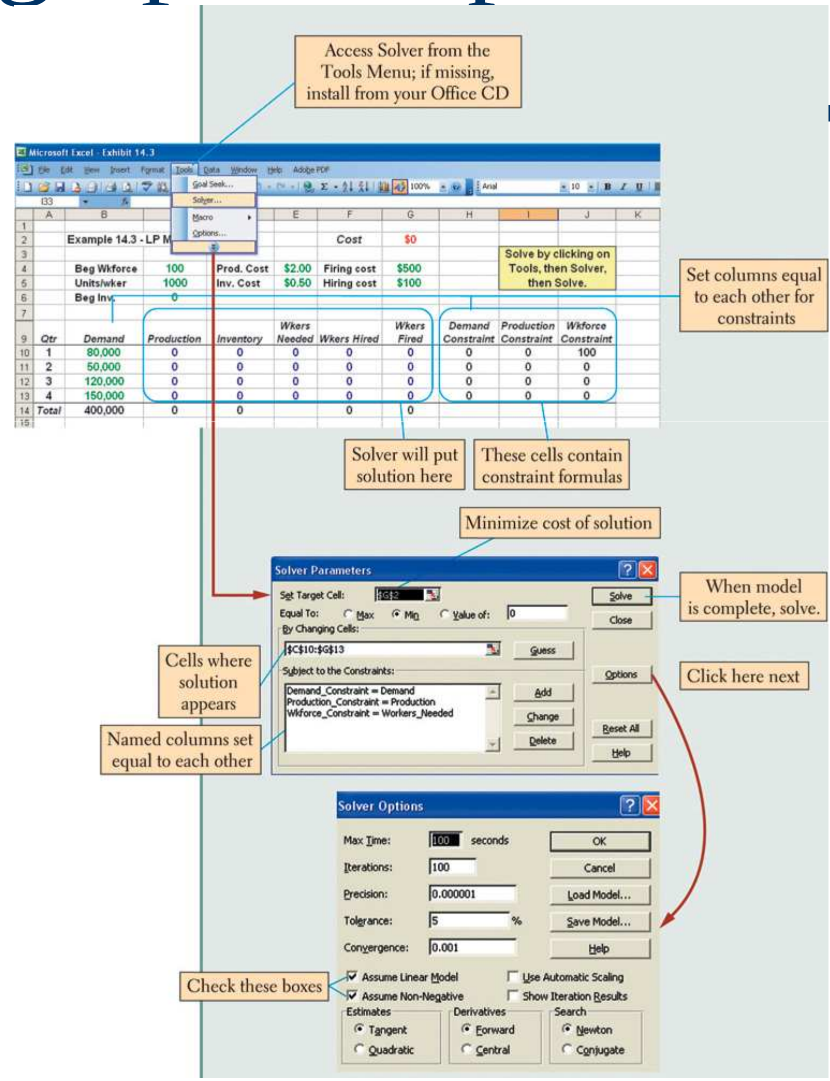
## LP MODEL

$$\text{Minimize } Z = \$100\,(H_1 + H_2 + H_3 + H_4) + \$500\,(F_1 + F_2 + F_3 + F_4) + \$0.50\,(I_1 + I_2 + I_3 + I_4) + \$2\,(P_1 + P_2 + P_3 + P_4)$$

Subject to

| | | |
|---|---|---|
| | $P_1 - I_1 = 80{,}000$ | (1) |
| Demand | $I_1 + P_2 - I_2 = 50{,}000$ | (2) |
| constraints | $I_2 + P_3 - I_3 = 120{,}000$ | (3) |
| | $I_3 + P_4 - I_4 = 150{,}000$ | (4) |
| Production | $1000\,W_1 = P_1$ | (5) |
| constraints | $1000\,W_2 = P_2$ | (6) |
| | $1000\,W_3 = P_3$ | (7) |
| | $1000\,W_4 = P_4$ | (8) |
| | $100 + H_1 - F_1 = W_1$ | (9) |
| Work force | $W_1 + H_2 - F_2 = W_2$ | (10) |
| constraints | $W_2 + H_3 - F_3 = W_3$ | (11) |
| | $W_3 + H_4 - F_4 = W_4$ | (12) |

# Setting up the Spreadsheet



# The LP Solution

Cost of optimal solution

Microsoft Excel - Exhibit 14.3

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Example 14.3 - LP Model | | | | Cost | $832,000 | | | |
| | Beg Wkforce | 100 | Prod. Cost | $2.00 | Firing cost | $500 | | | |
| | Units/wker | 1000 | Inv. Cost | $0.50 | Hiring cost | $100 | | | |
| | Beg Inv. | 0 | | | | | | | |
| Qtr | Demand | Production | Inventory | Wkers Needed | Wkers Hired | Wkers Fired | Demand Constraint | Production Constraint | Wkforce Constraint |
| 1 | 80,000 | 80,000 | 0 | 80 | 0 | 20 | 80,000 | 80,000 | 80 |
| 2 | 50,000 | 80,000 | 30,000 | 80 | 0 | 0 | 50,000 | 80,000 | 80 |
| 3 | 120,000 | 90,000 | 0 | 90 | 10 | 0 | 120,000 | 90,000 | 90 |
| 4 | 150,000 | 150,000 | 0 | 150 | 60 | 0 | 150,000 | 150,000 | 150 |
| Total | 400,000 | 400,000 | 30,000 | | 70 | 20 | | | |

Solve by clicking on Tools, then Solver, then Solve.

Optimal solution; mixture of inventory and workforce variations

# Transportation Method

| QUARTER | EXPECTED DEMAND | REGULAR CAPACITY | OVERTIME CAPACITY | SUBCONTRACT CAPACITY |
|---|---|---|---|---|
| 1 | 900 | 1000 | 100 | 500 |
| 2 | 1500 | 1200 | 150 | 500 |
| 3 | 1600 | 1300 | 200 | 500 |
| 4 | 3000 | 1300 | 200 | 500 |

| | |
|---|---|
| Regular production cost per unit | $20 |
| Overtime production cost per unit | $25 |
| Subcontracting cost per unit | $28 |
| Inventory holding cost per unit per period | $3 |
| Beginning inventory | 300 units |

# Transportation Tableau

| PERIOD OF PRODUCTION | | PERIOD OF USE: 1 | 2 | 3 | 4 | Unused Capacity | Capacity |
|---|---|---|---|---|---|---|---|
| | Beginning Inventory | 300 | — [0] | — [3] | — [6] | [9] | 300 |
| 1 | Regular | 600 [20] | 300 [23] | 100 [26] | — [29] | | 1000 |
| | Overtime | [25] | [28] | [31] | 100 [34] | | 100 |
| | Subcontract | [28] | [31] | [34] | [37] | | 500 |
| 2 | Regular | | 1200 [20] | — [23] | — [26] | | 1200 |
| | Overtime | | [25] | [28] | 150 [31] | | 150 |
| | Subcontract | | [28] | [31] | 250 [34] | 250 | 500 |
| 3 | Regular | | | 1300 [20] | — [23] | | 1300 |
| | Overtime | | | 200 [25] | — [28] | | 200 |
| | Subcontract | | | [28] | 500 [31] | | 500 |
| 4 | Regular | | | | 1300 [20] | | 1300 |
| | Overtime | | | | 200 [25] | | 200 |
| | Subcontract | | | | 500 [28] | | 500 |
| | *Demand* | 900 | 1500 | 1600 | 3000 | 250 | |

# Burruss' Production Plan

| PERIOD | DEMAND | REGULAR PRODUCTION | OVERTIME | SUB-CONTRACT | ENDING INVENTORY |
|---|---|---|---|---|---|
| 1 | 900 | 1000 | 100 | 0 | 500 |
| 2 | 1500 | 1200 | 150 | 250 | 600 |
| 3 | 1600 | 1300 | 200 | 500 | 1000 |
| 4 | 3000 | 1300 | 200 | 500 | 0 |
| Total | 7000 | 4800 | 650 | 1250 | 2100 |

# Using Excel for the Transportation Method of Aggregate Planning

Microsoft Excel - Exhibit 14.4

Exhibit 14.4 - The Transportation Method of Aggregate Planning

| Period of Production | | Period of Use 1 | | 2 | | 3 | | 4 | | Units Produced | Capacity | Unused Capacity |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Beg. Inventory | 300 | 0 | 0 | 3 | 0 | 6 | 0 | 9 | 300 | 300 | 0 |
| 1 | Regular | 600 | 20 | 0 | 23 | 0 | 26 | 400 | 29 | 1,000 | 1,000 | 0 |
| | Overtime | 0 | 25 | 0 | 28 | 0 | 31 | 0 | 34 | 0 | 100 | 100 |
| | Subk | 0 | 28 | 0 | 31 | 0 | 34 | 0 | 37 | 0 | 500 | 500 |
| 2 | Regular | 0 | | 1,000 | 20 | 0 | 23 | 200 | 26 | 1,200 | 1,200 | 0 |
| | Overtime | 0 | | 150 | 25 | 0 | 28 | 0 | 31 | 150 | 150 | 0 |
| | Subk | 0 | | 350 | 28 | 0 | 31 | 0 | 34 | 350 | 500 | 150 |
| 3 | Regular | 0 | | 0 | | 900 | 20 | 400 | 23 | 1,300 | 1,300 | 0 |
| | Overtime | 0 | | 0 | | 200 | 25 | 0 | 28 | 200 | 200 | 0 |
| | Subk | 0 | | 0 | | 500 | 28 | 0 | 31 | 500 | 500 | 0 |
| 4 | Regular | 0 | | 0 | | 0 | | 1,300 | 20 | 1,300 | 1,300 | 0 |
| | Overtime | 0 | | 0 | | 0 | | 200 | 25 | 200 | 200 | 0 |
| | Subk | 0 | | 0 | | 0 | | 500 | 28 | 500 | 500 | 0 |
| | Units Produced | 900 | | 1,500 | | 1,600 | | 3,000 | | 7,000 | 7,000 | 750 |
| | Demand | 900 | | 1,500 | | 1,600 | | 3,000 | | 7,000 | | |
| | Unmet Demand | 0 | | 0 | | 0 | | 0 | | | Total Cost = | $153,550 |

Production Plan

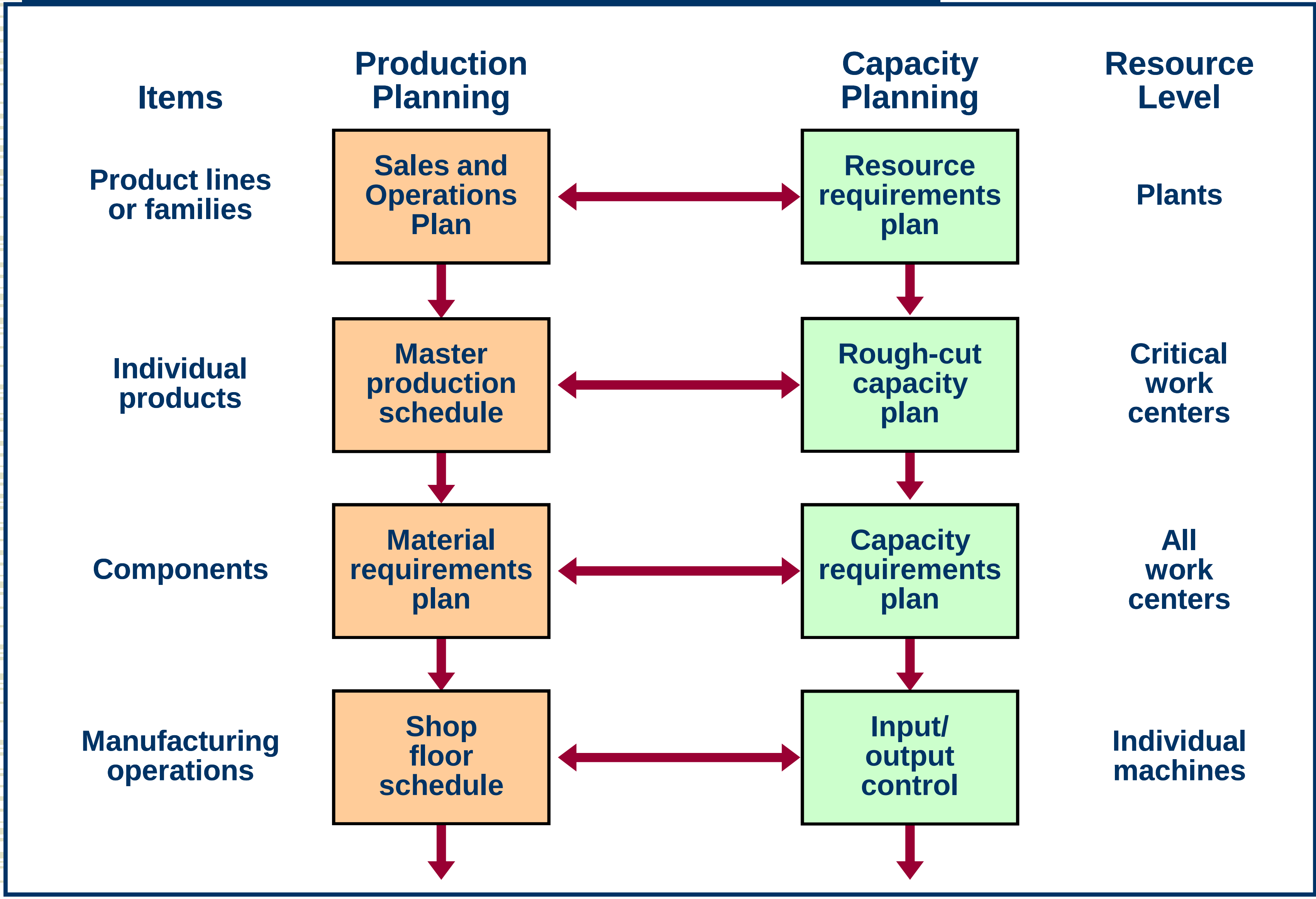
| Period | Demand | Reg. Prod. | Overtime | Subk | Ending Inventory |
|---|---|---|---|---|---|
| 1 | 900 | 1,000 | 0 | 0 | 400 |
| 2 | 1,500 | 1,200 | 150 | 350 | 600 |
| 3 | 1,600 | 1,300 | 200 | 500 | 1,000 |
| 4 | 3,000 | 1,300 | 200 | 500 | 0 |
| Total | 7,000 | 4,800 | 550 | 1,350 | 2,000 |

Total Cost = $153,550

# Other Quantitative Techniques

- Linear decision rule (LDR)
- Search decision rule (SDR)
- Management coefficients model

# Hierarchical Nature of Planning




- Disaggregation: process of breaking an aggregate plan into more detailed plans

# Collaborative Planning

- Sharing information and synchronizing production across supply chain
- Part of CPFR (collaborative planning, forecasting, and replenishment)
  - involves selecting products to be jointly managed, creating a single forecast of customer demand, and synchronizing production across supply chain

# Available-to-Promise (ATP)

- Quantity of items that can be promised to customer
- Difference between planned production and customer orders already received

AT in period 1 = (On-hand quantity + MPS in period 1) –
(CO until the next period of planned production)

ATP in period n = (MPS in period *n*) –
(CO until the next period of planned production)

- Capable-to-promise
  - quantity of items that can be produced and mad available at a later date

# ATP: Example

**Aggregate Production Plan**

| | Quarter | | | |
|---|---|---|---|---|
| **Product Family** | *1* | *2* | *3* | *4* |
| Juvenile Bikes | 800 | 1,000 | 1,500 | 4,000 |

**Master Production Schedule**

| | April | May | June | Total |
|---|---|---|---|---|
| Boys 26” | 150 | 100 | 150 | 400 |
| Girls 26” | 100 | 100 | 100 | 300 |
| Boys 20” | 30 | 20 | 50 | 100 |
| Girls 20” | 40 | 20 | 140 | 200 |
| Total | 320 | 240 | 440 | 1000 |

# ATP: Example (cont.)

**Available-to-Promise for Girls 26" Bike**

| **On Hand = 10** | *April* | *May* | *June* | *Total* |
|---|---|---|---|---|
| Forecast | 50 | 100 | 150 | 300 |
| Customer Orders | | | | |
| Master Production Schedule | 100 | 100 | 100 | 300 |
| Available-to-Promise | | | | |

| **On Hand = 10** | *April* | *May* | *June* | *Total* |
|---|---|---|---|---|
| Forecast | 50 | 100 | 150 | 300 |
| Customer Orders | **70** | **110** | **50** | **230** |
| Master Production Schedule | 100 | 100 | 100 | 300 |
| Available-to-Promise | | | | |

# ATP: Example (cont.)

| On Hand = 10 | April | May | June | Total |
|---|---|---|---|---|
| Forecast | 50 | 100 | 150 | 300 |
| Customer Orders | **70** | **110** | **50** | **230** |
| Master Production Schedule | 100 | 100 | 100 | 300 |
| Available-to-Promise | **30** | **0** | **50** | **80** |

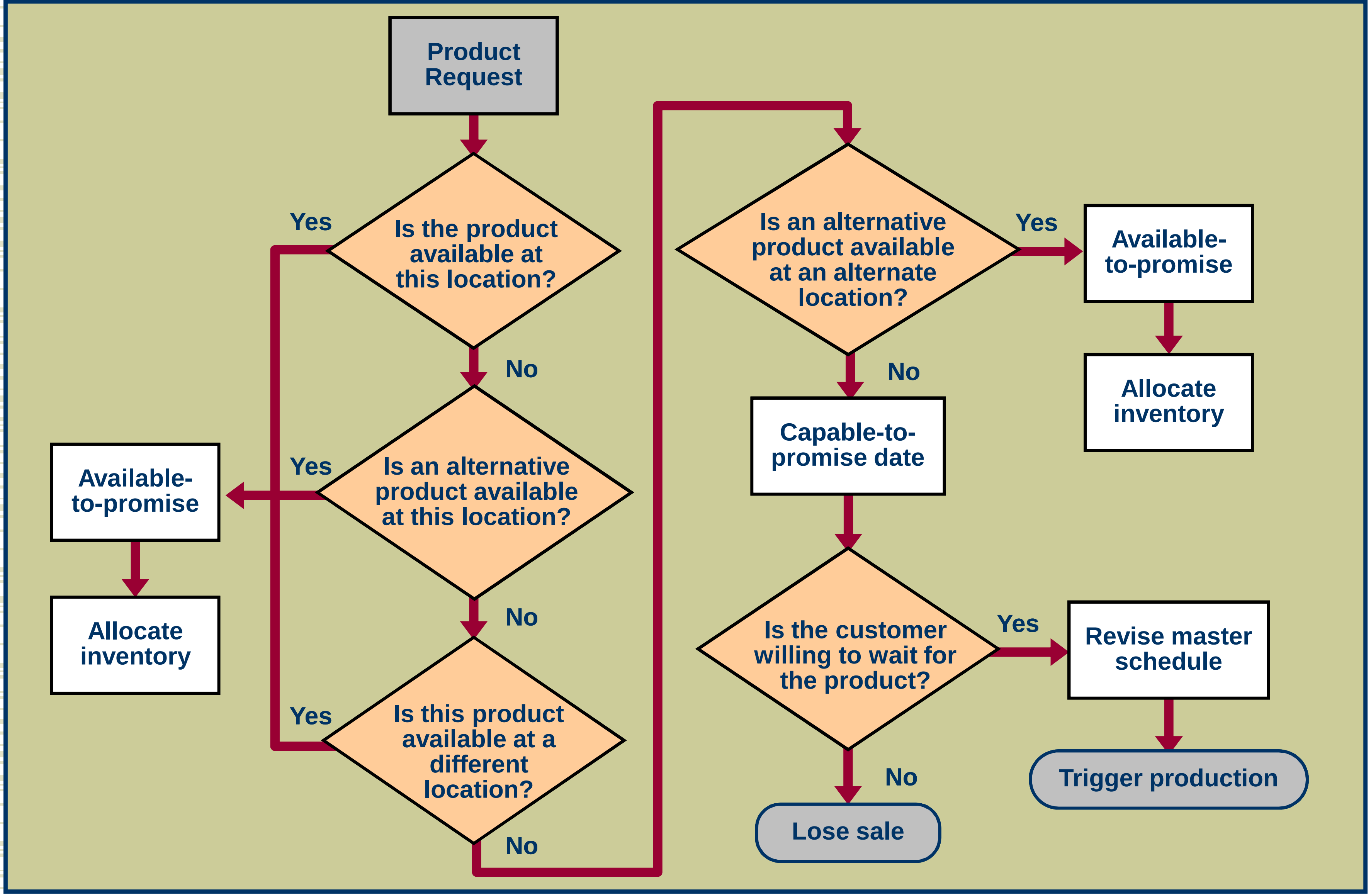
Take excess units from April

ATP in April = (10+100) – 70 = 40 = 30

ATP in May = 100 – 110 = –10 0

ATP in June = 100 – 50 = 50

# Rule Based ATP



# Aggregate Planning for Services

1. Most services cannot be inventoried
2. Demand for services is difficult to predict
3. Capacity is also difficult to predict
4. Service capacity must be provided at the appropriate place and time
5. Labor is usually the most constraining resource for services

# Yield Management

| Type of Problem | Type of Business | Probability of overestimating demand or no-shows, $P(N < X)$ | Optimal probability of demand or no-shows $\frac{C_u}{(C_u + C_o)}$ | Cost Description |
|---|---|---|---|---|
| Overbooking | Hotel, airlines, restaurants | N = number of no-shows<br>X = number of overbooked rooms or seats | $C_o$ = cost of overbooking<br>$C_u$ = cost of underbooking | Replacement cost<br>Lost profit |
| Fare Classes | Airlines, cruise ships, passenger trains, extended stay hotels | N = number of full-fare tickets that can be sold<br>X = seats reserved for full fare passengers | $C_o$ = cost of overestimating full fare passengers<br>$C_u$ = cost of underestimating full fare passengers | Lost full-fare (Full-Fare – discounted fare) |

# Yield Management (cont.)

| Type of Problem | Type of Business | Probability of overestimating demand or no-shows, $P(N < X)$ | Optimal probability of demand or no-shows $\frac{C_u}{(C_u + C_o)}$ | Cost Description |
|---|---|---|---|---|
| Premium seats | Stadiums, theaters | N = no. of premium tickets that can be sold | $C_o$ = cost of overestimating premium ticket sales | Lost regular revenue |
| | | X = seats reserved for premium ticket holders | $C_u$ = cost of underestimating premium ticket sales | (Premium ticket − regular ticket revenue) |
| Single Order Quantities | Newspapers, magazines, florists, nurseries, bakeries, sale items | N = number of items that can be sold | $C_o$ = cost of overestimating demand | (Cost − salvage value) |
| | | X = number of items ordered | $C_u$ = cost of underestimating demand | Lost profit |

# Yield Management: Example

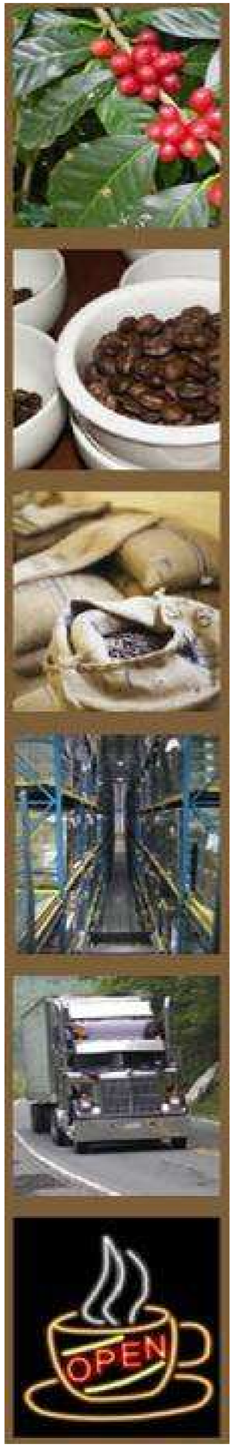
| NO-SHOWS | PROBABILITY | $P(N < X)$ |
|---|---|---|
| 0 | .15 | .00 |
| 1 | .25 | .15 |
| 2 | .30 | .40 |
| 3 | .30 | .70 |

.517

**Optimal probability of no-shows**

$$P(n < x) \leq \frac{C_u}{C_u + C_o} = \frac{75}{75 + 70} = .517$$

Hotel should be overbooked by two rooms



# Chapter 14 Supplement

## *Linear Programming*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Model Formulation
- Graphical Solution Method
- Linear Programming Model Solution
- Solving Linear Programming Problems with Excel
- Sensitivity Analysis

# Linear Programming (LP)

A model consisting of linear relationships
representing a firm's objective and resource constraints

LP is a mathematical modeling technique used to determine a level of operational activity in order to achieve an objective, subject to restrictions called constraints

# Types of LP

| Linear Programming Model Type | OM Application |
|---|---|
| Aggregate Production Planning | Determines the resource capacity needed to meet demand over an immediate time horizon, including units produced, workers hired and fired and inventory. (See Chapter 13.) |
| Product Mix | Mix of different products to produce that will maximize profit or minimize cost given resource constraints such as material, labor, budget, etc. |
| Transportation | Logistical flow of items (goods or services) from sources to destinations, for example, truckloads of goods from plants to warehouses. (See Supplement 10.) |
| Transshipment | Flow of items from sources to destinations with intermediate points, for example shipping from plant to distribution center and then to stores. (See Supplement 10.) |

# Types of LP (cont.)

| Linear Programming Model Type | OM Application |
|---|---|
| Assignment | Assigns work to limited resources, called "Loading," for example, assigning jobs or workers to different machines. (See Chapter 16.) |
| Multiperiod Scheduling | Schedules regular and overtime production, plus inventory to carry over, to meet demand in future periods. |
| Blend | Determines "recipe" requirements, for example, how to blend different petroleum components to produce different grades of gasoline and other petroleum products. |
| Diet | Menu of food items that meets nutritional or other requirements, for example, hospital or school cafeteria menus. |
| Investment/Capital Budgeting | Financial model that determines amount to invest in different alternatives given return objectives and constraints for risk, diversity, etc., for example, how much to invest in new plant, facilities or equipment. |

# Types of LP (cont.)

| Linear Programming Model Type | OM Application |
|---|---|
| Data Envelopment Analysis (DEA) | Compares service units of the same type—banks, hospitals, schools—based on their resources and outputs to see which units are less productive or inefficient. |
| Shortest Route | Shortest routes from sources to destinations, for example, the shortest highway truck route from coast to coast. |
| Maximal Flow | Maximizes the amount of flow from sources to destinations, for example, the flow of work-in process through an assembly operation. |
| Trim-Loss | Determines patterns to cut sheet items to minimize waste, for example, cutting lumber, film, cloth, glass, etc. |
| Facility Location | Selects facility locations based on constraints such as fixed, operating, and shipping costs, production capacity, etc. |
| Set Covering | Selection of facilities that can service a set of other facilities, for example, the selection of distribution hubs that will be able to deliver packages to a set of cities. |

# LP Model Formulation

- Decision variables
  - mathematical symbols representing levels of activity of an operation
- Objective function
  - a linear relationship reflecting the objective of an operation
  - most frequent objective of business firms is to *maximize profit*
  - most frequent objective of individual operational units (such as a production or packaging department) is to *minimize cost*
- Constraint
  - a linear relationship representing a restriction on decision making

# LP Model Formulation (cont.)

Max/min $z = c_1x_1 + c_2x_2 + ... + c_nx_n$

subject to:

$$\begin{cases} a_{11}x_1 + a_{12}x_2 + ... + a_{1n}x_n \ (\leq, =, \geq) \ b_1 \\ a_{21}x_1 + a_{22}x_2 + ... + a_{2n}x_n \ (\leq, =, \geq) \ b_2 \\ \qquad : \\ a_{n1}x1 + a_{n2}x_2 + ... + a_{nn}x_n \ (\leq, =, \geq) \ b_n \end{cases}$$

$x_j$ = decision variables
$b_i$ = constraint levels
$c_j$ = objective function coefficients
$a_{ij}$ = constraint coefficients

# LP Model: Example

| | RESOURCE REQUIREMENTS | | |
|---|---|---|---|
| PRODUCT | *Labor* *(hr/unit)* | *Clay* *(lb/unit)* | *Revenue* *($/unit)* |
| Bowl | 1 | 4 | 40 |
| Mug | 2 | 3 | 50 |

There are 40 hours of labor and 120 pounds of clay available each day

Decision variables

$x_1$ = number of bowls to produce

$x_2$ = number of mugs to produce

# LP Formulation: Example

Maximize $Z = \$40\, x_1 + 50\, x_2$

Subject to

$$x_1 + 2x_2 \leq 40 \text{ hr} \quad \text{(labor constraint)}$$
$$4x_1 + 3x_2 \leq 120 \text{ lb} \quad \text{(clay constraint)}$$
$$x_1, x_2 \geq 0$$

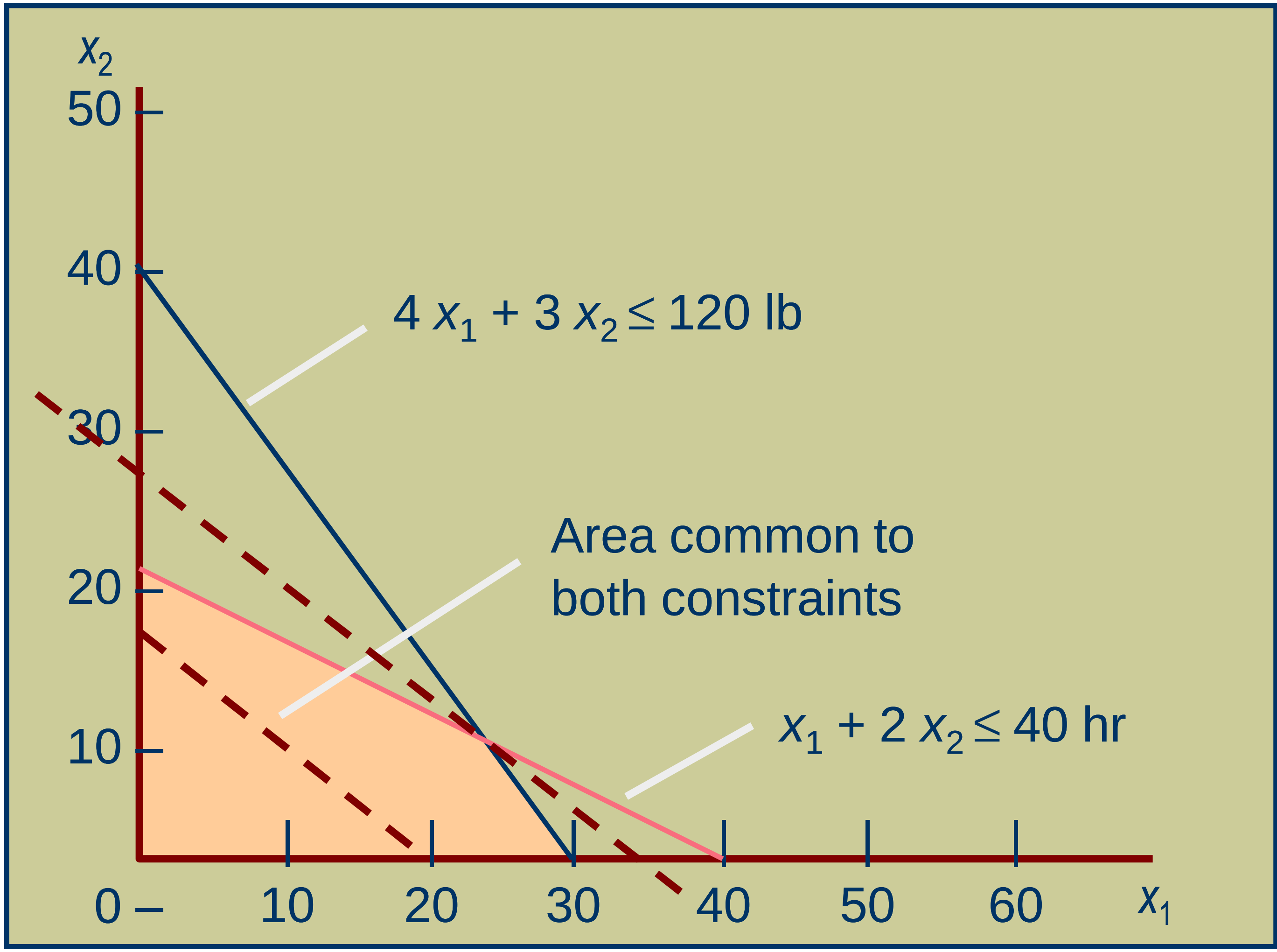
Solution is $x_1 = 24$ bowls $x_2 = 8$ mugs

