سلايدات:

تخطيط وضبط انتاج

PPC

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اللجنة الأكاديمية لقسم الهندسة الصناعية

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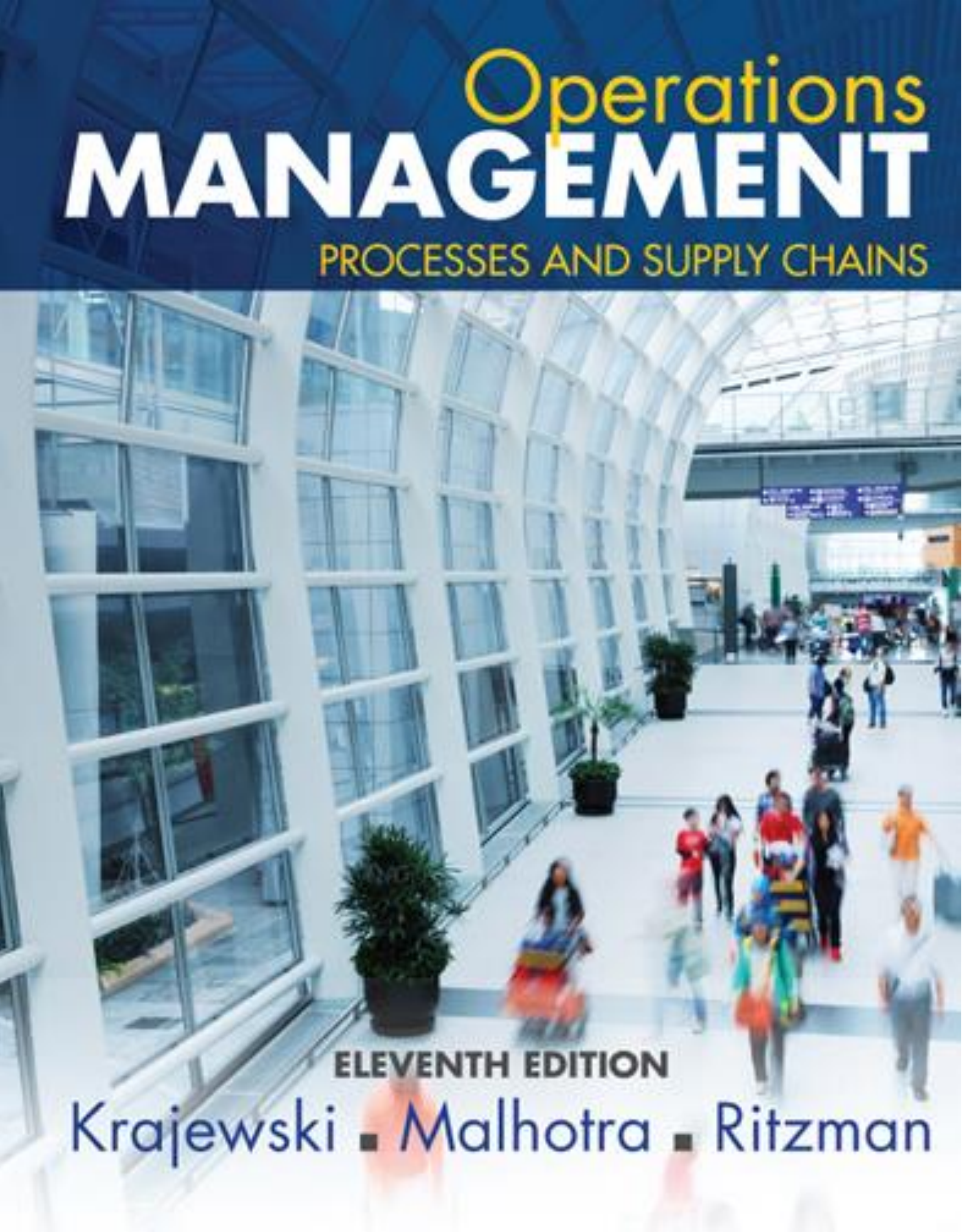


Using Operations to Create Value

Chapter 1

What is Operations Management?

Operations Management

The systematic design, direction, and control of processes that transform inputs into services and products for internal, as well as external, customers

- Process: Any activity or group of activities that takes one or more inputs, transforms them, and provides one or more outputs for its customers
- Operation :A group of resources performing all or part of one or more processes

What is Supply Chain Management?

Supply Chain Management

The synchronization of a firm's processes with those of its suppliers and customers to match the flow of materials, services, and information with customer demand

Supply Chain

An interrelated series of processes within and across firms the produces a service or product to the satisfaction of customers

Role of Operations in an Organization

Integration between Different Functional Areas of a Business

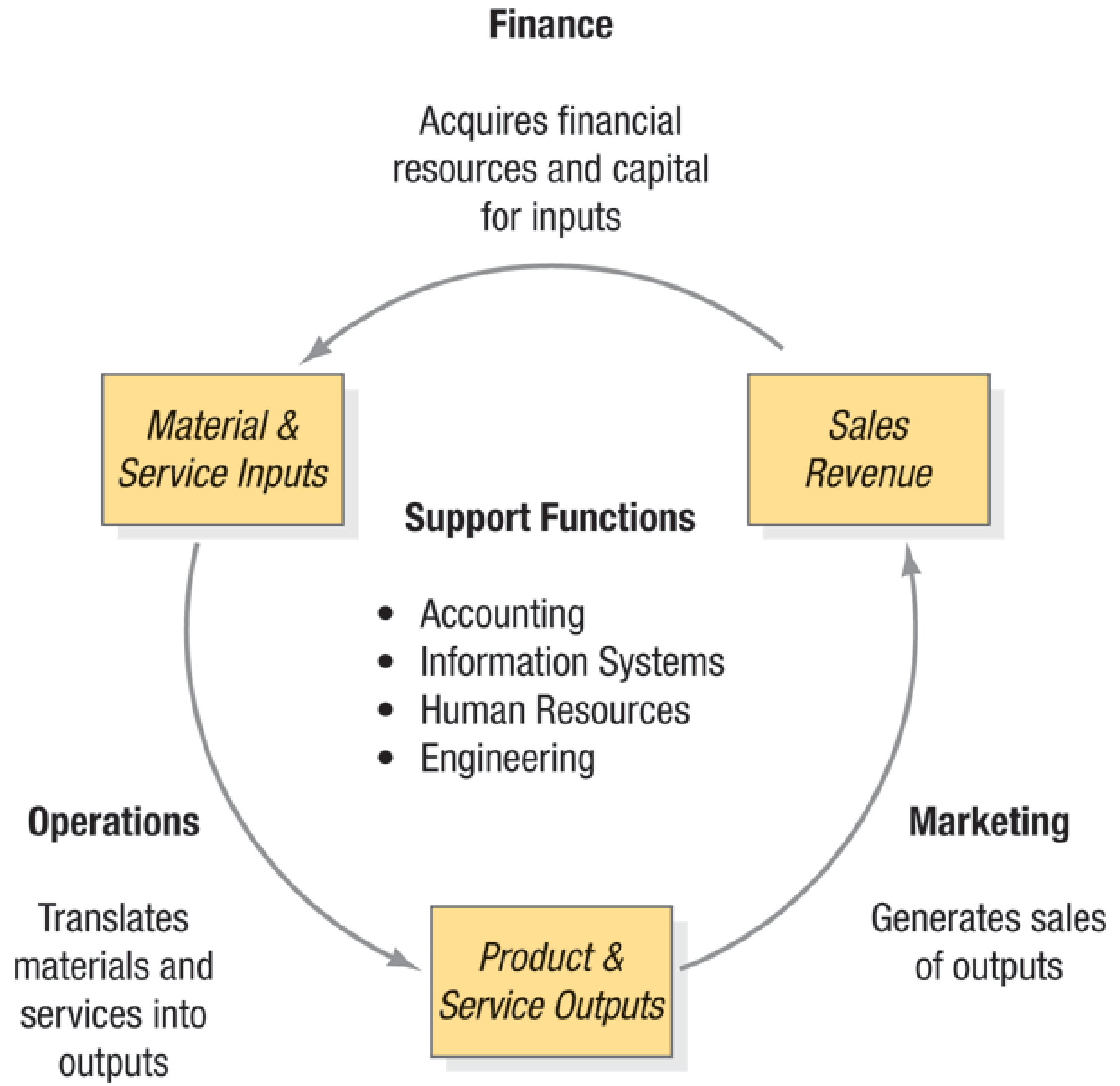


Figure 1.1

How Processes Work

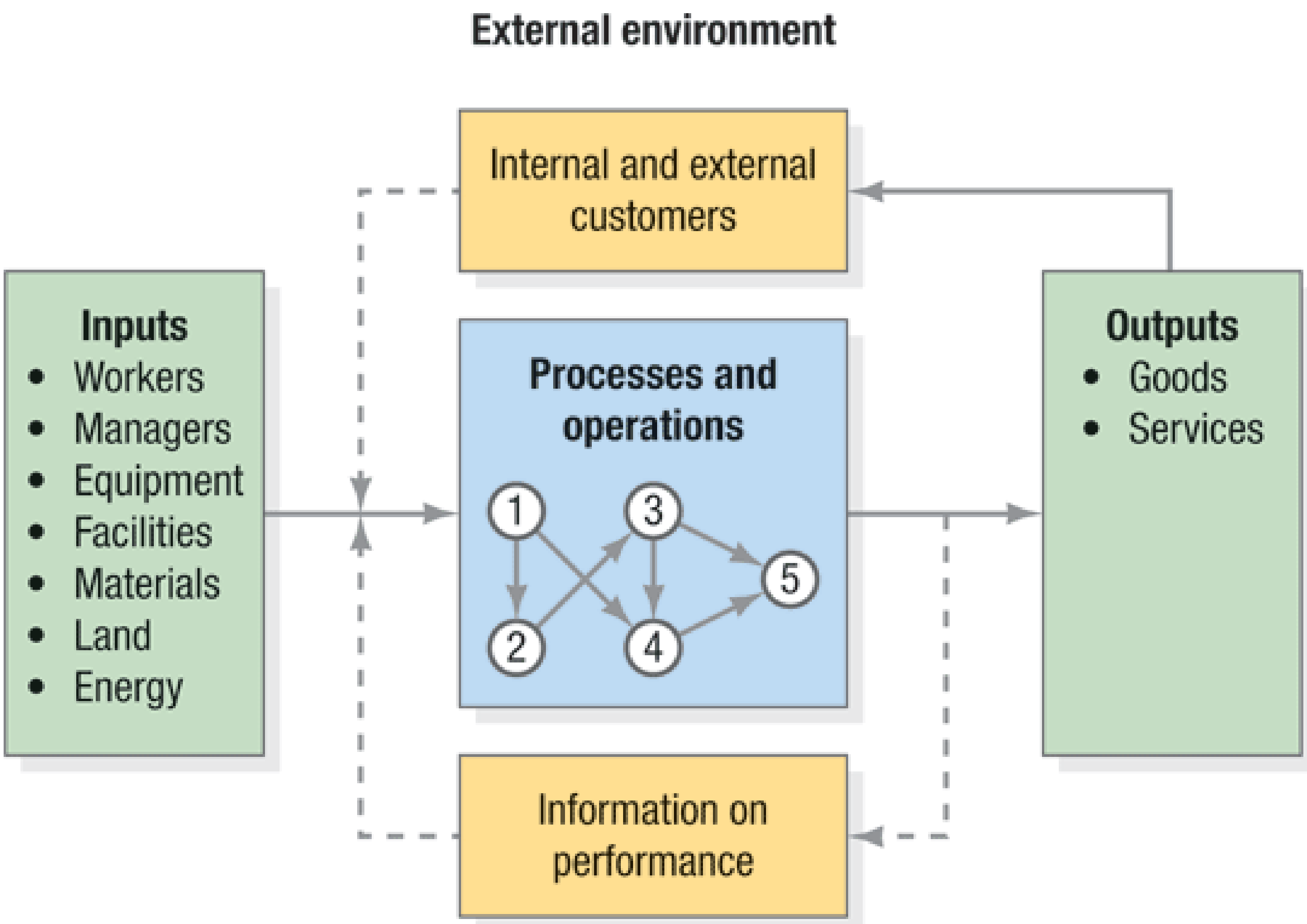


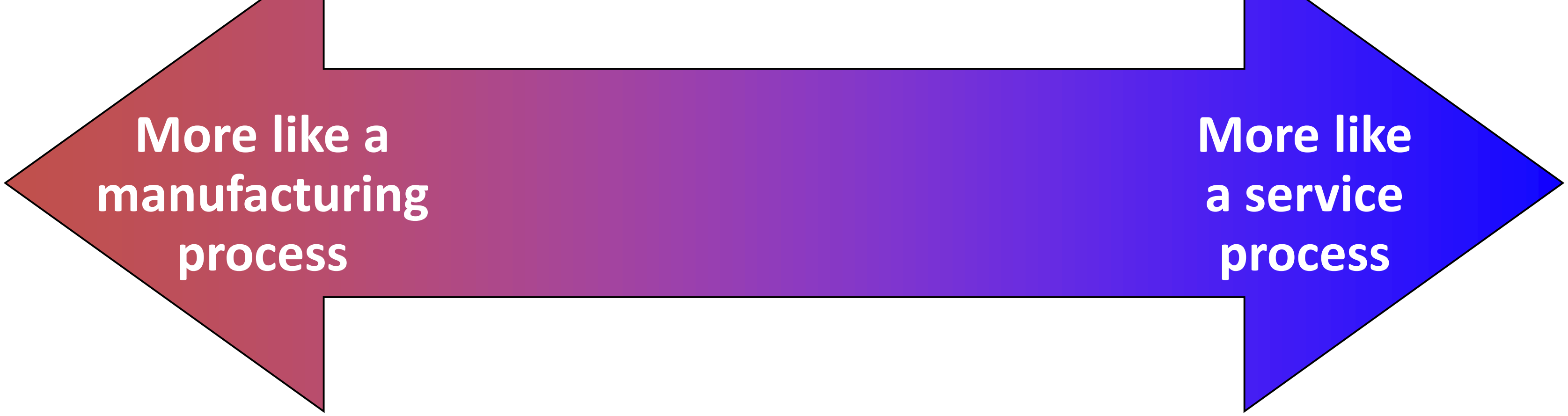
Figure 1.2

How Processes Work

- Every process and every person in the organization has customers
  - External customers
  - Internal customers
- Every process and every person in the organization relies on suppliers
  - External suppliers
  - Internal suppliers
- Nested Process
  - The concept of a process within a process

Service and Manufacturing Processes

Differ Across Nature of Output and Degree of Customer Contact



- Physical, durable output
- Output can be inventoried
- Low customer contact
- Long response time
- Capital intensive
- Quality easily measured

- Intangible, perishable output
- Output cannot be inventoried
- High customer contact
- Short response time
- Labor intensive
- Quality not easily measured

Figure 1.3

A Supply Chain View

Each activity in a process should add value to the preceding activities; waste and unnecessary cost should be eliminated.

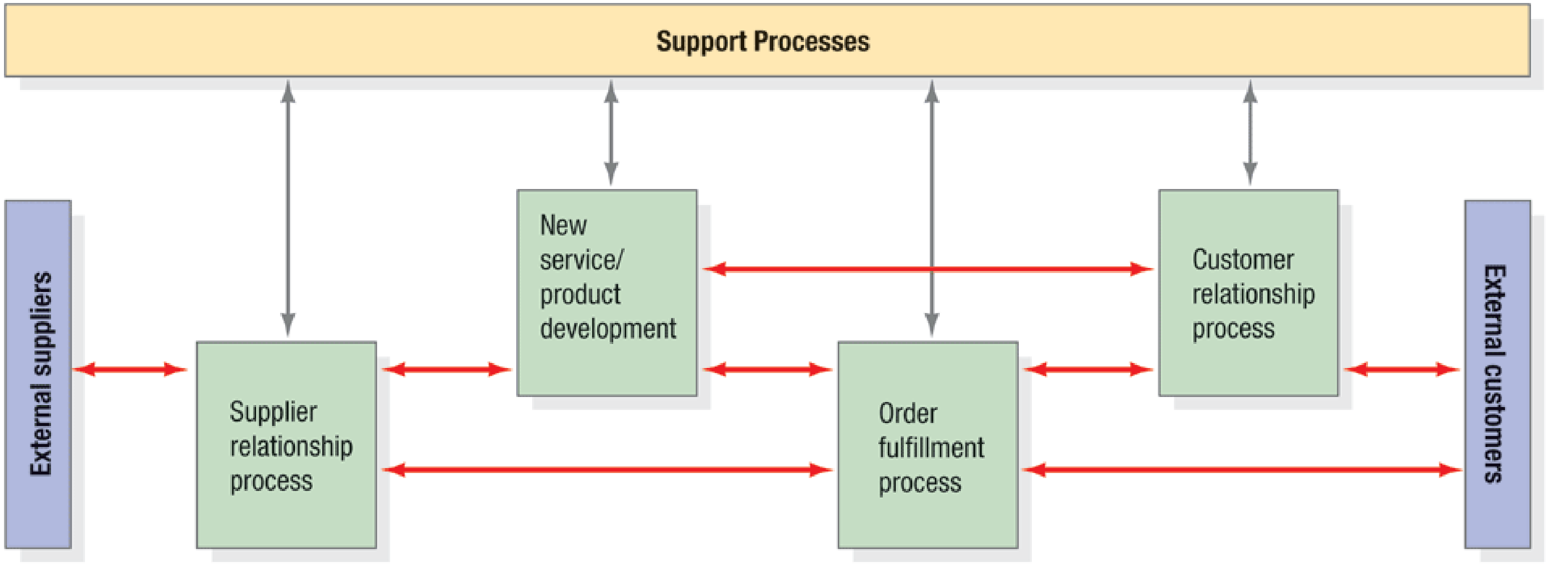


Figure 1.4

The Supply Chain

- **Supplier relationship process – A process that selects the suppliers of services, materials, and information and facilitates the timely and efficient flow of these items into the firm**
- **Order fulfillment process – A process that includes the activities required to produce and deliver the service or product to the external customer**
- **New service/product development – A process that designs and develops new services or products from inputs from external customer specifications or from the market**
- **Customer relationship process – A process that identifies, attracts and builds relationships with external customers and facilitates the placement of orders by customers**
- **Support Processes - Processes like Accounting, Finance, Human Resources, Management Information Systems and Marketing that provide vital resources and inputs to the core processes**

Supply Chain Process

- **Supply Chain Processes**
  - **Business processes that have external customers or suppliers**
  - **Examples**
    - Outsourcing
    - Warehousing
    - Sourcing
    - Customer Service
    - Logistics
    - Crossdocking

Operations Strategy

- Operations Strategy
  - The means by which operations implements the firm’s corporate strategy and helps to build a customer-driven firm

Operations Strategy

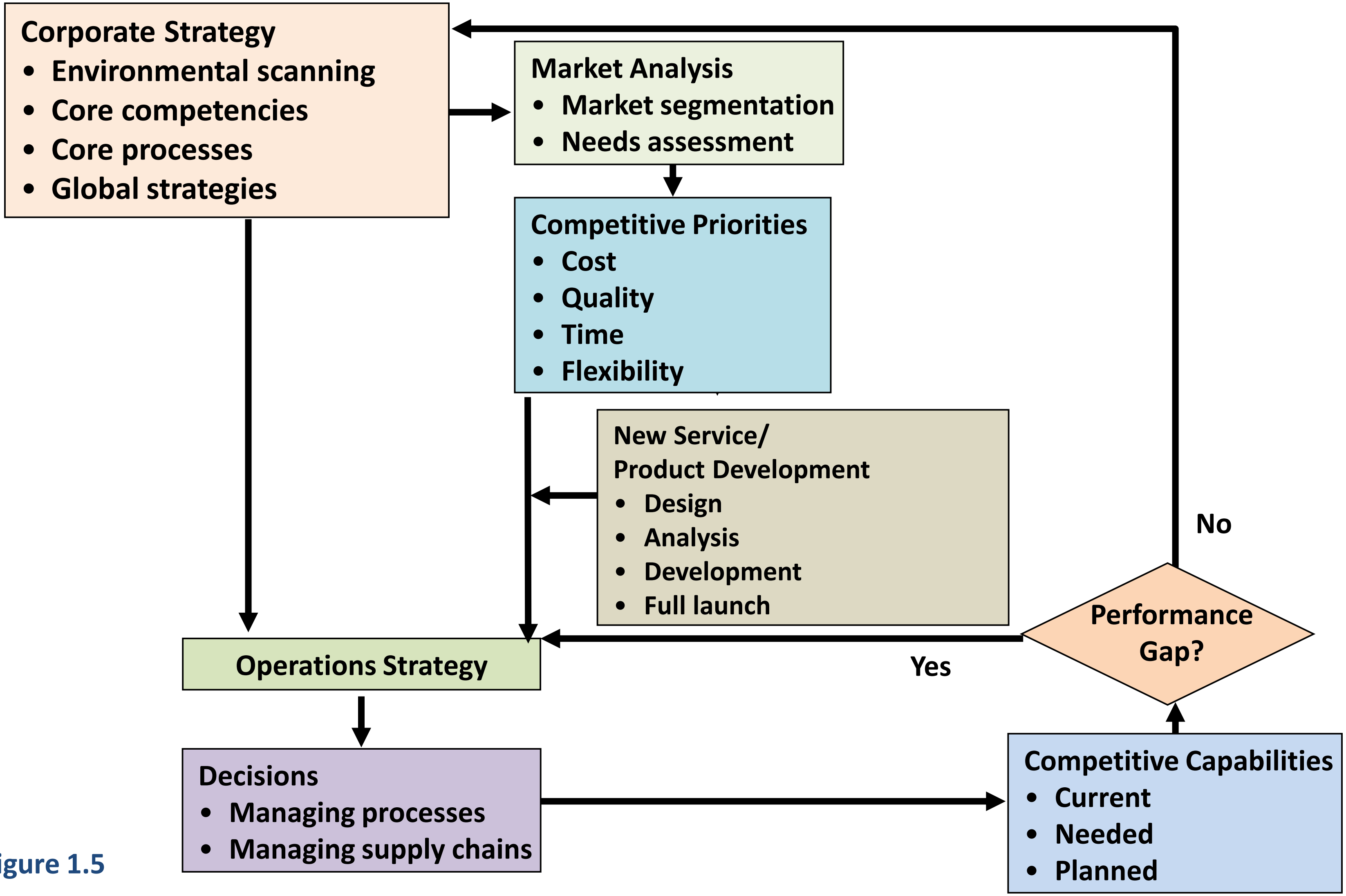


Figure 1.5

Corporate Strategy

- **Corporate Strategy**
  - **Provides an overall direction that serves as the framework for carrying out all the organization's functions**
    - Environmental Scanning
    - Core Competencies
    - Core Processes
    - Global Strategies

Market Analysis

- **Market Analysis**
  - **Understand what the customers want and how to provide it.**
    - Market Segmentation
    - Needs Assessment

Competitive Priorities and Capabilities

Competitive Priorities

The critical dimensions that a process or supply chain *must* possess to satisfy its internal or external customers, both now and in the future.