Revenue = $1,360

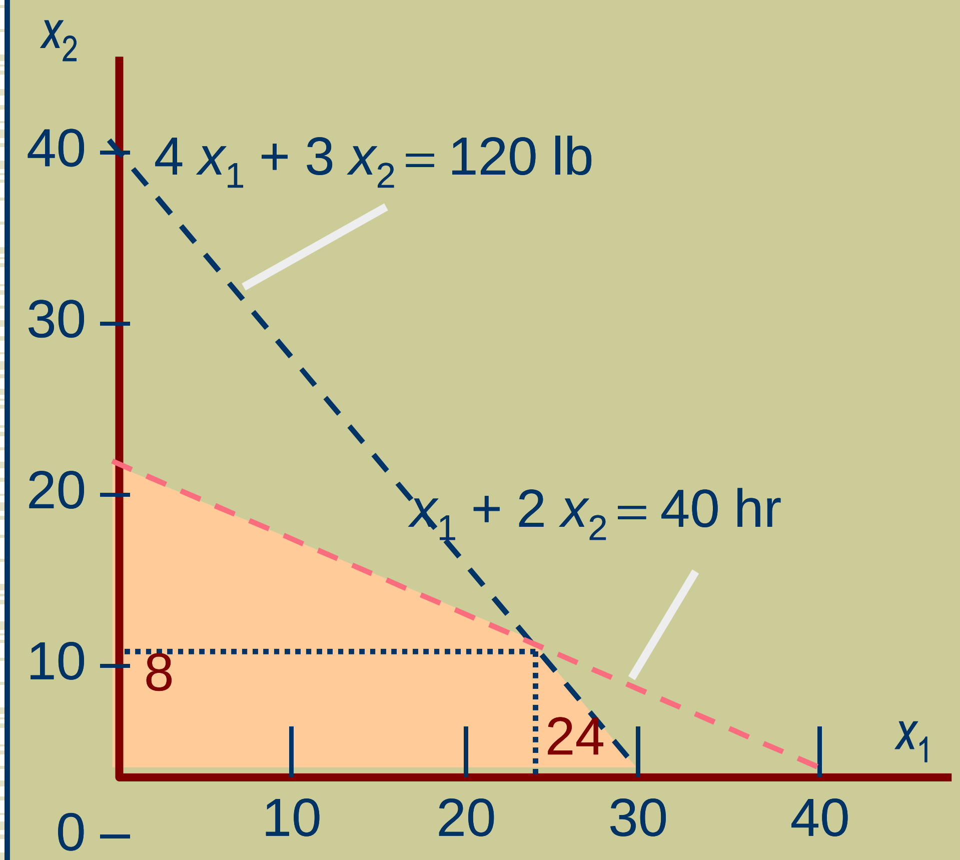
# Graphical Solution Method

1. Plot model constraint on a set of coordinates in a plane
2. Identify the feasible solution space on the graph where all constraints are satisfied simultaneously
3. Plot objective function to find the point on boundary of this space that maximizes (or minimizes) value of objective function

# Graphical Solution: Example



# Computing Optimal Values



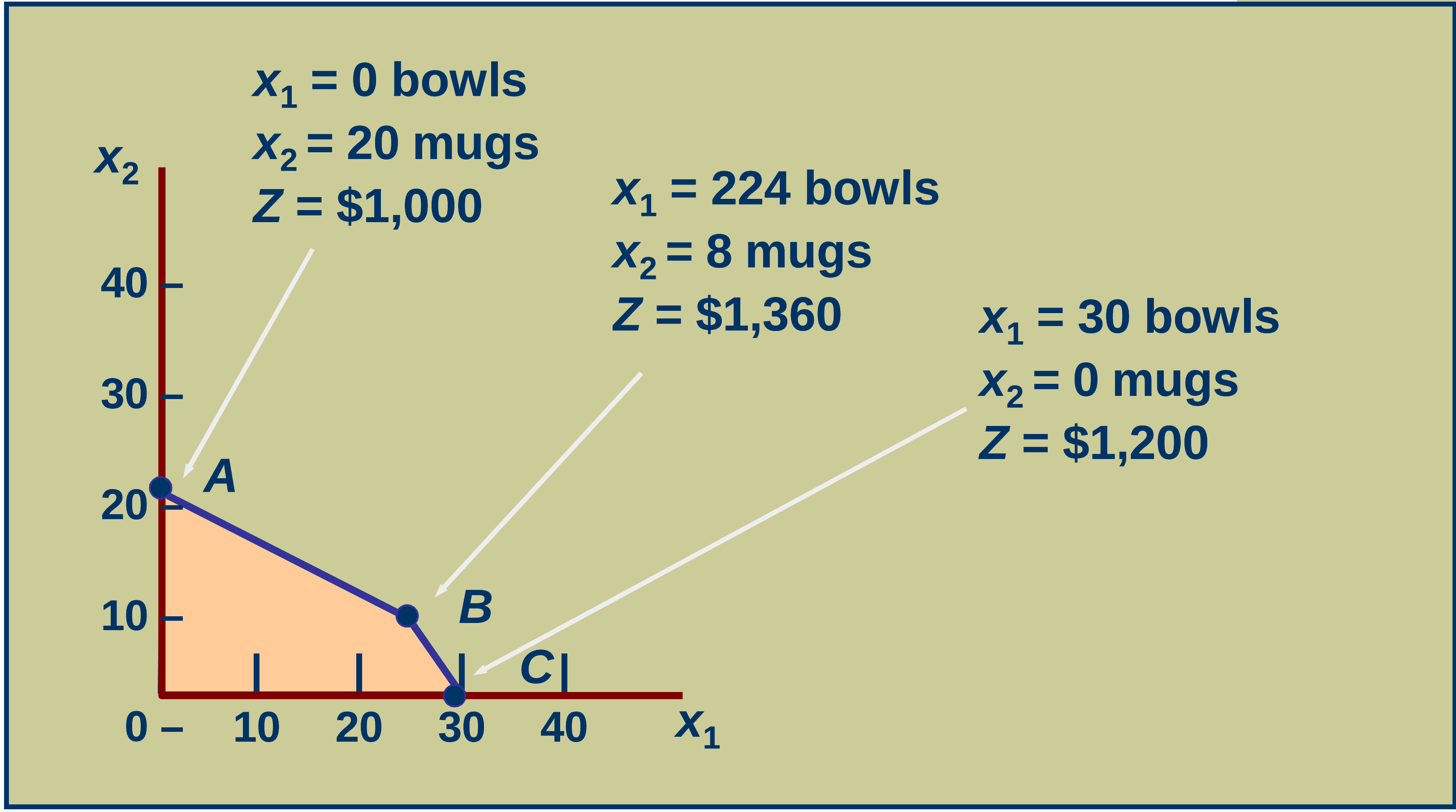

$$\begin{aligned} x_1 + 2x_2 &= 40 \\ 4x_1 + 3x_2 &= 120 \end{aligned}$$

$$\begin{aligned} 4x_1 + 8x_2 &= 160 \\ -4x_1 - 3x_2 &= -120 \\ \hline 5x_2 &= 40 \\ x_2 &= 8 \end{aligned}$$

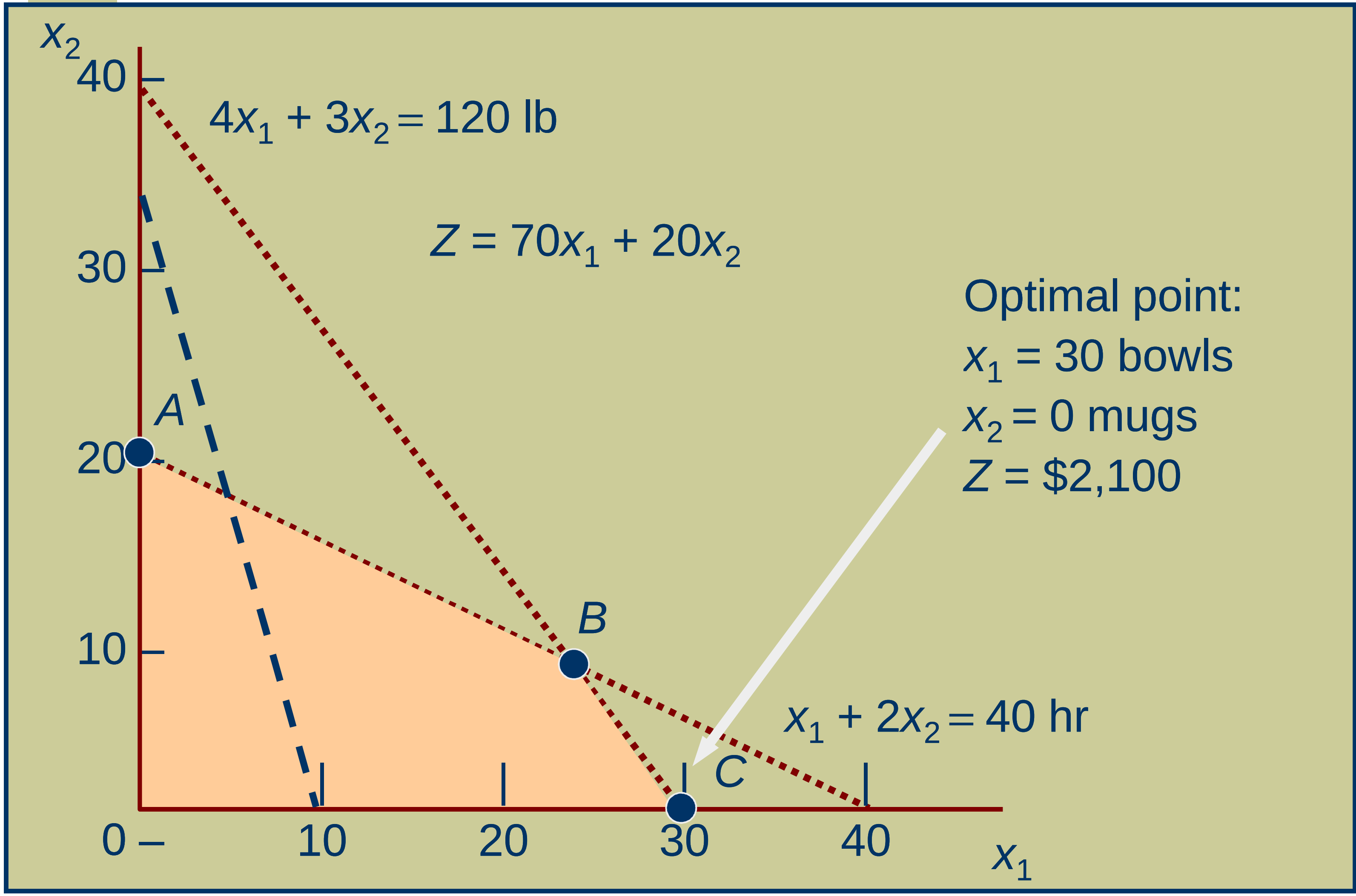
$$\begin{aligned} x_1 + 2(8) &= 40 \\ x_1 &= 24 \end{aligned}$$

$Z = \$40(24) + \$50(8) = \$1{,}360$

# Extreme Corner Points



# Objective Function



# Minimization Problem

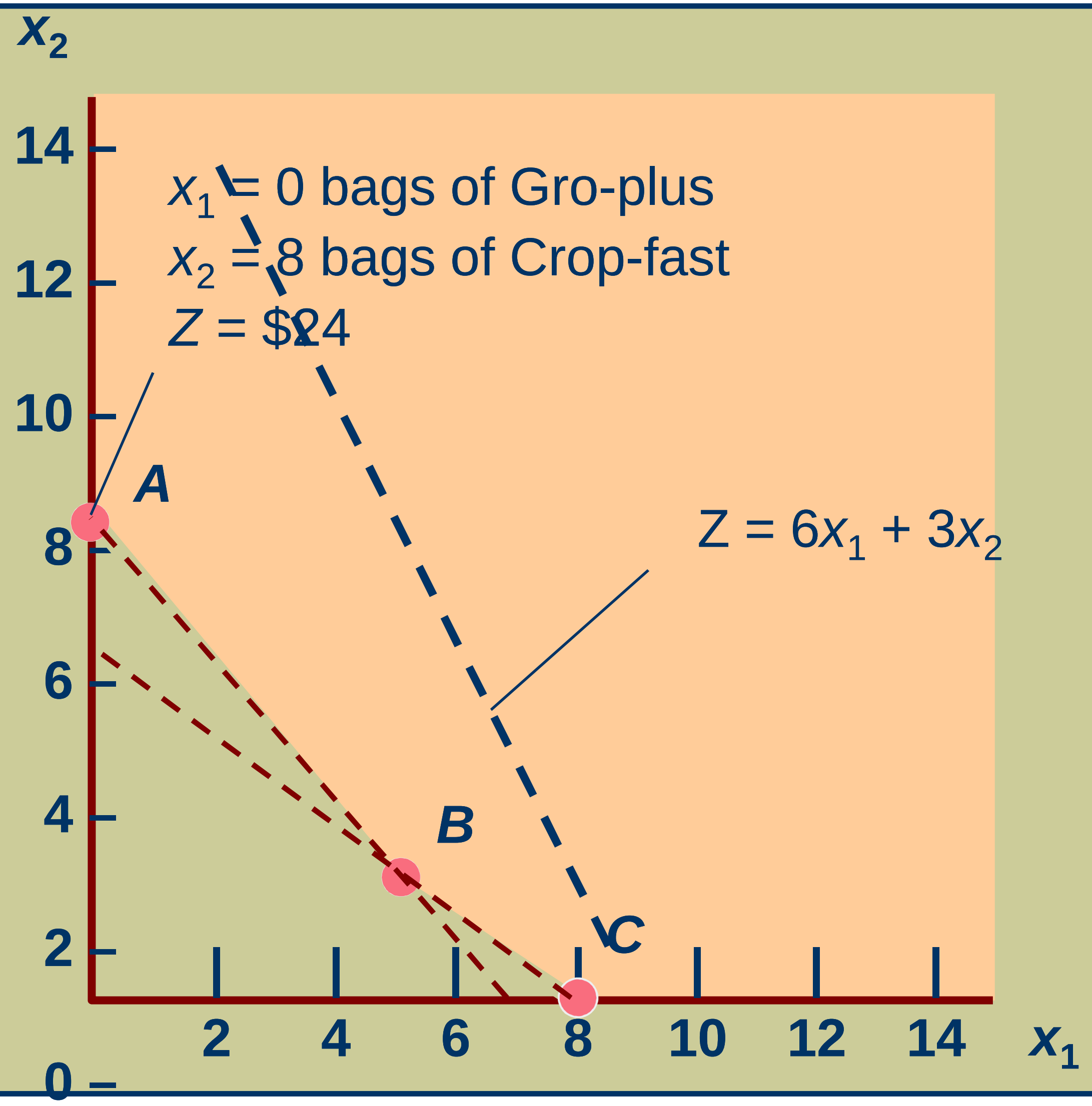
| | CHEMICAL CONTRIBUTION | |
|---|---|---|
| *Brand* | *Nitrogen (lb/bag)* | *Phosphate (lb/bag)* |
| Gro-plus | 2 | 4 |
| Crop-fast | 4 | 3 |

Minimize $Z = \$6x_1 + \$3x_2$

subject to

$$2x_1 + 4x_2 \geq 16 \text{ lb of nitrogen}$$
$$4x_1 + 3x_2 \geq 24 \text{ lb of phosphate}$$
$$x_1, x_2 \geq 0$$

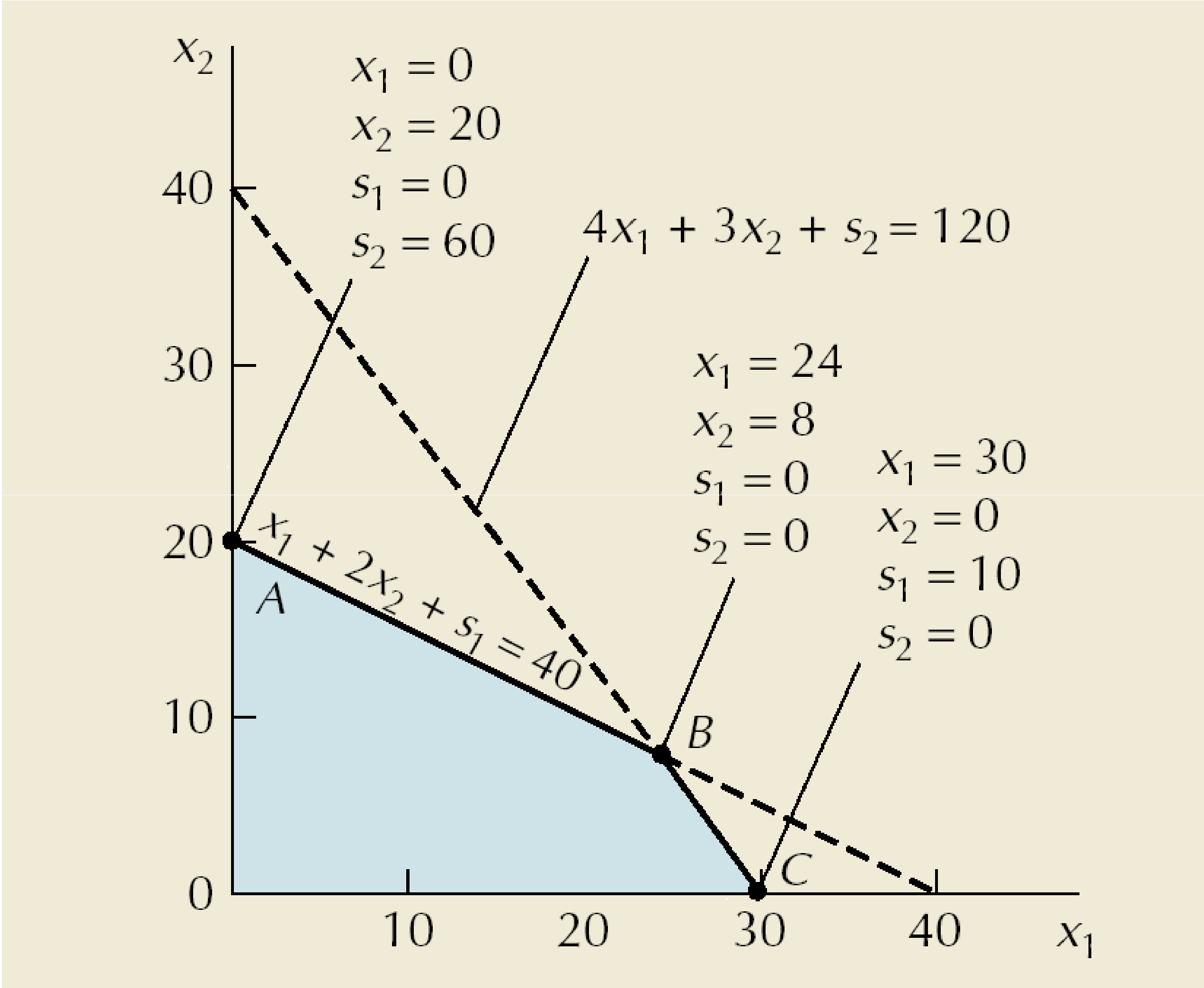
# Graphical Solution



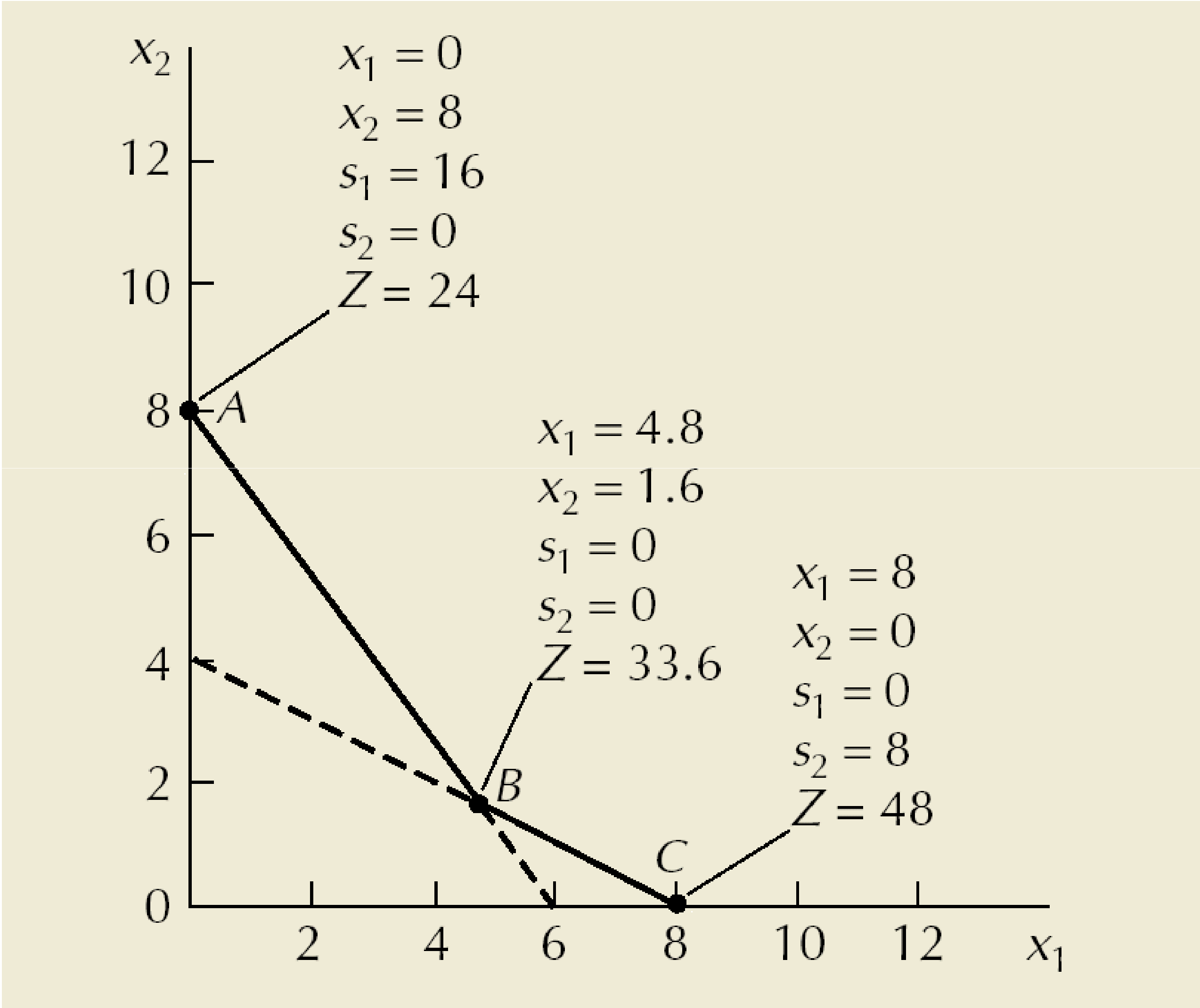
# Simplex Method

- A mathematical procedure for solving linear programming problems according to a set of steps
- Slack variables added to ≤ constraints to represent unused resources
  - $x_1 + 2x_2 + s_1 = 40$ hours of labor
  - $4x_1 + 3x_2 + s_2 = 120$ lb of clay
- Surplus variables subtracted from ≥ constraints to represent excess above resource requirement. For example,
  - $2x_1 + 4x_2 \geq 16$ is transformed into
  - $2x_1 + 4x_2 - s_1 = 16$
- Slack/surplus variables have a 0 coefficient in the objective function
  - $Z = \$40x_1 + \$50x_2 + 0s_1 + 0s_2$

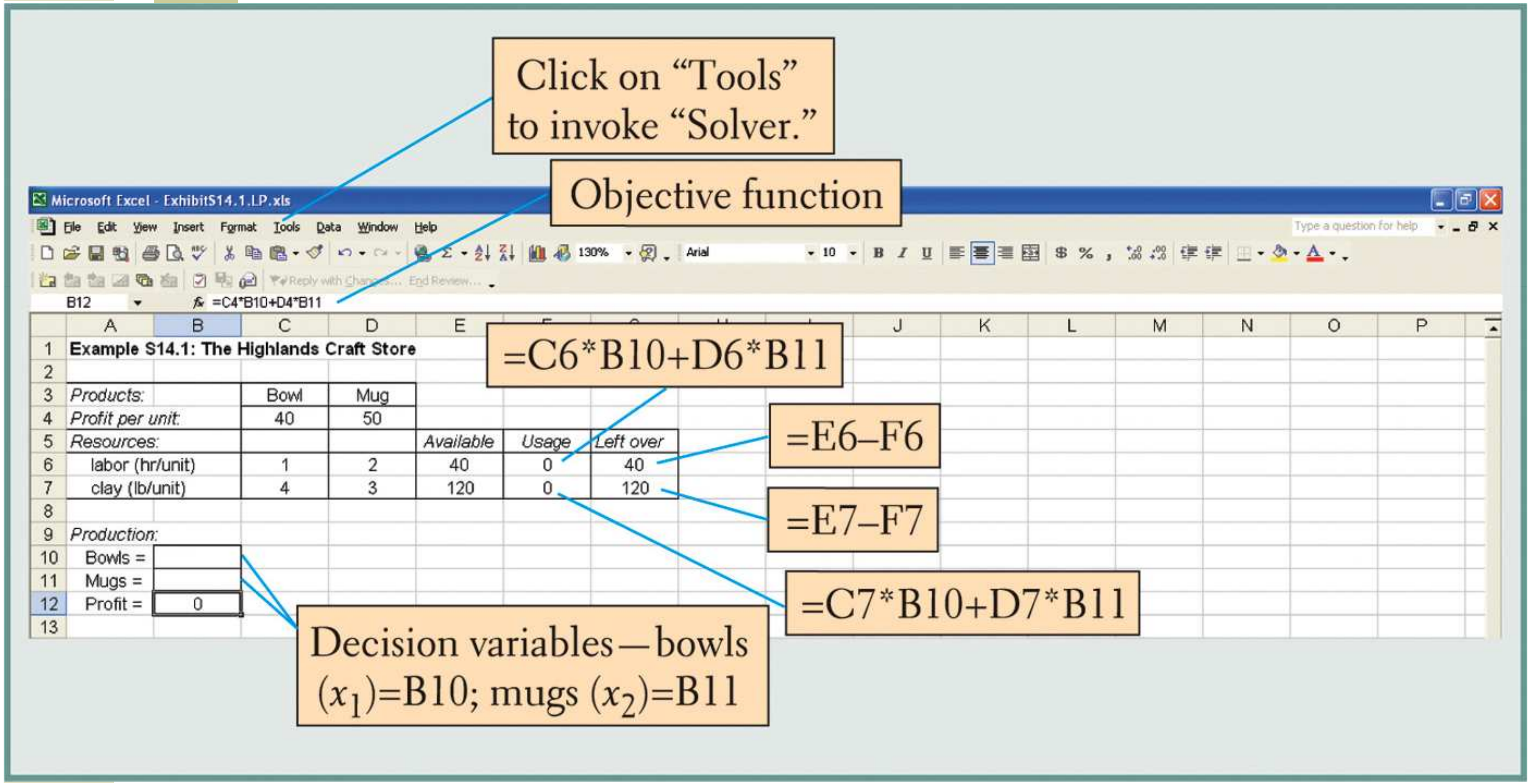
# Solution Points with Slack Variables



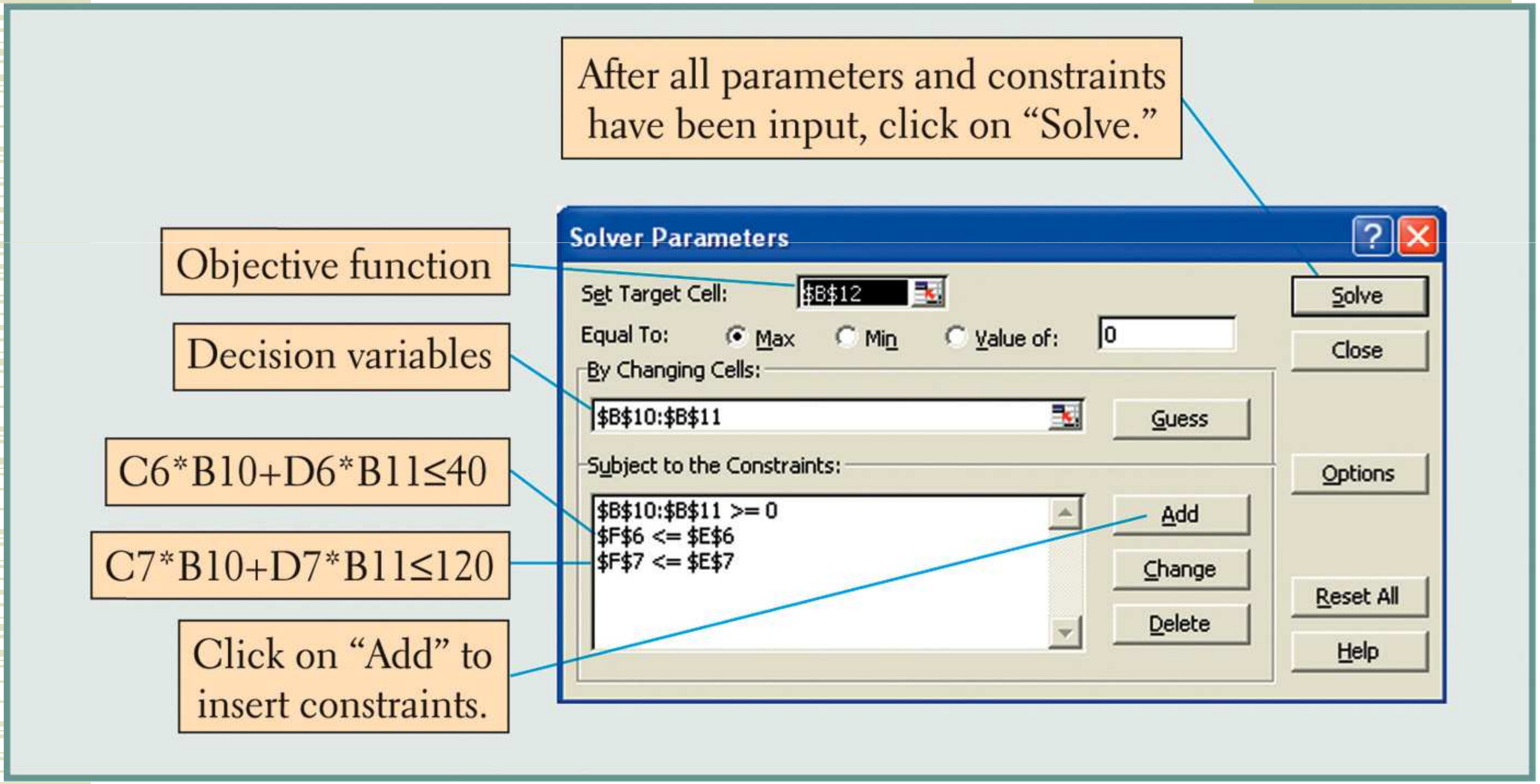
## Solution Points with Surplus Variables



# Solving LP Problems with Excel



# Solving LP Problems with Excel (cont.)



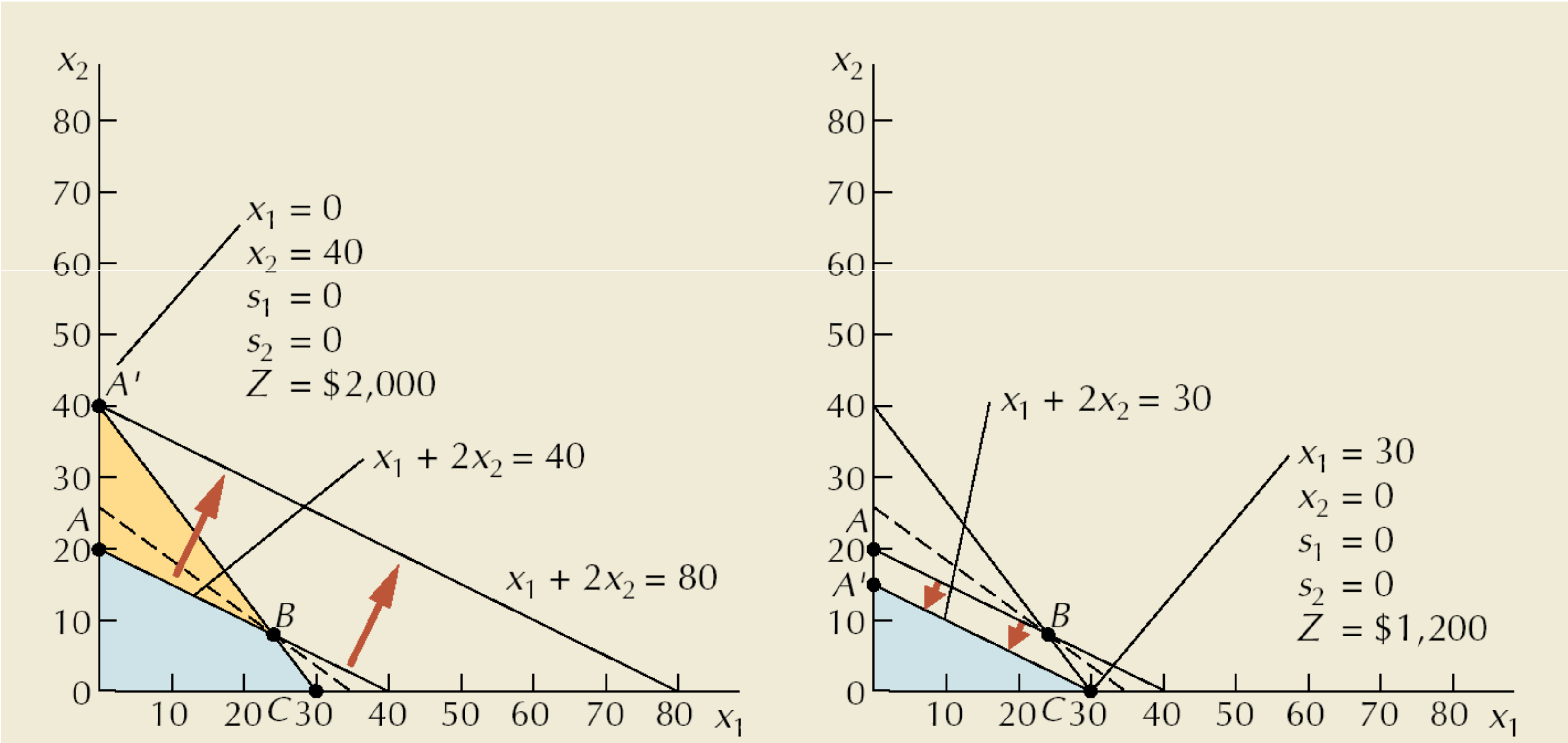
# Solving LP Problems with Excel (cont.)

Microsoft Excel - ExhibitS14.1.LP.xls

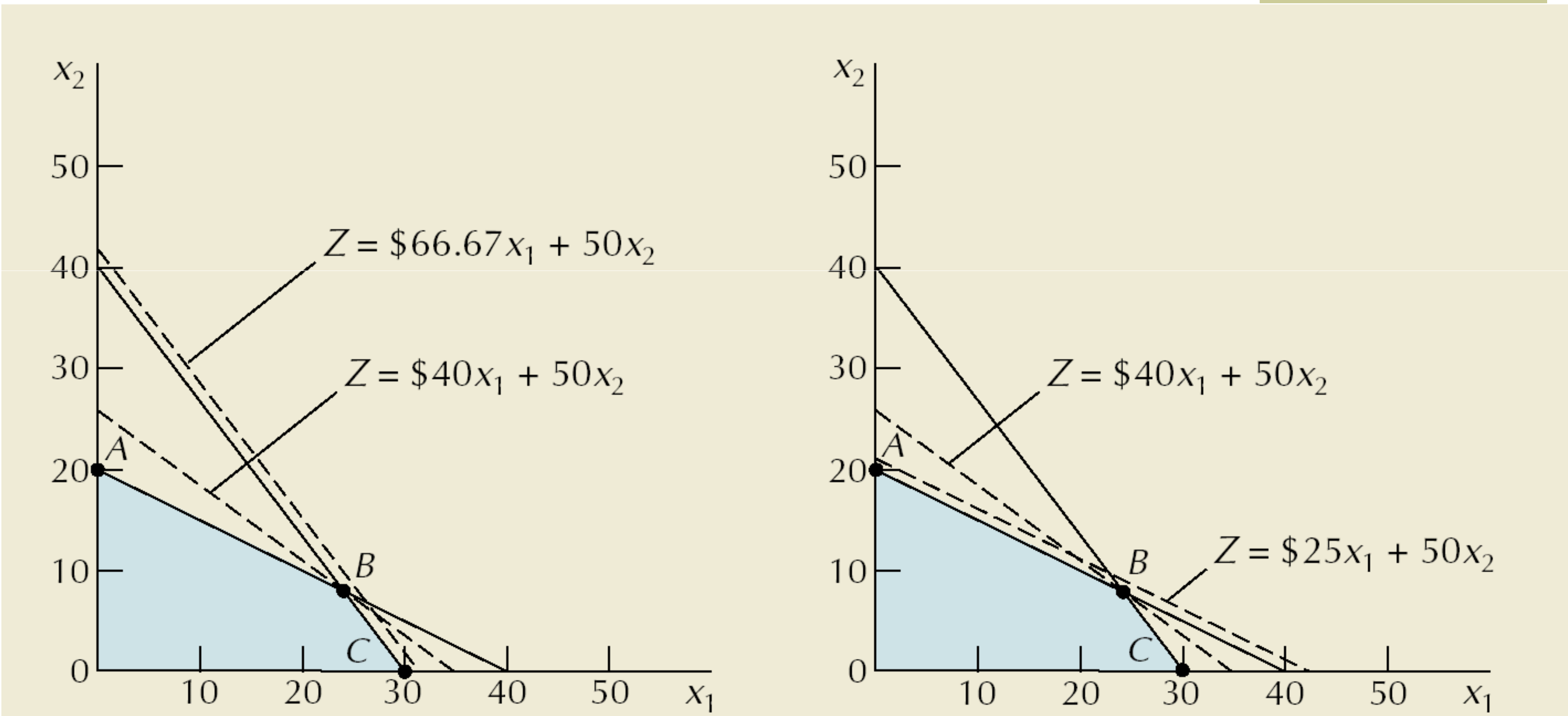
B12 $f_x$ =C4*B10+D4*B11

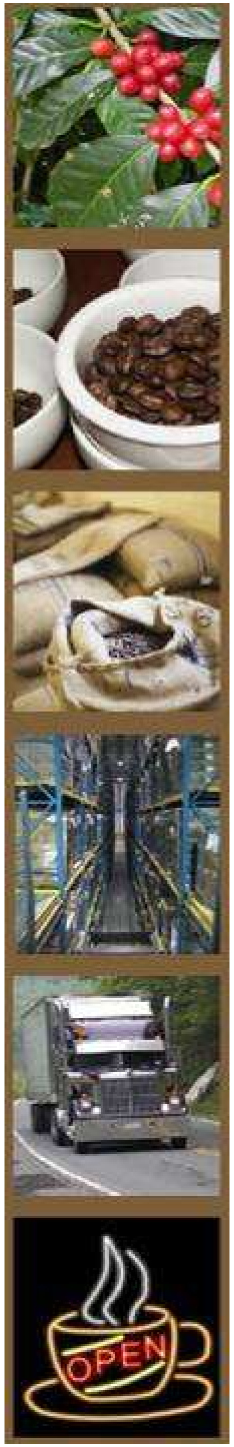
| | A | B | C | D | E | F | G | H |
|---|---|---|---|---|---|---|---|---|
| 1 | **Example S14.1: The Highlands Craft Store** | | | | | | | |
| 2 | | | | | | | | |
| 3 | *Products:* | | Bowl | Mug | | | | |
| 4 | *Profit per unit:* | | 40 | 50 | | | | |
| 5 | *Resources:* | | | | *Available* | *Usage* | *Left over* | |
| 6 | labor (hr/unit) | | 1 | 2 | 40 | 40 | 0 | |
| 7 | clay (lb/unit) | | 4 | 3 | 120 | 120 | 0 | |
| 8 | | | | | | | | |
| 9 | *Production:* | | | | | | | |
| 10 | Bowls = | 24 | | | | | | |
| 11 | Mugs = | 8 | | | | | | |
| 12 | Profit = | 1360 | | | | | | |
| 13 | | | | | | | | |

# Sensitivity Range for Labor Hours



# Sensitivity Range for Bowls





# Chapter 15

## *Resource Planning*

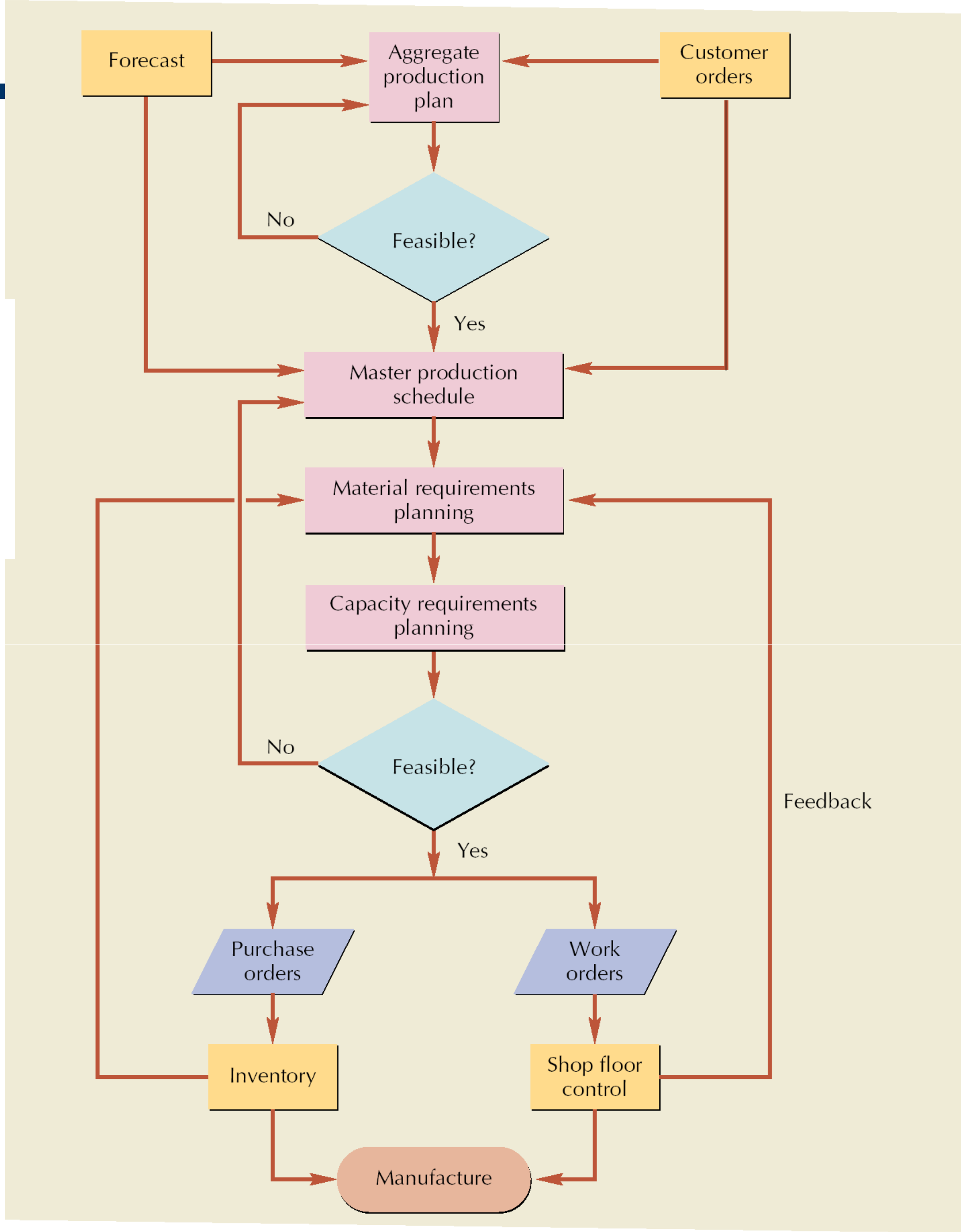
***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Material Requirements Planning (MRP)
- Capacity Requirements Planning (CRP)
- Enterprise Resource Planning (ERP)
- Customer Relationship Management (CRM)
- Supply Chain Management (SCM)
- Product Lifecycle Management (PLM)

# Resource Planning for Manufacturing



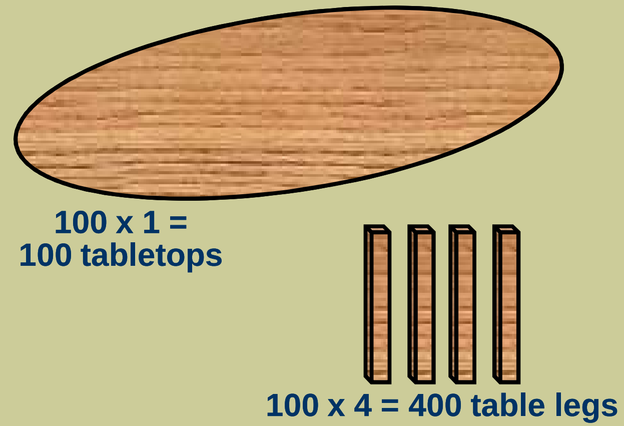
# Material Requirements Planning (MRP)

- Computerized inventory control and production planning system
- When to use MRP?
  - Dependent demand items
  - Discrete demand items
  - Complex products
  - Job shop production
  - Assemble-to-order environments

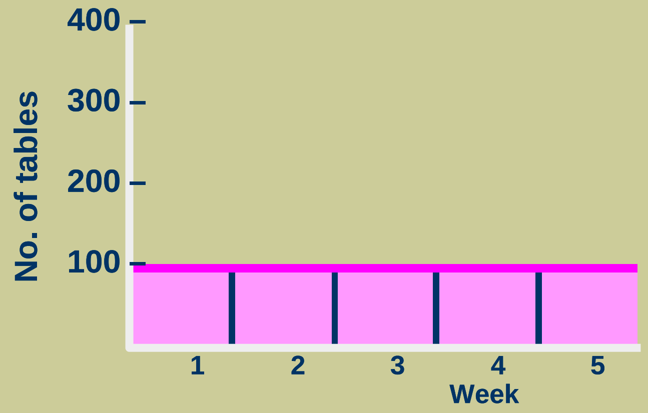
# Demand Characteristics

**Independent demand**

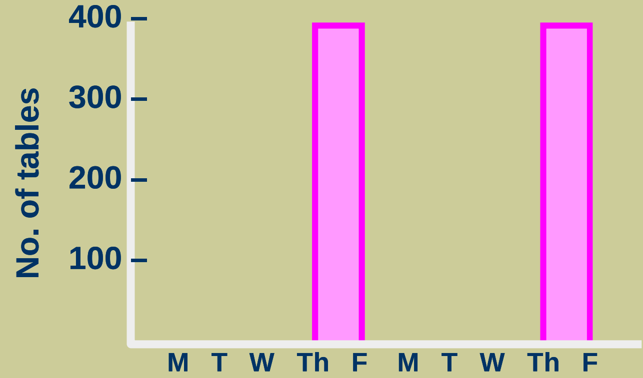

**Dependent demand**



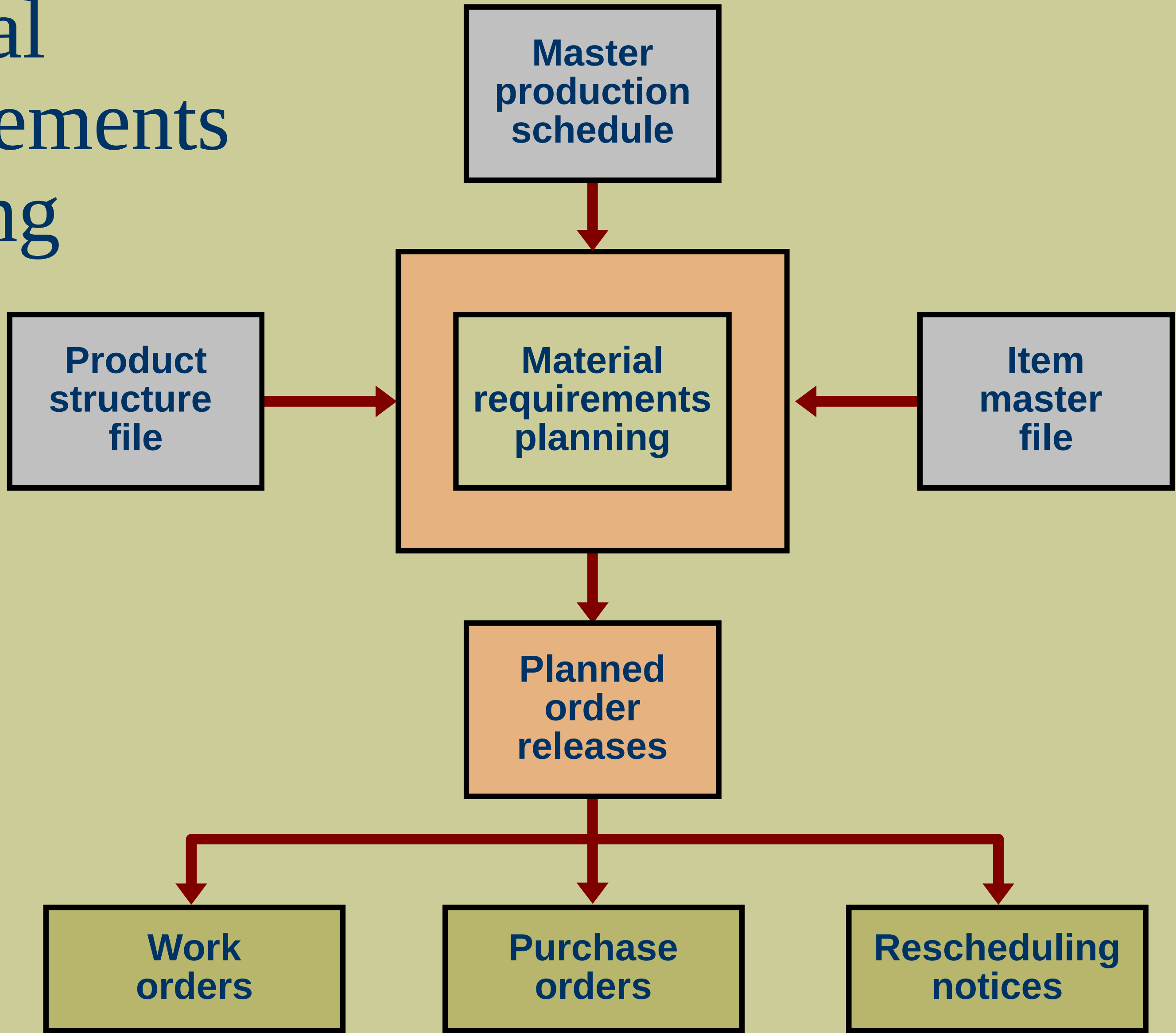

**Continuous demand**




**Discrete demand**



# Material Requirements Planning



# MRP Inputs and Outputs

- Inputs
  - Master production schedule
  - Product structure file
  - Item master file
- Outputs
  - Planned order releases
    - Work orders
    - Purchase orders
    - Rescheduling notices

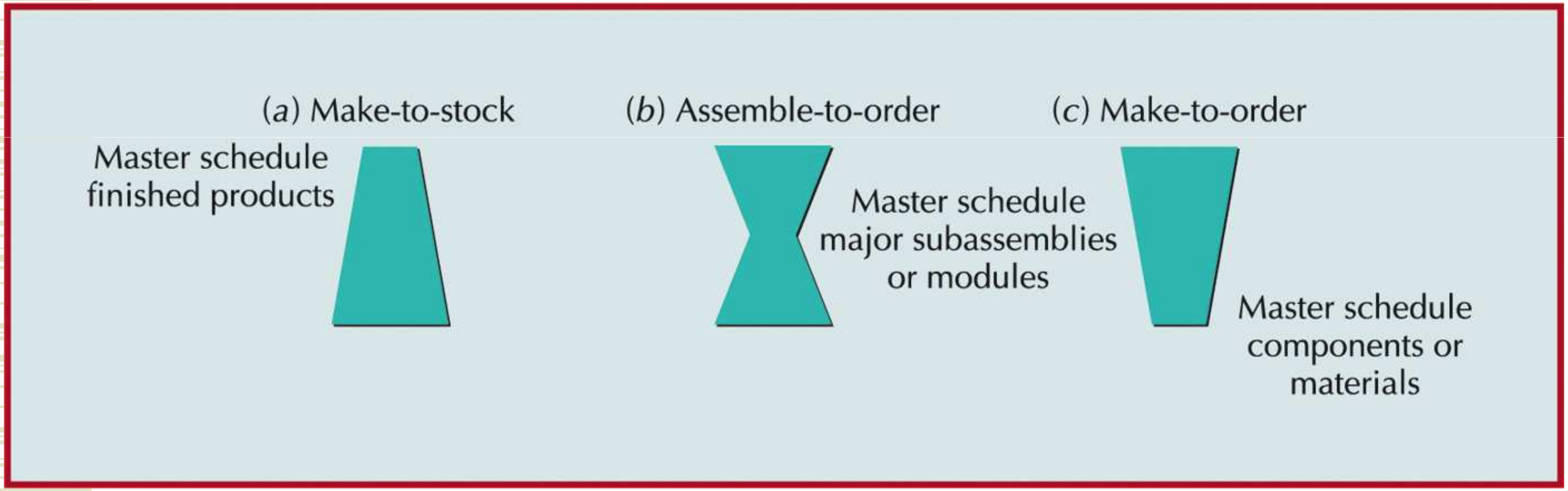
# Master Production Schedule

- Drives MRP process with a schedule of finished products
- Quantities represent production not demand
- Quantities may consist of a combination of customer orders and demand forecasts
- Quantities represent what needs to be produced, not what can be produced
- Quantities represent end items that may or may not be finished products

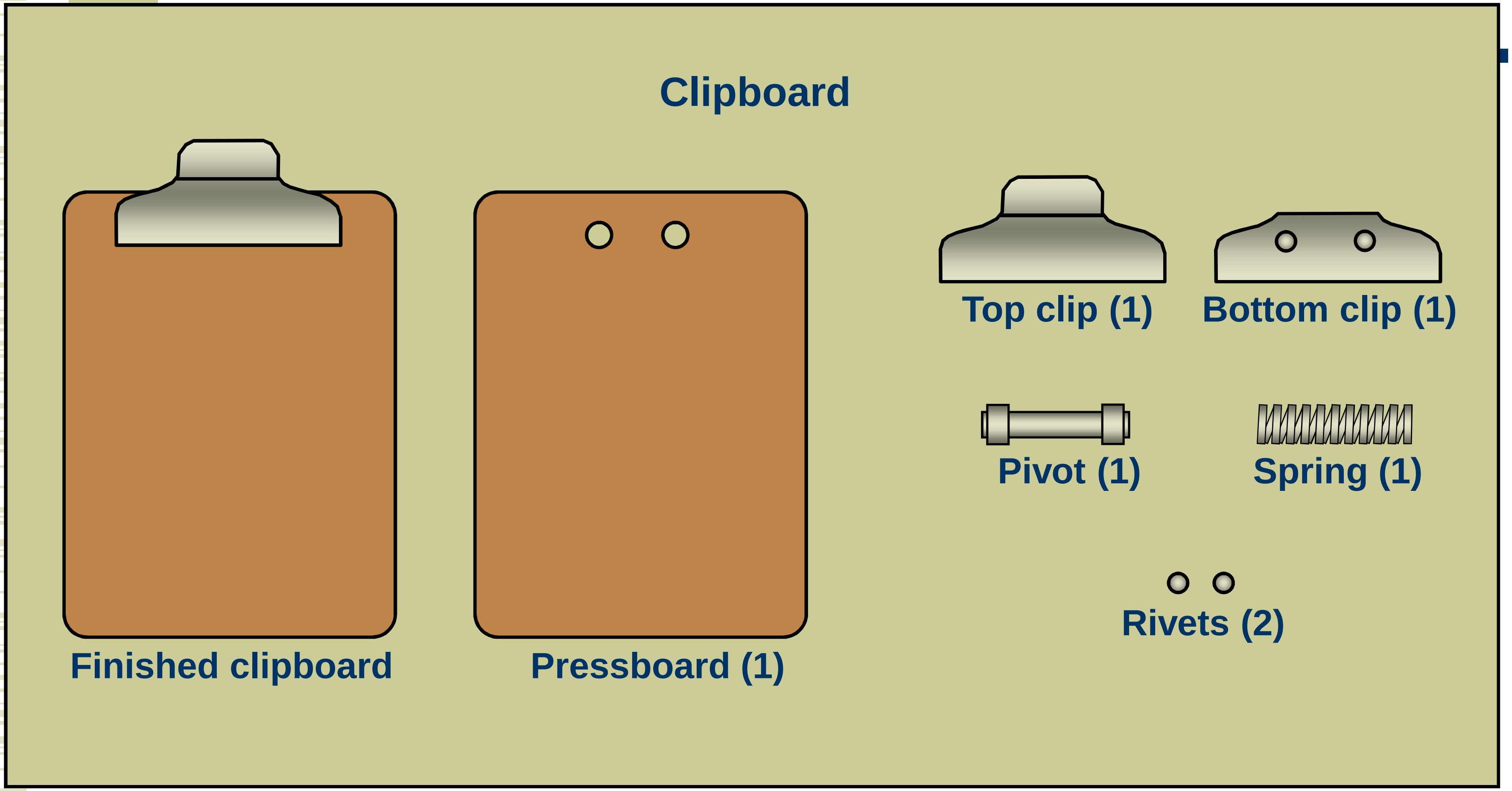
# Master Production Schedule (cont.)

| MPS ITEM | PERIOD 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Pencil Case | 125 | 125 | 125 | 125 | 125 |
| Clipboard | 85 | 95 | 120 | 100 | 100 |
| Lapboard | 75 | 120 | 47 | 20 | 17 |
| Lapdesk | 0 | 50 | 0 | 50 | 0 |

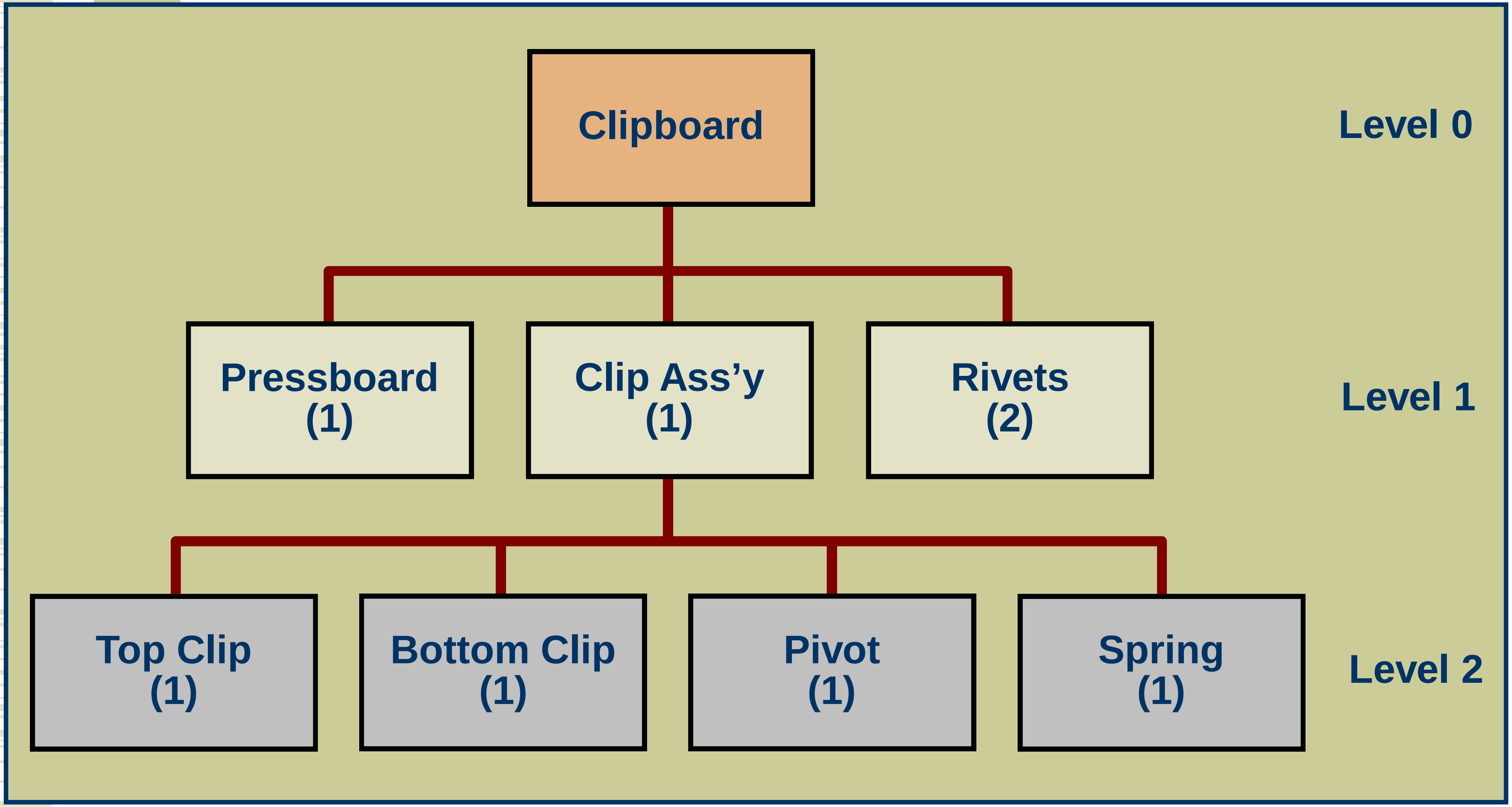
# Product Structure File



# Product Structure



# Product Structure Tree



# Multilevel Indented BOM

| LEVEL | ITEM | UNIT OF MEASURE | QUANTITY |
|---|---|---|---|
| 0 - - - - | Clipboard | ea | 1 |
| - 1 - - - | Clip Assembly | ea | 1 |
| - - 2 - - | Top Clip | ea | 1 |
| - - 2 - - | Bottom Clip | ea | 1 |
| - - 2 - - | Pivot | ea | 1 |
| - - 2 - - | Spring | ea | 1 |
| - 1 - - - | Rivet | ea | 2 |
| - 1 - - - | Press Board | ea | 1 |