Competitive Capabilities

The cost, quality, time, and flexibility dimensions that a process or supply chain *actually* possesses and is able to deliver.

Order Winners and Qualifiers

Order Winners

A criterion customers use to differentiate the services or products of one firm from those of another.

Order Qualifiers

Minimum level required from a set of criteria for a firm to do business in a particular market segment.

Order Winners and Qualifiers

COST	Definition	Process Considerations	Example
1. Low-cost operations	Delivering a service or a product at the lowest possible cost	Processes must be designed and operated to make them efficient	Costco
QUALITY			
2. Top quality	Delivering an outstanding service or product	May require a high level of customer contact and may require superior product features	Rolex
3. Consistent quality	Producing services or products that meet design specifications on a consistent basis	Processes designed and monitored to reduce errors and prevent defects	McDonald's

Table 1.3

Order Winners and Qualifiers

TIME	Definition	Process Considerations	Example
4. Delivery speed	Quickly filling a customer's order	Design processes to reduce lead time	Netflix
5. On-time delivery	Meeting delivery-time promises	Planning processes used to increase percent of customer orders shipped when promised	United Parcel Service (UPS)
6. Development speed	Quickly introducing a new service or a product	Cross-functional integration and involvement of critical external suppliers	Zara

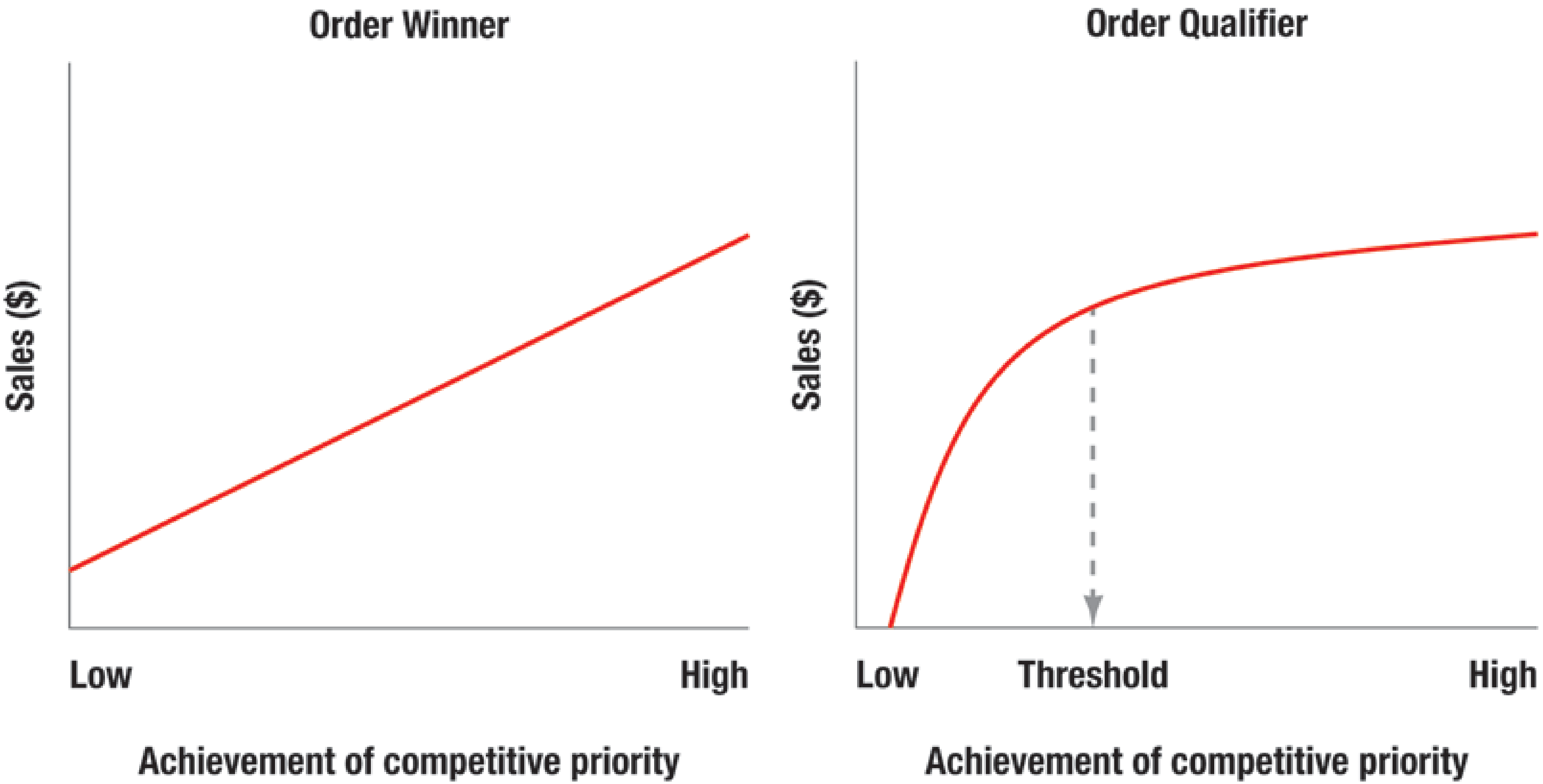
Table 1.3

Order Winners and Qualifiers

FLEXIBILITY	Definition	Process Considerations	Example
7.Customization	Satisfying the unique needs of each customer by changing service or product designs	Low volume, close customer contact, and easily reconfigured	Ritz Carlton
8.Variety	Handling a wide assortment of services or products efficiently	Capable of larger volumes than processes supporting customization	Amazon.com
9.Volume flexibility	Accelerating or decelerating the rate of production of services or products quickly to handle large fluctuations in demand	Processes must be designed for excess capacity and excess inventory	The United States Postal Service (USPS)

Table 1.3

Relationship of Order Winners to Competitive Priorities



Operations Strategy

OPERATIONS STRATEGY ASSESSMENT OF THE BILLING AND PAYMENT PROCESS				
Competitive Priority	**Measure**	**Capability**	**Gap**	**Action**
Low-cost operations	■ Cost per billing statement	■ $0.0813	■ Target is $0.06	■ Eliminate microfilming and storage of billing statements
	■ Weekly postage	■ $17,000	■ Target is $14,000	■ Develop Web-based process for posting bills
Consistent quality	■ Percent errors in bill information	■ 0.90%	■ Acceptable	■ No action
	■ Percent errors in posting payments	■ 0.74%	■ Acceptable	■ No action
Delivery speed	■ Lead time to process merchant payments	■ 48 hours	■ Acceptable	■ No action
Volume flexibility	■ Utilization	■ 98%	■ Too high to support rapid increase in volumes	■ Acquire temporary employees ■ Improve work methods

Table 1.5

Addressing the Trends and Challenges in Operations Management

Measuring Productivity

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}}$$

The Role of Management

Example 1.1

Calculate the Productivity for the following operations:

a. Three employees process 600 insurance policies in a week. They work 8 hours per day, 5 days per week.

$$\text{Labor productivity} = \frac{\text{Policies processed}}{\text{Employee hours}}$$

$$= \frac{\text{600 policies}}{\text{(3 employees)(40 hours/employee)}} = \textbf{5 policies/hour}$$

Example 1.1

b. A team of workers makes 400 units of a product, which is sold in the market for $10 each. The accounting department reports that for this job the actual costs are $400 for labor, $1,000 for materials, and $300 for overhead.

$$\text{Multifactor productivity} = \frac{\text{Value of output}}{\text{Labor cost + Materials cost + Overhead cost}}$$

$$= \frac{(400\text{ units})(\$10/\text{unit})}{\$400 + \$1{,}000 + \$300} = \frac{\$4{,}000}{\$1{,}700} = \mathbf{2.35}$$

Application 1.1

	This Year	Last Year	Year Before Last
Factory unit sales	2,762,103	2,475,738	2,175,447
Employment (hrs)	112,000	113,000	115,000
Sales of manufactured products ($)	$49,363	$40,831	—
Total manufacturing cost of sales ($)	$39,000	$33,000	—

- **Calculate the year-to-date labor productivity:**

	This Year	Last Year	Year Before Last
$\dfrac{\textit{factory unit sales}}{\textit{employment}}$	$\dfrac{2,762,103}{112,000}$ = 24.66/hr	$\dfrac{2,475,738}{113,000}$ = 21.91/hr	$\dfrac{2,175,447}{115,000}$ = $18.91/hr

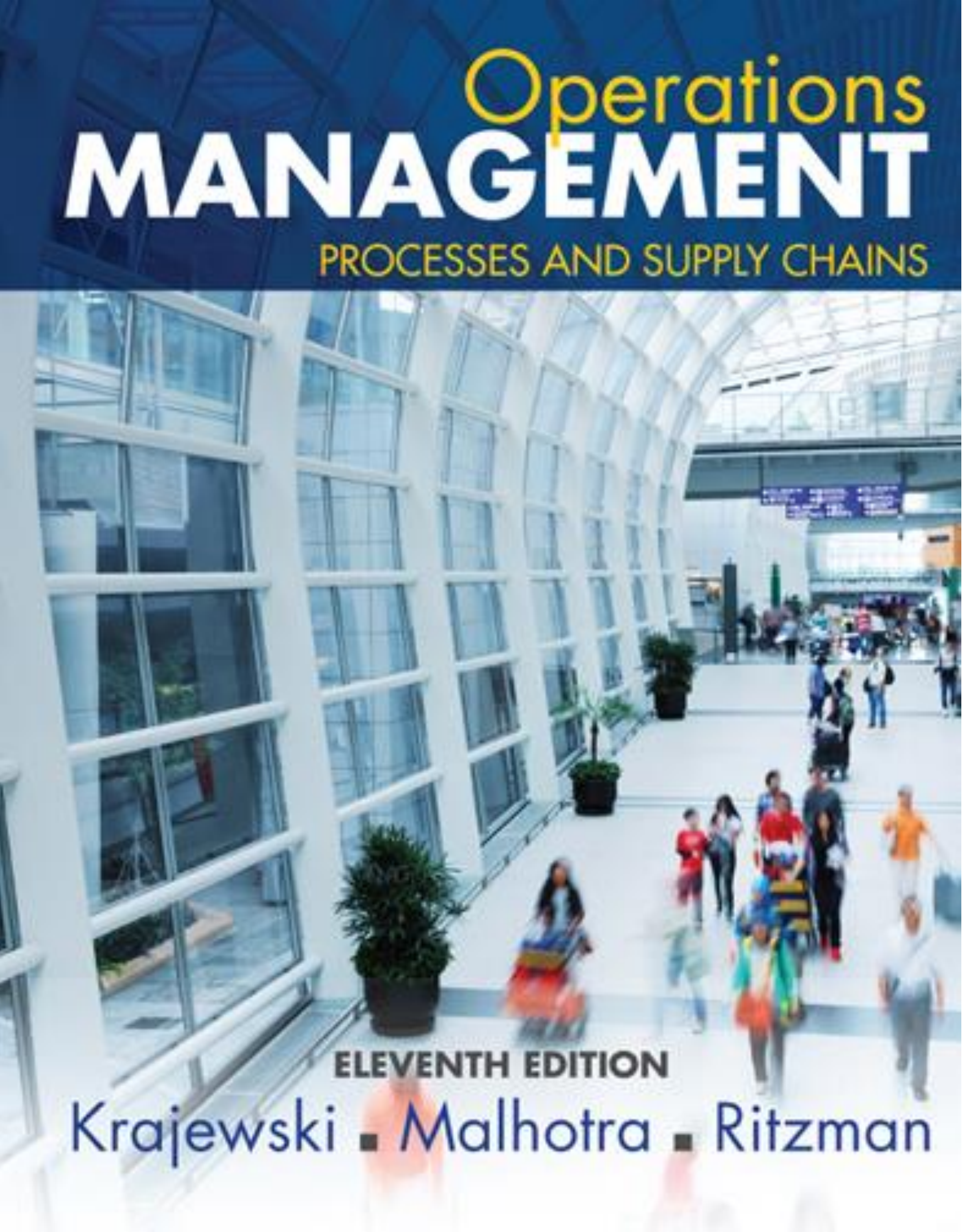
- **Calculate the multifactor productivity:**

	This Year	Last Year
$\dfrac{\textit{sales of mfg products}}{\textit{total mfg cost}}$	$\dfrac{\$49,363}{\$39,000}$ = 1.27	$\dfrac{\$40,831}{\$33,000}$ = 1.24

Addressing the Trends and Challenges in Operations Management

- **Global Competition**

- **Ethical, Workforce Diversity, and Environmental Issues**



Process Strategy and Analysis

Chapter 2

What is Process Strategy?

Process Strategy

The pattern of decisions made in managing processes so that they will achieve their competitive priorities

Process Strategy

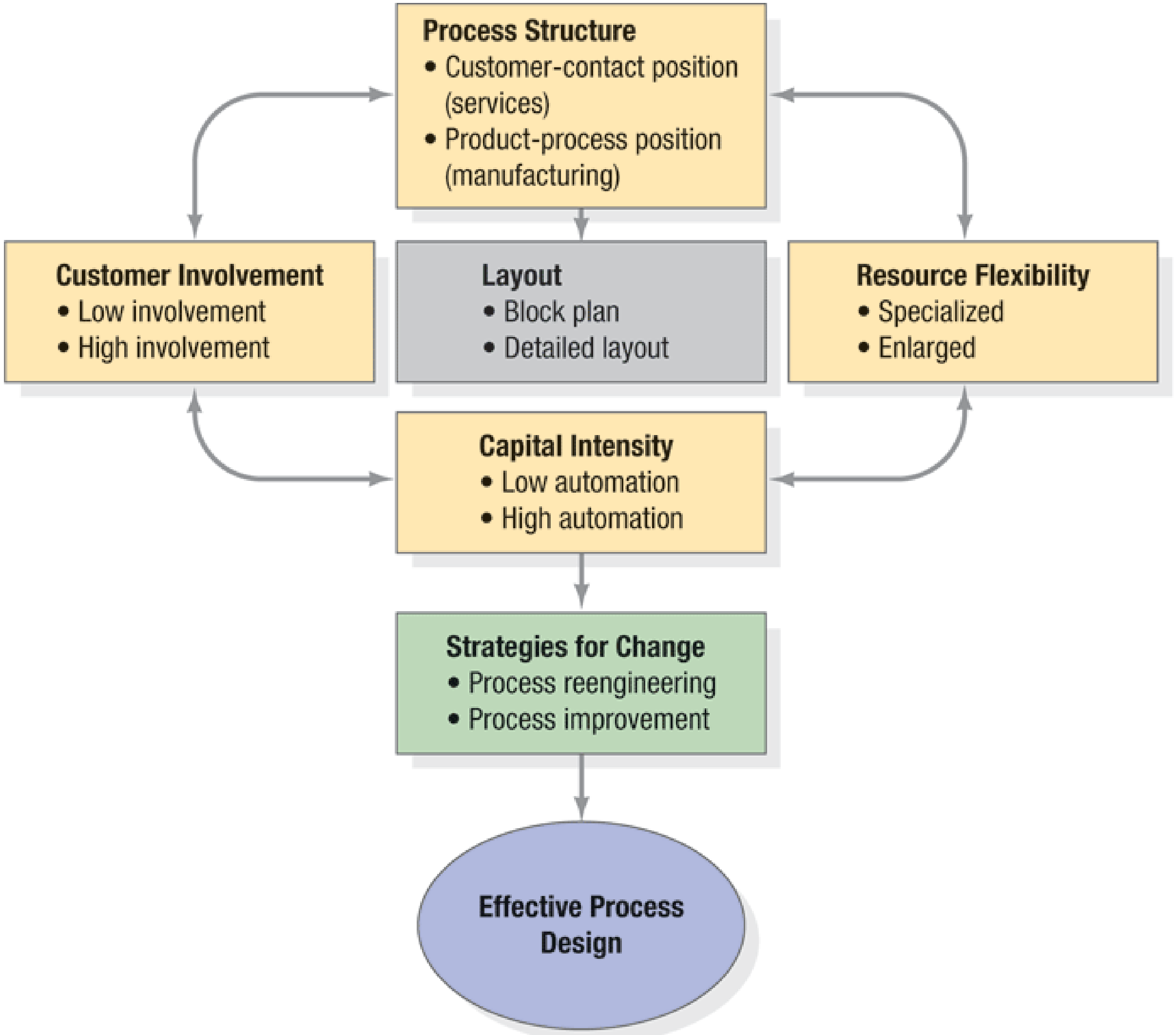


Figure 2.1

Process Structure in Services

DIMENSIONS OF CUSTOMER CONTACT IN SERVICE PROCESSES		
Dimension	**High Contact**	**Low Contact**
Physical presence	Present	Absent
What is processed	People	Possessions or information
Contact intensity	Active, visible	Passive, out of sight
Personal attention	Personal	Impersonal
Method of delivery	Face-to-face	Regular mail or e-mail

Table 2.1

Process Structure in Services

- **Customer Contact**
  - The extent to which the customer is present, is actively involved, and receives personal attention during the service process
- **Customization**
  - Service level ranging from highly customized to standardized
- **Process Divergence**
  - The extent to which the process is highly customized with considerable latitude as to how its tasks are performed
- **Flow**
  - How the work progresses through the sequence of steps in a process