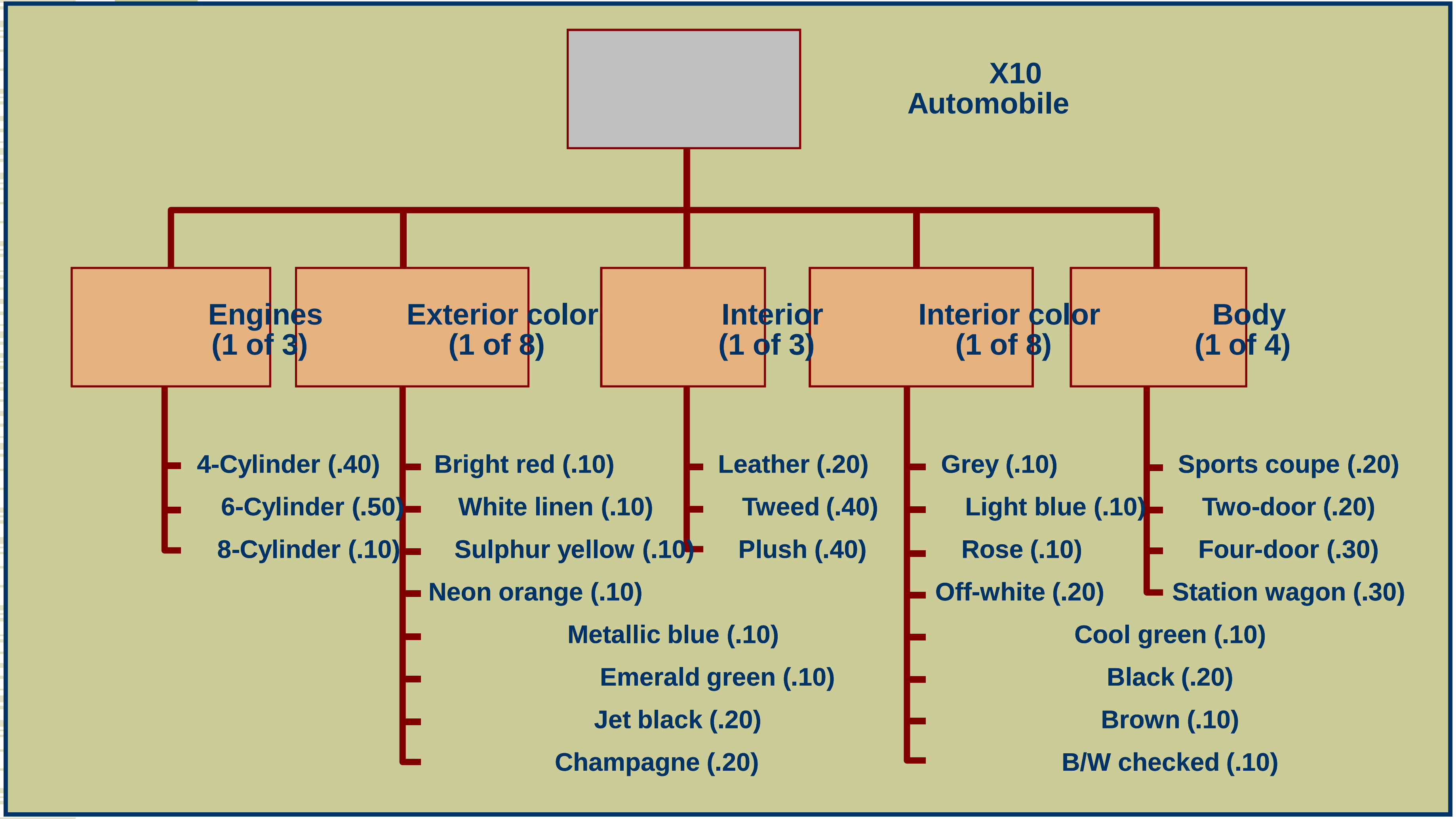
# Specialized BOMs

- Phantom bills
  - Transient subassemblies
  - Never stocked
  - Immediately consumed in next stage
- K-bills
  - Group small, loose parts under pseudo-item number
  - Reduces paperwork, processing time, and file space

# Specialized BOMs (cont.)

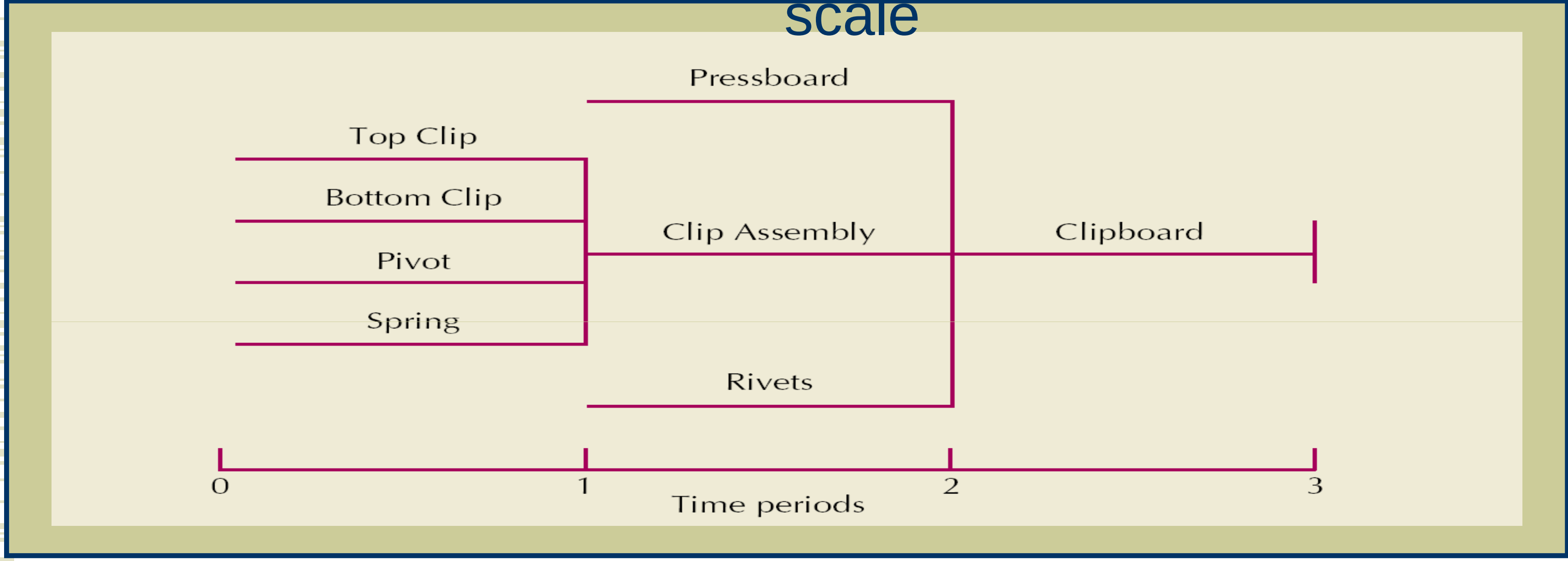
- Modular bills
  - Product assembled from major subassemblies and customer options
  - Modular bill kept for each major subassembly
  - Simplifies forecasting and planning
  - X10 automobile example
    - 3 x 8 x 3 x 8 x 4 = 2,304 configurations
    - 3 + 8 + 3 + 8 + 4 = 26 modular bills

# Modular BOMs



# Time-phased Bills

an assembly chart shown against a time scale




**Forward scheduling:** start at today's date and schedule forward to determine the earliest date the job can be finished. If each item takes one period to complete, the clipboards can be finished in three periods

**Backward scheduling:** start at the due date and schedule backwards to determine when to begin work. If an order for clipboards is due by period three, we should start production now

# Item Master File

| DESCRIPTION | | INVENTORY POLICY | |
|---|---|---|---|
| Item | Pressboard | Lead time | 1 |
| Item no. | 7341 | Annual demand | 5000 |
| Item type | Purch | Holding cost | 1 |
| Product/sales class | Comp | Ordering/setup cost | 50 |
| Value class | B | Safety stock | 0 |
| Buyer/planner | RSR | Reorder point | 39 |
| Vendor/drawing | 07142 | EOQ | 316 |
| Phantom code | N | Minimum order qty | 100 |
| Unit price/cost | 1.25 | Maximum order qty | 500 |
| Pegging | Y | Multiple order qty | 1 |
| LLC | 1 | Policy code | 3 |

# Item Master File (cont.)

| PHYSICAL INVENTORY | | USAGE/SALES | |
|---|---|---|---|
| On hand | 150 | YTD usage/sales | 1100 |
| Location | W142 | MTD usage/sales | 75 |
| On order | 100 | YTD receipts | 1200 |
| Allocated | 75 | MTD receipts | 0 |
| Cycle | 3 | Last receipt | 8/25 |
| Last count | 9/5 | Last issue | 10/5 |
| Difference | -2 | **CODES** | |
| | | Cost acct. | 00754 |
| | | Routing | 00326 |
| | | Engr | 07142 |

# MRP Processes

- Exploding the bill of material
- Netting out inventory
- Lot sizing
- Time-phasing requirements

- Netting
  - process of subtracting on-hand quantities and scheduled receipts from gross requirements to produce net requirements
- Lot sizing
  - determining the quantities in which items are usually made or purchased

# MRP Matrix

| Item<br>Lot size | LLC<br>LT | Period<br>1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|---|
| Gross Requirements | | *Derived from MPS or planned order releases of the parent* | | | | |
| Scheduled Receipts | | *On order and scheduled to be received* | | | | |
| Projected on Hand | Beg Inv | *Anticipated quantity on hand at the end of the period* | | | | |
| Net Requirements | | *Gross requirements net of inventory and scheduled receipts* | | | | |
| Planned Order Receipts | | *When orders need to be received* | | | | |
| Planned Order Releases | | *When orders need to be placed to be received on time* | | | | |

# MRP: Example

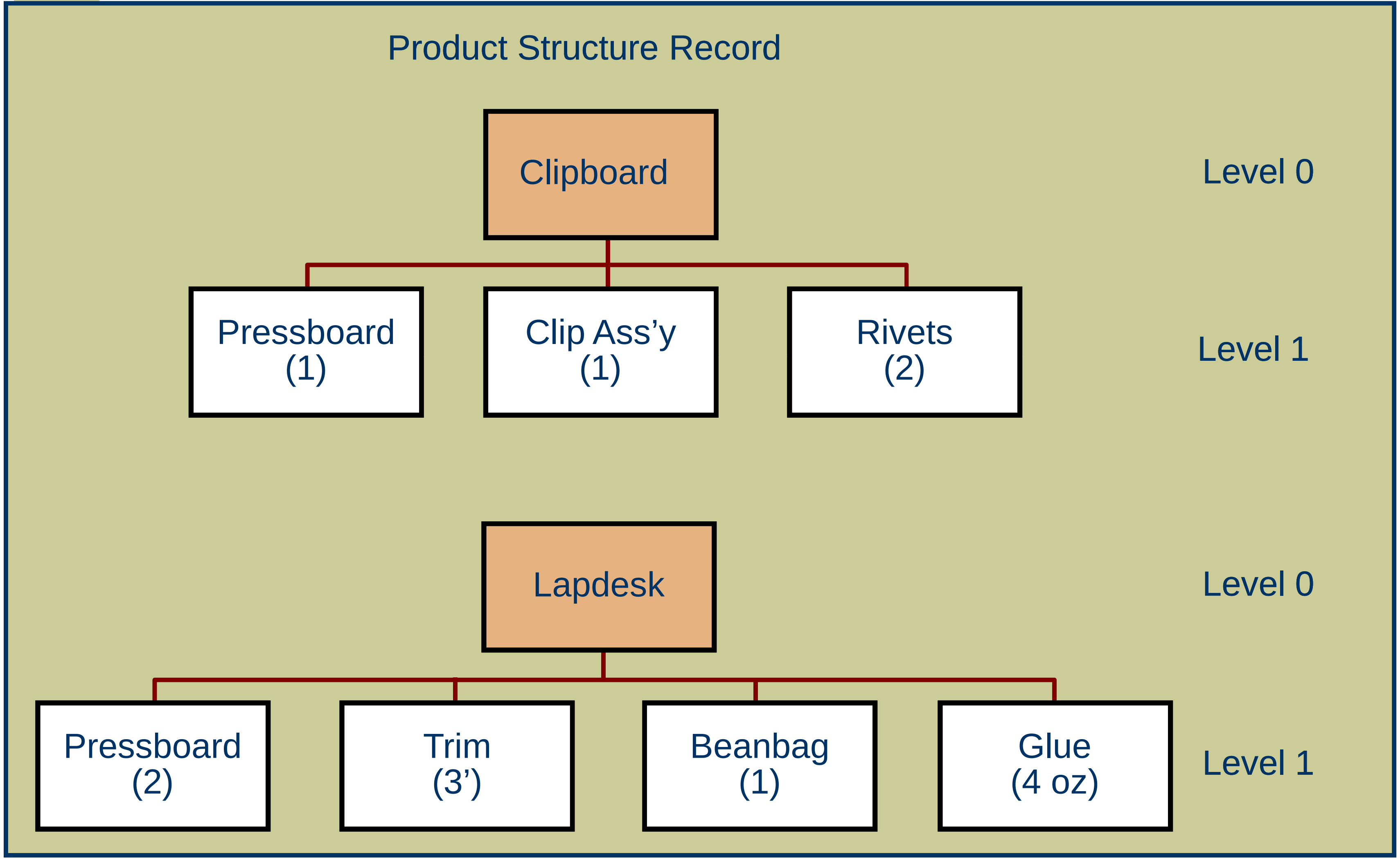
Master Production Schedule

| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Clipboard | 85 | 95 | 120 | 100 | 100 |
| Lapdesk | 0 | 60 | 0 | 60 | 0 |

Item Master File

| | CLIPBOARD | LAPDESK | PRESSBOARD |
|---|---|---|---|
| On hand | 25 | 20 | 150 |
| On order | 175 (Period 1) (sch receipt) | 0 | 0 |
| LLC | 0 | 0 | 1 |
| Lot size | L4L | Mult 50 | Min 100 |
| Lead time | 1 | 1 | 1 |

# MRP: Example (cont.)



# MRP: Example (cont.)

| ITEM: CLIPBOARD | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: L4L | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 85 | 95 | 120 | 100 | 100 |
| Scheduled Receipts | | | | 175 | | |
| Projected on Hand | 25 | | | | | |
| Net Requirements | | | | | | |
| Planned Order Receipts | | | | | | |
| Planned Order Releases | | | | | | |

# MRP: Example (cont.)

| ITEM: CLIPBOARD | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: L4L | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 85 | 95 | 120 | 100 | 100 |
| Scheduled Receipts | | | | 175 | | |
| Projected on Hand | | 25 | 115 | | | |
| Net Requirements | | | | 0 | | |
| Planned Order Receipts | | | | | | |
| Planned Order Releases | | | | | | |

**(25 + 175) = 200 units available**
**(200 - 85) = 115 on hand at the end of Period 1**

# MRP: Example (cont.)

| | | | | | | |
|---|---|---|---|---|---|---|
| ITEM: CLIPBOARD | LLC: 0 | PERIOD | | | | |
| LOT SIZE: L4L | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 85 | 95 | 120 | 100 | 100 |
| Scheduled Receipts | | | | 175 | | |
| Projected on Hand | 25 | | 115 | 20 | | |
| Net Requirements | | | 0 | 0 | | |
| Planned Order Receipts | | | | | | |
| Planned Order Releases | | | | | | |

**115 units available**

**(115 - 85) = 20 on hand at the end of Period 2**

# MRP: Example (cont.)

| ITEM: CLIPBOARD | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: L4L | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 85 | 95 | 120 | 100 | 100 |
| Scheduled Receipts | | | | 175 | | |
| Projected on Hand | 25 | 115 | 20 | 0 | | |
| Net Requirements | | 0 | 0 | 100 | | |
| Planned Order Receipts | | | | 100 | | |
| Planned Order Releases | | | | 100 | | |

**20 units available**

**(20 - 120) = -100 — 100 additional Clipboards are required**

**Order must be placed in Period 2 to be received in Period 3**

# MRP: Example (cont.)

| ITEM: CLIPBOARD | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: L4L | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 85 | 95 | 120 | 100 | 100 |
| Scheduled Receipts | | | | 175 | | |
| Projected on Hand | 25 | 115 | 20 | 0 | 0 | 0 |
| Net Requirements | | 0 | 0 | 100 | 100 | 100 |
| Planned Order Receipts | | | | 100 | 100 | 100 |
| Planned Order Releases | | | 100 | 100 | 100 | |

**Following the same logic Gross Requirements in Periods 4 and 5 develop Net Requirements, Planned Order Receipts, and Planned Order Releases**

# MRP: Example (cont.)

| ITEM: LAPDESK | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: MULT 50 | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 0 | 60 | 0 | 60 | 0 |
| Scheduled Receipts | | | | | | |
| Projected on Hand | 20 | | | | | |
| Net Requirements | | | | | | |
| Planned Order Receipts | | | | | | |
| Planned Order Releases | | | | | | |

# MRP: Example (cont.)

| ITEM: LAPDESK | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: MULT 50 | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 0 | 60 | 0 | 60 | 0 |
| Scheduled Receipts | | | | | | |
| Projected on Hand | 20 | 20 | 10 | 10 | 0 | 0 |
| Net Requirements | | 0 | 40 | | 50 | |
| Planned Order Receipts | | | 50 | | 50 | |
| Planned Order Releases | | 50 | | 50 | | |

**Following the same logic, the Lapdesk MRP matrix is completed as shown**

# MRP: Example (cont.)

| ITEM: CLIPBOARD | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: L4L | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Planned Order Releases | | | 100 | 100 | 100 | |

| ITEM: LAPDESK | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: MULT 50 | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Planned Order Releases | | 50 | | 50 | | |

| ITEM: PRESSBOARD | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: MIN 100 | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | | | | | |
| Scheduled Receipts | | | | | | |
| Projected on Hand | | 150 | | | | |
| Net Requirements | | | | | | |
| Planned Order Receipts | | | | | | |
| Planned Order Releases | | | | | | |

# MRP: Example (cont.)

| ITEM: CLIPBOARD | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: L4L | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Planned Order Releases | | | 100 | 100 | 100 | |

| ITEM: LAPDESK | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: MULT 50 | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Planned Order Releases | | 50 | | 50 | | |

| ITEM: PRESSBOARD | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: MIN 100 | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 100 | 100 | 200 | 100 | 0 |
| Scheduled Receipts | | | | | | |
| Projected on Hand | | 150 | | | | |
| Net Requirements | | | | | | |
| Planned Order Receipts | | | | | | |
| Planned Order Releases | | | | | | |

# MRP: Example (cont.)

| ITEM: CLIPBOARD | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: L4L | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Planned Order Releases | | | 100 | 100 | 100 | |

| ITEM: LAPDESK | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: MULT 50 | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Planned Order Releases | | 50 | | 50 | | |

| ITEM: PRESSBOARD | LLC: 0 | PERIOD | | | | |
|---|---|---|---|---|---|---|
| LOT SIZE: MIN 100 | LT: 1 | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 100 | 100 | 200 | 100 | 0 |
| Scheduled Receipts | | | | | | |
| Projected on Hand | 150 | 50 | 50 | 0 | 0 | 0 |
| Net Requirements | | | 50 | 150 | 100 | |
| Planned Order Receipts | | | 100 | 150 | 100 | |
| Planned Order Releases | | 100 | 150 | 100 | | |

# MRP: Example (cont.)

**Planned Order Report**

| ITEM | PERIOD 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Clipboard | | 100 | 100 | 100 | |
| Lapdesk | 50 | | 50 | | |
| Pressboard | 100 | 150 | 100 | | |

# Lot Sizing in MRP Systems

- Lot-for-lot ordering policy
- Fixed-size lot ordering policy
  - Minimum order quantities
  - Maximum order quantities
  - Multiple order quantities
  - Economic order quantity
  - Periodic order quantity

# Using Excel for MRP Calculations

Microsoft Excel - Exhibit 14.1

## Example 14.1 - School Mate Products

### INPUT

***Master Production Schedule***

| *Item no.* | *Item* | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|---|
| 1 | Clipboard | 85 | 95 | 120 | 100 | 100 |
| 2 | Lapdesk | 0 | 60 | 0 | 60 | 0 |

***Scheduled Receipts***

| *Item no.* | *Item* | *1* | *2* | *3* | *4* | *5* |
|---|---|---|---|---|---|---|
| 1 | Clipboard | 175 | | | | |
| 2 | Lapdesk | | | | | |
| 3 | Pressboard | | | | | |

***Item Master File***

| *Item no.* | *Item* | *LLC* | *LT* | *Lot Size* | | *On Hand* |
|---|---|---|---|---|---|---|
| 1 | Clipboard | 0 | 1 | L4L | 1 | 25 |
| 2 | Lapdesk | 0 | 1 | Mult | 50 | 20 |
| 3 | Pressboard | 1 | 1 | Min | 100 | 150 |

***Product Structure File***

| *Level* | *Item* | *No.* | *Qty** |
|---|---|---|---|
| 0 | Clipboard | 1 | |
| 1 | Pressboard | 3 | 1 |
| 0 | Lapdesk | 2 | |
| 1 | Pressboard | 3 | 2 |

** quantity per next level of assembly*

### CALCULATIONS

| *Item:* Clipboard | *LLC:* 0 | | *Period* | | | |
|---|---|---|---|---|---|---|
| *Lot Size:* L4L 1 | *LT:* 1 | | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | | 85 | 95 | 120 | 100 | 100 |
| Scheduled Receipts | | | 175 | 0 | 0 | 0 | 0 |
| Projected on Hand | | 25 | 115 | 20 | 0 | 0 | 0 |
| Net Requirements | | | 0 | 0 | 100 | 100 | 100 |
| Planned Order Receipts | | | 0 | 0 | 100 | 100 | 100 |
| Planned Order Releases | | | 0 | 100 | 100 | 100 | 0 |

| *Item:* Lapdesk | *LLC:* 0 | | *Period* | | | | |
|---|---|---|---|---|---|---|---|
| *Lot Size:* Mult 50 | *LT:* 1 | | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | | 0 | 60 | 0 | 60 | 0 |
| Scheduled Receipts | | | 0 | 0 | 0 | 0 | 0 |
| Projected on Hand | | 20 | 20 | 10 | 10 | 0 | 0 |
| Net Requirements | | | 0 | 40 | 0 | 50 | 0 |
| Planned Order Receipts | | | 0 | 50 | 0 | 50 | 0 |
| Planned Order Releases | | | 50 | 0 | 50 | 0 | 0 |

| *Item:* Pressboard | *LLC:* 0 | | *Period* | | | | |
|---|---|---|---|---|---|---|---|
| *Lot Size:* Min 100 | *LT:* 1 | | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | | 100 | 100 | 200 | 100 | 0 |
| Scheduled Receipts | | | 0 | 0 | 0 | 0 | 0 |
| Projected on Hand | | 150 | 50 | 50 | 0 | 0 | 0 |
| Net Requirements | | | 0 | 50 | 150 | 100 | 0 |
| Planned Order Receipts | | | 0 | 100 | 150 | 100 | 0 |
| Planned Order Releases | | | 100 | 150 | 100 | 0 | 0 |

### OUTPUT

***Planned Order Report***

| | *Period* | | | | |
|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* |
| Clipboard | 0 | 100 | 100 | 100 | 0 |
| Lapdesk | 50 | 0 | 50 | 0 | 0 |
| Pressboard | 100 | 150 | 100 | 0 | 0 |

# Advanced Lot Sizing Rules: L4L

| Period | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Gross Requirements | 30 | 50 | 20 | 10 | 40 |

$C_o = \$60$

$C_c = \$1$

$\bar{d} = (30 + 50 + 20 + 10 + 40)/5 = 30$

| **Item: Rod** | **LLC: 0** | **Period** | | | | |
|---|---|---|---|---|---|---|
| **Lot size: L4L** | **LT: 1** | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 30 | 50 | 20 | 10 | 40 |
| Scheduled Receipts | | | | | | |
| Projected on hand | 30 | 0 | 0 | 0 | 0 | 0 |
| Net Requirements | | | 50 | 20 | 10 | 40 |
| Planned Order Receipts | | | 50 | 20 | 10 | 40 |
| Planned Order Releases | | 50 | 20 | 10 | 40 | |

Total cost of L4L = (4 X \$60) + (0 X \$1) = \$240

# Advanced Lot Sizing Rules: EOQ

$$EOQ = \sqrt{\frac{2(30)(60}{1}} = 60$$ minimum order quantity

| Item: Rod | LLC: 0 | Period | | | | |
|---|---|---|---|---|---|---|
| **Lot size: EOQ 60** | **LT: 1** | *1* | *2* | *3* | *4* | *5* |
| Gross Requirements | | 30 | 50 | 20 | 10 | 40 |
| Scheduled Receipts | | | | | | |
| Projected on hand | 30 | 0 | 10 | 50 | 40 | 0 |
| Net Requirements | | | 50 | 10 | | |
| Planned Order Receipts | | | 60 | 60 | | |
| Planned Order Releases | | 60 | 60 | | | |

Total cost of EOQ = (2 X $60) + [(10 + 50 + 40) X $1)] = $220

# Advanced Lot Sizing Rules: POQ

$POQ = Q / \bar{d} = 60 / 30 = 2$ periods worth of requirements

| Item: Rod | LLC: 0 | Period | | | | |
|---|---|---|---|---|---|---|
| Lot size: POQ 2 | LT: 1 | 1 | 2 | 3 | 4 | 5 |
| Gross Requirements | | 30 | 50 | 20 | 10 | 40 |
| Scheduled Receipts | | | | | | |
| Projected on hand | 30 | 0 | 20 | 0 | 40 | 0 |
| Net Requirements | | | 50 | | 10 | |
| Planned Order Receipts | | | 70 | | 50 | |
| Planned Order Releases | | 70 | | 50 | | |

Total cost of POQ = (2 X $60) + [(20 + 40) X $1] = $180

# Planned Order Report

| | | | |
|---|---|---|---|
| Item | #2740 | Date | 9 - 25 - 05 |
| On hand | 100 | Lead time | 2 weeks |
| On order | 200 | Lot size | 200 |
| Allocated | 50 | Safety stock | 50 |

| DATE | ORDER NO. | GROSS REQS. | SCHEDULED RECEIPTS | PROJECTED ON HAND | ACTION |
|---|---|---|---|---|---|
| | | | | 50 | |
| 9-26 | AL 4416 | 25 | | 25 | |
| 9-30 | AL 4174 | 25 | | 0 | |
| 10-01 | GR 6470 | 50 | | - 50 | |
| 10-08 | SR 7542 | | 200 | 150 | Expedite SR 10-01 |
| 10-10 | CO 4471 | 75 | | 75 | |
| 10-15 | GR 6471 | 50 | | 25 | |
| 10-23 | GR 6471 | 25 | | 0 | |
| 10-27 | GR 6473 | 50 | | - 50 | Release PO 10-13 |

Key: AL = allocated; WO = work order
CO = customer order; SR = scheduled receipt
PO = purchase order; GR = gross requirement

# MRP Action Report

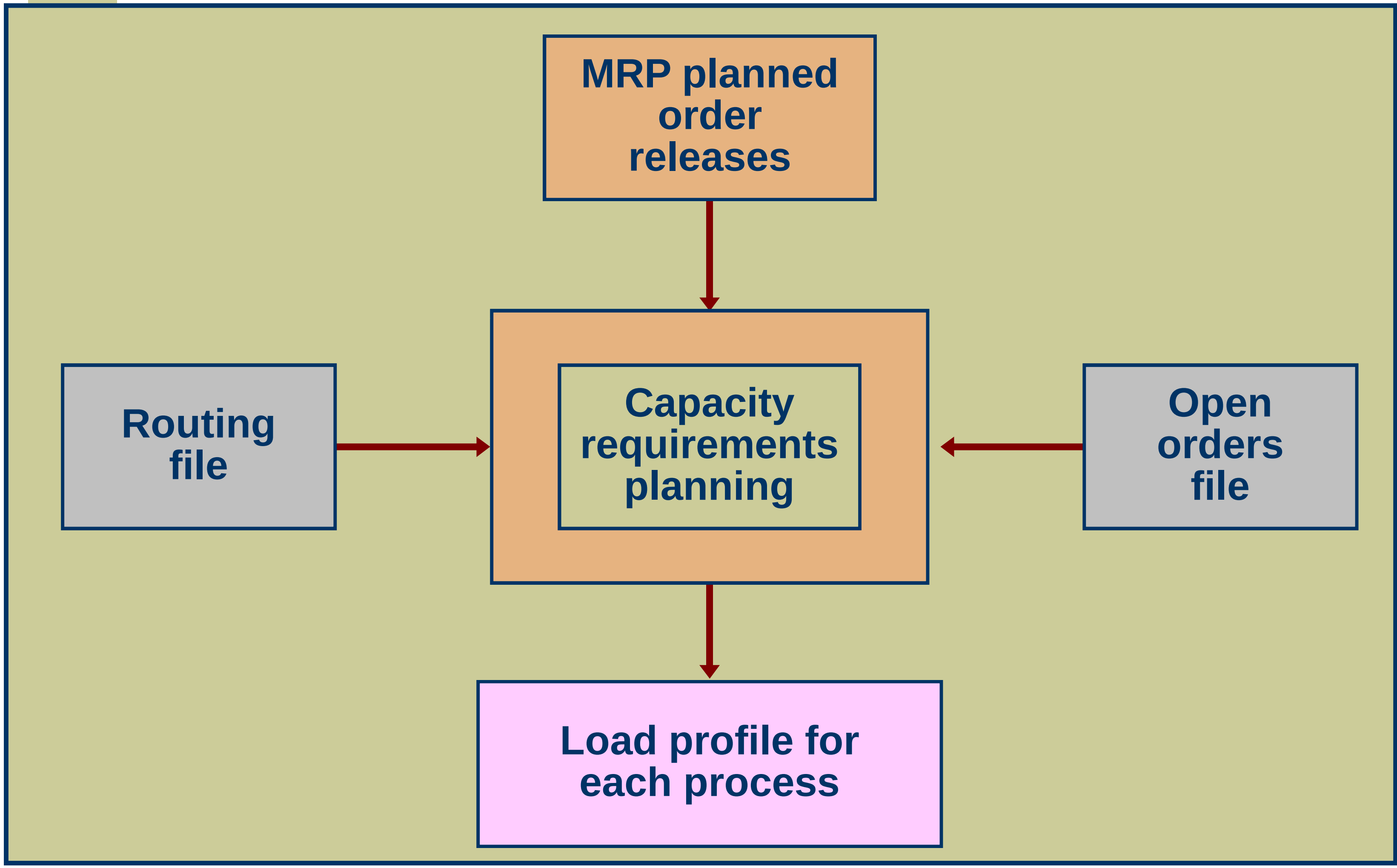
Current date 9-25-08

| ITEM | DATE | ORDER NO. | QTY. | ACTION | | |
|---|---|---|---|---|---|---|
| #2740 | 10-08 | 7542 | 200 | Expedite | SR | 10-01 |
| #3616 | 10-09 | | | Move forward | PO | 10-07 |
| #2412 | 10-10 | | | Move forward | PO | 10-05 |
| #3427 | 10-15 | | | Move backward | PO | 10-25 |
| #2516 | 10-20 | 7648 | 100 | De-expedite | SR | 10-30 |
| #2740 | 10-27 | | 200 | Release | PO | 10-13 |
| #3666 | 10-31 | | 50 | Release | WO | 10-24 |

# Capacity Requirements Planning (CRP)

- Creates a load profile
- Identifies under-loads and over-loads
- Inputs
  - Planned order releases
  - Routing file
  - Open orders file

# CRP



MRP planned order releases
Routing file
Capacity requirements planning
Open orders file
Load profile for each process

# Calculating Capacity

- Maximum capability to produce
- Rated Capacity
  - Theoretical output that could be attained if a process were operating at full speed without interruption, exceptions, or downtime
- Effective Capacity
  - Takes into account the efficiency with which a particular product or customer can be processed and the utilization of the scheduled hours or work

Effective Daily Capacity = (no. of machines or workers) x (hours per shift) x (no. of shifts) x (utilization) x ( efficiency)

# Calculating Capacity (cont.)

- Utilization
  - Percent of available time spent working
- Efficiency
  - How well a machine or worker performs compared to a standard output level
- Load
  - Standard hours of work assigned to a facility
- Load Percent
  - Ratio of load to capacity

$$\text{Load Percent} = \frac{\text{load}}{\text{capacity}} \times 100\%$$

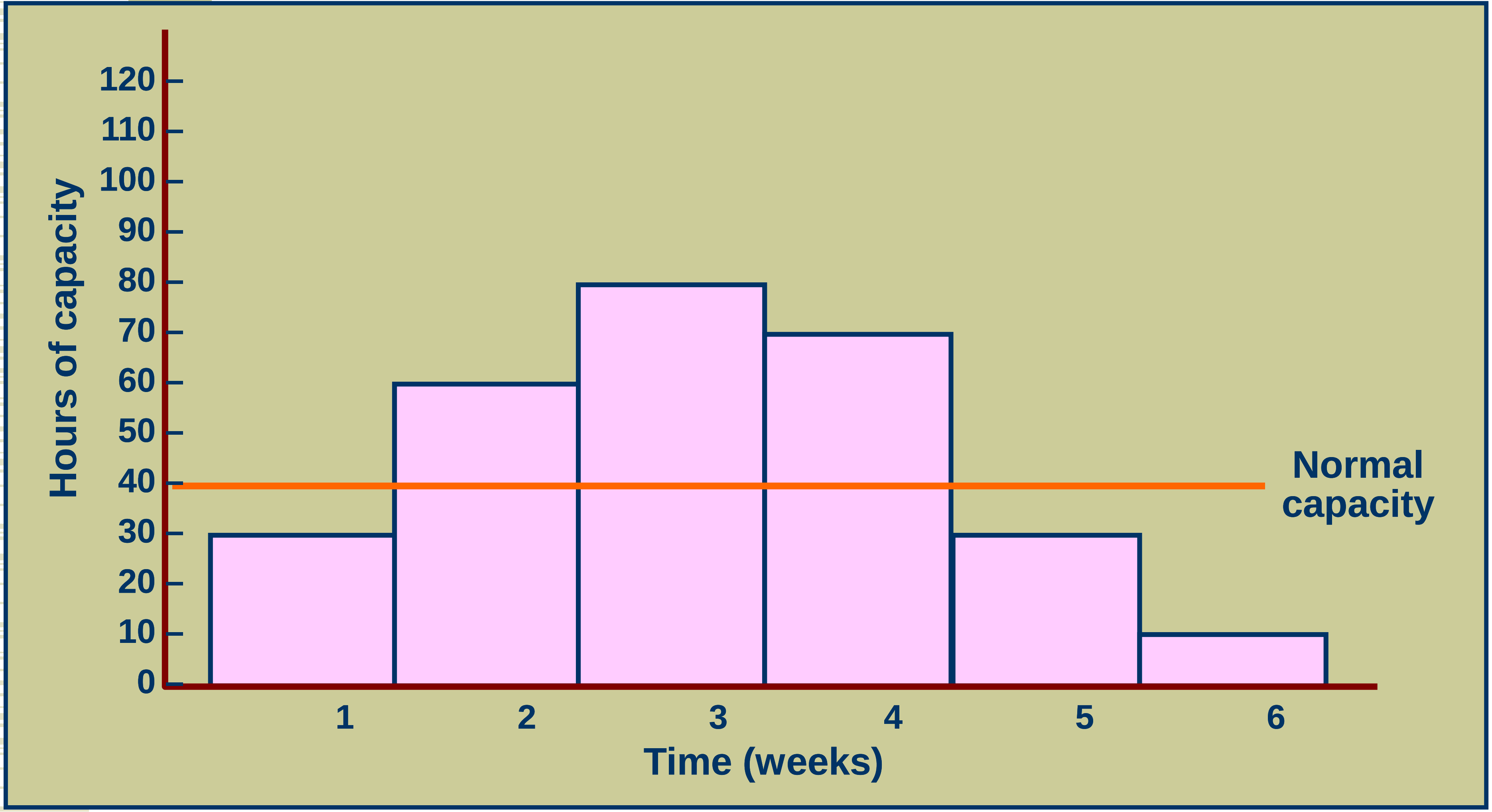
# Load Profiles

- graphical comparison of load versus capacity
- Leveling underloaded conditions:
  - Acquire more work
  - Pull work ahead that is scheduled for later time periods
  - Reduce normal capacity

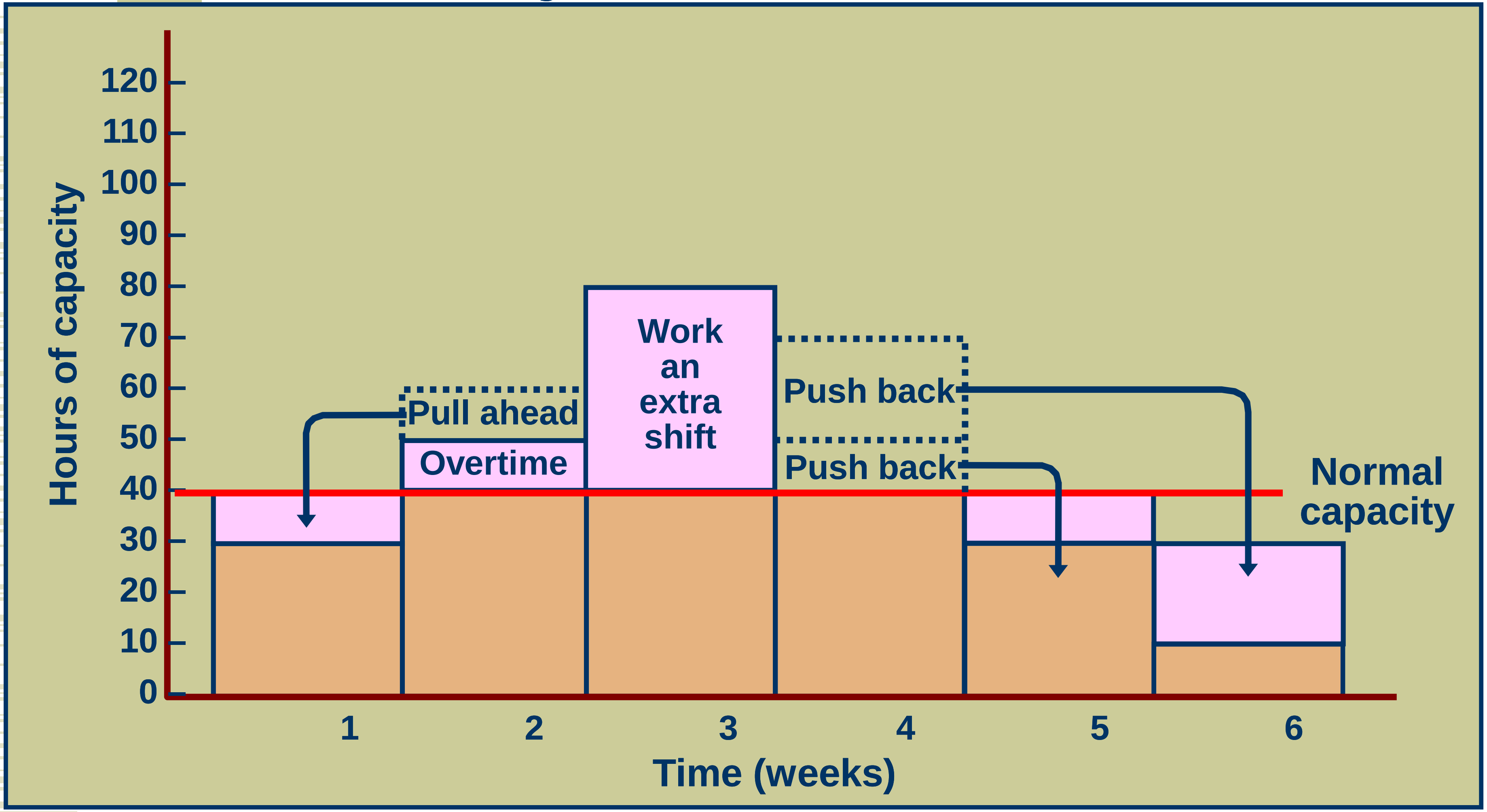
# Reducing Over-load Conditions

1. Eliminating unnecessary requirements
2. Rerouting jobs to alternative machines, workers, or work centers
3. Splitting lots between two or more machines
4. Increasing normal capacity
5. Subcontracting
6. Increasing efficiency of the operation
7. Pushing work back to later time periods
8. Revising master schedule

# Initial Load Profile



# Adjusted Load Profile




- Load leveling
  - process of balancing underloads and overloads

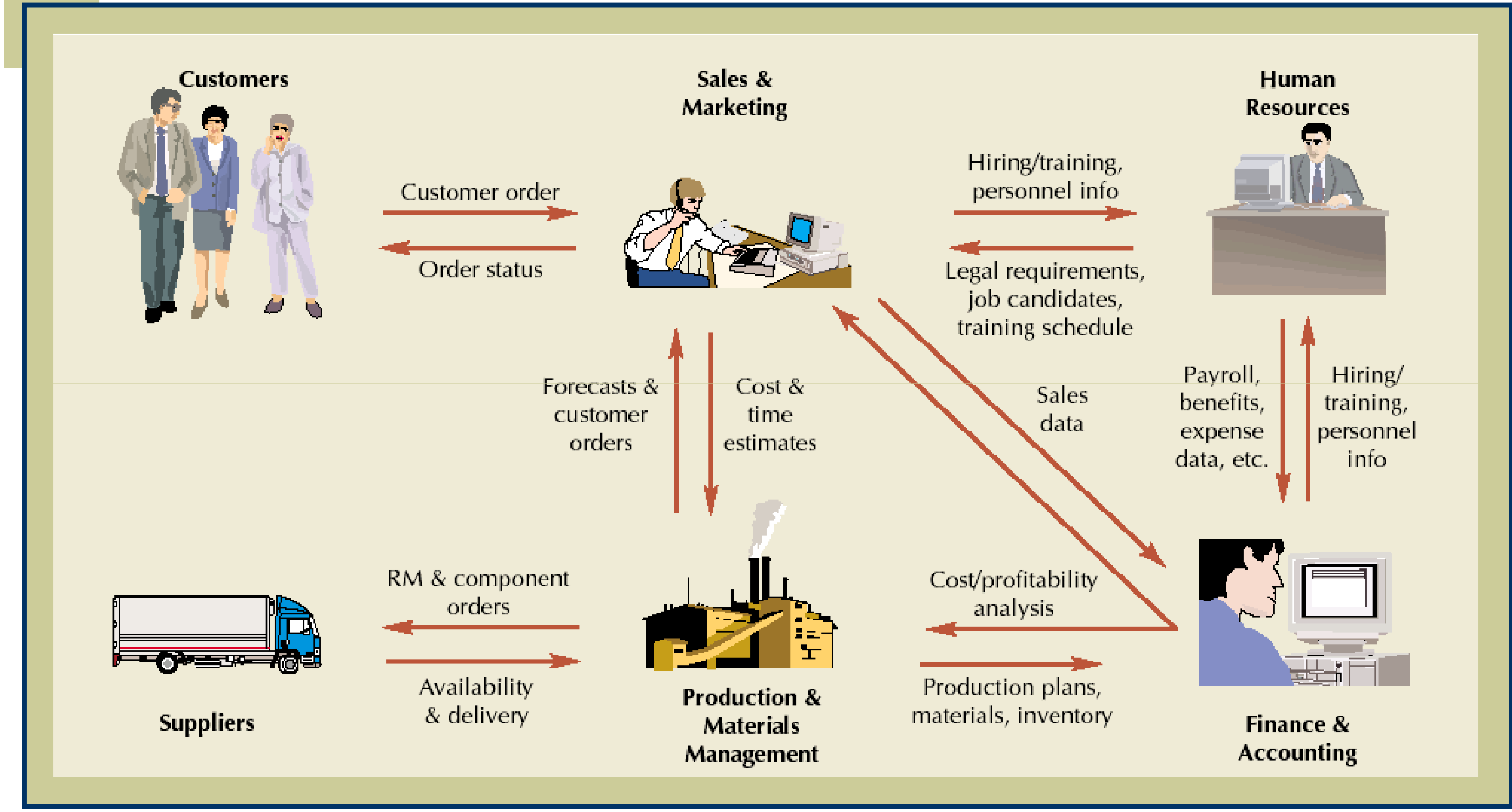
# Relaxing MRP Assumptions

- Material is not always the most constraining resource
- Lead times can vary
- Not every transaction needs to be recorded
- Shop floor may require a more sophisticated scheduling system
- Scheduling in advance may not be appropriate for on-demand production.

# Enterprise Resource Planning (ERP)

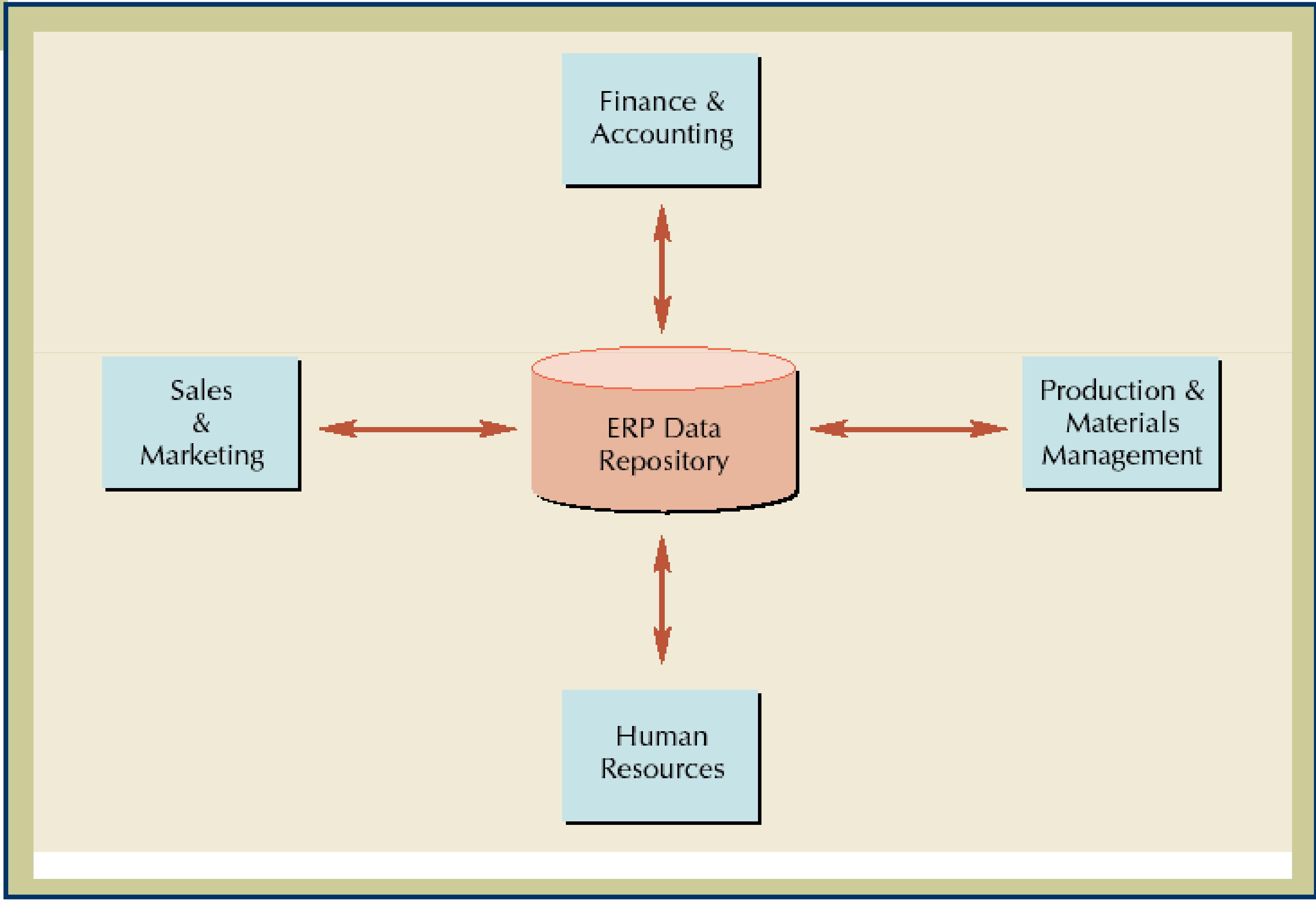
- Software that organizes and manages a company's business processes by
  - sharing information across functional areas
  - integrating business processes
  - facilitating customer interaction
  - providing benefit to global companies

# Organizational Data Flows




*Source:* Adapted from Joseph Brady, Ellen Monk, and Bret Wagner, *Concepts in Enterprise Resource Planning* (Boston: Course Technology, 2001), pp. 7–12

# ERP's Central Database



# Selected Enterprise Software Vendors

| Vendor | Specialty |
|---|---|
| 1. SAP | Large enterprise discrete manufacturing ERP, SCM |
| 2. Oracle Corp. | Large enterprise discrete manufacturing and services |
| 3.Oracle's PeopleSoft | Human resources and employee relationship management |
| 4. Oracle's Siebel Systems | Customer relationship management (CRM) |
| 5. i2 Technologies | Supply chain management (SCM) |
| 6. PTC, EDS, Dassault Systems | Product life cycle management (PLM) |
| 7. Siemens Energy & Automation | Manufacturing execution systems (MES) |
| 8. SCT | Process industry; education; energy |
| 9. QAD | Multinational midmarket manufacturing |
| 10. Microsoft Dynamics | Small to midmarket CRP, CRM |

# ERP Implementation

- Analyze business processes
- Choose modules to implement
  - Which processes have the biggest impact on customer relations?
  - Which process would benefit the most from integration?
  - Which processes should be standardized?
- Align level of sophistication
- Finalize delivery and access
- Link with external partners

# Customer Relationship Management (CRM)

- Software that
  - Plans and executes business processes
  - Involves customer interaction
  - Changes focus from managing products to managing customers
  - Analyzes point-of-sale data for patterns used to predict future behavior

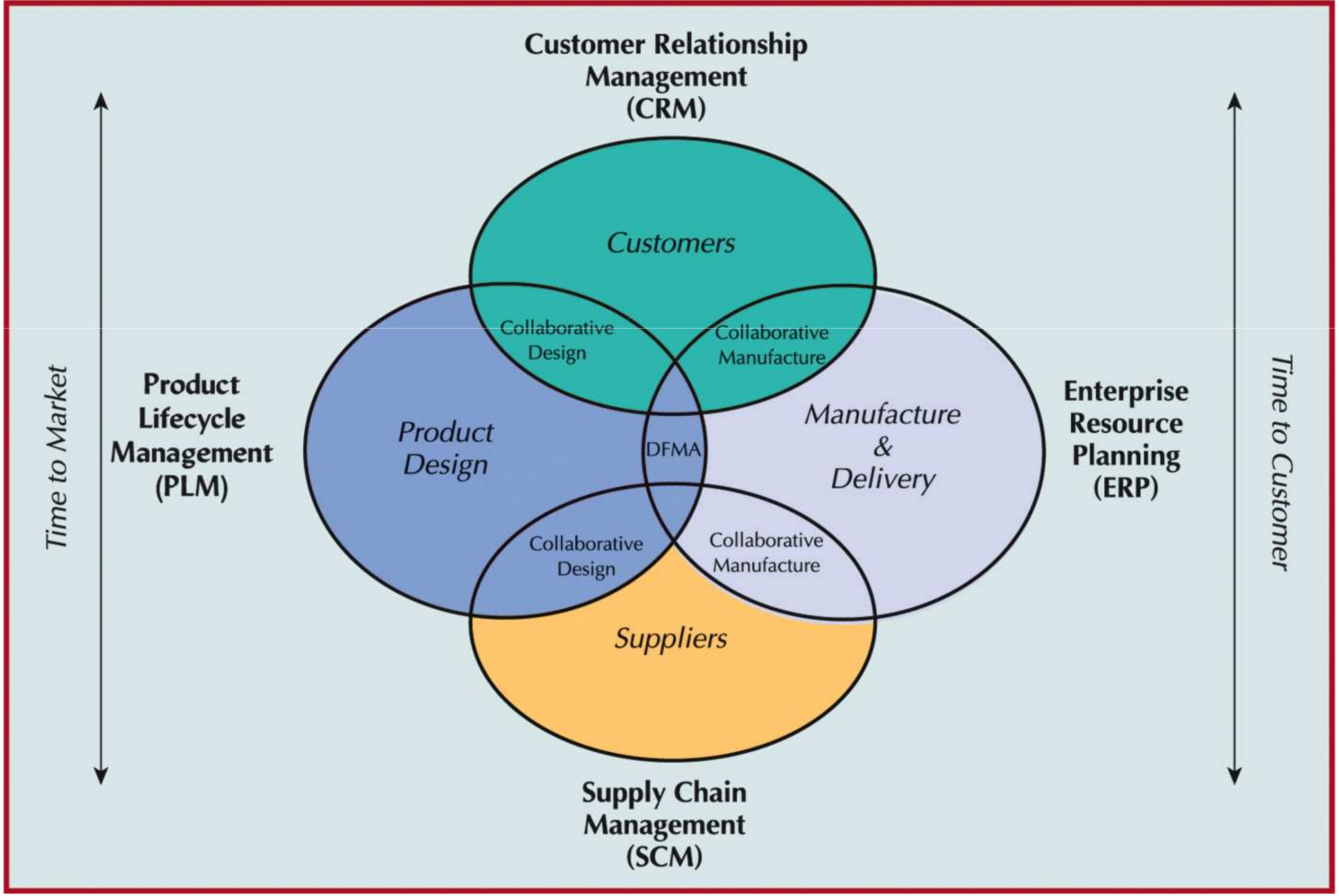
# Supply Chain Management

- Software that plans and executes business processes related to supply chains
- Includes
  - Supply chain planning
  - Supply chain execution
  - Supplier relationship management
- Distinctions between ERP and SCM are becoming increasingly blurred

# Product Lifecycle Management (PLM)

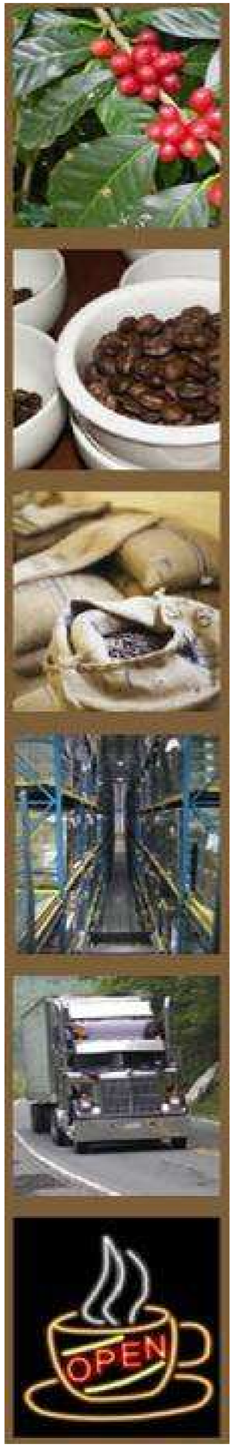
- Software that
  - Incorporates new product design and development and product life cycle management
  - Integrates customers and suppliers in the design process though the entire product life cycle

# ERP and Software Systems



# Connectivity

- Application programming interfaces (APIs)
  - give other programs well-defined ways of speaking to them
- Enterprise Application Integration (EAI) solutions
- EDI is being replaced by XML, business language of Internet
- Service-oriented architecture (SOA)
  - collection of "services" that communicate with each other within software or between software



# Chapter 16

## *Lean Systems*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

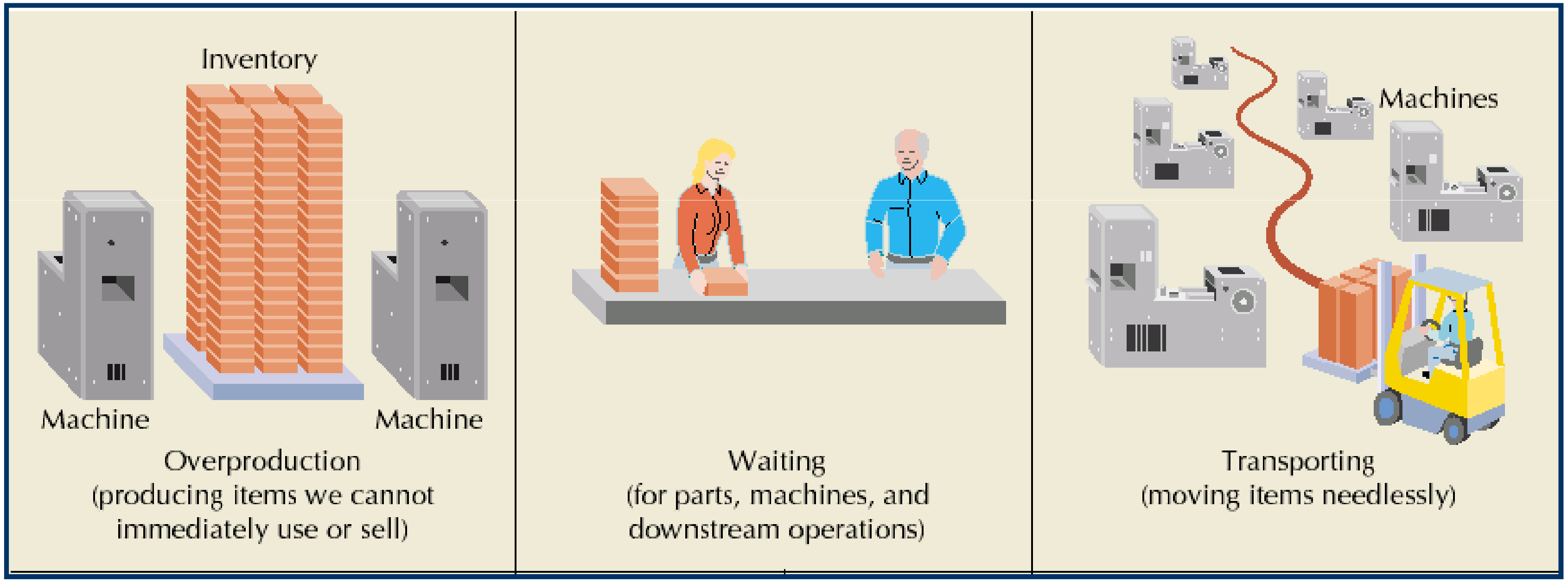
# Lecture Outline

- Basic Elements of Lean Production
- Benefits of Lean Production
- Implementing Lean Production
- Lean Services
- Leaning the Supply Chain
- Lean Six Sigma
- Lean and the Environment
- Lean Consumption

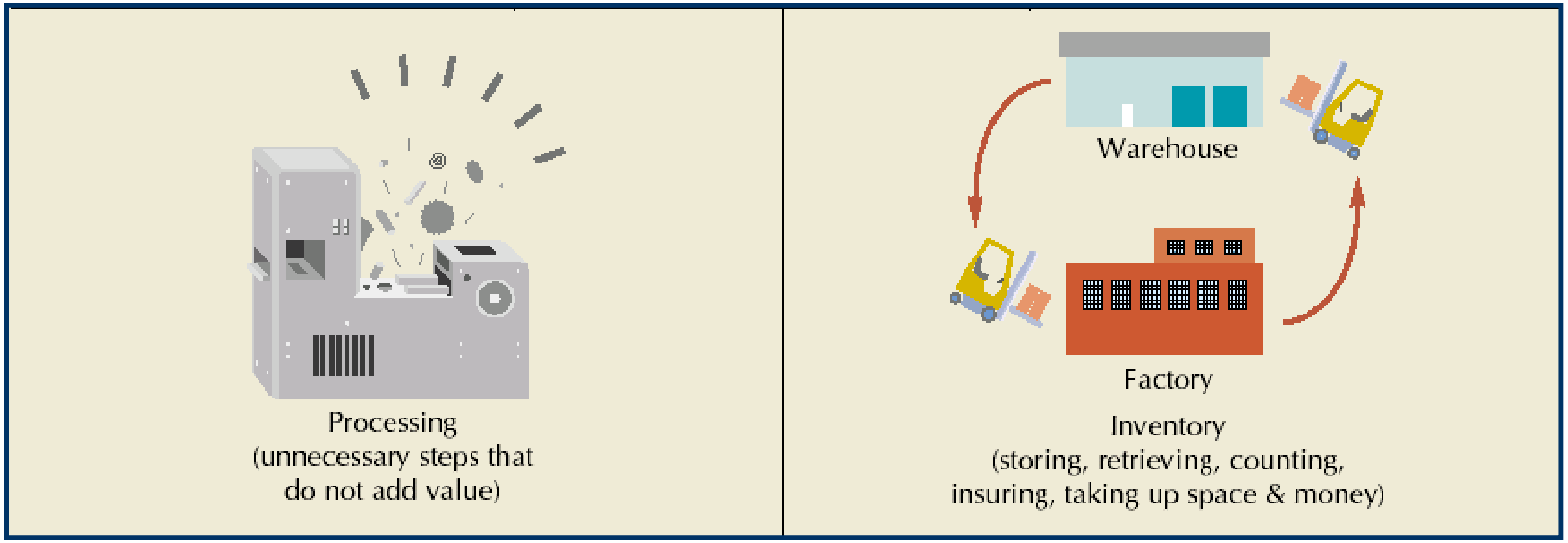
# Lean Production

- Doing more with less inventory, fewer workers, less space
- Just-in-time (JIT)
  - smoothing the *flow* of material to arrive just as it is needed
  - “JIT” and “Lean Production” are used interchangeably
- Muda
  - waste, anything other than that which adds value to product or service

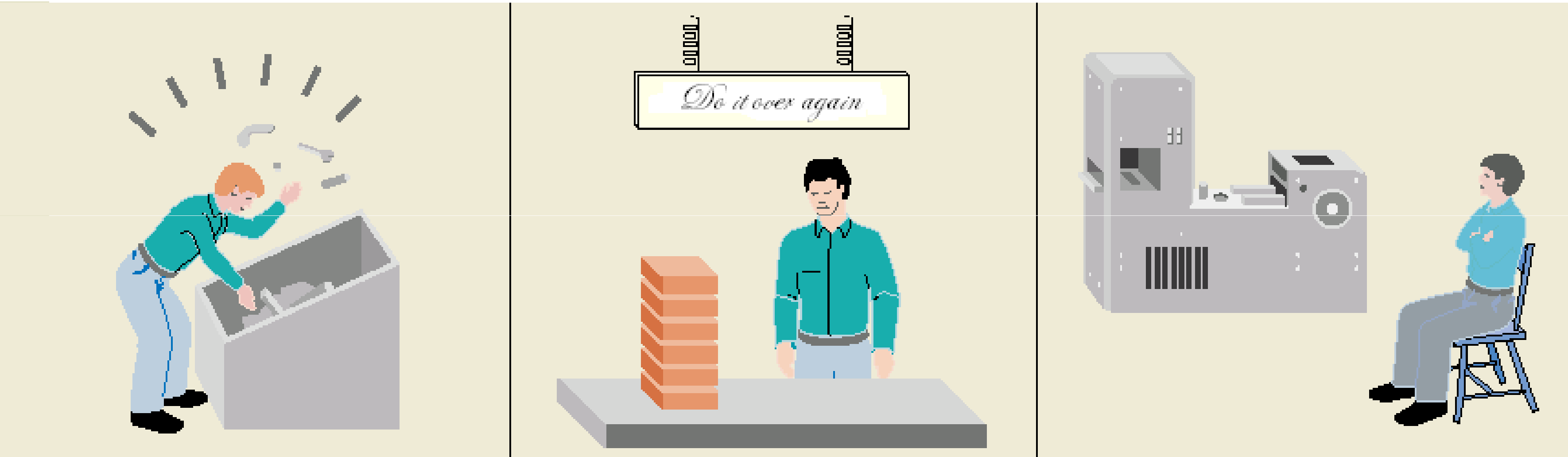
# Waste in Operations



# Waste in Operations (cont.)



# Waste in Operations (cont.)



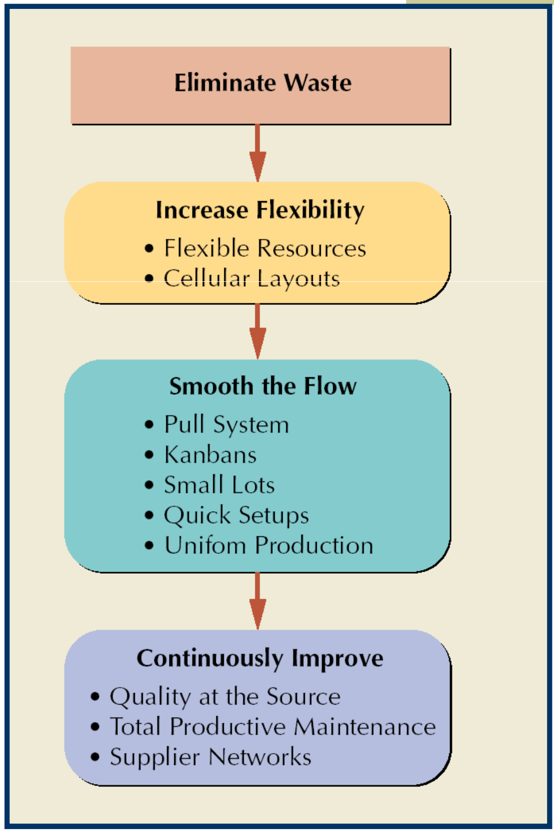

Movement
(searching for tools, parts, instruction, approval)