Customer-Contact Matrix

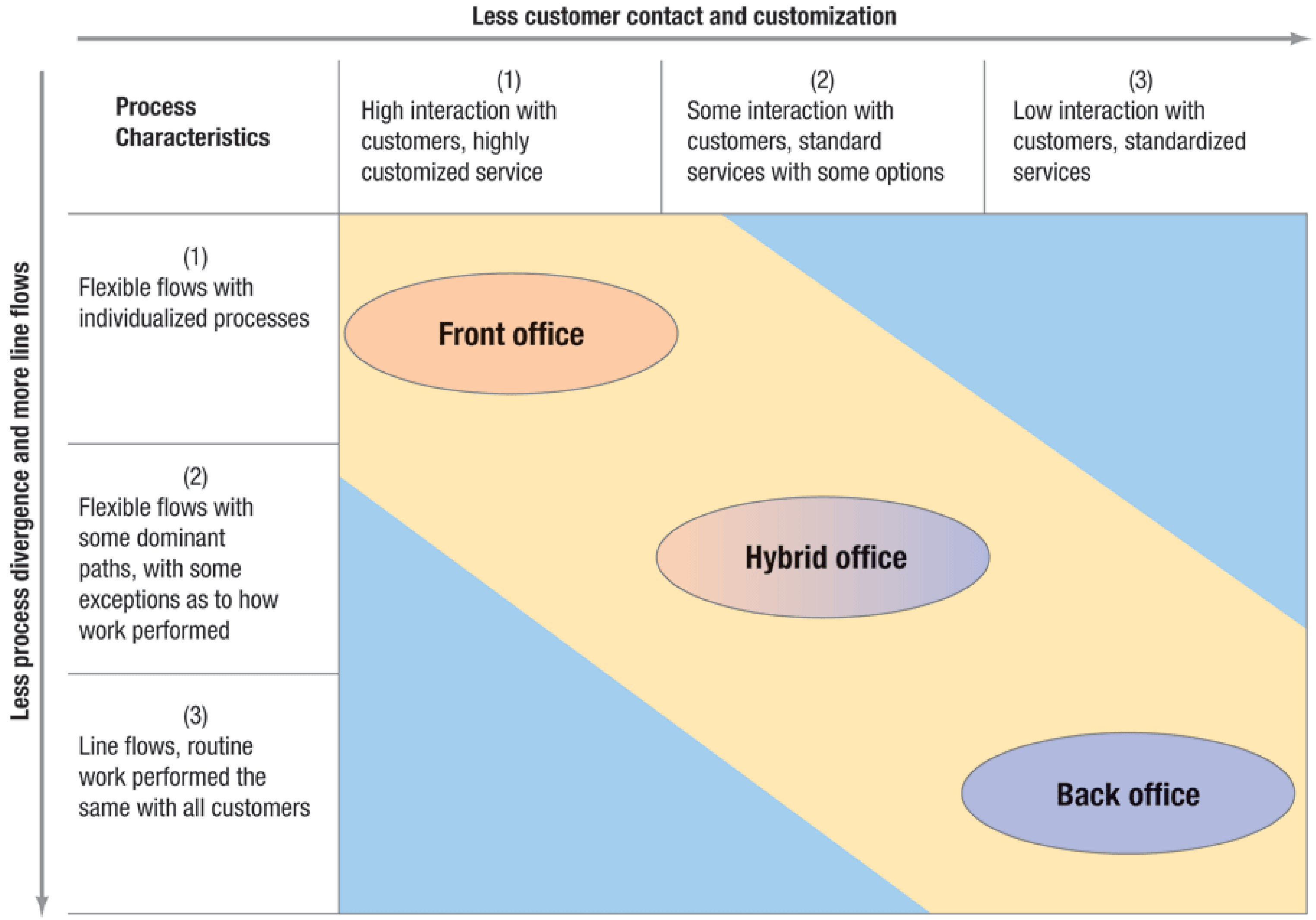


Figure 2.2

Process Structure in Manufacturing

- Process Choice
  - A way of structuring the process by organizing resources around the process or organizing them around the products.
- Job Process
- Batch Process
  - Small or Large
- Line Process
- Continuous-Flow

Process Structure in Manufacturing

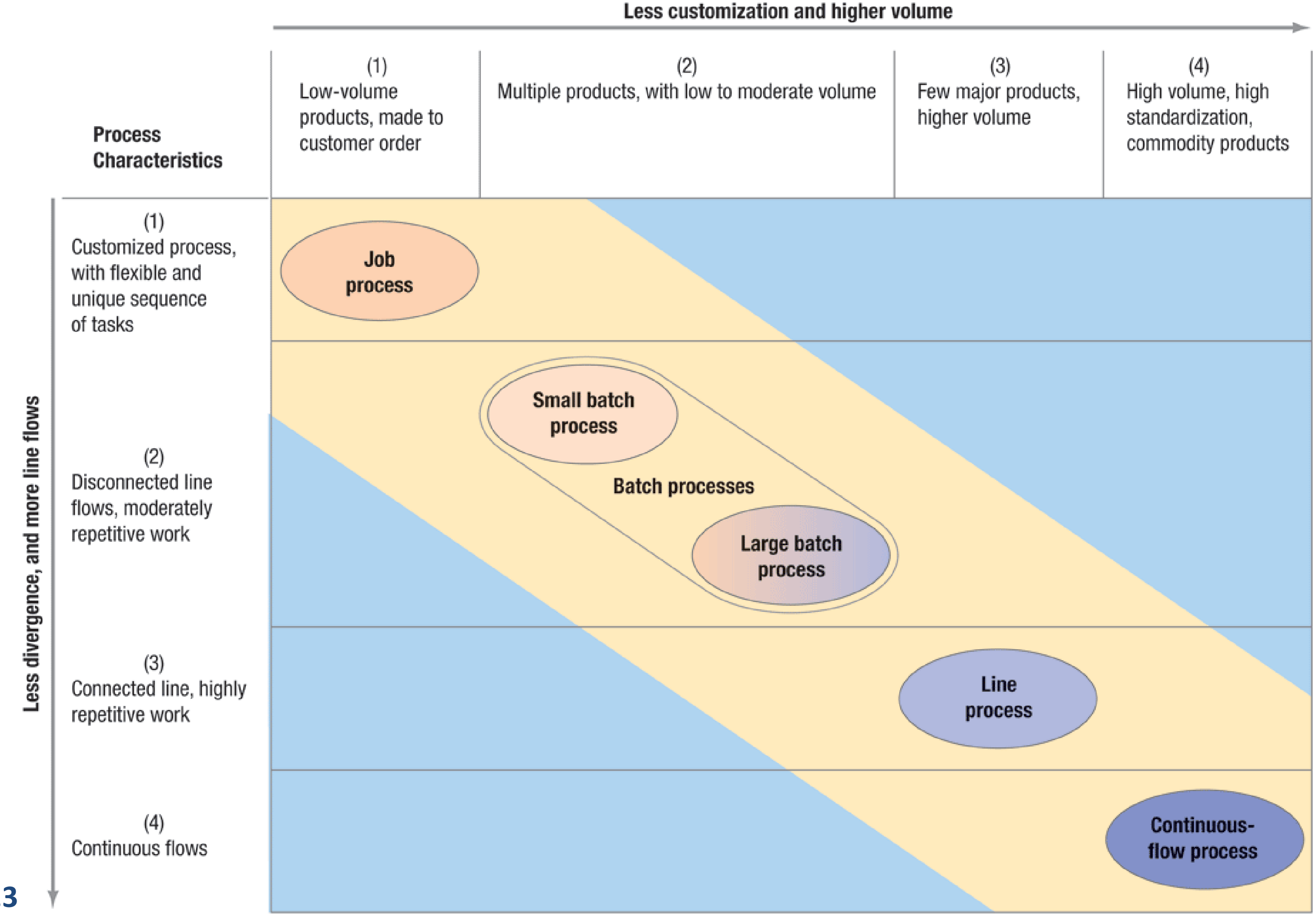


Figure 2.3

Production and Inventory Strategies

- Design-to-Order
- Make-to-Order
- Assemble-to-Order
  - Postponement
  - Mass Customization
- Make-to-Stock
  - Mass Production

Layout

- Layout - The physical arrangement of operations (or departments) relative to each other
  - Operation - A group of human and capital resources performing all or part of one or more processes

Process Strategy Decisions

- Customer Involvement
- Resource Flexibility
- Capital Intensity

Customer Involvement

- **Possible Advantages**
  - **Increased net value to the customer**
  - **Better quality, faster delivery, greater flexibility, and lower cost**
  - **Reduction in product, shipping, and inventory costs**
  - **Coordination across the supply chain**

Customer Involvement

- **Possible Disadvantages**
  - **Can be disruptive**
  - **Managing timing and volume can be challenging**
  - **Quality measurement can be difficult**
  - **Requires interpersonal skills**
  - **Multiple locations may be necessary**

Resource Flexibility

- **Workforce**
  - Flexible workforce
- **Equipment**
  - General-purpose
  - Special-purpose

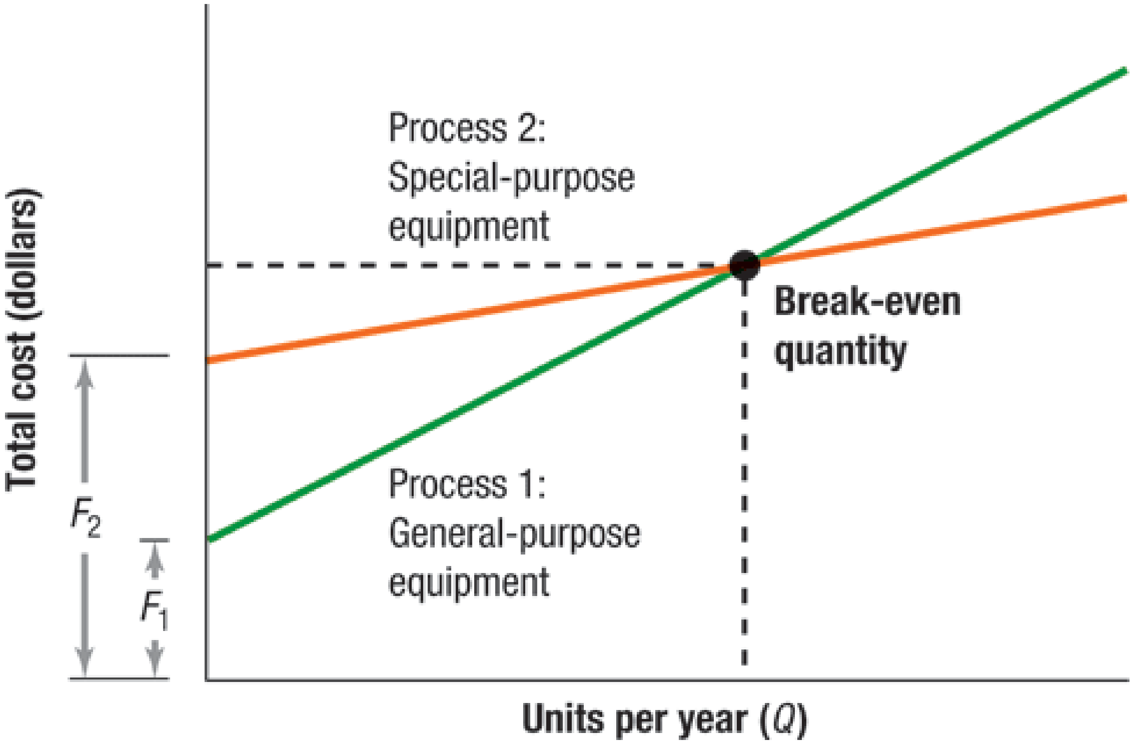


Figure 2.4

Application 2.1

BBC is deciding whether to weld bicycle frames manually or to purchase a welding robot. If welded manually, investment costs for equipment are only $10,000. The per-unit cost of manually welding a bicycle frame is $50.00 per frame. On the other hand, a robot capable of performing the same work costs $400,000. Robot operating costs including support labor are $20.00 per frame.

	Welded manually (Make)	Welded by robot (Buy)
Fixed costs	$10,000	$400,000
Variable costs	$50	$20

At what volume would BBC be indifferent to these alternative methods?

$$Q = \frac{F_m - F_b}{c_b - c_m} = \frac{\$10{,}000 - \$400{,}000}{\$20 - \$50} = \text{13,000 frames}$$

Capital Intensity

- Automating Manufacturing Processes
  - Fixed Automation
  - Flexible (Programmable) Automation
- Automating Service Processes
- Economies of Scope

Decision Patterns for Manufacturing Processes

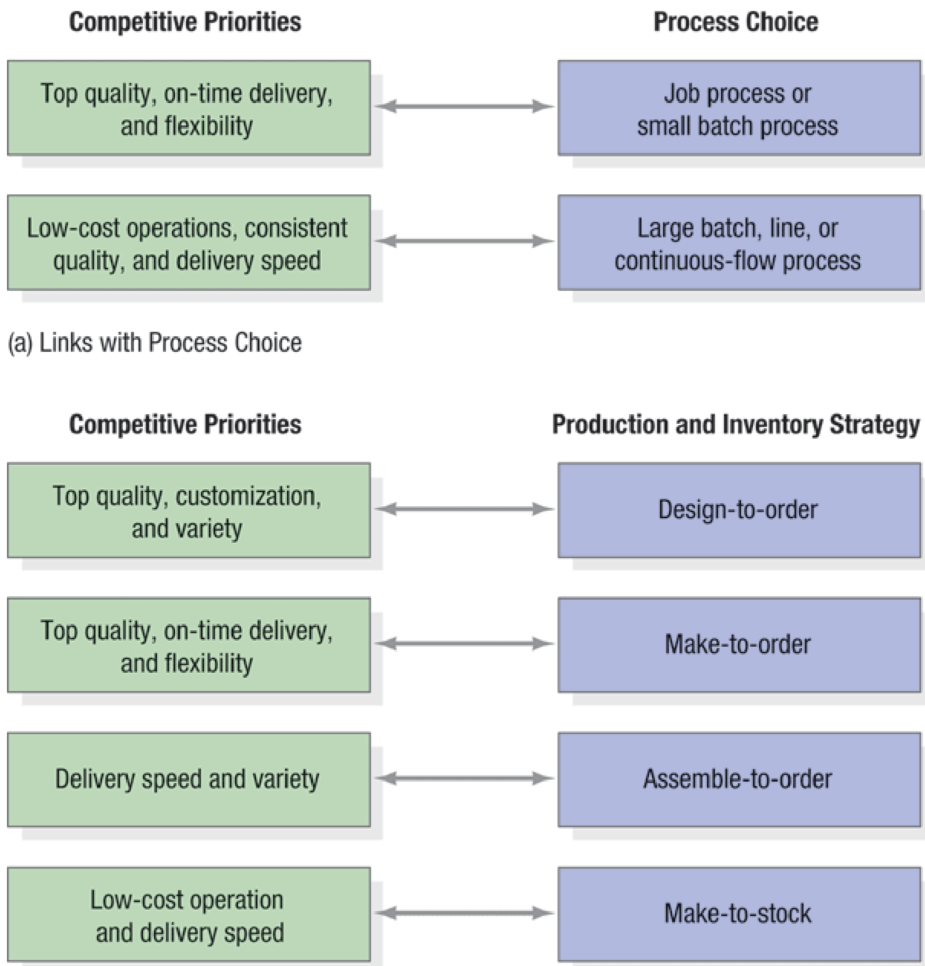


Figure 2.5

(b) Links with Production and Inventory Strategy

Gaining Focus

- Focus by Process Segments
  - Plant within plants (PWPs)
    - Different operations within a facility with individualized competitive priorities, processes, and workforces under the same roof.
  - Focused Service Operations
  - Focused Factories
    - The result of a firm’s splitting large plants that produced all the company’s products into several specialized smaller plants.

Process Reengineering

- **Reengineering**
  - The fundamental rethinking and radical redesign of processes to improve performance dramatically in terms of cost, quality, service, and speed

Process Reengineering

- Key elements
  - Critical processes
  - Strong leadership
  - Cross-functional teams
  - Information technology
  - Clean-slate philosophy
  - Process analysis

Process Improvement

- Process Improvement
  - The systematic study of the activities and flows of each process to improve it

What is Process Analysis?

Process Analysis

The documentation and detailed understanding of how work is performed and how is can be redesigned

Six Sigma
Process Improvement Model

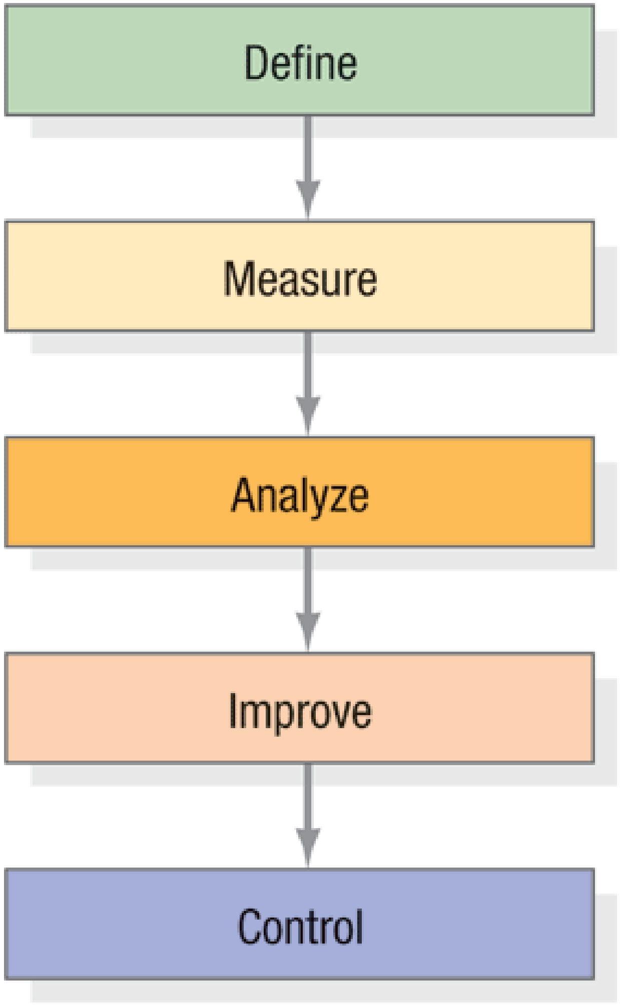


Figure 2.6

Documenting and Evaluating the Process

- Flowcharts
- Work Measurement Techniques
- Process Charts

Documenting and Evaluating the Process

Flowchart – A diagram that traces the flow of information, customers, equipment, or materials through the various steps of a process

Service Blueprint – A special flowchart of a service process that shows which steps have high customer contact

Swim Lane Flowchart

Swim Lane Flowchart – A visual representation that groups functional areas responsible for different sub-processes into lanes.

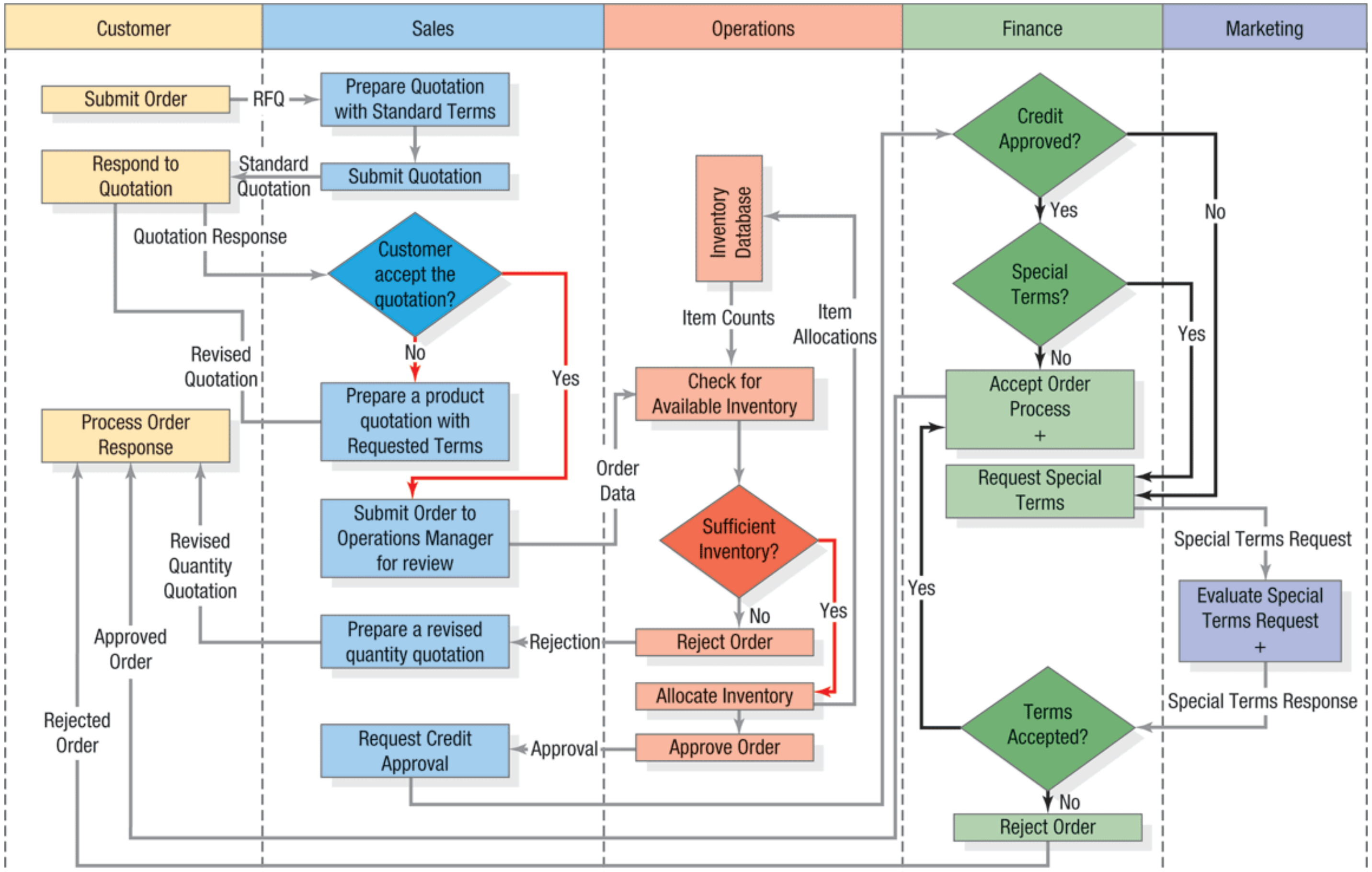


Figure 2.7

Documenting and Evaluating the Process

- **Work Measurement Techniques**
  - Time Study
  - Elemental Standard Data approach
  - Predetermined Data Approach
  - Work Sampling Method
  - Learning Curve Analysis

Example 2.1

A process at a watch assembly plant has been changed. The process is divided into three work elements. A time study has been performed with the following results. The time standard for process previously was **14.5 minutes**. Based on the new time study, should the time standard be revised?