Defects
(rework and scrap)

Talent
(underutilization of worker knowledge and skills)

# Basic Elements

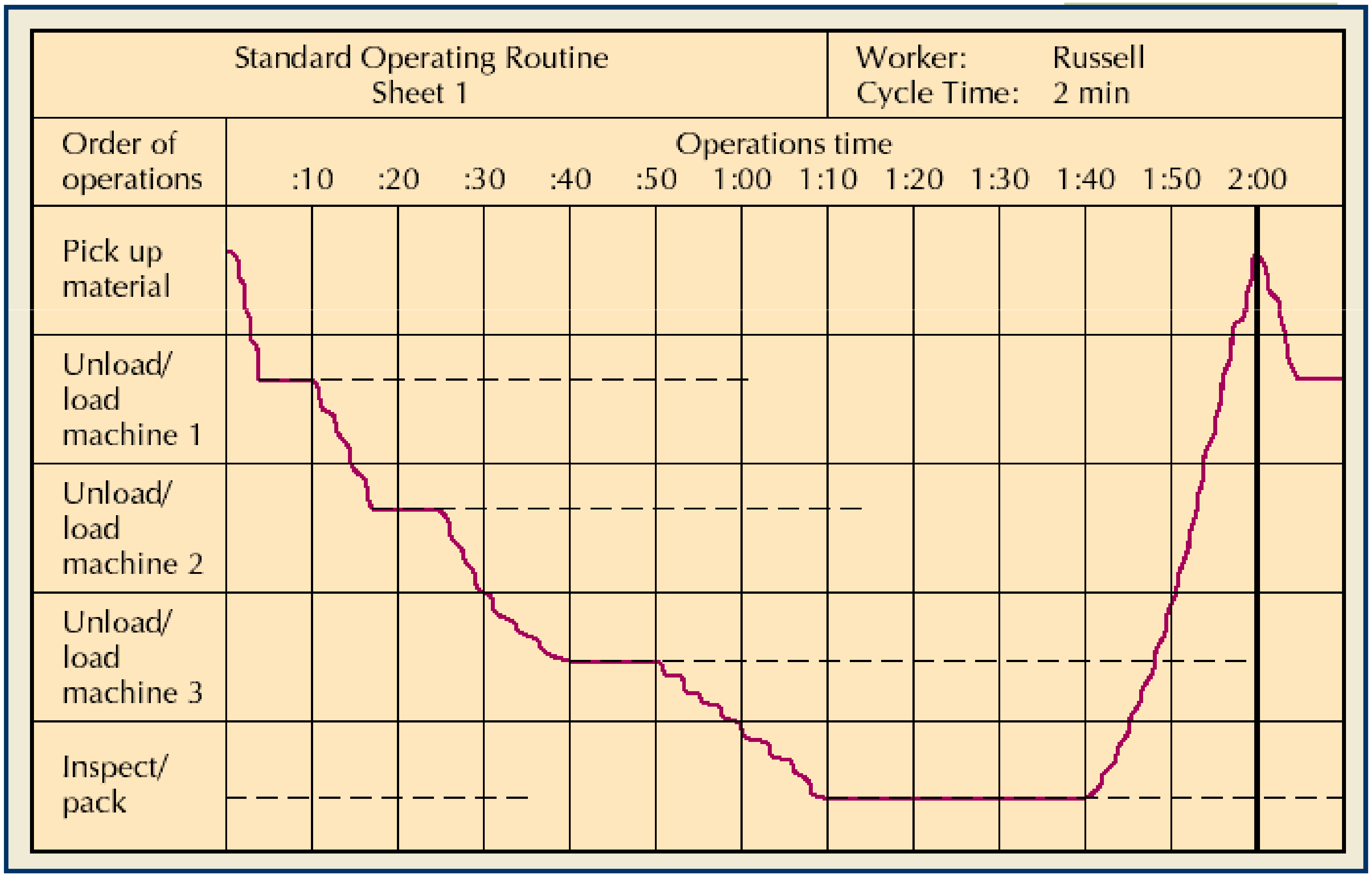
1. Flexible resources
2. Cellular layouts
3. Pull system
4. Kanbans
5. Small lots
6. Quick setups
7. Uniform production levels
8. Quality at the source
9. Total productive maintenance
10. Supplier networks



# Flexible Resources

- Multifunctional workers
  - perform more than one job
  - general-purpose machines perform several basic functions
- Cycle time
  - time required for the worker to complete one pass through the operations assigned
- Takt time
  - paces production to customer demand

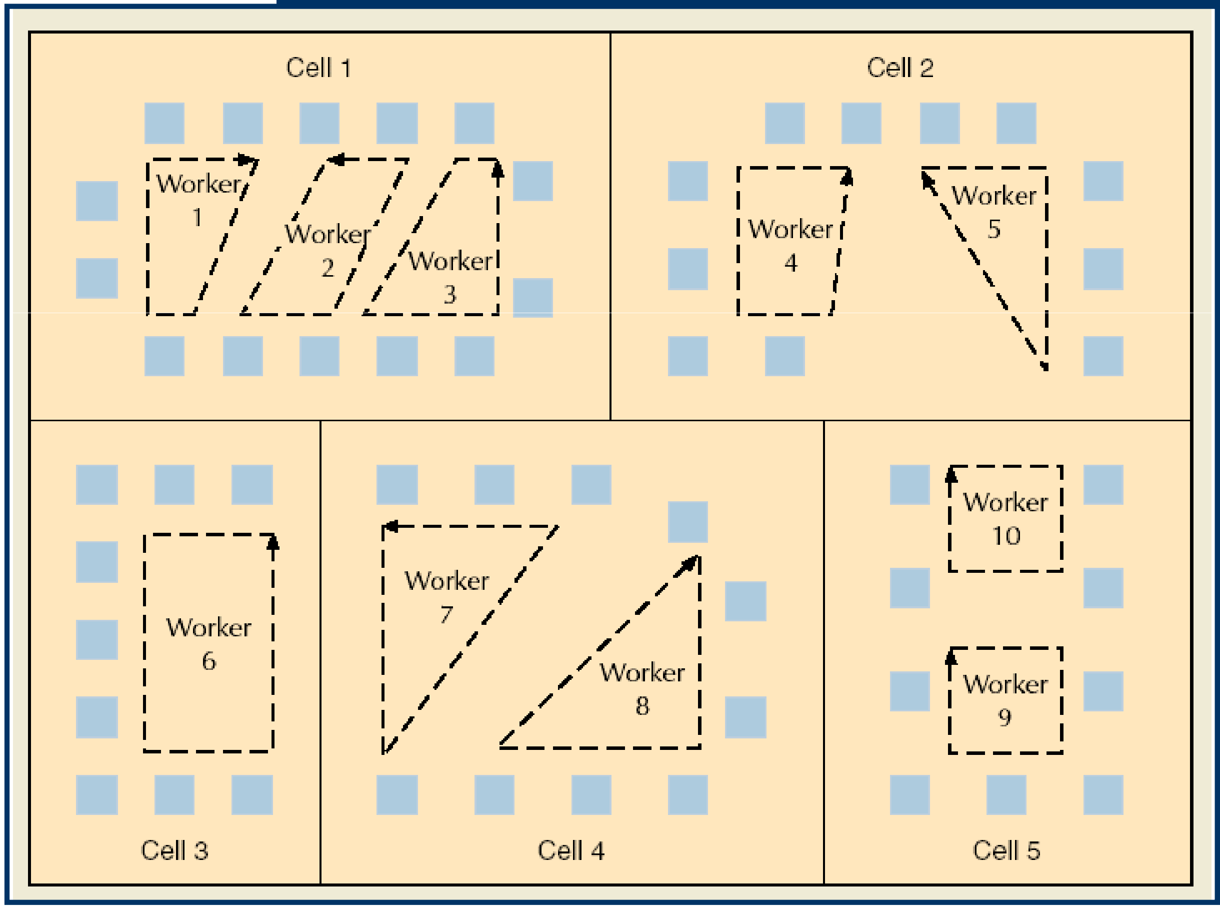
# Standard Operating Routine for a Worker



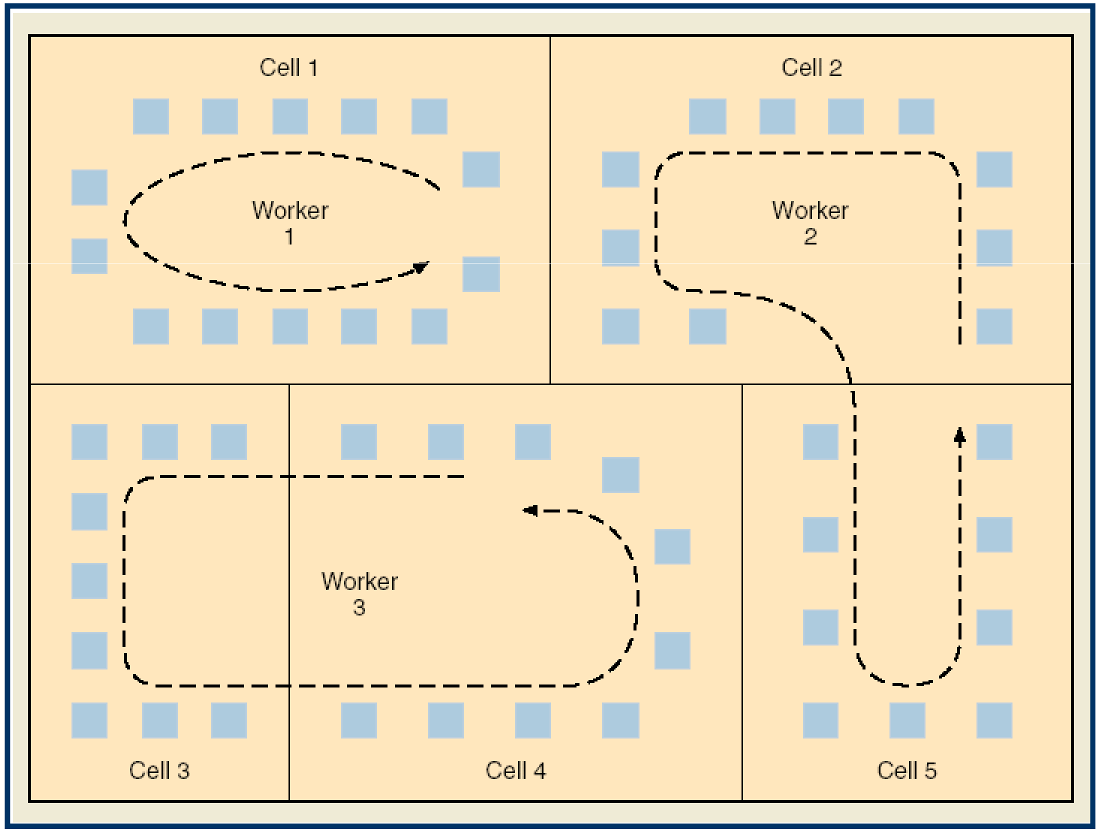
# Cellular Layouts

- Manufacturing cells
  - comprised of dissimilar machines brought together to manufacture a family of parts
- Cycle time is adjusted to match takt time by changing worker paths

# Cells with Worker Routes



# Worker Routes Lengthen as Volume Decreases



# Pull System

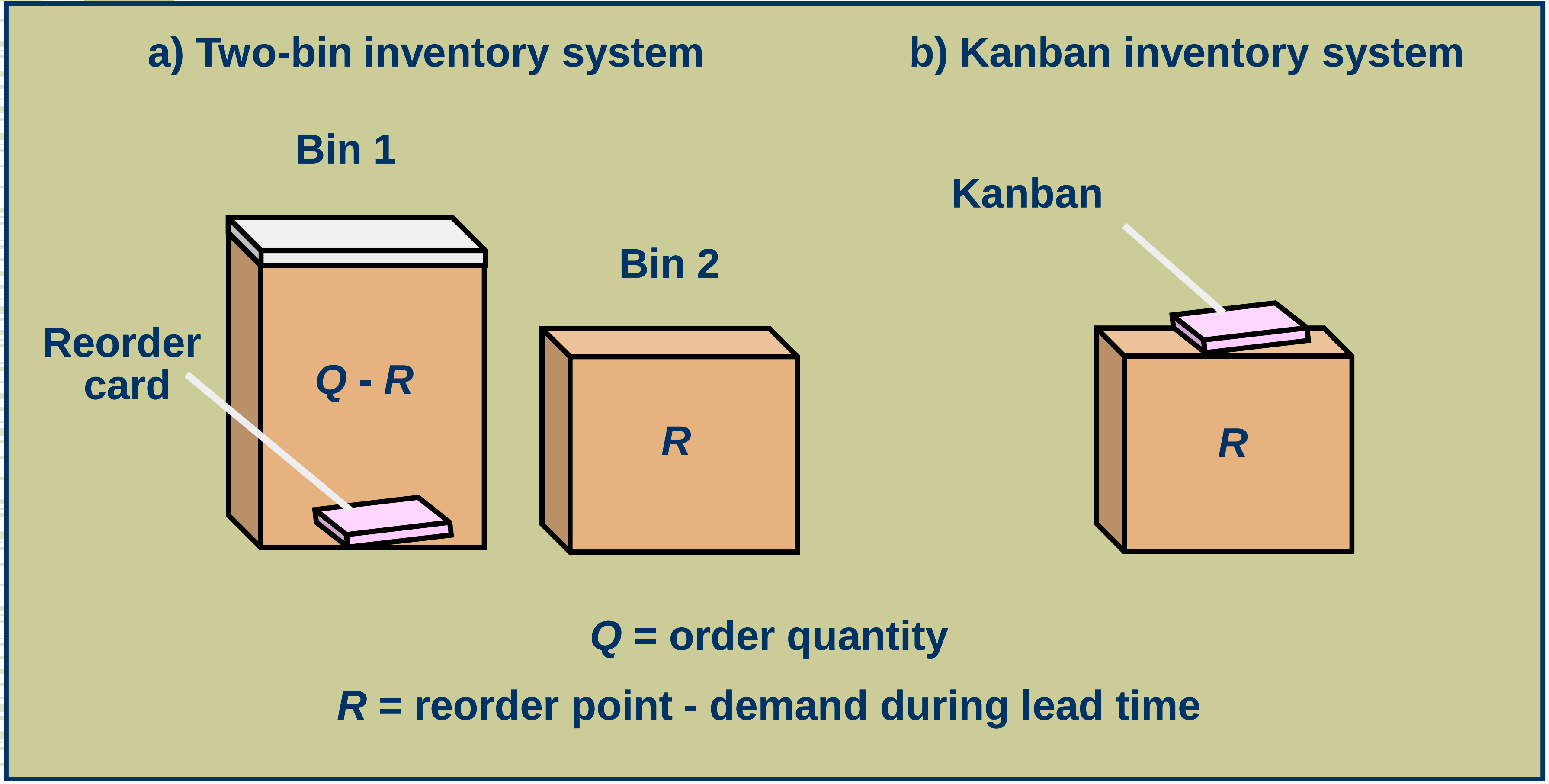
- Material is pulled through the system when needed
- Reversal of traditional push system where material is pushed according to a schedule
- Forces cooperation
- Prevent over and underproduction
- While push systems rely on a predetermined schedule, pull systems rely on customer requests

# Kanbans

- Card which indicates standard quantity of production
- Derived from two-bin inventory system
- Maintain discipline of pull production
- Authorize production and movement of goods

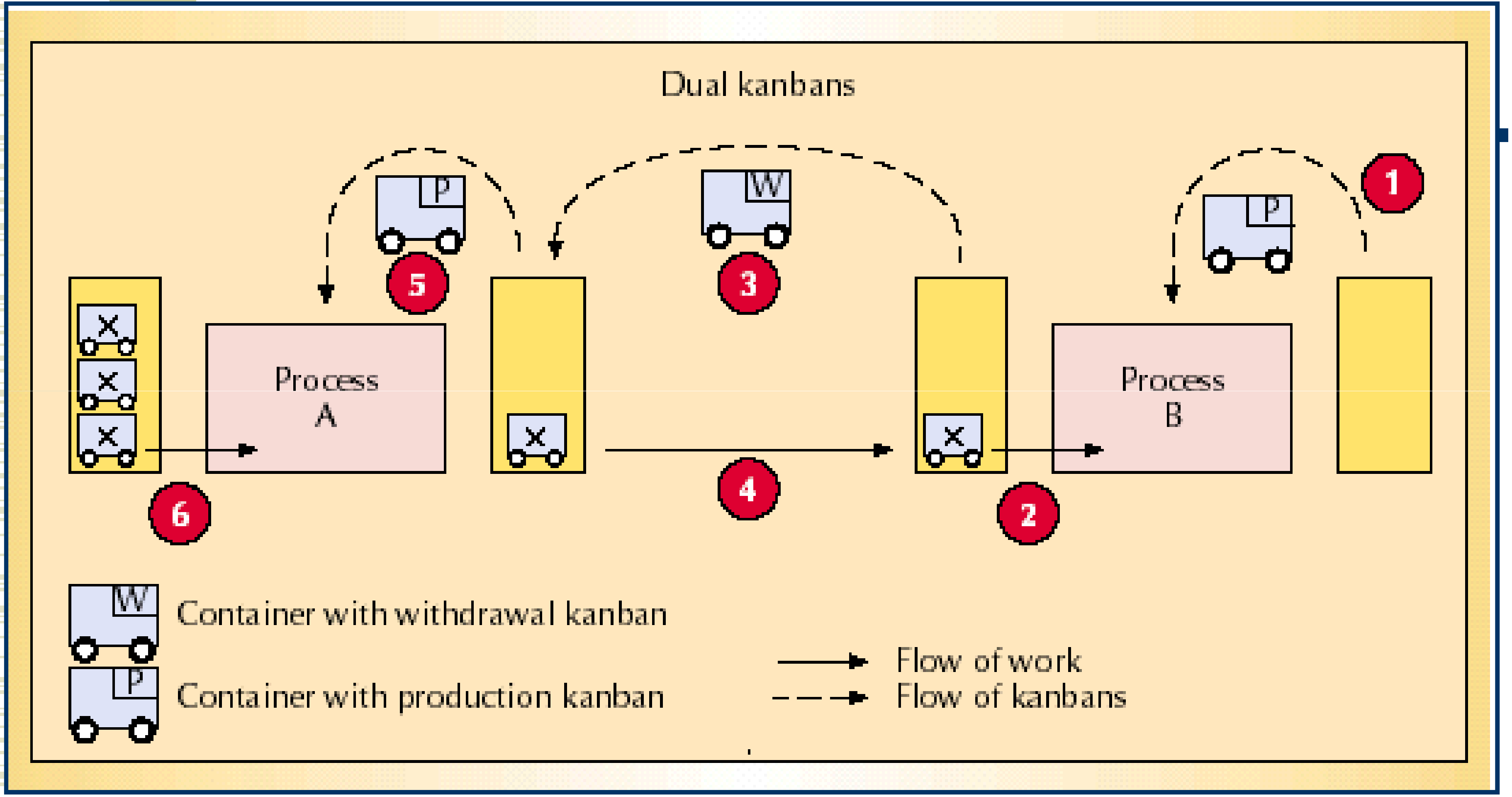
# Sample Kanban

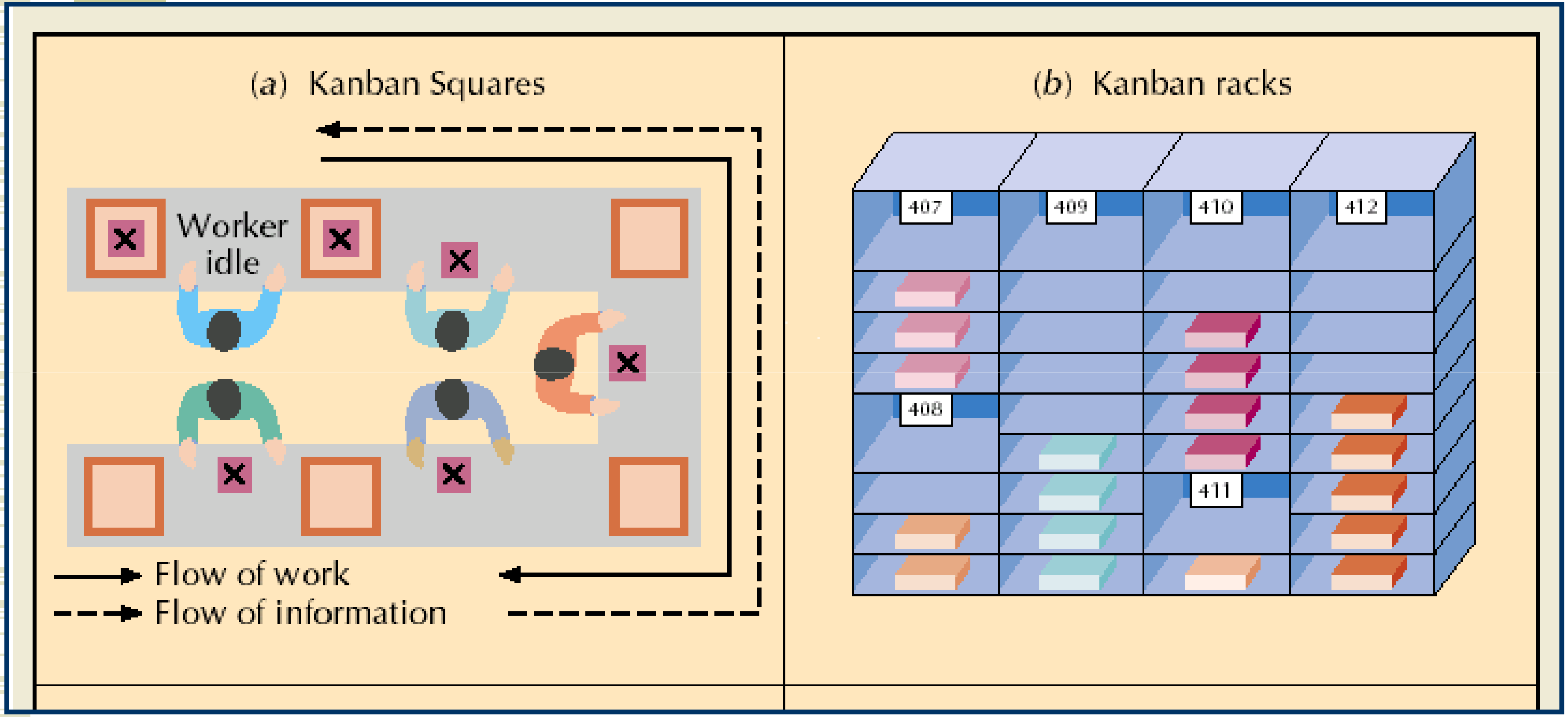
# Origin of Kanban

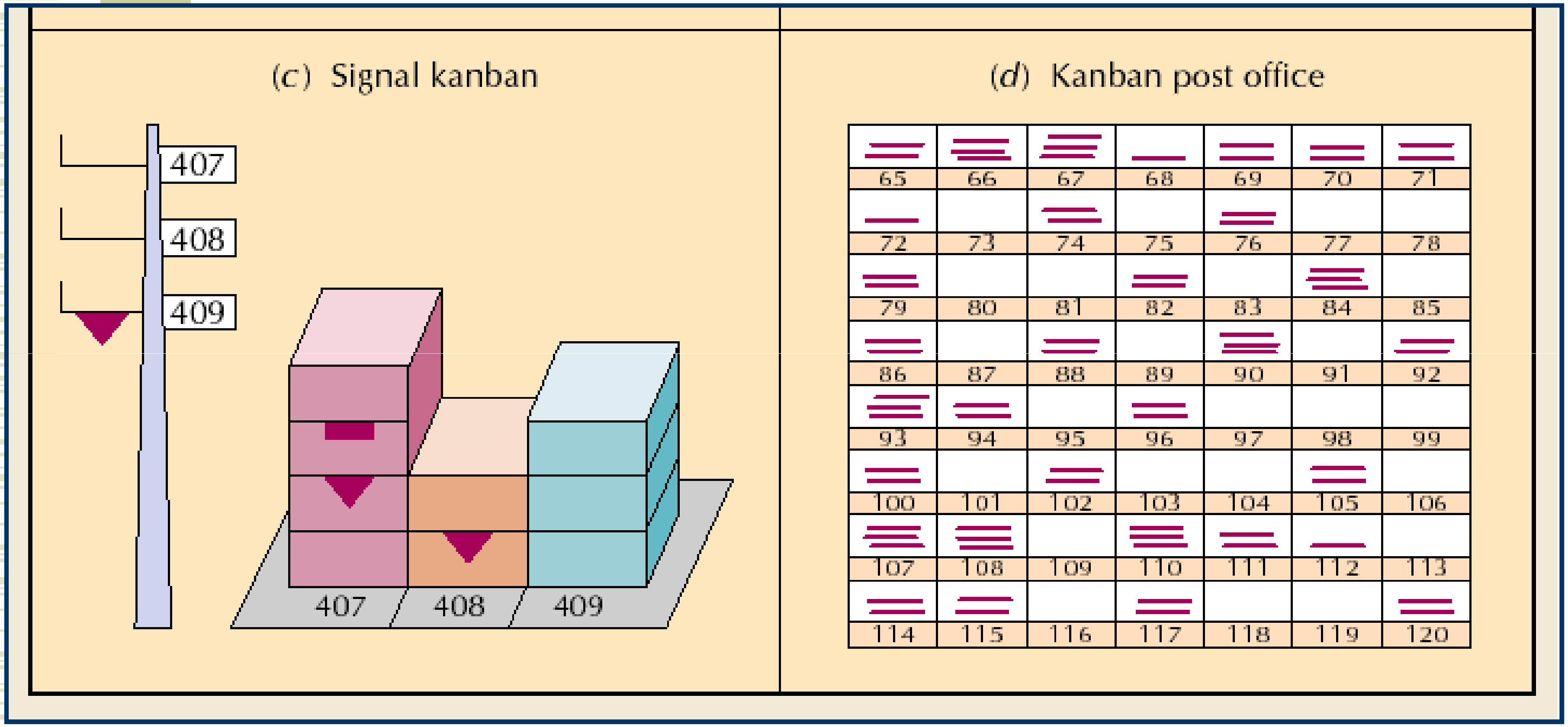


# Types of Kanban

- Production kanban
  - authorizes production of goods
- Withdrawal kanban
  - authorizes movement of goods
- Kanban square
  - a marked area designated to hold items
- Signal kanban
  - a triangular kanban used to signal production at the previous workstation
- Material kanban
  - used to order material in advance of a process
- Supplier kanban
  - rotates between the factory and suppliers


Dual kanbans
P
W
P
1
Process
A
Process
B
5
3
6
4
2
W
Container with withdrawal kanban
P
Container with production kanban
Flow of work
Flow of kanbans


(a) Kanban Squares
Worker idle
Flow of work
Flow of information
(b) Kanban racks
407
409
410
412
408
411


(c) Signal kanban
407
408
409
407
408
409
(d) Kanban post office
65 66 67 68 69 70 71
72 73 74 75 76 77 78
79 80 81 82 83 84 85
86 87 88 89 90 91 92
93 94 95 96 97 98 99
100 101 102 103 104 105 106
107 108 109 110 111 112 113
114 115 116 117 118 119 120

# Determining Number of Kanbans

$$\text{No. of Kanbans} = \frac{\text{average demand during lead time + safety stock}}{\text{container size}}$$

$$N = \frac{\bar{d}L + S}{C}$$

where

$N$ = number of kanbans or containers
$\bar{d}$ = average demand over some time period
$L$ = lead time to replenish an order
$S$ = safety stock
$C$ = container size

# Determining Number of Kanbans: Example

$\bar{d}$ = 150 bottles per hour

$L$ = 30 minutes = 0.5 hours

$S$ = 0.10(150 x 0.5) = 7.5

$C$ = 25 bottles

$$N = \frac{\bar{d}L + S}{C} = \frac{(150 \times 0.5) + 7.5}{25}$$

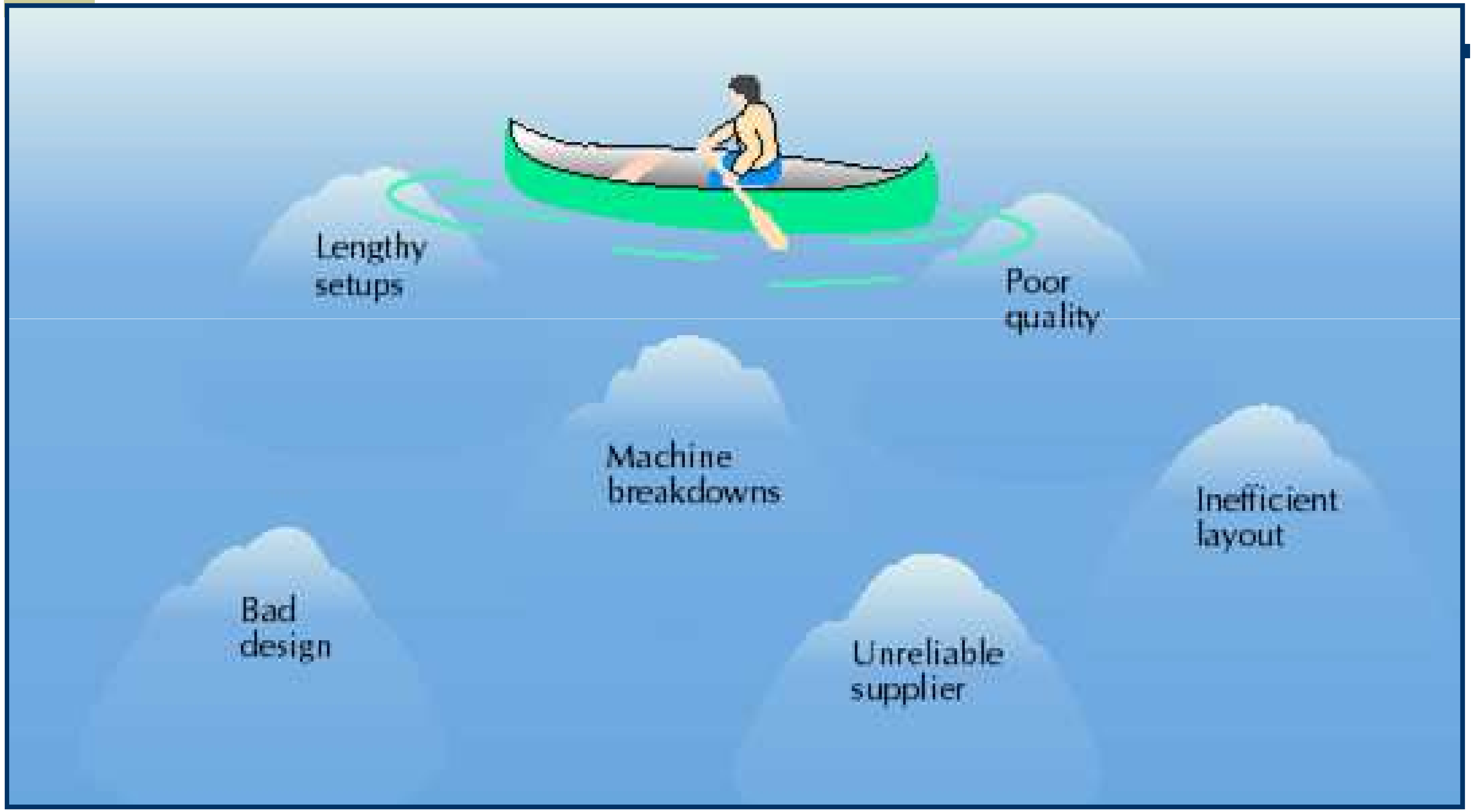
$$= \frac{75 + 7.5}{25} = 3.3 \text{ kanbans or containers}$$

Round up to 4 (to allow some slack) or down to 3 (to force improvement)

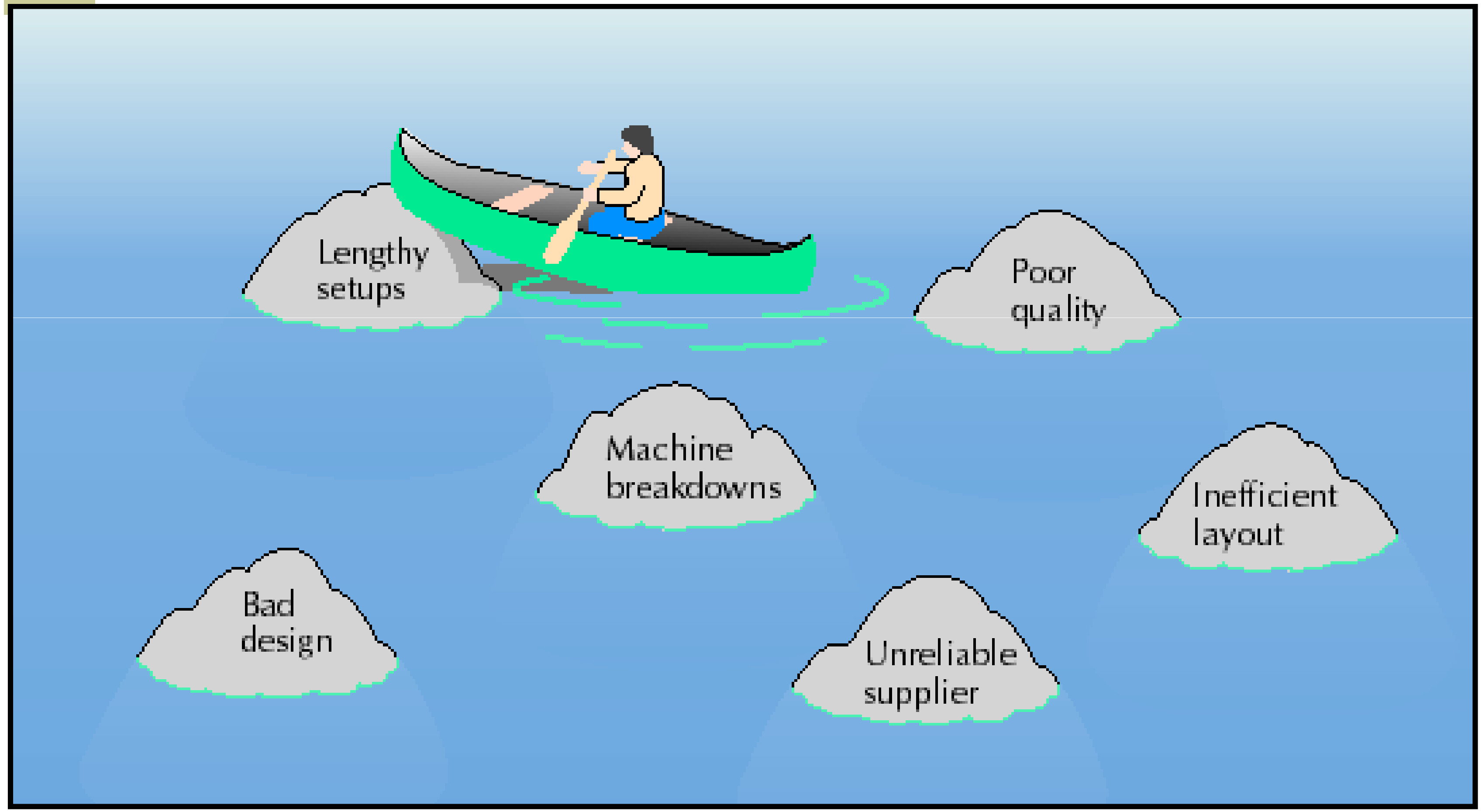
# Small Lots

- Require less space and capital investment
- Move processes closer together
- Make quality problems easier to detect
- Make processes more dependent on each other

# Inventory Hides Problems



## Less Inventory Exposes Problems



# Components of Lead Time

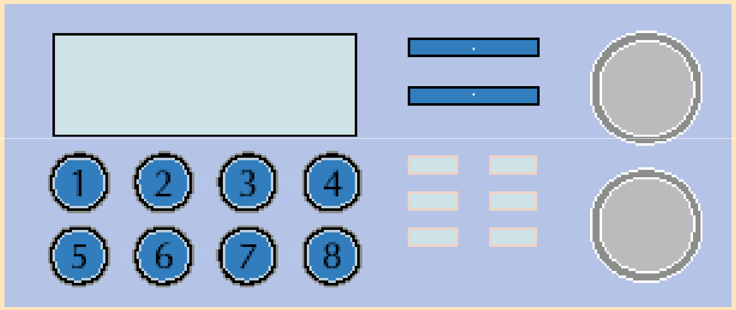
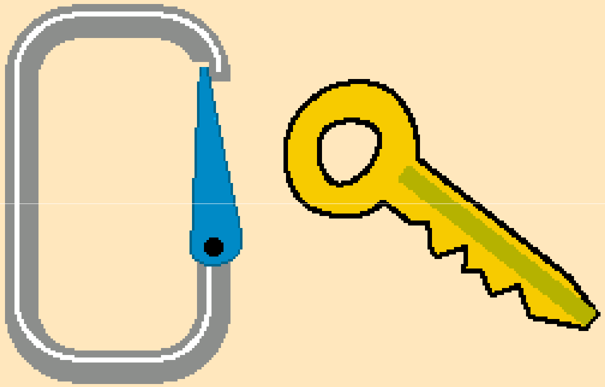
- Processing time
  - Reduce number of items or improve efficiency
- Move time
  - Reduce distances, simplify movements, standardize routings
- Waiting time
  - Better scheduling, sufficient capacity
- Setup time
  - Generally the biggest bottleneck

# Quick Setups

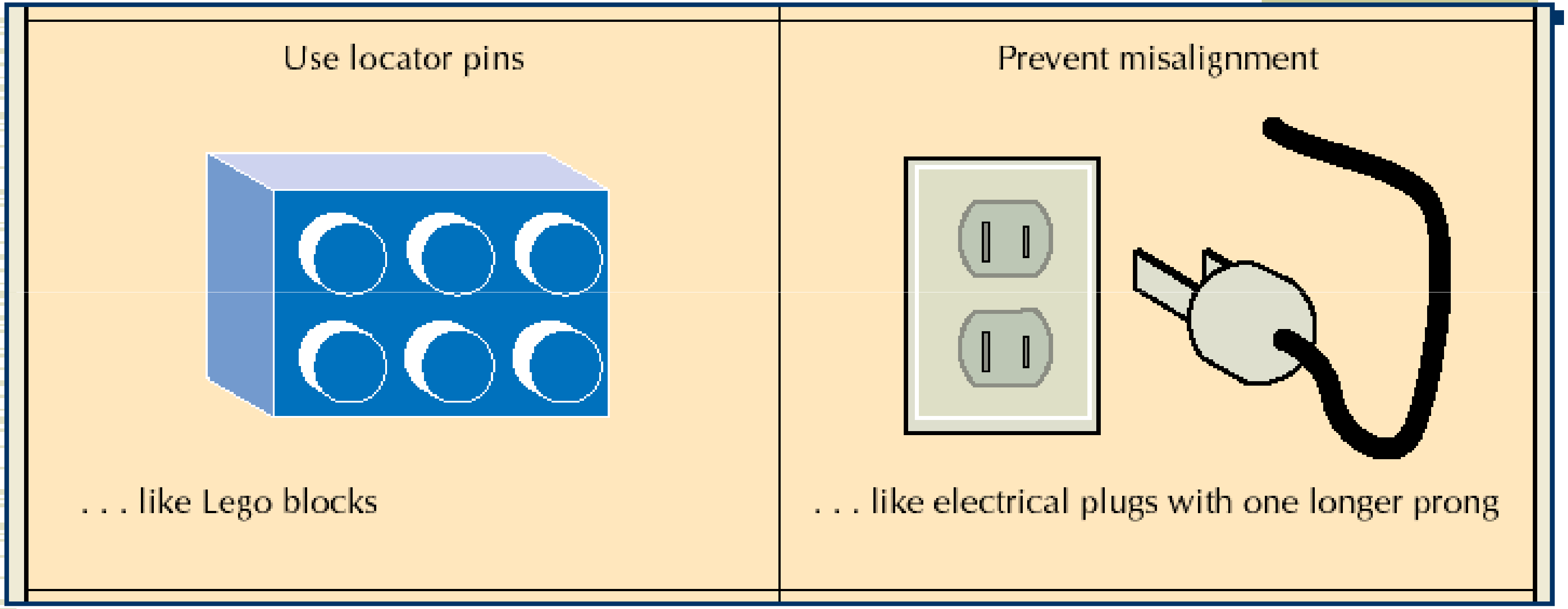
- Internal setup
  - Can be performed only when a process is stopped
- External setup
  - Can be performed in advance

- SMED Principles
  - Separate internal setup from external setup
  - Convert internal setup to external setup
  - Streamline all aspects of setup
  - Perform setup activities in parallel or eliminate them entirely

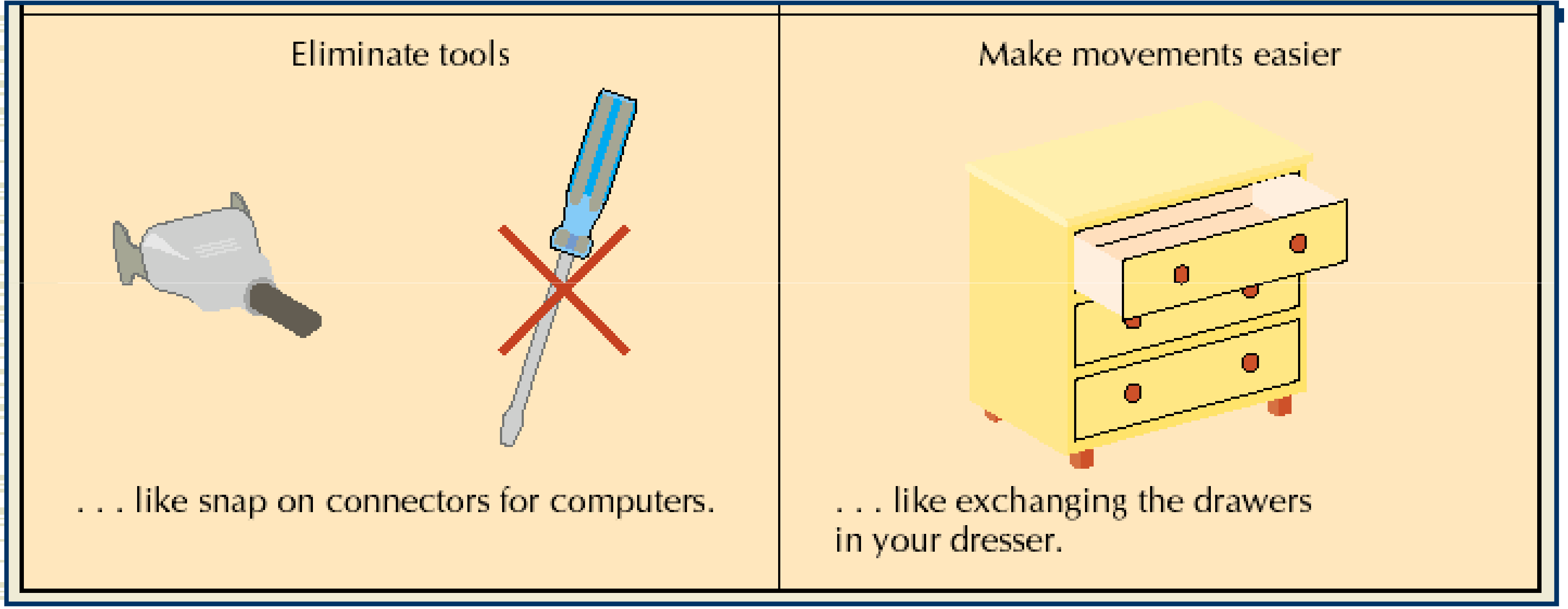
# Common Techniques for Reducing Setup Time

| Preset desired settings | Use quick fasteners |
| --- | --- |
|  |  |
| . . . like the stations on your car radio. | . . . like key rings that allow keys to be added easily. |

# Common Techniques for Reducing Setup Time (cont.)



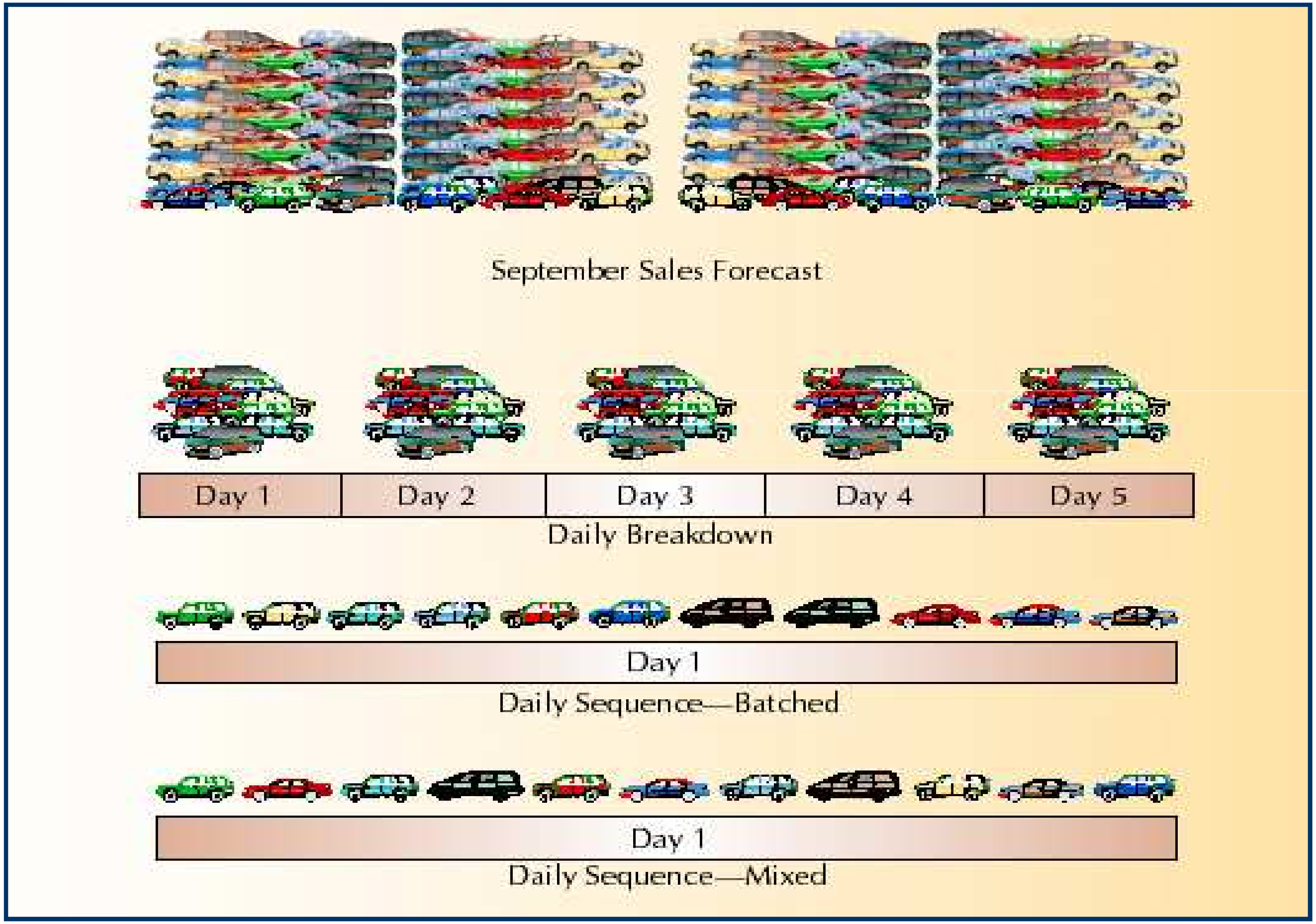
# Common Techniques for Reducing Setup Time (cont.)



# Uniform Production Levels

- Result from smoothing production requirements on final assembly line
- Kanban systems can handle +/- 10% demand changes
- Reduce variability with more accurate forecasts
- Smooth demand across planning horizon
- Mixed-model assembly steadies component production

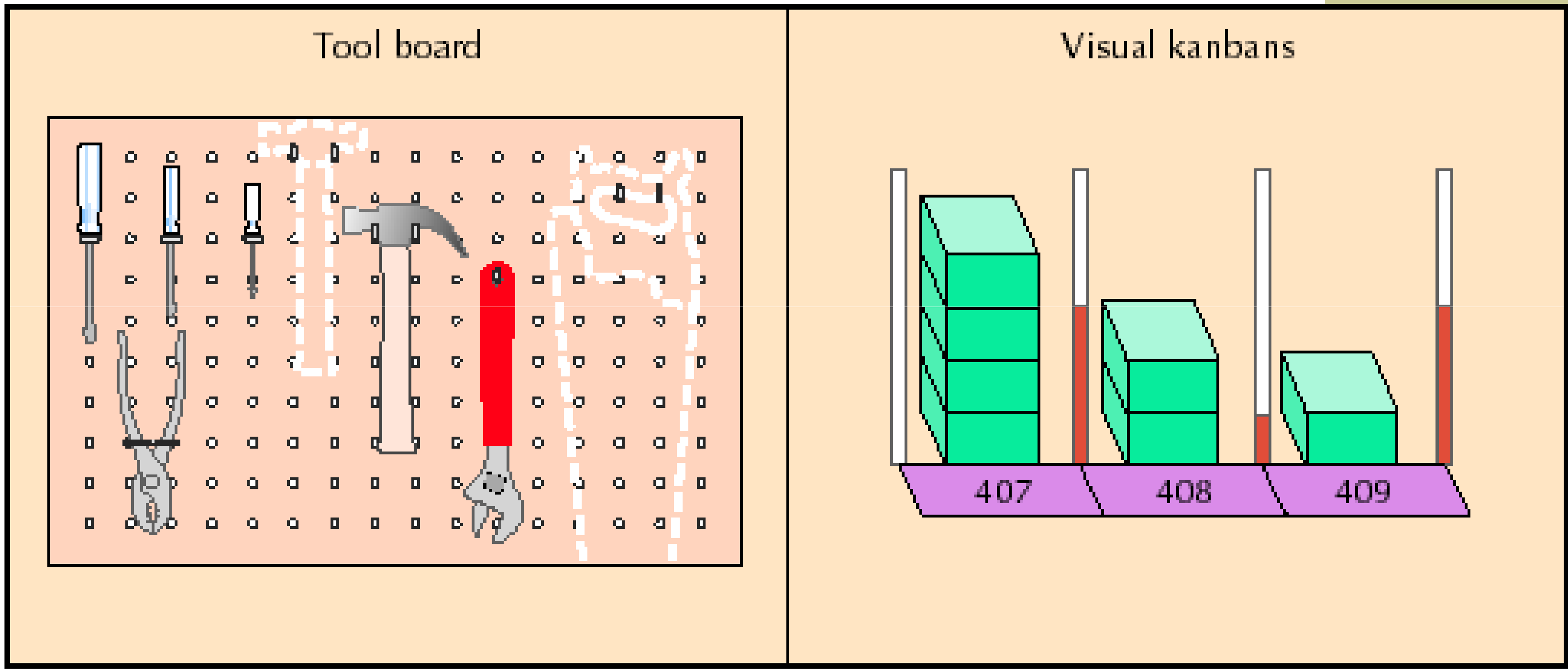
# Mixed-Model Sequencing



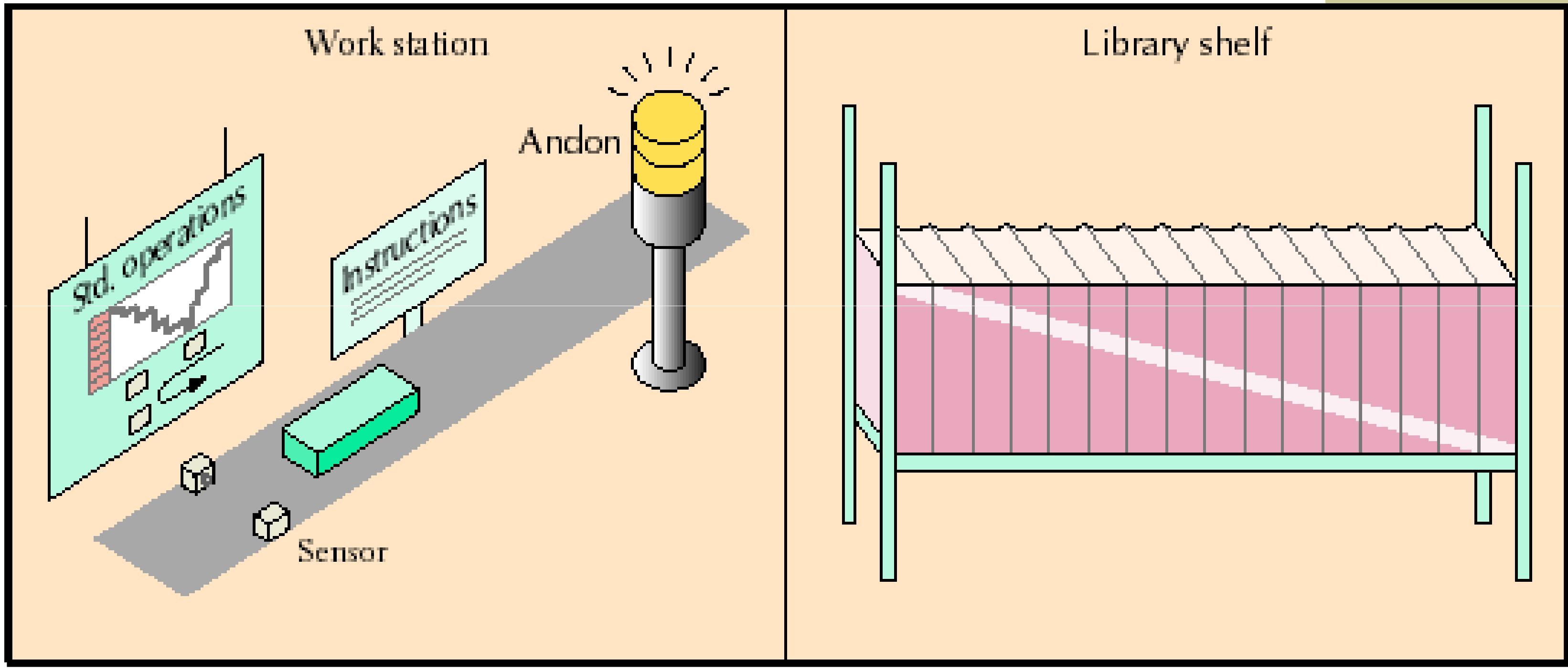
# Quality at the Source

- Visual control
  - makes problems visible
- Poka-yokes
  - prevent defects from occurring
- Kaizen
  - a system of continuous improvement; “change for the good of all”
- Jidoka
  - authority to stop the production line
- Andons
  - call lights that signal quality problems
- Under-capacity scheduling
  - leaves time for planning, problem solving, and maintenance

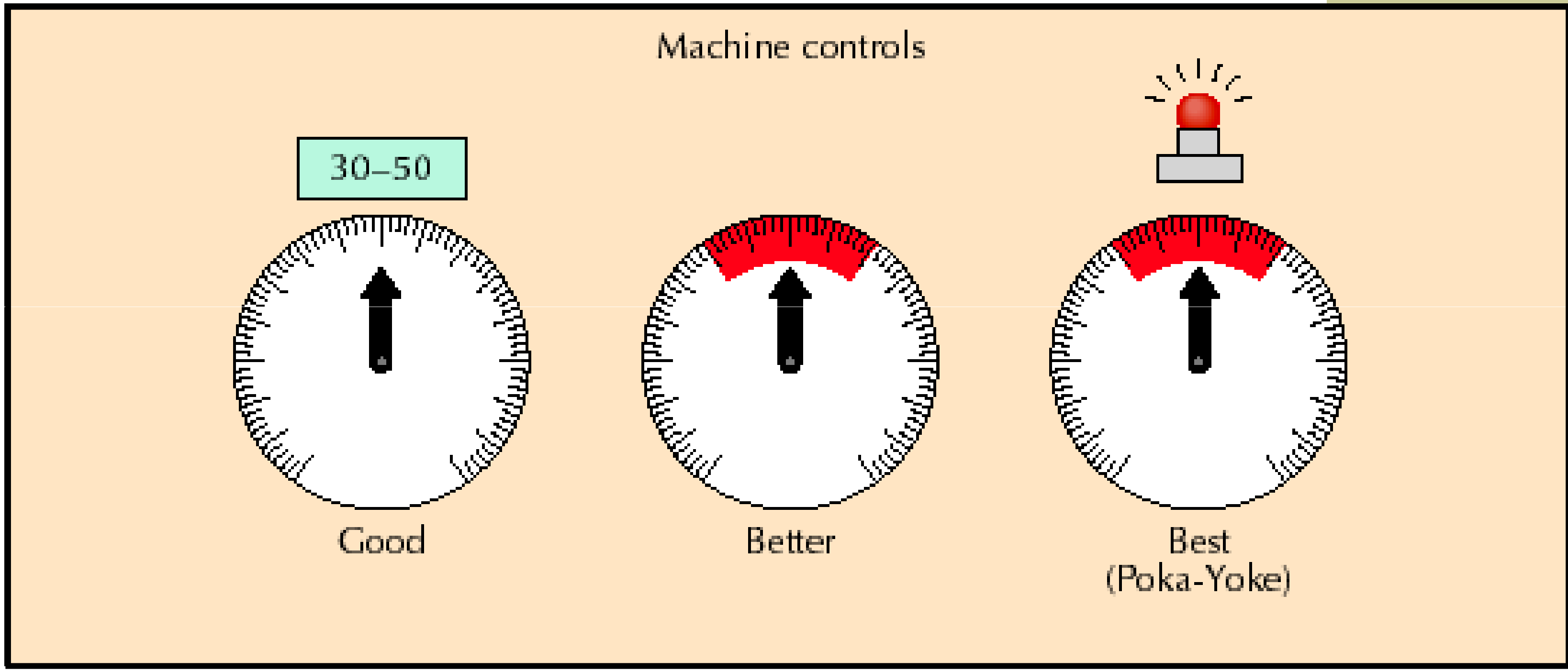
# Examples of Visual Control



# Examples of Visual Control (cont.)



# Examples of Visual Control (cont.)



# 5 Whys

- One of the keys to an effective Kaizen is finding the root cause of a problem and eliminating it
- A practice of asking “why?” repeatedly until the underlying cause is identified (usually requiring five questions)
- Simple, yet powerful technique for finding the root cause of a problem

# Total Productive Maintenance (TPM)

- Breakdown maintenance
  - Repairs to make failed machine operational
- Preventive maintenance
  - System of periodic inspection and maintenance to keep machines operating
- TPM combines preventive maintenance and total quality concepts

# TPM Requirements

- Design products that can be easily produced on existing machines
- Design machines for easier operation, changeover, maintenance
- Train and retrain workers to operate machines
- Purchase machines that maximize productive potential
- Design preventive maintenance plan spanning life of machine

| 5S Scan | Goal | Eliminate or Correct |
| --- | --- | --- |
| Seiri(*sort*) | Keep only what you need | Unneeded equipment, tools, furniture; unneeded items on walls, bulletins; items blocking aisles or stacked in corners; unneeded inventory, supplies, parts; safety hazards |
| Seiton(*set in order*) | A place for everything and everything in its place | Items not in their correct places; correct places not obvious; aisles, workstations, & equipment locations not indicated; items not put away immediately after use |
| Seisou (*shine*) | Cleaning, and looking for ways to keep clean and organized | Floors, walls, stairs, equipment, & surfaces not clean; cleaning materials not easily accessible; lines, labels, signs broken or unclean; other cleaning problems |
| Seiketsu (*standardize*) | Maintaining and monitoring the first three categories | Necessary information not visible; standards not known; checklists missing; quantities and limits not easily recognizable; items can't be located within 30 seconds |
| Shisuke (*sustain*) | Sticking to the rules | Number of workers without 5S training; number of daily 5S inspections not performed; number of personal items not stored; number of times job aids not available or up-to-date |

# Supplier Networks

- Long-term supplier contracts
- Synchronized production
- Supplier certification
- Mixed loads and frequent deliveries
- Precise delivery schedules
- Standardized, sequenced delivery
- Locating in close proximity to the customer

# Benefits of Lean Production

- Reduced inventory
- Improved quality
- Lower costs
- Reduced space requirements
- Shorter lead time
- Increased productivity

# Benefits of Lean Production (cont.)

- Greater flexibility
- Better relations with suppliers
- Simplified scheduling and control activities
- Increased capacity
- Better use of human resources
- More product variety

# Implementing Lean Production

- Use lean production to finely tune an operating system
- Somewhat different in USA than Japan
- Lean production is still evolving
- Lean production is not for everyone

# Lean Services

- Basic elements of lean production apply equally to services
- Most prevalent applications
  - lean retailing
  - lean banking
  - lean health care

# Leaning the Supply Chain

- "pulling" a smooth flow of material through a series of suppliers to support frequent replenishment orders and changes in customer demand
- Firms need to share information and coordinate demand forecasts, production planning, and inventory replenishment with suppliers and supplier's suppliers throughout supply chain

# Leaning the Supply Chain (cont.)

- Steps in Leaning the Supply Chain:
  - Build a highly collaborative business environment
  - Adopt the technology to support your system

# Lean Six Sigma

- Lean and Six Sigma are natural partners for process improvement
- Lean
  - Eliminates waste and creates flow
  - More continuous improvement
- Six Sigma
  - Reduces variability and enhances process capabilities
  - Requires breakthrough improvements

# Lean and the Environment

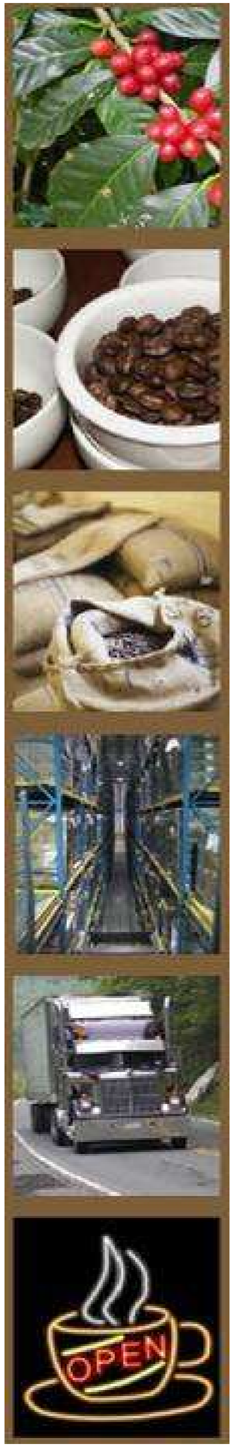
- Lean's mandate to eliminate waste and operate only with those resources that are absolutely necessary aligns well with environmental initiatives
- Environmental waste is often an indicator of poor process design and inefficient production

# EPA Recommendations

- Commit to eliminate environmental waste through lean implementation
- Recognize new improvement opportunities by incorporating environmental, heath and safety (EHS) icons and data into value stream maps
- Involve staff with EHS expertise in planning
- Find and drive out environmental wastes in specific process by using lean process-improvement tools
- Empower and enable workers to eliminate environmental wastes in their work areas