Example 2.1

- The new time study had an initial sample of four observations, with the results shown in the following table. The performance rating factor (RF) is shown for each element, and the allowance for the whole process is 18 percent of the total normal time.

	Obs 1	Obs 2	Obs 3	Obs 4	Average (min)	RF	Normal Time
Element 1	2.60	2.34	3.12	2.86	2.730	1.0	2.730
Element 2	4.94	4.78	5.10	4.68	4.875	1.1	5.363
Element 3	2.18	1.98	2.13	2.25	2.135	0.9	1.922
Total Normal Time = 10.015							

Example 2.1

The normal time for an element in the table is its average time, multiplied by the RF.

The total normal time for the whole process is the sum of the normal times for the three elements, or 10.01 minutes. To get the standard time (ST) for the process, just add in the allowance, or

$$ST = 10.015(1 + 0.18) = 11.82 \text{ minutes/watch}$$

Yes, change the time standard from 14.5 minutes to 11.82 minutes.

Work Measurement Techniques

- **Work Sampling**

(b) Idle Time and Observations Required

Portion of idle times	0.2381
Total observations required	279
Additional observations required	237

(a) Input Data and Numerical Results

Increase Observations | Remove An Observation

Documenting and Evaluating the Process

Confidence z	1.96	Precision p	0.05

Observation Period	Times Busy	Times Idle	Observations
Monday	6	1	7
Tuesday	5	2	7
Wednesday	7	0	7
Thursday	9	2	11
Friday	5	5	10
Total	32	10	42

Figure 2.8

Work Measurement Techniques

- **Learning Curves**

Time for first unit	120,000
Unit number	10
Time for unit 10	57,172
Cumulative average time per unit	75,784

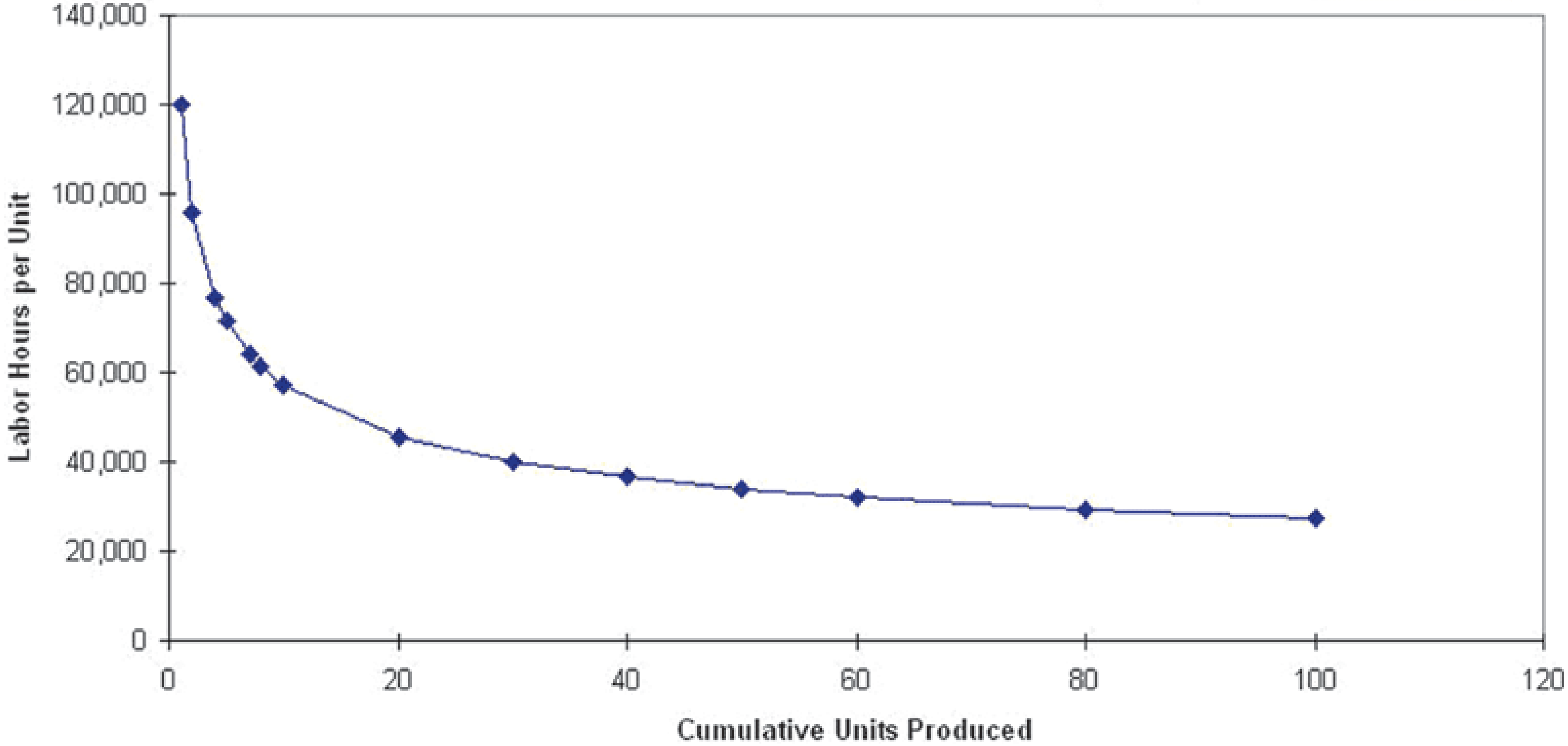


Figure 2.9

Process Charts

- Process Charts - An organized way of documenting all the activities performed by a person or group, at a workstation, with a customer, or working with certain materials
- Activities are typically organized into five categories
  - Operation, ●
  - Transportation, ➡
  - Inspection, ■
  - Delay, ◗
  - Storage, ▼

Process Charts

Step No.	Time (min)	Distance (ft)	●	➡	■	D	▼	Step Description
1	0.50	15.0						Enter emergency room, approach patient window
2	10.00							Sit down and fill out patient history
3	0.75	40.0						Nurse escorts patient to ER triage room
4	3.00							Nurse inspects injury
5	0.75	40.0						Return to waiting room
6	1.00							Wait for available bed
7	1.00	60.0						Go to ER bed
8	4.00							Wait for doctor
9	5.00							Doctor inspects injury and questions patient
10	2.00	200.0						Nurse takes patient to radiology
11	3.00							Technician x-rays patient
12	2.00	200.0						Return to bed in ER
13	3.00							Wait for doctor to return
14	2.00							Doctor provides diagnosis and advice
15	1.00	60.0						Return to emergency entrance area
16	4.00							Check out
17	2.00	180.0						Walk to pharmacy
18	4.00							Pick up prescription
19	1.00	20.0						Leave the building

Figure 2.10

Process Charts

Step No.	Time (min)	Distance (ft)	●	➡				
1	0.50	15.0		X				
2	10.00		X					
3	0.75	40.0		X				
4	3.00							
5	0.75	40.0		X				
6	1.00							
7	1.00	60.0		X				
8	4.00							
9	5.00							
10	2.00	200.0		X				
11	3.00		X					Technician x-rays patient
12	2.00	200.0		X				Return to bed in ER
13	3.00					X		Wait for doctor to return
14	2.00		X					Doctor provides diagnosis and advice
15	1.00	60.0		X				Return to emergency entrance area
16	4.00		X					Check out
17	2.00	180.0		X				Walk to pharmacy
18	4.00		X					Pick up prescription
19	1.00	20.0		X				Leave the building

Summary

Activity		Number of Steps	Time (min)	Distance (ft)
Operation	●	5	23.00	
Transport	➡	9	11.00	815
Inspect	■	2	8.00	
Delay	◗	3	8.00	
Store	▼	—	—	

Figure 2.10

Process Charts

- The annual cost of an entire process can be estimated
- It is the product of
  1) Time in hours to perform the process each time
  2) Variable costs per hour
  3) Number of times the process is performed each year

$$\text{Annual labor cost} = \left(\begin{array}{c}\text{Time to perform}\\ \text{the process in hours}\end{array}\right)\left(\begin{array}{c}\text{Variable costs}\\ \text{per hour}\end{array}\right)\left(\begin{array}{c}\text{Number of times process}\\ \text{performed each year}\end{array}\right)$$

Process Charts

- If the average time to serve a customer is 4 hours
- The variable cost is $25 per hour
- And 40 customers are served per year
- The total labor cost is

$$4 \text{ hrs/customer} \times \$25\text{/hr} \times 40 \text{ customers/yr} = \$4{,}000$$

Data Analysis Tools

- Checklists
- Histograms and Bar Charts
- Pareto Charts
- Scatter Diagrams
- Cause-and-Effect Diagrams (Fishbone)
- Graphs

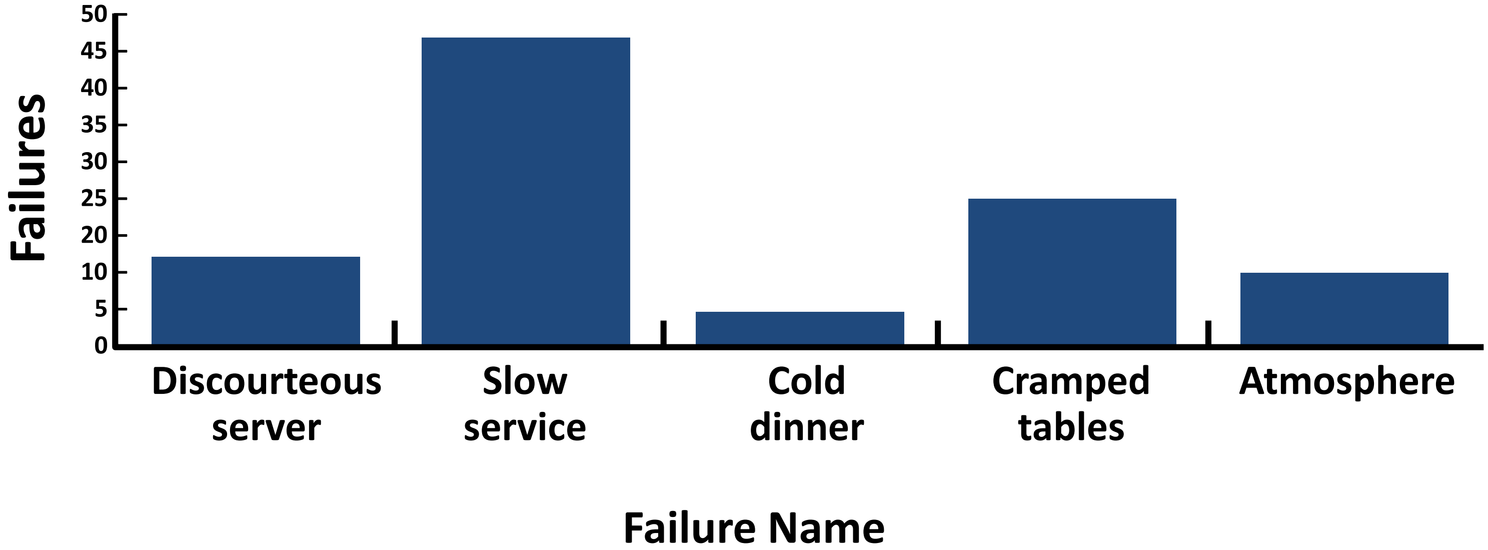
Example 2.2

The manager of a neighborhood restaurant is concerned about the smaller numbers of customers patronizing his eatery. Complaints have been rising, and he would like to find out what issues to address and present the findings in a way his employees can understand.

The manager surveyed his customers over several weeks and collected the following data:

Complaint	Frequency
Discourteous server	12
Slow service	42
Cold dinner	5
Cramped table	20
Atmosphere	10

Example 2.2



Bar Chart

Figure 2.11

Example 2.2

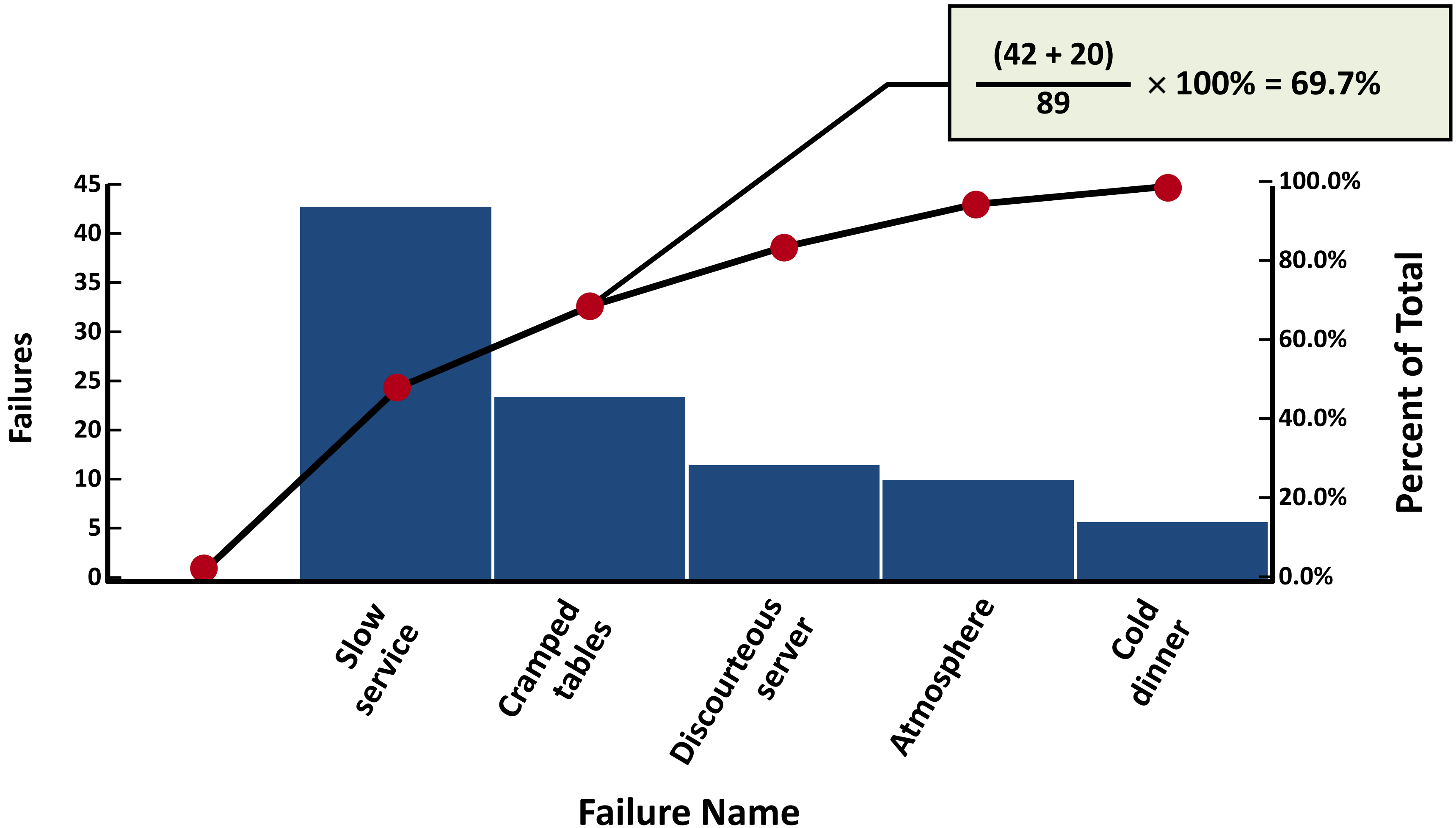


Figure 2.12

Pareto Chart

Example 2.3

A process improvement team is working to improve the production output at the Johnson Manufacturing plant’s Header Cell that manufactures a key component, headers, used in commercial air conditioners.

Currently the header production cell is scheduled separately from the main work in the plant.

Example 2.3

- The team conducted extensive on-site observations across the six processing steps within the cell and they are as follows:
  1. Cut copper pipes to the appropriate length
  2. Punch vent and sub holes into the copper log
  3. Weld a steel supply valve onto the top of the copper log
  4. Braze end caps and vent plugs to the copper log
  5. Braze sub tubes into each stub hole in the copper log
  6. Add plastic end caps to protect the newly created header

Example 2.3

- To analyze all the possible causes of that problem, the team constructed a cause-and-effect diagram.

- Several suspected causes were identified for each major category.

Example 2.3

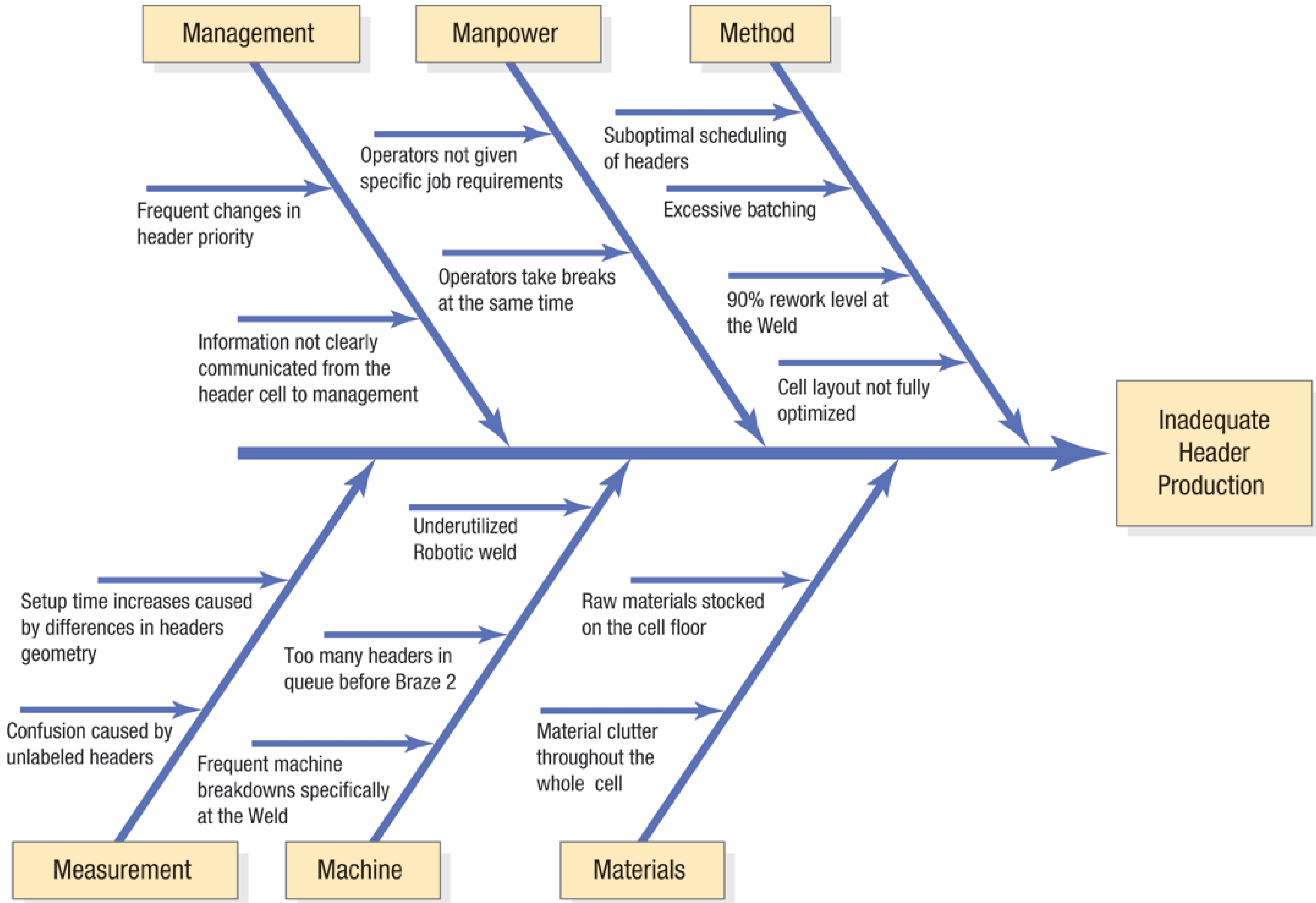


Figure 2.13

Example 2.4

The Wellington Fiber Board Company produces headliners, the fiberglass components that form the inner roof of passenger cars. Management wanted to identify which process failures were most prevalent and to find the cause.