# Lean Consumption

- Consumptions process involves locating, buying, installing, using, maintaining, repairing, and recycling.
- Lean Consumption seeks to:
  - Provide customers what they want, where and when they want it
  - Resolve customer problems quickly and completely
  - Reduce the number of problems customers need to solve



# Chapter 17

## *Scheduling*

***Operations Management***

**Roberta Russell & Bernard W. Taylor, III**

# Lecture Outline

- Objectives in Scheduling
- Loading
- Sequencing
- Monitoring
- Advanced Planning and Scheduling Systems
- Theory of Constraints
- Employee Scheduling

# What is Scheduling?

- Last stage of planning before production occurs
- Specifies when labor, equipment, and facilities are needed to produce a product or provide a service

# Scheduled Operations

- Process Industry
  - Linear programming
  - EOQ with non-instantaneous replenishment
- Mass Production
  - Assembly line balancing
- Project
  - Project -scheduling techniques (PERT, CPM)
- Batch Production
  - Aggregate planning
  - Master scheduling
  - Material requirements planning (MRP)
  - Capacity requirements planning (CRP)

# Objectives in Scheduling

- Meet customer due dates
- Minimize job lateness
- Minimize response time
- Minimize completion time
- Minimize time in the system
- Minimize overtime
- Maximize machine or labor utilization
- Minimize idle time
- Minimize work-in-process inventory

# Shop Floor Control (SFC)

- scheduling and monitoring of day-to-day production in a job shop
- also called *production control* and *production activity control* (PAC)
- usually performed by production control department
  - Loading
    - Check availability of material, machines, and labor
  - Sequencing
    - Release work orders to shop and issue dispatch lists for individual machines
  - Monitoring
    - Maintain progress reports on each job until it is complete

# Loading

- Process of assigning work to limited resources
- Perform work with most efficient resources
- Use assignment method of linear programming to determine allocation

# Assignment Method

1. Perform row reductions
   - subtract minimum value in each row from all other row values
2. Perform column reductions
   - subtract minimum value in each column from all other column values
3. Cross out all zeros in matrix
   - use minimum number of horizontal and vertical lines
4. If number of lines equals number of rows in matrix, then optimum solution has been found. Make assignments where zeros appear
   - Else modify matrix
     - subtract minimum uncrossed value from all uncrossed values
     - add it to all cells where two lines intersect
     - other values in matrix remain unchanged
5. Repeat steps 3 and 4 until optimum solution is reached

# Assignment Method: Example

| Initial Matrix | PROJECT *1* | *2* | *3* | *4* |
|---|---|---|---|---|
| Bryan | 10 | 5 | 6 | 10 |
| Kari | 6 | 2 | 4 | 6 |
| Noah | 7 | 6 | 5 | 6 |
| Chris | 9 | 5 | 4 | 10 |

Row reduction

| | | | |
|---|---|---|---|
| 5 | 0 | 1 | 5 |
| 4 | 0 | 2 | 4 |
| 2 | 1 | 0 | 1 |
| 5 | 1 | 0 | 6 |

Column reduction

| | | | |
|---|---|---|---|
| 3 | 0 | 1 | 4 |
| 2 | 0 | 2 | 3 |
| 0 | 1 | 0 | 0 |
| 3 | 1 | 0 | 5 |

Cover all zeros

| | | | |
|---|---|---|---|
| 3 | 0 | 1 | 4 |
| 2 | 0 | 2 | 3 |
| 0 | 1 | 0 | 0 |
| 3 | 1 | 0 | 5 |

Number lines ≠ number of rows so modify matrix

# Assignment Method: Example (cont.)

**Modify matrix**

| | | | |
|---|---|---|---|
| 1 | 0 | 1 | 2 |
| 0 | 0 | 2 | 1 |
| 0 | 3 | 2 | 0 |
| 1 | 1 | 0 | 3 |

**Cover all zeros**

| | | | |
|---|---|---|---|
| 1 | 0 | 1 | 2 |
| 0 | 0 | 2 | 1 |
| 0 | 3 | 2 | 0 |
| 1 | 1 | 0 | 3 |

Number of lines = number of rows so at optimal solution

| | PROJECT | | | |
|---|---|---|---|---|
| | *1* | *2* | *3* | *4* |
| Bryan | 1 | 0 | 1 | 2 |
| Kari | 0 | 0 | 2 | 1 |
| Noah | 0 | 3 | 2 | 0 |
| Chris | 1 | 1 | 0 | 3 |

| | PROJECT | | | |
|---|---|---|---|---|
| | *1* | *2* | *3* | *4* |
| Bryan | 10 | 5 | 6 | 10 |
| Kari | 6 | 2 | 4 | 6 |
| Noah | 7 | 6 | 5 | 6 |
| Chris | 9 | 5 | 4 | 10 |

Project Cost = (5 + 6 + 4 + 6) X \$100 = \$2,100

# Sequencing

Prioritize jobs assigned to a resource

If no order specified use first-come first-served (FCFS)

Other Sequencing Rules

FCFS - first-come, first-served

LCFS - last come, first served

DDATE - earliest due date

CUSTPR - highest customer priority

SETUP - similar required setups

SLACK - smallest slack

CR - smallest critical ratio

SPT - shortest processing time

LPT - longest processing time

# Minimum Slack and Smallest Critical Ratio

SLACK considers both work and time remaining

SLACK = (due date – today's date) – (processing time)

CR recalculates sequence as processing continues and arranges information in ratio form

$$CR = \frac{\text{time remaining}}{\text{work remaining}} = \frac{\text{due date - today's date}}{\text{remaining processing time}}$$

If CR > 1, job ahead of schedule

If CR < 1, job behind schedule

If CR = 1, job on schedule

# Sequencing Jobs through One Process

- Flow time (completion time)
  - Time for a job to flow through system
- Makespan
  - Time for a group of jobs to be completed
- Tardiness
  - Difference between a late job's due date and its completion time

# Simple Sequencing Rules

| JOB | PROCESSING TIME | DUE DATE |
|---|---|---|
| A | 5 | 10 |
| B | 10 | 15 |
| C | 2 | 5 |
| D | 8 | 12 |
| E | 6 | 8 |

# Simple Sequencing Rules: FCFS

| FCFS SEQUENCE | START TIME | PROCESSING TIME | COMPLETION TIME | DUE DATE | TARDINESS |
|---|---|---|---|---|---|
| A | 0 | 5 | 5 | 10 | 0 |
| B | 5 | 10 | 15 | 15 | 0 |
| C | 15 | 2 | 17 | 5 | 12 |
| D | 17 | 8 | 25 | 12 | 13 |
| E | 25 | 6 | 31 | 8 | 23 |
| Total | | | 93 | | 48 |
| Average | | | 93/5 = 18.60 | | 48/5 = 9.6 |

# Simple Sequencing Rules: DDATE

| DDATE SEQUENCE | START TIME | PROCESSING TIME | COMPLETION TIME | DUE DATE | TARDINESS |
|---|---|---|---|---|---|
| C | 0 | 2 | 2 | 5 | 0 |
| E | 2 | 6 | 8 | 8 | 0 |
| A | 8 | 5 | 13 | 10 | 3 |
| D | 13 | 8 | 21 | 12 | 9 |
| B | 21 | 10 | 31 | 15 | 16 |
| Total | | | 75 | | 28 |
| Average | | | 75/5 = 15.00 | | 28/5 = 5.6 |

# Simple Sequencing Rules: SLACK

A(10-0) – 5 = 5
B(15-0) – 10 = 5
C(5-0) – 2 = 3
D(12-0) – 8 = 4
E(8-0) – 6 = 2

| SEQUENCE | SLACK TIME | START TIME | PROCESSING TIME | COMPLETION DATE | DUE TARDINESS |
|---|---|---|---|---|---|
| E | 0 | 6 | 6 | 8 | 0 |
| C | 6 | 2 | 8 | 5 | 3 |
| D | 8 | 8 | 16 | 12 | 4 |
| A | 16 | 5 | 21 | 10 | 11 |
| B | 21 | 10 | 31 | 15 | 16 |
| Total | | | 82 | | 34 |
| Average | | | 82/5 = 16.40 | | 34/5 = 6.8 |

# Simple Sequencing Rules: SPT

| SEQUENCE | SPT START TIME | PROCESSING TIME | COMPLETION TIME | DUE DATE | TARDINESS |
|---|---|---|---|---|---|
| C | 0 | 2 | 2 | 5 | 0 |
| A | 2 | 5 | 7 | 10 | 0 |
| E | 7 | 6 | 13 | 8 | 5 |
| D | 13 | 8 | 21 | 12 | 9 |
| B | 21 | 10 | 31 | 15 | 16 |
| Total | | | 74 | | 30 |
| Average | | | 74/5 = 14.80 | | 30/5 = 6 |

# Simple Sequencing Rules: Summary

| RULE | AVERAGE COMPLETION TIME | AVERAGE TARDINESS | NO. OF JOBS TARDY | MAXIMUM TARDINESS |
|---|---|---|---|---|
| FCFS | 18.60 | 9.6 | 3 | 23 |
| DDATE | 15.00 | 5.6 | 3 | 16 |
| SLACK | 16.40 | 6.8 | 4 | 16 |
| SPT | 14.80 | 6.0 | 3 | 16 |

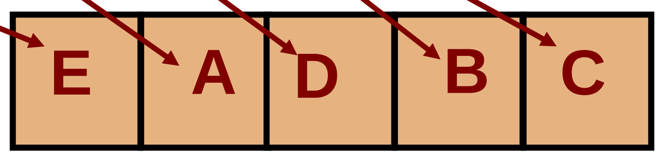
# Sequencing Jobs Through Two Serial Process

## Johnson's Rule

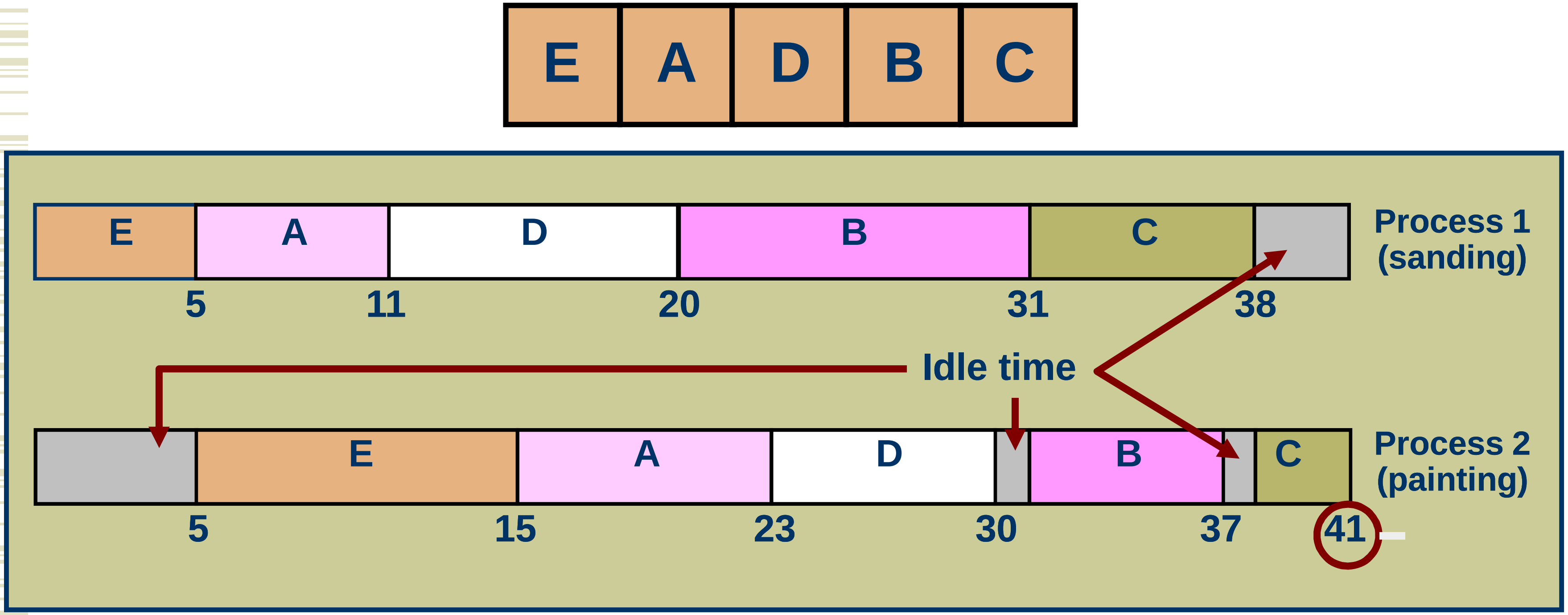
1. List time required to process each job at each machine. Set up a one-dimensional matrix to represent desired sequence with # of slots equal to # of jobs.
2. Select smallest processing time at either machine. If that time is on machine 1, put the job as near to beginning of sequence as possible.
3. If smallest time occurs on machine 2, put the job as near to the end of the sequence as possible.
4. Remove job from list.
5. Repeat steps 2-4 until all slots in matrix are filled and all jobs are sequenced.

# Johnson's Rule

| JOB | PROCESS 1 | PROCESS 2 |
|---|---|---|
| A | 6 | 8 |
| B | 11 | 6 |
| C | 7 | 3 |
| D | 9 | 7 |
| E | 5 | 10 |



# Johnson's Rule (cont.)




Completion time = 41
Idle time = 5+1+1+3=10

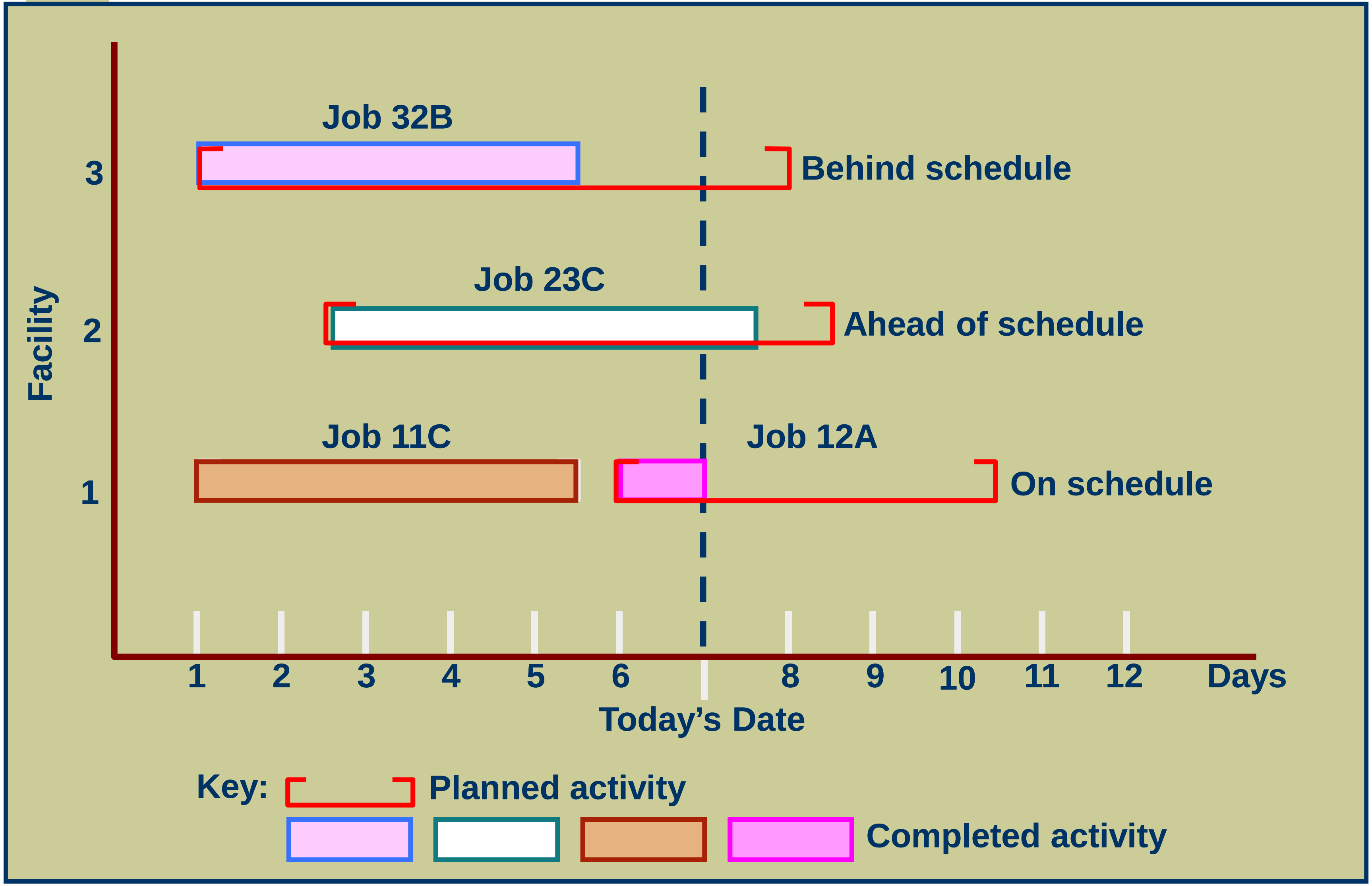
# Guidelines for Selecting a Sequencing Rule

1. SPT most useful when shop is highly congested
2. Use SLACK for periods of normal activity
3. Use DDATE when only small tardiness values can be tolerated
4. Use LPT if subcontracting is anticipated
5. Use FCFS when operating at low-capacity levels
6. Do not use SPT to sequence jobs that have to be assembled with other jobs at a later date

# Monitoring

- Work package
  - Shop paperwork that travels with a job
- Gantt Chart
  - Shows both planned and completed activities against a time scale
- Input/Output Control
  - Monitors the input and output from each work center

# Gantt Chart



Job 32B
Behind schedule
Job 23C
Ahead of schedule
Job 11C
Job 12A
On schedule
Facility
3
2
1
1
2
3
4
5
6
8
9
10
11
12
Days
Today's Date
Key:
Planned activity
Completed activity

# Input/Output Control

Input/Output Report

| PERIOD | 1 | 2 | 3 | 4 | TOTAL |
|---|---|---|---|---|---|
| Planned input | 65 | 65 | 70 | 70 | 270 |
| Actual input | | | | | 0 |
| Deviation | | | | | 0 |
| Planned output | 75 | 75 | 75 | 75 | 300 |
| Actual output | | | | | 0 |
| Deviation | | | | | 0 |
| Backlog | 30 | | | | |
| | 20 | 10 | 5 | 0 | |

# Input/Output Control (cont.)

Input/Output Report

| PERIOD | 1 | 2 | 3 | 4 | TOTAL |
|---|---|---|---|---|---|
| Planned input | 65 | 65 | 70 | 70 | 270 |
| Actual input | 60 | 60 | 65 | 65 | 250 |
| Deviation | -5 | -5 | -5 | -5 | -20 |
| Planned output | 75 | 75 | 75 | 75 | 300 |
| Actual output | 75 | 75 | 65 | 65 | 280 |
| Deviation | -0 | -0 | -10 | -10 | -20 |
| Backlog | 30 | 15 | 0 | 0 | 0 |

# Advanced Planning and Scheduling Systems

- Infinite - assumes infinite capacity
  - Loads without regard to capacity
  - Then levels the load and sequences jobs
- Finite - assumes finite (limited) capacity
  - Sequences jobs as part of the loading decision
  - Resources are never loaded beyond capacity

# Advanced Planning and Scheduling Systems (cont.)

- Advanced planning and scheduling (APS)
  - Add-ins to ERP systems
  - Constraint-based programming (CBP) identifies a solution space and evaluates alternatives
  - Genetic algorithms based on natural selection properties of genetics
  - Manufacturing execution system (MES) monitors status, usage, availability, quality

# Theory of Constraints

- Not all resources are used evenly
- Concentrate on the” bottleneck” resource
- Synchronize flow through the bottleneck
- Use process and transfer batch sizes to move product through facility

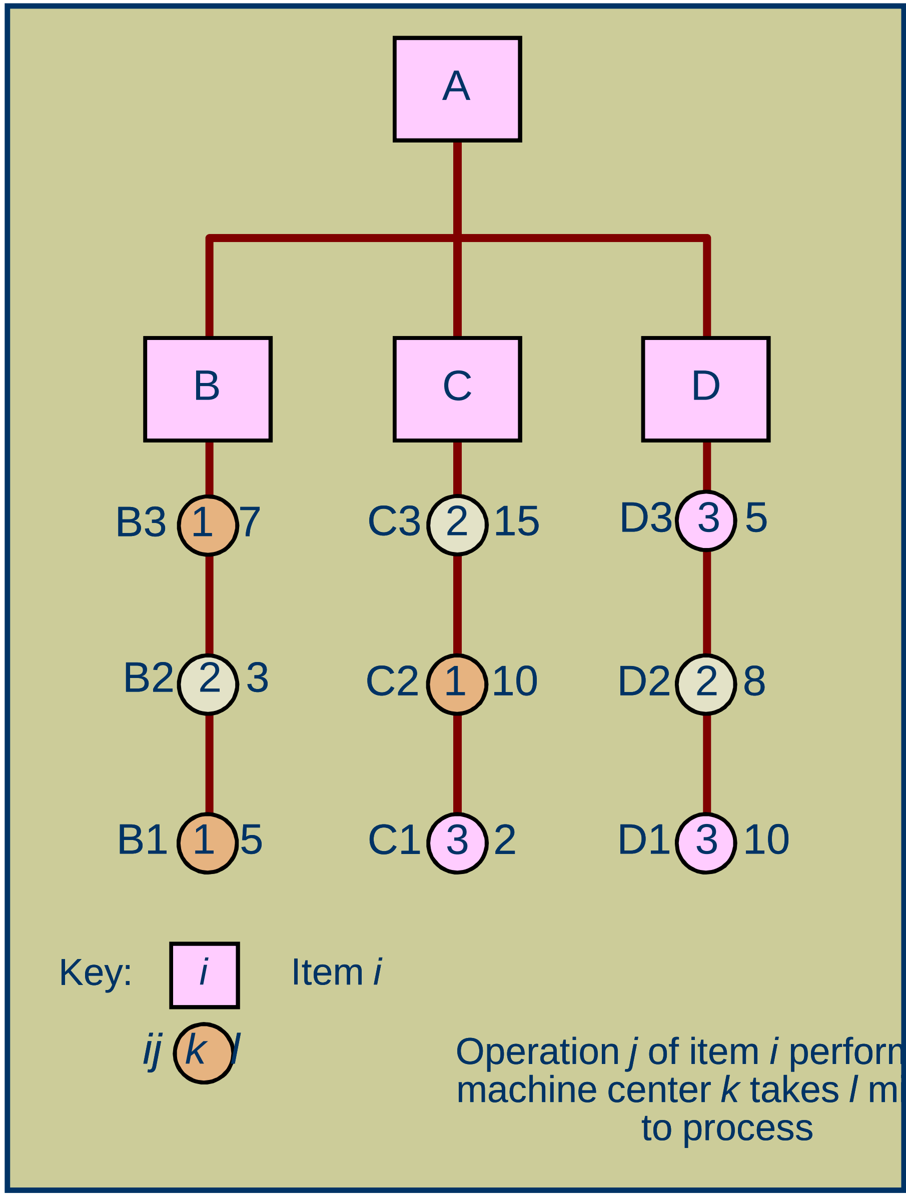
# Drum-Buffer-Rope

- Drum
  - Bottleneck, beating to set the pace of production for the rest of the system
- Buffer
  - Inventory placed in front of the bottleneck to ensure it is always kept busy
  - Determines output or throughput of the system
- Rope
  - Communication signal; tells processes upstream when they should begin production

# TOC Scheduling Procedure

- Identify bottleneck
- Schedule job first whose lead time to bottleneck is less than or equal to bottleneck processing time
- Forward schedule bottleneck machine
- Backward schedule other machines to sustain bottleneck schedule
- Transfer in batch sizes smaller than process batch size

# Synchronous Manufacturing



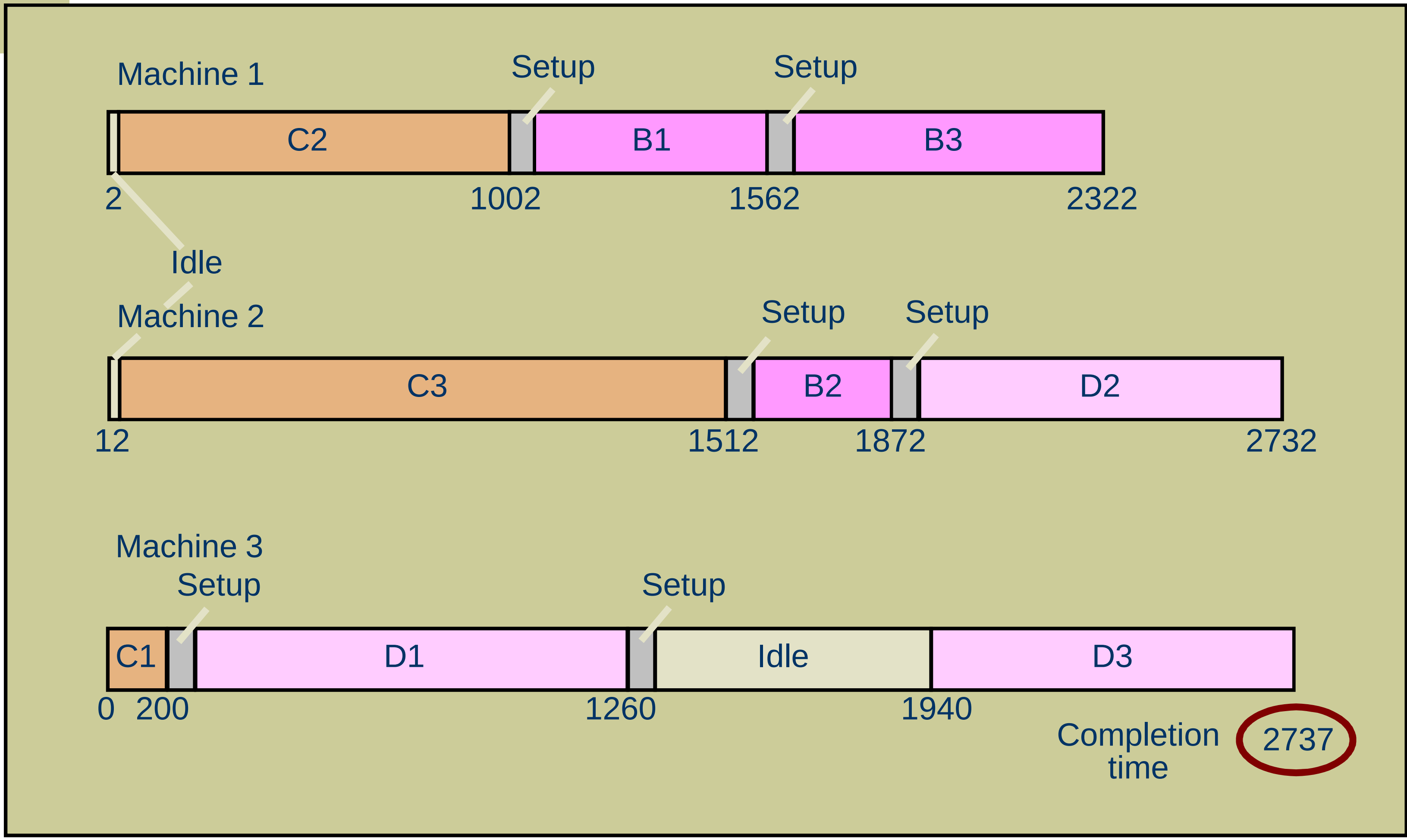
# Synchronous Manufacturing (cont.)

Demand = 100 A's
Machine setup time = 60 minutes

| MACHINE 1 | | MACHINE 2 | | MACHINE 3 | |
|---|---|---|---|---|---|
| B1 | 5 | B2 | 3 | C1 | 2 |
| B3 | 7 | C3 | 15 | D3 | 5 |
| C2 | 10 | D2 | 8 | D1 | 10 |
| Sum | 22 | | 26* | | 17 |

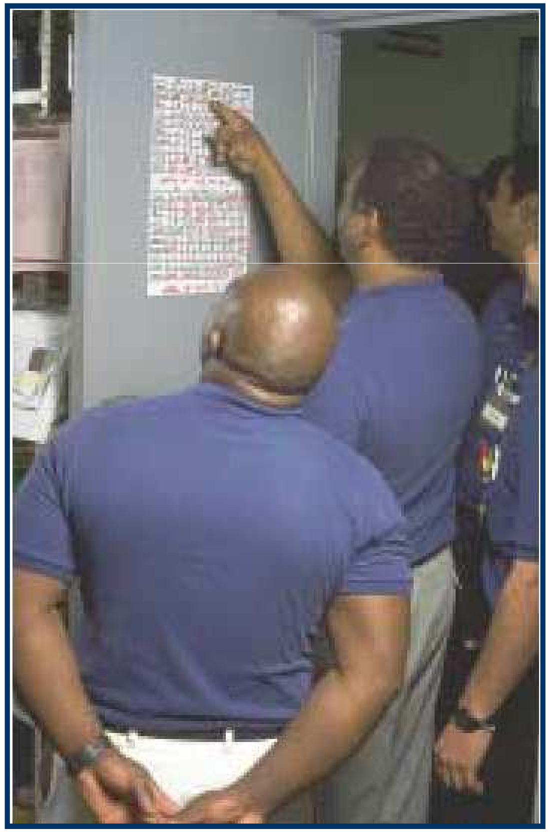
* Bottleneck

# Synchronous Manufacturing (cont.)



# Employee Scheduling

- Labor is very flexible resource
- Scheduling workforce is complicated, repetitive task
- Assignment method can be used
- Heuristics are commonly used



# Employee Scheduling Heuristic

1. Let $N$ = no. of workers available
   $D_i$ = demand for workers on day i
   X = day working
   O = day off
2. Assign the first $N - D_1$ workers day 1 off. Assign the next $N - D_2$ workers day 2 off. Continue in a similar manner until all days are have been scheduled
3. If number of workdays for full time employee < 5, assign remaining workdays so consecutive days off are possible
4. Assign any remaining work to part-time employees
5. If consecutive days off are desired, consider switching schedules among days with the same demand requirements

# Employee Scheduling

| DAY OF WEEK | M | T | W | TH | F | SA | SU |
|---|---|---|---|---|---|---|---|
| MIN NO. OF WORKERS REQUIRED | 3 | 3 | 4 | 3 | 4 | 5 | 3 |
| Taylor | | | | | | | |
| Smith | | | | | | | |
| Simpson | | | | | | | |
| Allen | | | | | | | |
| Dickerson | | | | | | | |

# Employee Scheduling (cont.)

| DAY OF WEEK | M | T | W | TH | F | SA | SU |
|---|---|---|---|---|---|---|---|
| MIN NO. OF WORKERS REQUIRED | 3 | 3 | 4 | 3 | 4 | 5 | 3 |
| Taylor | O | X | X | O | X | X | X |
| Smith | O | X | X | O | X | X | X |
| Simpson | X | O | X | X | O | X | X |
| Allen | X | O | X | X | X | X | O |
| Dickerson | X | X | O | X | X | X | O |

Completed schedule satisfies requirements but has no consecutive days off

# Employee Scheduling (cont.)

| DAY OF WEEK | M | T | W | TH | F | SA | SU |
|---|---|---|---|---|---|---|---|
| MIN NO. OF WORKERS REQUIRED | 3 | 3 | 4 | 3 | 4 | 5 | 3 |
| Taylor | O | O | X | X | X | X | X |
| Smith | O | O | X | X | X | X | X |
| Simpson | X | X | O | O | X | X | X |
| Allen | X | X | X | O | X | X | O |
| Dickerson | X | X | X | X | O | X | O |

Revised schedule satisfies requirements with consecutive days off for most employees

# Automated Scheduling Systems

- Staff Scheduling
- Schedule Bidding
- Schedule Optimization

# Thank You

www.bookfiesta4u.com