Step 1: A checklist of different types of process failures is constructed from last month's production records.

Step 2: A Pareto chart is prepared from the checklist data.

Step 3: A cause-and-effect diagram identified several potential causes for the problem.

Step 4: The manager reorganizes the production reports into a bar chart according to shift because the personnel on the three shifts had varied amounts of experience.

Example 2.4

Checklists

Step 1. Checklist

Headliner failures

Process failure	Tally	Total
A. Tears in fabric	IIII	4
B. Discolored fabric	III	3
C. Broken fiber board	𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 𝍸 I	36
D. Ragged edges	𝍸 II	7
		Total 50

Pareto Chart

Step 2. Pareto Chart

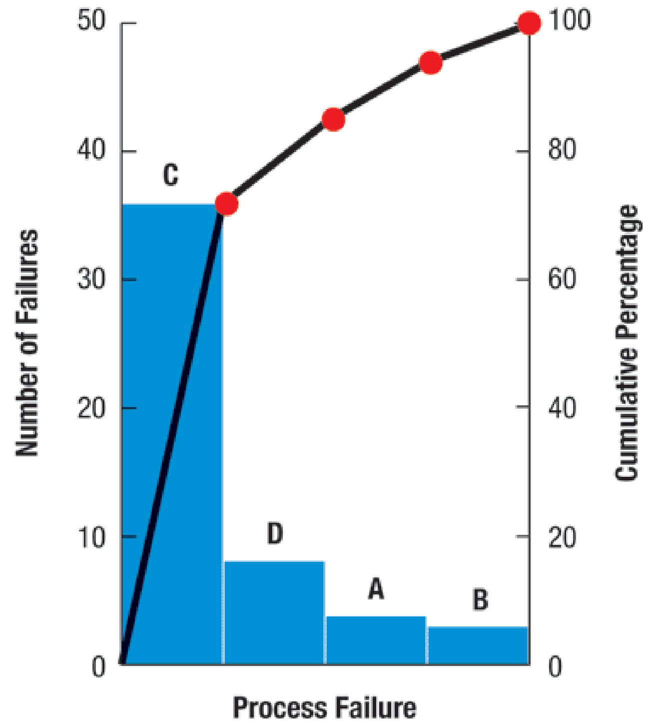


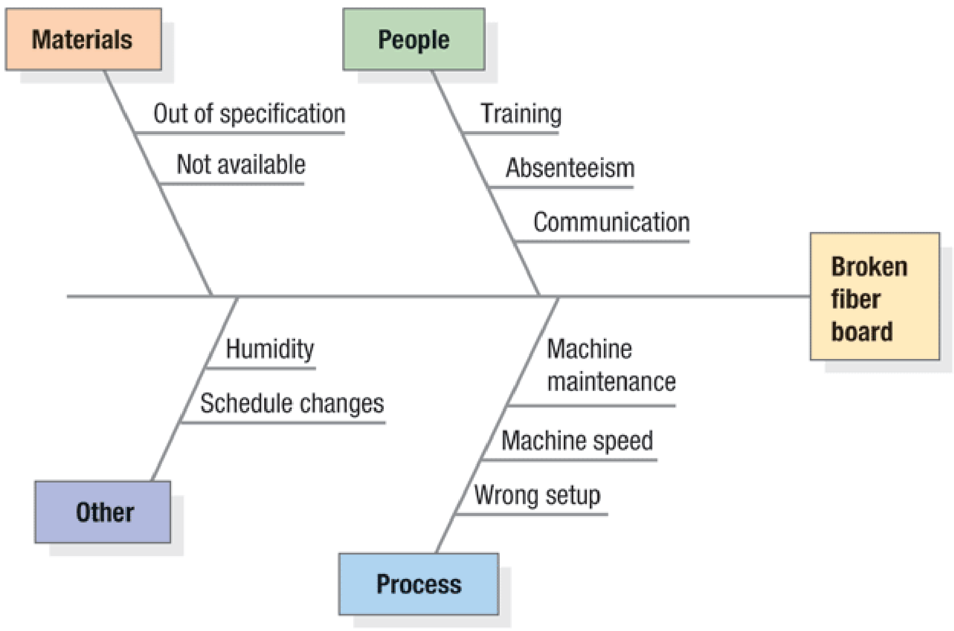
Figure 2.14

Example 2.4

Cause-and-Effect Diagram

Bar Chart

Step 3. Cause-and-Effect Diagram



Step 4. Bar Chart

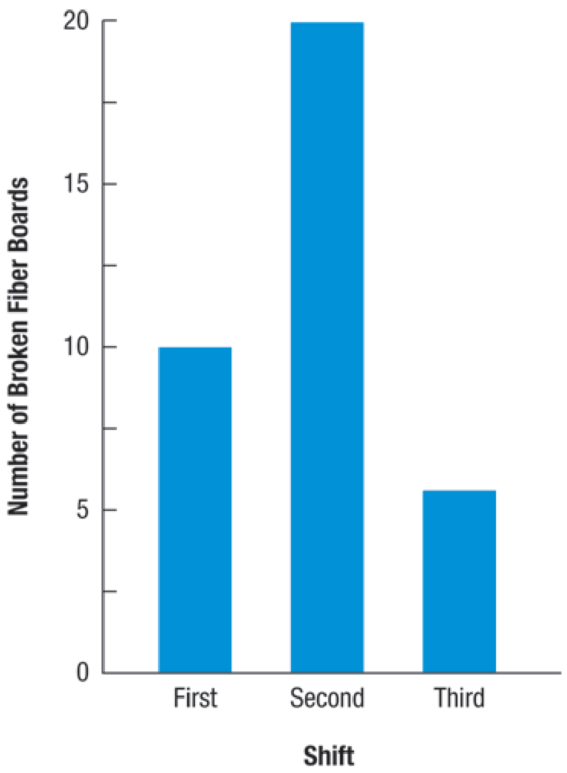


Figure 2.14

Redesigning and Managing Process Improvements

- Questioning and Brainstorming
- Benchmarking
- Implementing

Redesigning and Managing Process Improvements

- Questioning and Brainstorming
- Ideas can be uncovered by asking six questions
  1. *What* is being done?
  2. *When* is it being done?
  3. *Who* is doing it?
  4. *Where* is it being done?
  5. *How* is it being done?
  6. *How well* does it do on the various metrics of importance?

Redesigning and Managing Process Improvements

- **Benchmarking**
  - **A systematic procedure that measures a firm's processes, services, and products against those of industry leaders**

Redesigning and Managing Process Improvements

- Implementing
  - Avoid the following seven mistakes
    1. Not connecting with strategic issues
    2. Not involving the right people in the right way
    3. Not giving the design teams and process analysts a clear charter, and then holding them accountable
    4. Not being satisfied unless fundamental “reengineering” changes are made
    5. Not considering the impact on people
    6. Not giving attention to implementation
    7. Not creating an infrastructure for continuous process improvement

Solved Problem 1

Create a flowchart for the following telephone-ordering process at a retail chain that specializes in selling books and music CDs. It provides an ordering system via the telephone to its time-sensitive customers besides its regular store sales.

The automated system greets customers, asks them to choose a tone or pulse phone, and routes them accordingly.

The system checks to see whether customers have an existing account. They can wait for the service representative to open a new account.

Customers choose between order options and are routed accordingly.

Customers can cancel the order. Finally, the system asks whether the customer has additional requests; if not, the process terminates.

Solved Problem 1

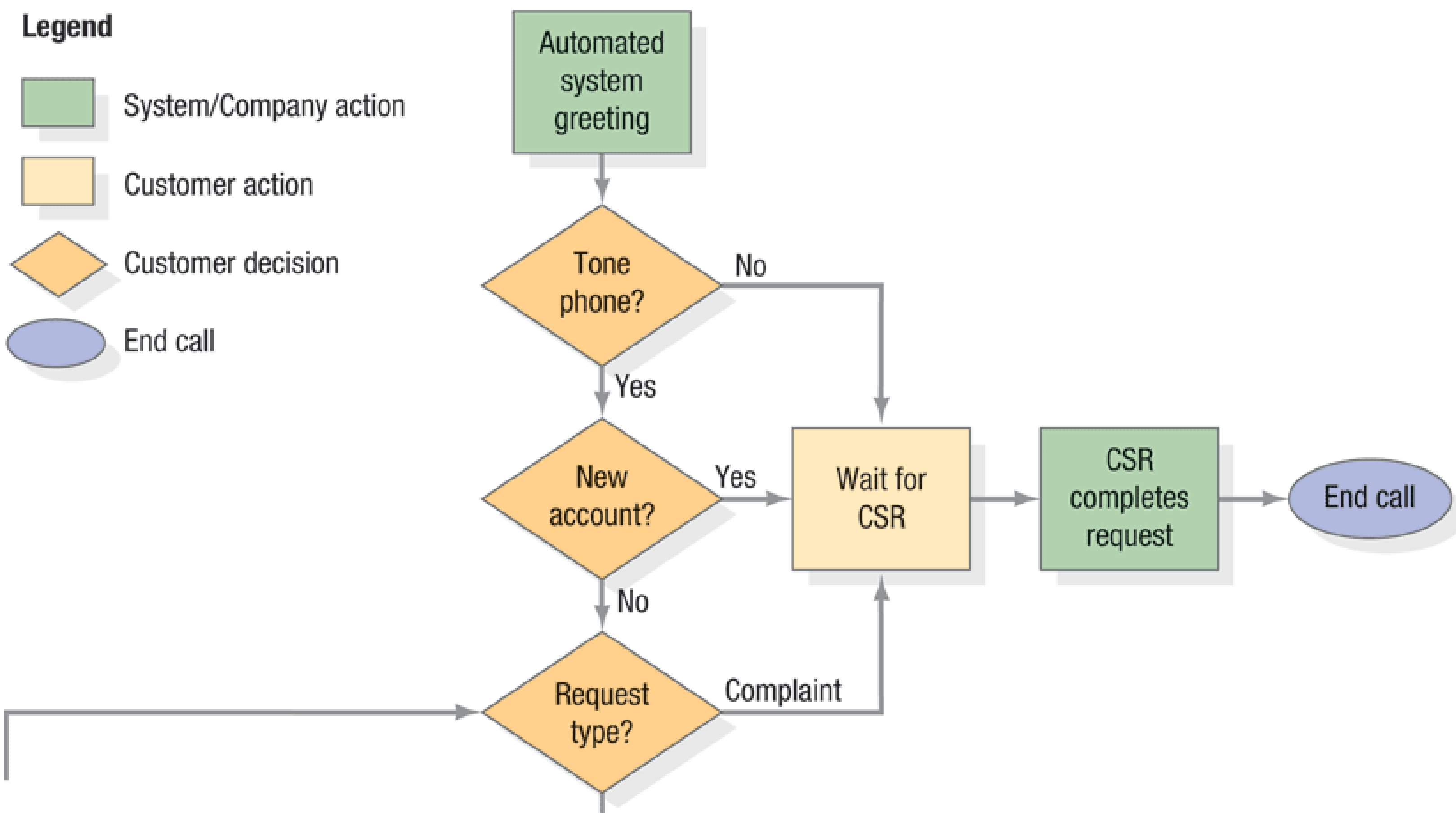


Figure 2.16

Continued on Next Slide

Solved Problem 1

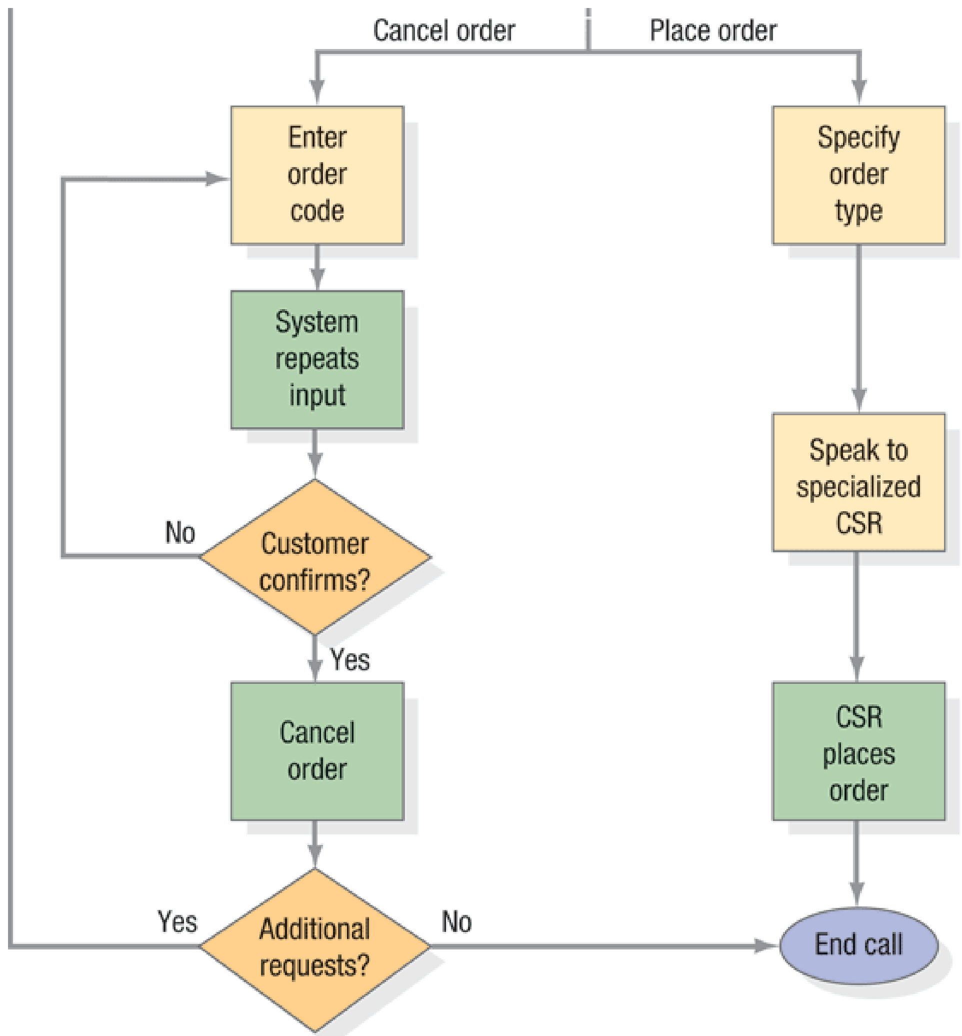


Figure 2.16

Solved Problem 2

An automobile service is having difficulty providing oil changes in the 29 minutes or less mentioned in its advertising. You are to analyze the process of changing automobile engine oil. The subject of the study is the service mechanic. The process begins when the mechanic directs the customer's arrival and ends when the customer pays for the services.

The times add up to 28 minutes, which does not allow much room for error if the 29-minute guarantee is to be met and the mechanic travels a total of 420 feet.

Step No.	Time (min)	Distance (ft)	●	➡	■	◗	▼	Step Description
1	0.80	50.0		X				
2	1.80		X					
3	2.30				X			
4	0.80	0.30		X				
5	0.60		X					
6	0.70							
7	0.90	70.0		X				
8	1.90		X					
9	0.40				X			
10	0.60	50.0		X				
11	4.20		X					
12	0.70	40.0		X				
13	2.70		X					
14	1.30				X			Inspect for leaks
15	0.50	40.0		X				Walk to pit
16	1.00				X			Inspect for leaks
17	3.00		X					Clean and organize work area
18	0.70	80.0		X				Return to auto, drive from bay
19	0.30						X	Park the car
20	0.50	60.0		X				Walk to customer waiting area
21	2.30		X					Total charges, receive payment

Summary

Activity		Number of Steps	Time (min)	Distance (ft)
Operation	●	7	16.50	
Transport	➡	8	5.50	420
Inspect	■	4	5.00	
Delay	◗	1	0.70	
Store	▼	1	0.30	

Figure 2.17

Solved Problem 3

What improvement can you make in the process shown in Solved Problem 2?

a. **Move Step 17 to Step 21.** Customers should not have to wait while the mechanic cleans the work area.

b. **Store small inventories of frequently used filters in the pit.** Steps 7 and 10 involve travel to and from the storeroom.

c. **Use two mechanics.** Steps 10, 12, 15, and 17 involve running up and down the steps to the pit. Much of this travel could be eliminated.

Solved Problem 4

Vera Johnson and Merris Williams manufacture vanishing cream. Their packaging process has four steps: (1) mix, (2) fill, (3) cap, and (4) label. They have had the reported process failures analyzed, which shows the following:

Defect	Frequency
Lumps of unmixed product	7
Over- or underfilled jars	18
Jar lids did not seal	6
Labels rumpled or missing	29
Total	60

Draw a Pareto chart to identify the vital defects.

Solved Problem 4

Defective labels account for 48.33 percent of the total number of defects:

$$\frac{29}{60} \times 100\% = 48.33\%$$

Improperly filled jars account for 30 percent of the total number of defects:

$$\frac{18}{60} \times 100\% = 30.00\%$$

The cumulative percent for the two most frequent defects is

$$48.33\% + 30.00\% = 78.33\%$$

Solved Problem 4

Lumps represent $\frac{7}{60} \times 100\% = 11.67\%$ of defects;

the cumulative percentage is

$$78.33\% + 11.67\% = 90.00\%$$

Defective seals represent $\frac{6}{60} \times 100\% = 10\%$ of defects;

the cumulative percentage is

$$10\% + 90\% = 100.00\%$$

Solved Problem 4

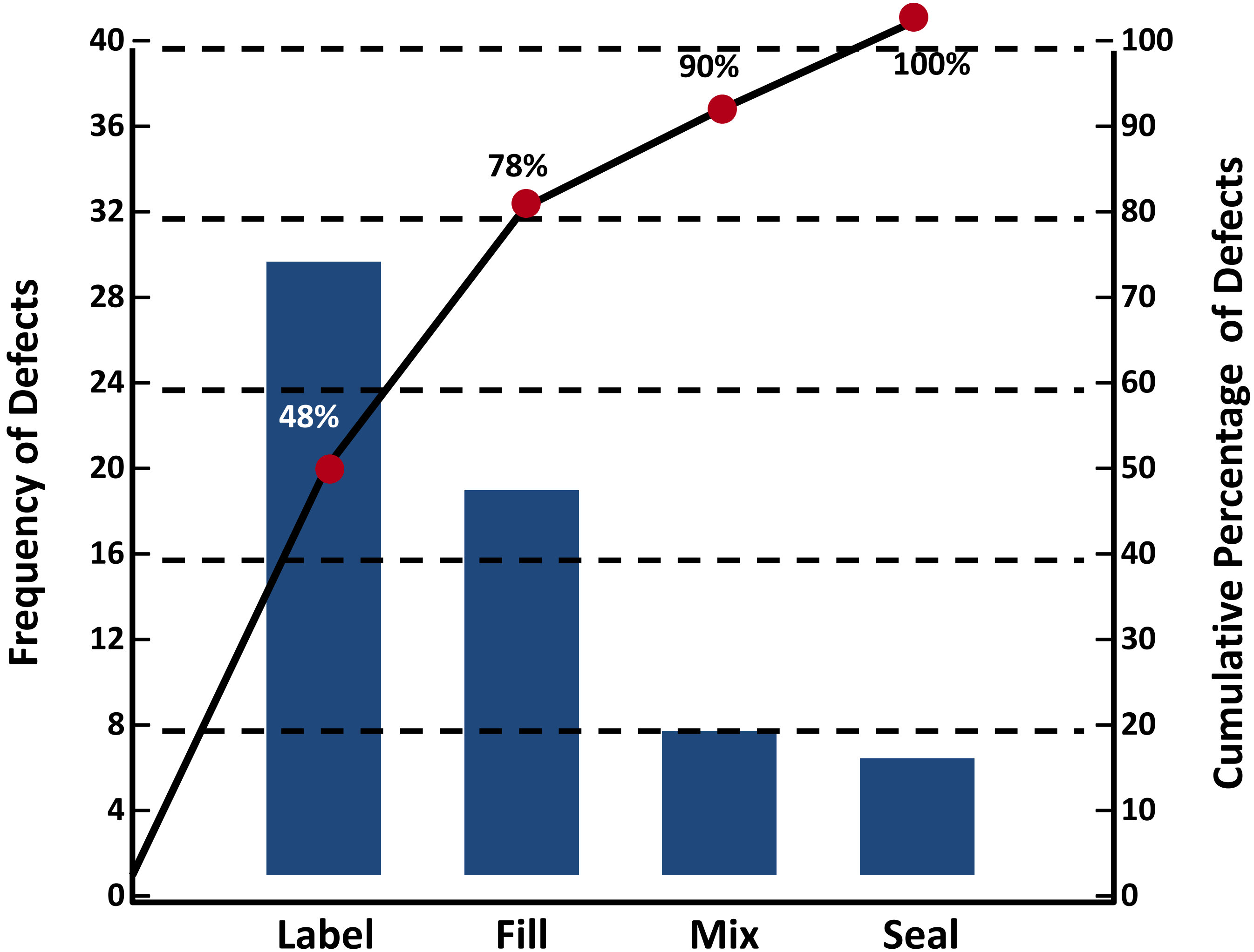
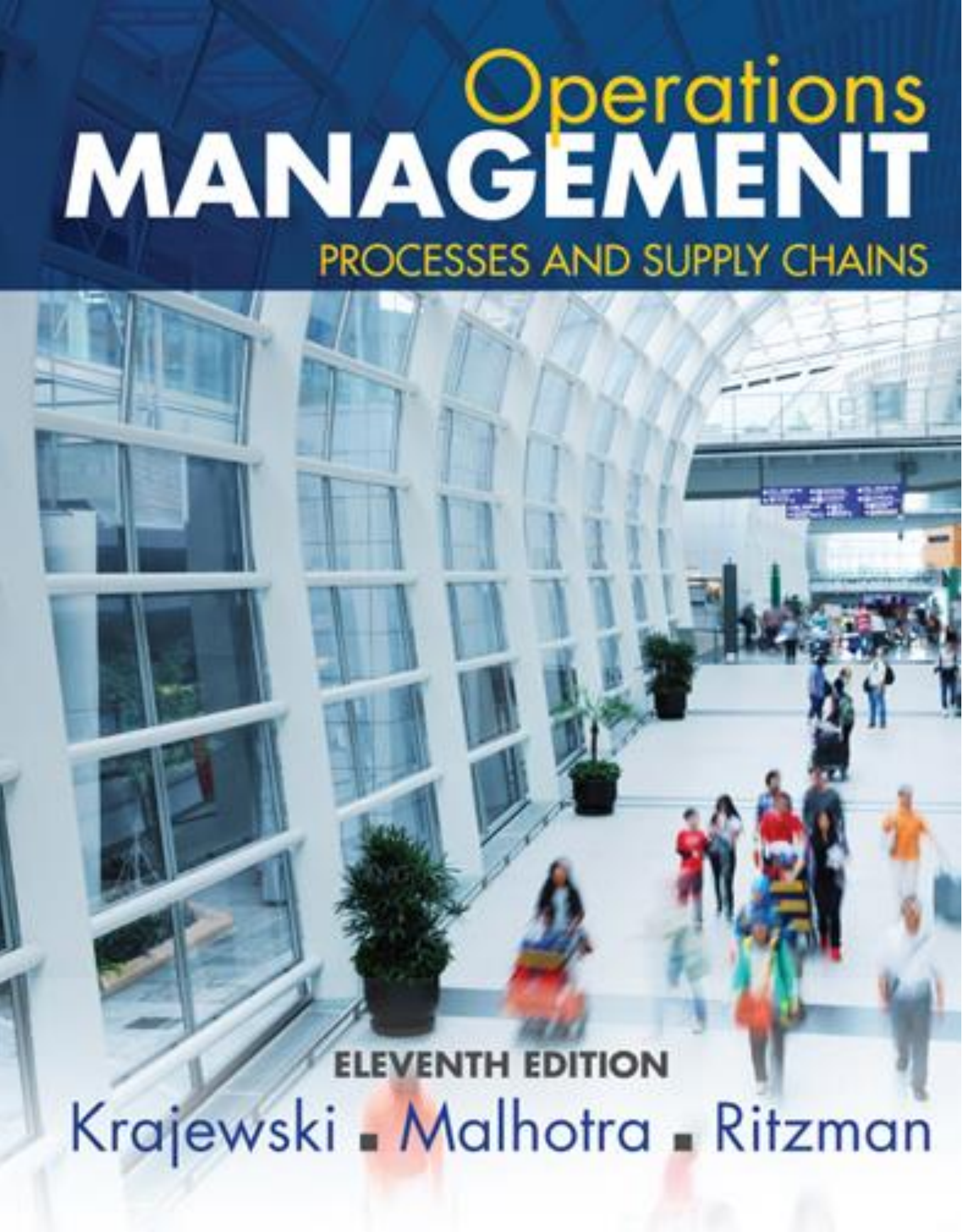


Figure 2.18



Capacity Planning

Chapter 4

What is Capacity?

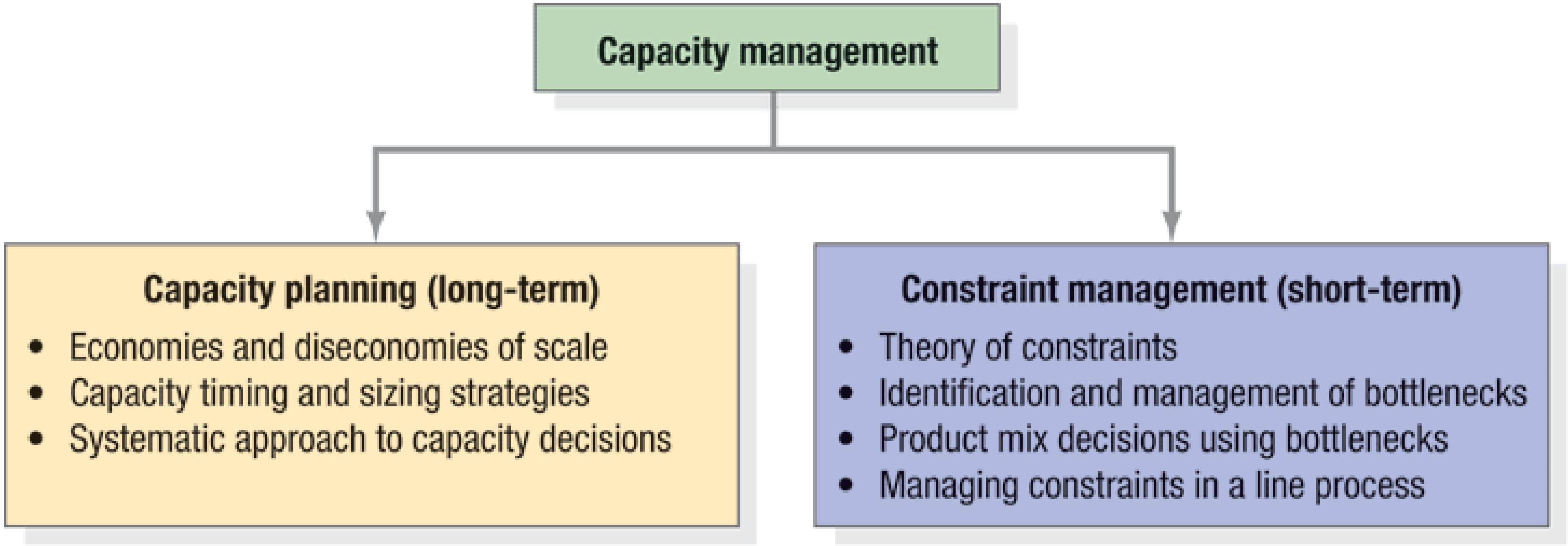
Capacity

The maximum rate of output of a process or a system.

What is Capacity Management?

Capacity

The maximum rate of output of a process or a system.



Measures of Capacity and Utilization

- Output Measures of Capacity
- Input Measures of Capacity
- Utilization

$$\text{Utilization} = \frac{\text{Average output rate}}{\text{Maximum capacity}} \times 100\%$$

Measures of Capacity

- Use Output Measures when:
  - The firm uses high volume, standardized processes
- Use Input Measures when:
  - The firm uses low-volume, flexible processes

Economies and Diseconomies of Scale

- Economies of scale
  - Spreading fixed costs
  - Reducing construction costs
  - Cutting costs of purchased materials
  - Finding process advantages
- Diseconomies of scale
  - Complexity
  - Loss of focus
  - Inefficiencies

Economies and Diseconomies of Scale

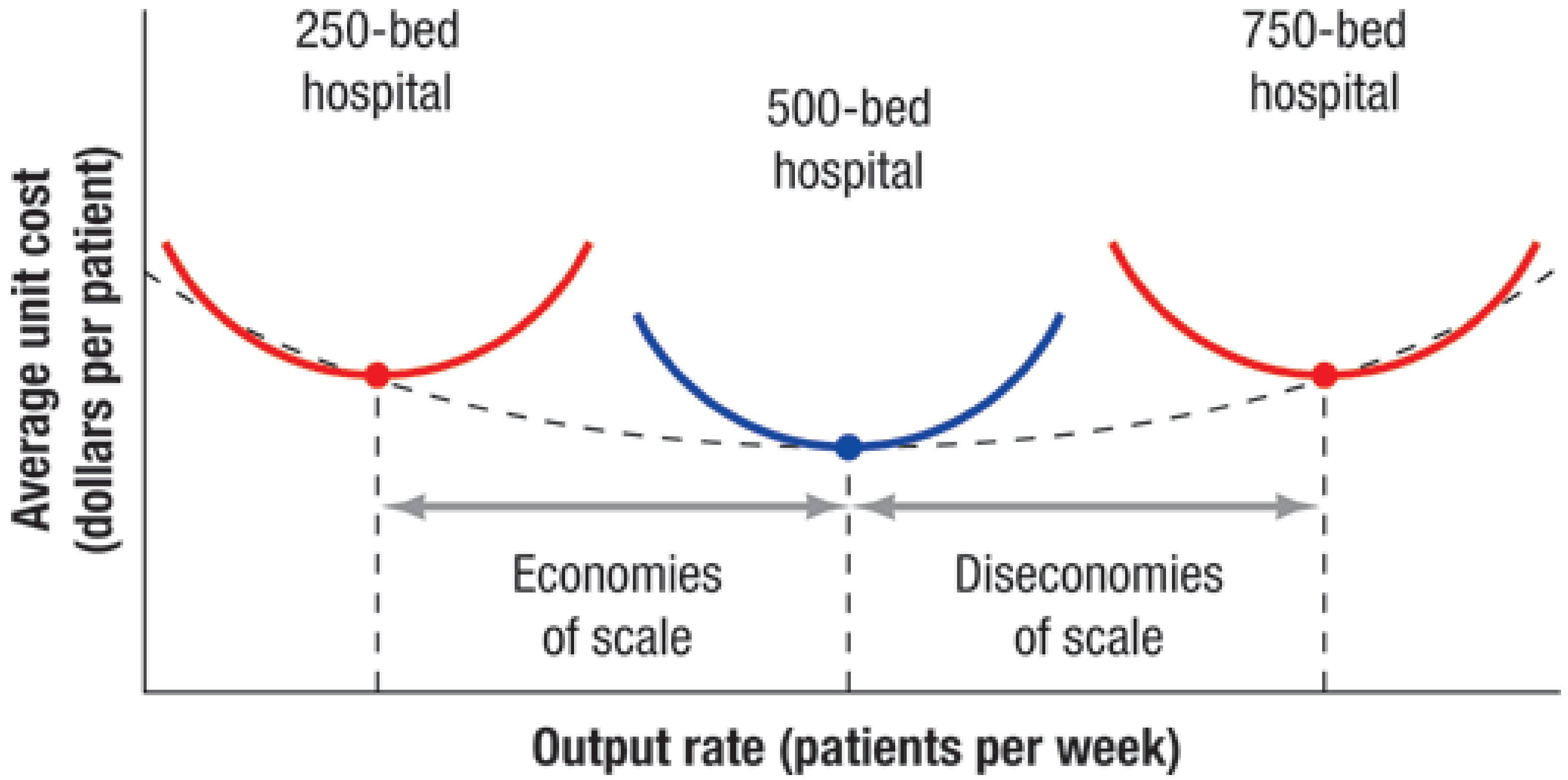


Figure 4.1

Capacity Timing and Sizing Strategies

- Sizing Capacity Cushions
- Timing and Sizing Expansion
- Linking Process Capacity and Other Decisions

Sizing Capacity Cushions

- Capacity cushions – the amount of reserve capacity a process uses to handle sudden increases in demand or temporary losses of production capacity.
  - It measures the amount by which the average utilization (in terms of total capacity) falls below 100 percent.

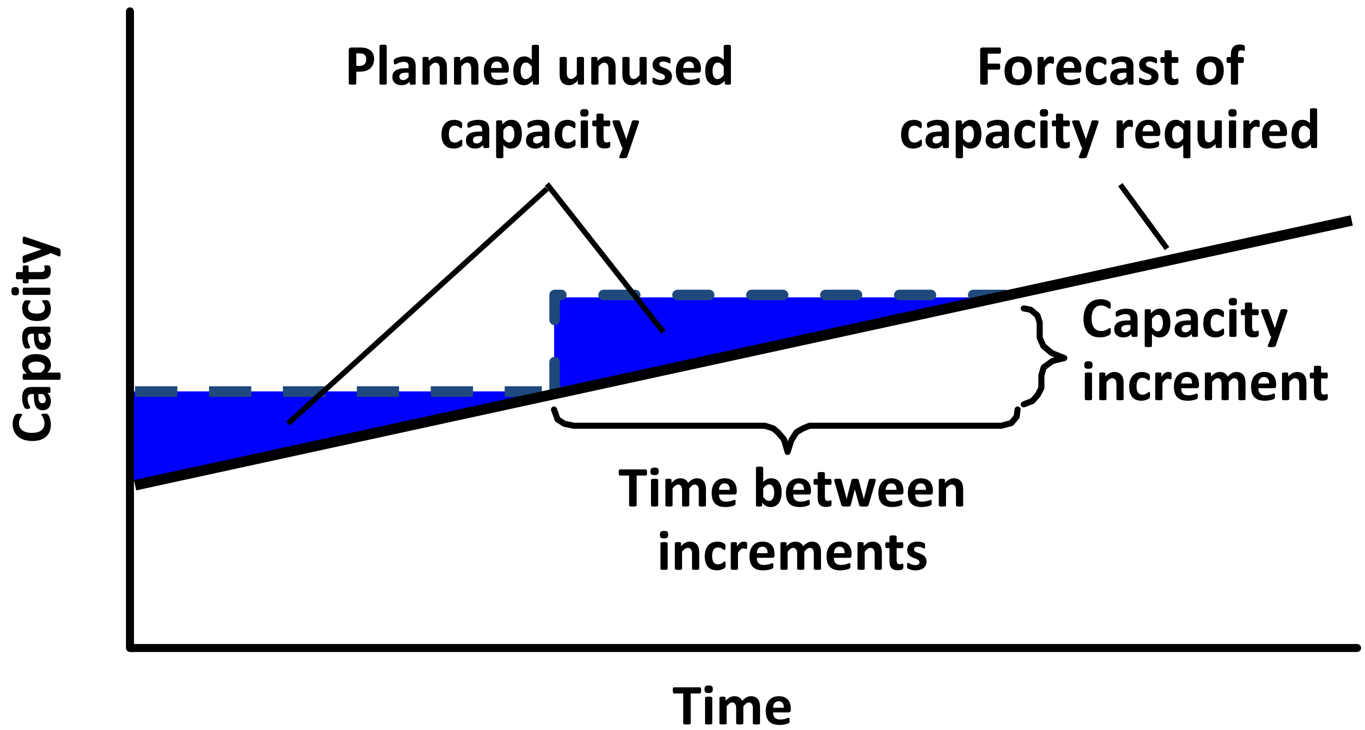
Sizing Capacity Cushions

- Capacity cushion =

  100% – Average Utilization rate (%)

  – Capacity cushions vary with industry
  – Capital intensive industries prefer cushions well under 10 percent while hotel industry can live with 30 to 40 percent cushion.

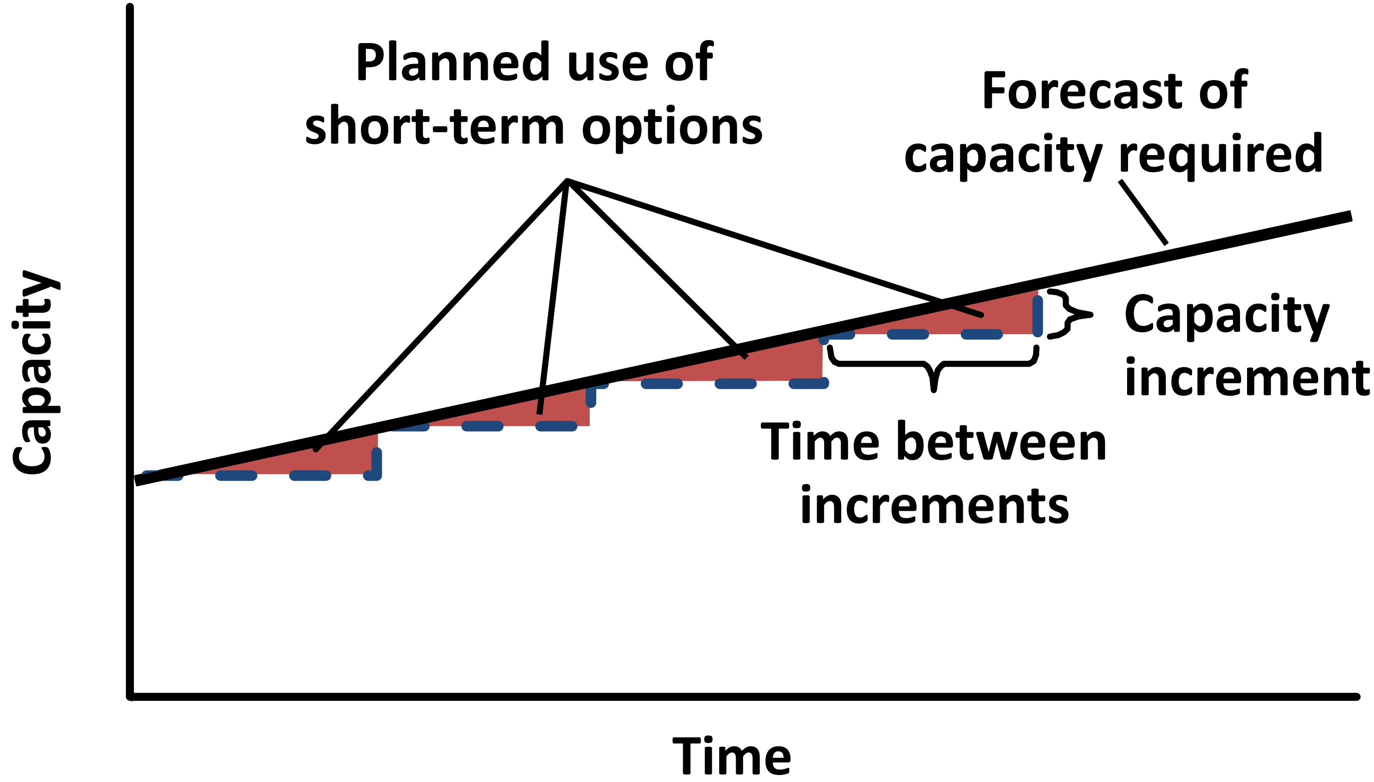
Capacity Timing and Sizing



(a) Expansionist strategy

Figure 4.2

Capacity Timing and Sizing



(b) Wait-and-see strategy

Figure 4.2

A Systematic Approach to Long-Term Capacity Decisions

1. Estimate future capacity requirements
2. Identify gaps by comparing requirements with available capacity
3. Develop alternative plans for reducing the gaps
4. Evaluate each alternative, both qualitatively and quantitatively, and make a final choice

Step 1 - Estimate Capacity Requirements

For one service or product processed at one operation with a one year time period, the capacity requirement, M, is

$$\text{Capacity requirement} = \frac{\text{Processing hours required for year's demand}}{\text{Hours available from a single capacity unit (such as an employee or machine) per year, after deducting desired cushion}}$$

$$M = \frac{Dp}{N[1 - (C/100)]}$$

where

D = demand forecast for the year (number of customers served or units produced)

p = processing time (in hours per customer served or unit produced)

N = total number of hours per year during which the process operates

C = desired capacity cushion (expressed as a percent)

Step 1 - Estimate Capacity Requirements

Setup times may be required if multiple products are produced

$$\text{Capacity requirement} = \frac{\text{Processing and setup hours required for year's demand, summed over all services or products}}{\text{Hours available from a single capacity unit per year, after deducting desired cushion}}$$

$$M = \frac{[Dp + (D/Q)s]_{\text{product 1}} + [Dp + (D/Q)s]_{\text{product 2}} + \ldots + [Dp + (D/Q)s]_{\text{product } n}}{N[1 - (C/100)]}$$

where

Q = number of units in each lot

s = setup time in hours per lot

Example 4.1

A copy center in an office building prepares bound reports for two clients. The center makes multiple copies (the lot size) of each report. The processing time to run, collate, and bind each copy depends on, among other factors, the number of pages. The center operates 250 days per year, with one 8-hour shift. Management believes that a capacity cushion of 15 percent (beyond the allowance built into time standards) is best. It currently has three copy machines. Based on the following information, determine how many machines are needed at the copy center.

Item	Client X	Client Y
Annual demand forecast (copies)	2,000	6,000
Standard processing time (hour/copy)	0.5	0.7
Average lot size (copies per report)	20	30
Standard setup time (hours)	0.25	0.40

Example 4.1

$$M = \frac{[Dp + (D/Q)s]_{\text{product 1}} + [Dp + (D/Q)s]_{\text{product 1}} + \ldots + [Dp + (D/Q)s]_{\text{product } n}}{N[1 - (C/100)]}$$

$$= \frac{[2{,}000(0.5) + (2{,}000/20)(0.25)]_{\text{client X}} + [6{,}000(0.7) + (6{,}000/30)(0.40)]_{\text{client Y}}}{[(250 \text{ day/year})(1 \text{ shift/day})(8 \text{ hours/shift})][1.0 - (15/100)]}$$

$$= \frac{5{,}305}{1{,}700} = 3.12$$

Rounding up to the next integer gives a requirement of four machines.

Application Problem 4.1

You have been asked to put together a capacity plan for a critical operation at the Surefoot Sandal Company. Your capacity measure is number of machines. Three products (men's, women's, and children's sandals) are manufactured. The time standards (processing and setup), lot sizes, and demand forecasts are given in the following table. The firm operates two 8-hour shifts, 5 days per week, 50 weeks per year. Experience shows that a capacity cushion of 5 percent is sufficient.

	Time Standards			
Product	Processing (hr/pair)	Setup (hr/pair)	Lot size (pairs/lot)	Demand Forecast (pairs/yr)
Men's sandals	0.05	0.5	240	80,000
Women's sandals	0.10	2.2	180	60,000
Children's sandals	0.02	3.8	360	120,000

a. How many machines are needed?

b. If the operation currently has two machines, what is the capacity gap?

Application Problem 4.1

a. The number of hours of operation per year, N, is N = (2 shifts/day)(8 hours/shifts) (250 days/machine-year) = 4,000 hours/machine-year

The number of machines required, M, is the sum of machine-hour requirements for all three products divided by the number of productive hours available for one machine:

$$M = \frac{[Dp + (D/Q)s]_{\text{men}} + [Dp + (D/Q)s]_{\text{women}} + [Dp + (D/Q)s]_{\text{children}}}{N[1 - (C/100)]}$$

$$= \frac{[80{,}000(0.05) + (80{,}000/240)0.5] + [60{,}000(0.10) + (60{,}000/180)2.2] + [120{,}000(0.02) + (120{,}000/360)3.8]}{4{,}000[1 - (5/100)]}$$

$$= \frac{14{,}567 \text{ hours/year}}{3{,}800 \text{ hours/machine-year}} = 3.83 \text{ or } 4 \text{ machines}$$

Application Problem 4.1

b. The capacity gap is 1.83 machines (3.83 –2). Two more machines should be purchased, unless management decides to use short-term options to fill the gap.

The *Capacity Requirements* Solver in OM Explorer confirms these calculations, as Figure 6.5 shows, using only the "Expected" scenario for the demand forecasts.

Shifts/Day	2
Hours/Shift	8
Days/Week	5
Weeks/Year	50
Cushion (as %)	5%
Current capacity	2

Components: 3

▲ More Components
▼ Fewer Components

Components	Processing (hr/unit)	Setup (hr/lot)	Lot Size (units/lot)	Demand Forecasts: Pessimistic	Demand Forecasts: Expected	Demand Forecasts: Optimistic
Men's sandals	0.05	0.5	240		80,000	
Women's sandals	0.10	2.2	180		60,000	
Children's sandals	0.02	3.8	360		120,000	

Productive hours from one capacity unit for a year	3,800

Application Problem 4.1

	Pessimistic		Expected		Optimistic	
	Process	Setup	Process	Setup	Process	Setup
Men's sandals	0	0.0	4,000	166.7	0	0.0
Women's sandals	0	0.0	6,000	733.3	0	0.0
Children's sandals	0	0.0	2,400	1,266.7	0	0.0
	0	0.0	12,400	2,166.7	0	0.0
Total hours required		0.0		14,566.7		0.0
Total capacity requirements (M)		0.00		3.83		0.00
Rounded		0		4		0
Scenarios that can be met with current system/capacity:			Pessimistic, Optimistic			
If capacity increased by		0%				
Expanded current capacity		3,800				
Total capacity requirements (M)		0.00		3.83		0.00
Rounded		0		4		0
Scenarios that can be met with expanded current capacity:			Pessimistic, Optimistic			

Step 2 - Identify Gaps

- Identify gaps between projected capacity requirements (M) and current capacity
  - Complicated by multiple operations and resource inputs

Steps 3 and 4 –
Develop and Evaluate Alternatives

- Base case is to do nothing and suffer the consequences
- Many different alternatives are possible
- Qualitative concerns include strategic fit and uncertainties.
- Quantitative concerns may include cash flows and other quantitative measures.

Example 4.2

Grandmother's Chicken Restaurant is experiencing a boom in business. The owner expects to serve 80,000 meals this year. Although the kitchen is operating at 100 percent capacity, the dining room can handle 105,000 diners per year. Forecasted demand for the next five years is 90,000 meals for next year, followed by a 10,000-meal increase in each of the succeeding years. One alternative is to expand both the kitchen and the dining room now, bringing their capacities up to 130,000 meals per year. The initial investment would be $200,000, made at the end of this year (year 0). The average meal is priced at $10, and the before-tax profit margin is 20 percent. The 20 percent figure was arrived at by determining that, for each $10 meal, $8 covers variable costs and the remaining $2 goes to pretax profit.

What are the pretax cash flows from this project for the next five years compared to those of the base case of doing nothing?

Example 4.2

- The base case of doing nothing results in losing all potential sales beyond 80,000 meals.
- With the new capacity, the cash flow would equal the extra meals served by having a 130,000-meal capacity, multiplied by a profit of $2 per meal.
- In year 0, the only cash flow is –$200,000 for the initial investment.
- In year 1, the incremental cash flow is (90,000 – 80,000)($2) = $20,000.

Year 2: Demand = 100,000; Cash flow = (100,000 – 80,000)$2 = $40,000

Year 3: Demand = 110,000; Cash flow = (110,000 – 80,000)$2 = $60,000

Year 4: Demand = 120,000; Cash flow = (120,000 – 80,000)$2 = $80,000

Year 5: Demand = 130,000; Cash flow = (130,000 – 80,000)$2 = $100,000

Example 4.2

- The owner should account for the time value of money, applying such techniques as the net present value or internal rate of return methods (see Supplement F, "Financial Analysis," in MyOMLab).
- For instance, the net present value (NPV) of this project at a discount rate of 10 percent is calculated here, and equals $13,051.76.

$$\begin{aligned} NPV &= -200{,}000 + [(20{,}000/1.1)] + [40{,}000/(1.1)^2] + \\ &\quad [60{,}000/(1.1)^3] + [80{,}000/(1.1)^4] + [100{,}000/(1.1)^5] \\ &= -\$200{,}000 + \$18{,}181.82 + \$33{,}057.85 + \$45{,}078.89 + \\ &\quad \$54{,}641.07 + \$62{,}092.13 \\ &= \$13{,}051.76 \end{aligned}$$

Application Problem 4.2

The base case for Grandmother's Chicken Restaurant (see Example 6.2) is to do nothing. The capacity of the kitchen in the base case is 80,000 meals per year. A capacity alternative for Grandmother's Chicken Restaurant is a two-stage expansion. This alternative expands the kitchen at the end of year 0, raising its capacity from 80,000 meals per year to that of the dining area (105,000 meals per year). If sales in year 1 and 2 live up to expectations, the capacities of both the kitchen and the dining room will be expanded at the end of year 3 to 130,000 meals per year. This upgraded capacity level should suffice up through year 5. The initial investment would be $80,000 at the end of year 0, and an additional investment of $170,000 at the end of year 3. The pretax profit is $2 per meal. What are the pretax cash flows for this alternative through year 5, compared with the base case?

Application Problem 4.2

- The following table shows the cash inflows and outflows.
- Year 3 cash flow:
  - The cash inflow from sales is $50,000 rather than $60,000.
  - The increase in sales over the base is 25,000 meals (105,000 – 10,000) instead of 30,000 meals (110,000 – 80,000)
  - A cash outflow of $170,000 occurs at the end of year 3, when the second-stage expansion occurs.
- The net cash flow for year 3 is $50,000 – $170,000 = **–$120,000**

Application Problem 4.2

CASH FLOWS FOR TWO-STAGE EXPANSION AT GRANDMOTHER'S CHICKEN RESTAURANT				
Year	Projected Demand (meals/yr)	Projected Capacity (meals/yr)	Calculation of Incremental Cash Flow Compared to Base Case (80,000 meals/yr)	Cash Inflow (outflow)
0	80,000	80,000	Increase kitchen capacity to 105,000 meals =	-$80,000
1	90,000	105,000	90,000 – 80,000 = (10,000 meals)($2/meal) =	$20,000
2	100,000	105,000	100,000 – 80,000 = (20,000 meals)($2/meal) =	$40,000
3	110,000	105,000	105,000 – 80,000 = (25,000 meals)($2/meal) =	$50,000
			Increase total capacity to 130,000 meals =	-$170,000
				-$120,000
4	120,000	130,000	120,000 – 80,000 = (40,000 meals)($2/meal) =	$80,000
5	130,000	130,000	130,000 – 80,000 = (50,000 meals)($2/meal) =	$100,000

Application Problem 4.2

For comparison purposes, the NPV of this project at a discount rate of 10 percent is calculated as follows, and equals negative $2,184.90.

$$NPV = -80{,}000 + (20{,}000/1.1) + [40{,}000/(1.1)^2] - [120{,}000/(1.1)^3] + [80{,}000/(1.1)^4] + [100{,}000/(1.1)^5]$$

$$= -\$80{,}000 + \$18{,}181.82 + \$33{,}057.85 - \$90{,}157.77 + \$54{,}641.07 + \$62{,}092.13$$

$$= -\$2{,}184.90$$

- **On a purely monetary basis, a single-stage expansion seems to be a better alternative than this two-stage expansion.**
- **However, other qualitative factors as mentioned earlier must be considered as well.**

Tools for Capacity Planning

- Waiting-line models
  - Useful in high customer-contact processes
- Simulation
  - Useful when models are too complex for waiting-line analysis
- Decision trees
  - Useful when demand is uncertain and sequential decisions are involved

Waiting Line Models

Waiting Lines Results

Example Solution						
Parameter	Value	Parameter	Value	Minutes	Seconds	
Single-Server Model		Average server utilization	.5			
Arrival rate(lambda)	3	Average number in the line(Lq)	.5			
Service rate(mu)	6	Average number in the system(L)	1			
Number of servers	1	Average time in the line(Wq)	.17	10	600	
		Average time in the system(W)	.33	20	1200	

Table of Probabilities

Example Solution			
k	Prob (num in sys = k)	Prob (num in sys <= k)	Prob (num in sys >k)
0	.5	.5	.5
1	.25	.75	.25
2	.13	.88	.13
3	.06	.94	.06
4	.03	.97	.03
5	.02	.98	.02
6	.01	1	.01
7	.0	1	.0

Figure 4.3

Decision Trees

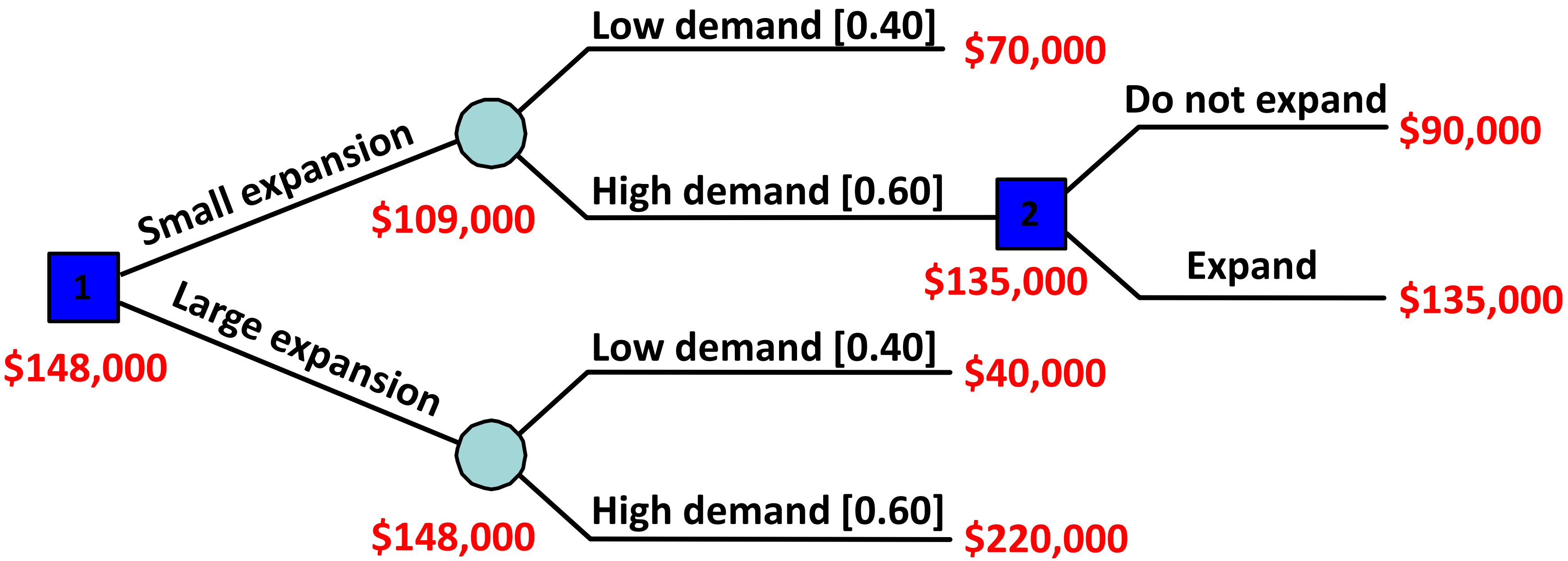
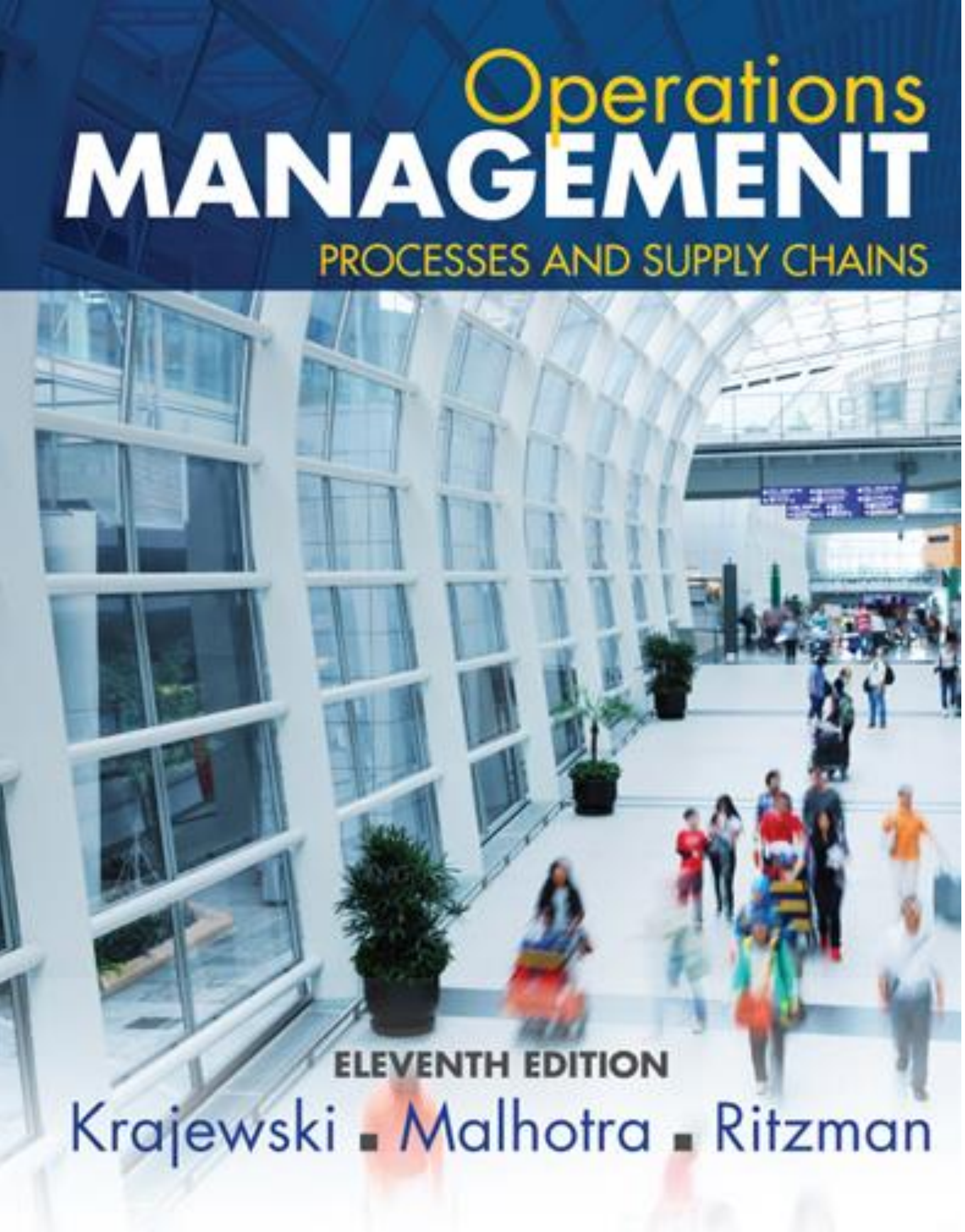


Figure 4.4



Constraint Management

Chapter 5

What is a Constraint?

Constraint

Any factor that limits the performance of a system and restricts its output.

Bottleneck

A capacity constraint resource (CCR) whose available capacity limits the organization's ability to meet the product volume, product mix, or demand fluctuations required by the marketplace

The Theory of Constraints

- **The Theory of Constraints (TOC)**
  - **A systematic management approach that focuses on actively managing those constraints that impede a firm's progress toward its goal**

The Theory of Constraints

Operational Measures	TOC View	Relationship to Financial Measures
Inventory (I)	All the money invested in a system in purchasing things that it intends to sell	A decrease in I leads to an increase in net profit, ROI, and cash flow.
Throughput (T)	Rate at which a system generates money through sales	An increase in T leads to an increase in net profit, ROI, and cash flows.
Operating Expense (OE)	All the money a system spends to turn inventory into throughput	A decrease in OE leads to an increase in net profit, ROI, and cash flows.
Utilization (U)	The degree to which equipment, space, or workforce is currently being used; it is measured as the ratio of average output rate to maximum capacity, expressed as a percentage	An increase in U at the bottleneck leads to an increase in net profit, ROI, and cash flows.

Table 5.1

Key Principles of the TOC

1. The focus should be on balancing flow, not on balancing capacity.
2. Maximizing the output and efficiency of every resource may not maximize the throughput of the entire system.
3. An hour lost at a bottleneck or constrained resource is an hour lost for the whole system.
   - An hour saved at a nonbottleneck resource does not make the system more productive.
4. Inventory is needed only in front of bottlenecks and in front of assembly and shipping points.

Key Principles of the TOC

5. Work should be released into the system only as frequently as needed by the bottlenecks.
   – Bottleneck flows = market demand
6. Activating a nonbottleneck resource is not the same as utilizing a bottleneck resource.
   – It doesn’t increase throughput or promote better performance.
7. Every capital investment must be viewed from the perspective of the global impact on overall throughput, inventory, and operating expense.

The Theory of Constraints

1. Identify the System Bottleneck(s)
2. Exploit the Bottleneck(s)
3. Subordinate All Other Decisions to Step 2
4. Elevate the Bottleneck(s)
5. Do Not Let Inertia Set In

Managing Bottlenecks in Service Processes

- **Throughput time**
  - **Total elapsed time from the start to the finish of a job or a customer being processed at one or more work centers**

Example 5.1

- Managers at the First Community Bank are attempting to shorten the time it takes customers with approved loan applications to get their paperwork processed. The flowchart for this process is shown in the next slide.
- Approved loan applications first arrive at activity or step 1, where they are checked for completeness and put in order.
- At step 2, the loans are categorized into different classes according to the loan amount and whether they are being requested for personal or commercial reasons.
- While credit checking commences at step 3, loan application data are entered in parallel into the information system for record-keeping purposes at step 4.
- Finally, all paperwork for setting up the new loan is finished at step 5. The time taken in minutes is given in parentheses.

Example 5.1

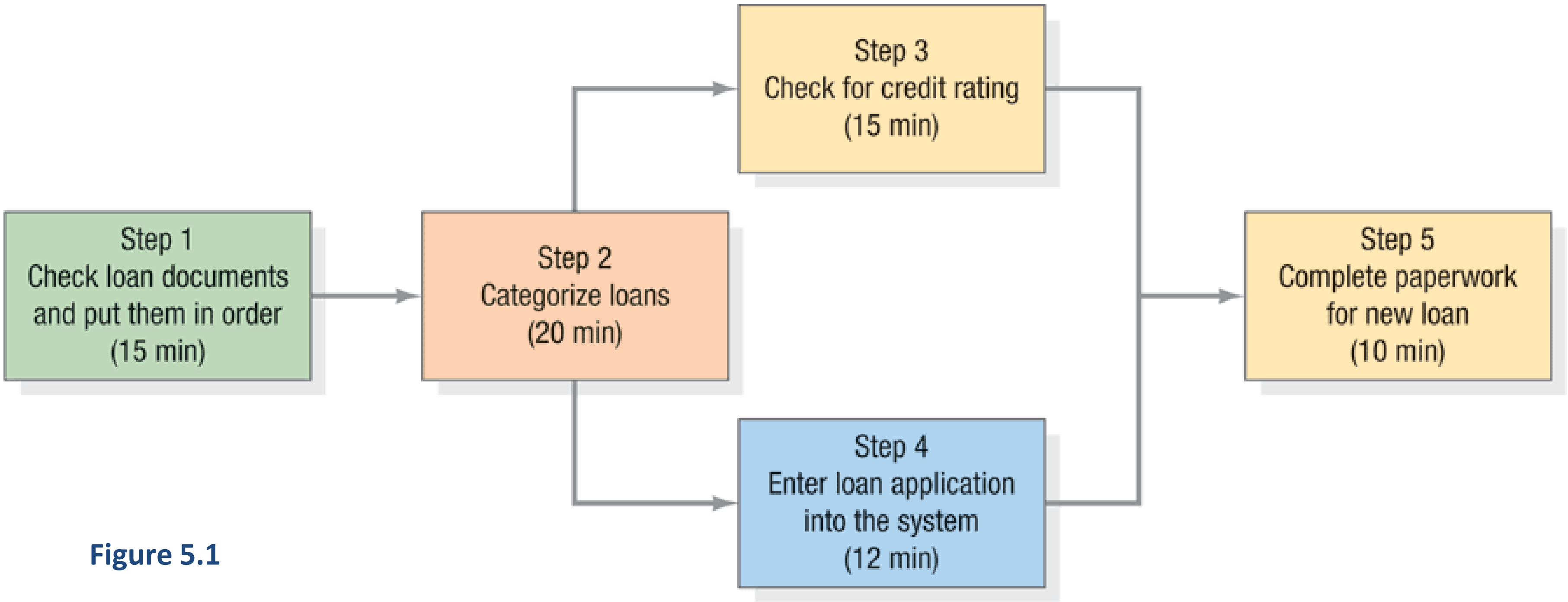


Figure 5.1

Which single step is the bottleneck? The management is also interested in knowing the maximum number of approved loans this system can process in a 5-hour work day.

Example 5.1

- We define the bottleneck as step 2, which has the highest time per loan processed.
- The throughput time to complete an approved loan application is 15 + 20 + max(15, 12) + 10 = 60 minutes.
- The actual time taken for completing an approved loan will be longer than 60 minutes due to nonuniform arrival of applications, variations in actual processing times, and the related factors.
- The capacity for loan completions is derived by translating the "minutes per customer" at the bottleneck step to "customer per hour." At First Community Bank, it is 3 customers per hour because the bottleneck step 2 can process only 1 customer every 20 minutes (60/3).

Example 5.1

- **Step 2 is the bottleneck constraint.**
- **The bank will be able to complete a maximum of only three loan accounts per hour, or 15 new loan accounts, in a 5-hour day.**
- **Management can increase the flow of loan applications by increasing the capacity of Step 2 up to the point where another step becomes the bottleneck.**

Managing Bottlenecks in Manufacturing Processes

- Identifying Bottlenecks
  - Setup times and their associated costs affect the size of the lots traveling through the job or batch processes.

Example 5.2

Diablo Electronics manufactures four unique products (A, B, C, and D) that are fabricated and assembled in five different workstations (V, W, X, Y, and Z) using a small batch process. Each workstation is staffed by a worker who is dedicated to work a single shift per day at an assigned workstation. Batch setup times have been reduced to such an extent that they can be considered negligible. Figure 5.2 is a flowchart of the manufacturing process. Diablo can make and sell up to the limit of its demand per week, and no penalties are incurred for not being able to meet all the demand.

Which of the five workstations (V, W, X, Y, or Z) has the highest utilization, and thus serves as the bottleneck for Diablo Electronics?

Example 5.2

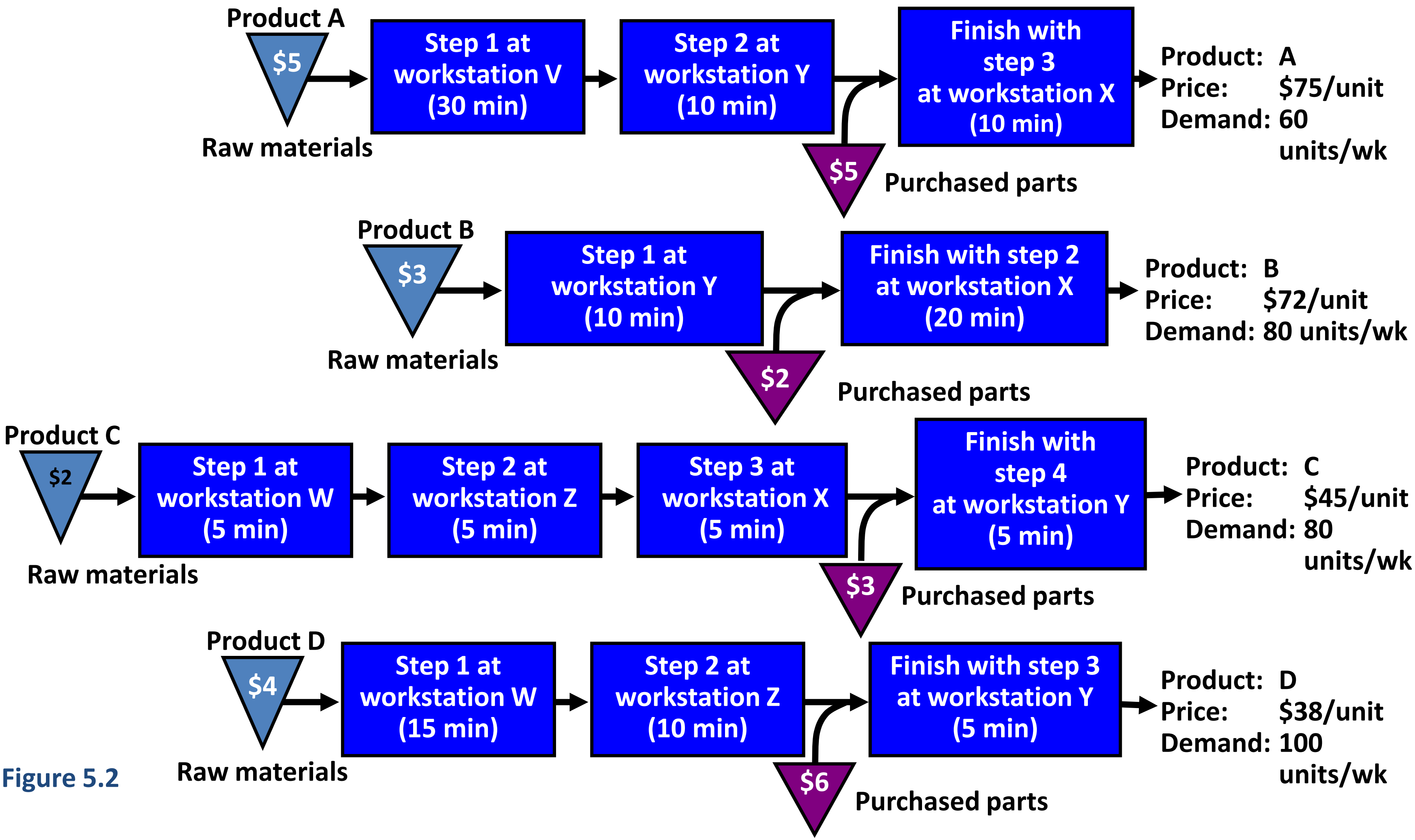


Figure 5.2

Example 5.2

- Identify the bottleneck by computing aggregate workloads at each workstation.
- The firm wants to satisfy as much of the product demand in a week as it can.
- Each week consists of 2,400 minutes of available production time.
- Multiplying the processing time at each station for a given product with the number of units demanded per week yields the workload represented by that product.
- These loads are summed across all products going through a workstation to arrive at the total load for the workstation, which is then compared with the others and the existing capacity of 2,400 minutes.

Example 5.2

Workstation	Load from Product A	Load from Product B	Load from Product C	Load from Product D	Total Load (min)
V	60 x 30 = 1800	0	0	0	1,800
W	0	0	80 x 5 = 400	100 x 15 = 1,500	1,900
X	60 × 10 = 600	80 x 20 = 1,600	80 x 5 = 400	0	2,600
Y	60 × 10 = 600	80 x 10 = 800	80 x 5 = 400	100 x 5 = 500	2,300
Z	0	0	80 x 5 = 400	100 x 10 = 1,000	1,400

These calculations show that workstation X is the bottleneck, because the aggregate work load at X exceeds the available capacity of 2,400 minutes per week.

Drum-Buffer-Rope Systems

Drum-Buffer-Rope

A planning and control system that regulates the flow of work-in-process materials at the bottleneck or the capacity constrained resource (CCR) in a productive system

Drum-Buffer-Rope Systems

- The bottleneck schedule is the **drum** because it sets the beat or the production rate for the entire plant and is linked to market demand.
- The **buffer** is the time buffer that plans early flows into the bottleneck and thus protects it from disruption.
- The **rope** represents the tying of material release to the drum beat, which is the rate at which the bottleneck controls the throughput of the entire plant.

Drum-Buffer-Rope Systems

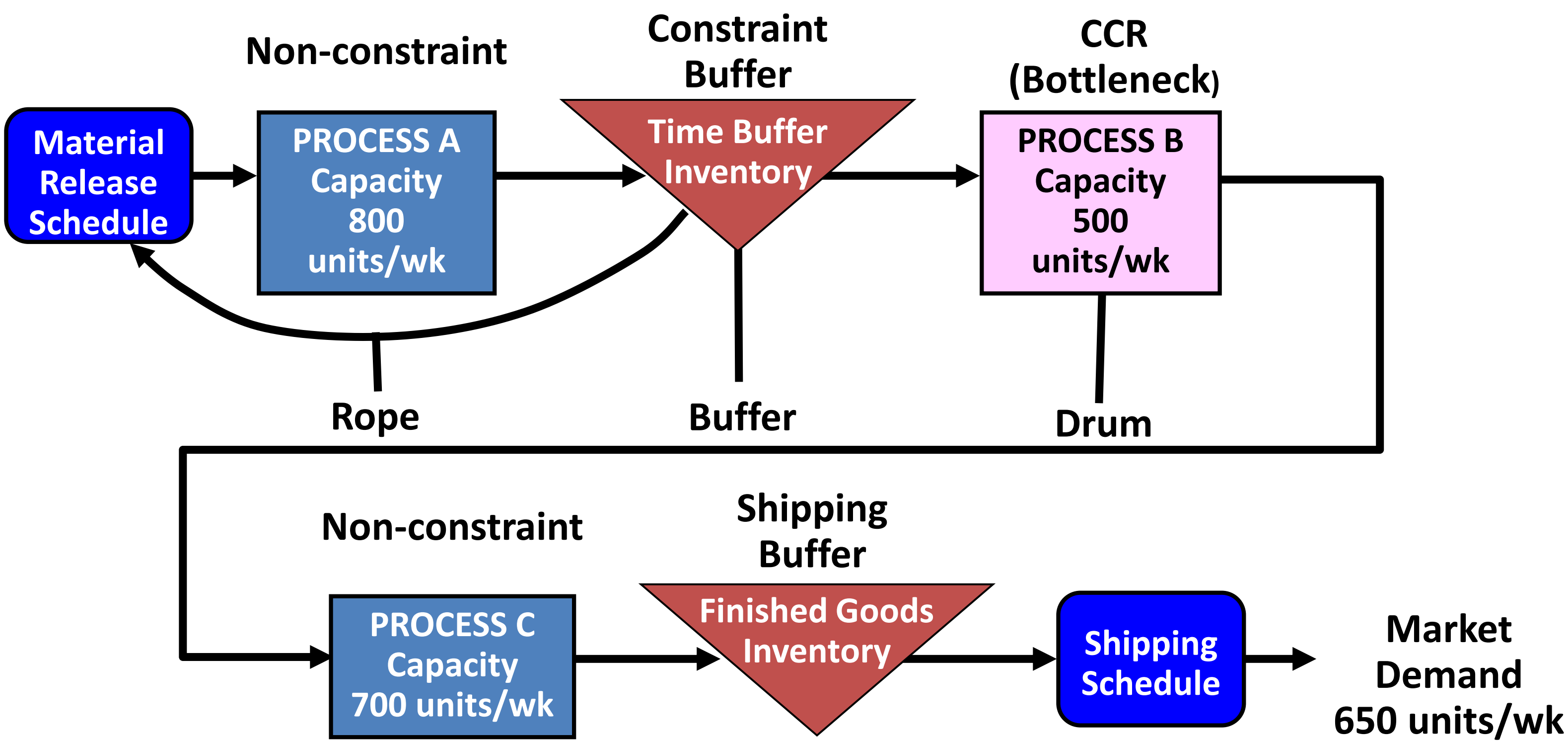


Figure 5.3

Applying the Theory of Constraints to Product Mix Decisions

- Contribution margin
  - The amount each product contributes to profits and overhead; no fixed costs are considered when making the product mix decision

Example 5.3

The senior management at Diablo Electronics (see Example 5.2) wants to improve profitability by accepting the right set of orders.

They collected the following financial data:

- Variable overhead costs are $8,500 per week.
- Each worker is paid $18 per hour and is paid for an entire week, regardless of how much the worker is used.
- Labor costs are fixed expenses.
- The plant operates one 8-hour shift per day, or 40 hours each week.

Currently, decisions are made using the traditional method, which is to accept as much of the highest contribution margin product as possible (up to the limit of its demand), followed by the next highest contribution margin product, and so on until no more capacity is available.

Example 5.3

Pedro Rodriguez, the newly hired production supervisor, is knowledgeable about the Theory of Constraints and bottleneck-based scheduling. He believes that profitability can indeed be improved if bottleneck resources were exploited to determine the product mix.

What is the change in profits if, instead of the traditional method used by Diablo Electronics, the bottleneck method advocated by Pedro is used to select the product mix?

Example 5.3

Decision Rule 1: Traditional Method

Step 1: Calculate the contribution margin per unit of each product as shown here.

	A	B	C	D
Price	$75.00	$72.00	$45.00	$38.00
Raw material and purchased parts	–10.00	–5.00	–5.00	–10.00
= Contribution margin	$65.00	$67.00	$40.00	$28.00

When ordered from highest to lowest, the contribution margin per unit sequence of these products is B, A, C, D.

Example 5.3

Step 2: Allocate resources V, W, X, Y, and Z to the products in the order decided in Step 1. Satisfy each demand until the bottleneck resource (workstation X) is encountered. Subtract minutes away from 2,400 minutes available for each week at each stage.

Work Center	Minutes at the Start	Minutes Left After Making 80 B	Minutes Left After Making 60 A	Can Only Make 40 C	Can Only Make 100 D
V	2,400	2,400	600	600	600
W	2,400	2,400	2,400	2,200	700
X	2,400	800	200	0	0
Y	2,400	1,600	1,000	800	300
Z	2,400	2,400	2,400	2,200	1,200

The best product mix according to this traditional approach is then 60 A, 80 B, 40 C, and 100 D.

Example 5.3

Step 3: Compute profitability for the selected product mix.

Profits			
Revenue	(60 × \$75) + (80 × \$72) + (40 × \$45) + (100 × \$38)	=	\$15,860
Materials	(60 × \$10) + (80 × \$5) + (40 × \$5) + (100 × \$10)	=	–\$2,200
Labor	(5 workers) × (8 hours/day) × (5 days/week) × (\$18/hour)	=	–\$3,600
Overhead		=	–\$8,500
Profit		=	\$1,560

Manufacturing the product mix of 60 A, 80 B, 40 C, and 100 D will yield a profit of \$1,560 per week.

Example 5.3

Decision Rule 2: Bottleneck Method

Select the best product mix according to the dollar contribution margin per minute of processing time at the bottleneck workstation X. This method would take advantage of the principles outlined in the Theory of Constraints and get the most dollar benefit from the bottleneck.

Example 5.3

Step 1: Calculate the contribution margin/minute of processing time at bottleneck workstation X:

	Product A	Product B	Product C	Product D
Contribution margin	$65.00	$67.00	$40.00	$28.00
Time at bottleneck	10 minutes	20 minutes	5 minutes	0 minutes
Contribution margin per minute	$6.50	$3.35	$8.00	Not defined

When ordered from highest to lowest contribution margin/ minute at the bottleneck, the manufacturing sequence of these products is D, C, A, B, which is reverse of the earlier order. Product D is scheduled first because it does not consume any resources at the bottleneck.

Example 5.3

Step 2: Allocate resources V, W, X, Y, and Z to the products in the order decided in step 1. Satisfy each demand until the bottleneck resource (workstation X) is encountered. Subtract minutes away from 2,400 minutes available for each week at each stage.

Work Center	Minutes at the Start	Minutes Left After Making 100 D	Minutes Left After Making 80 C	Minutes Left After Making 60 A	Can Only Make 70 B
V	2,400	2,400	2,400	600	600
W	2,400	900	500	500	500
X	2,400	2,400	2,000	1,400	0
Y	2,400	1,900	1,500	900	200
Z	2,400	1,400	1,000	1,000	1,000

The best product mix according to this bottleneck based approach is then 60 A, 70 B, 80 C, and 100 D.

Example 5.3

Step 3: Compute profitability for the selected product mix.

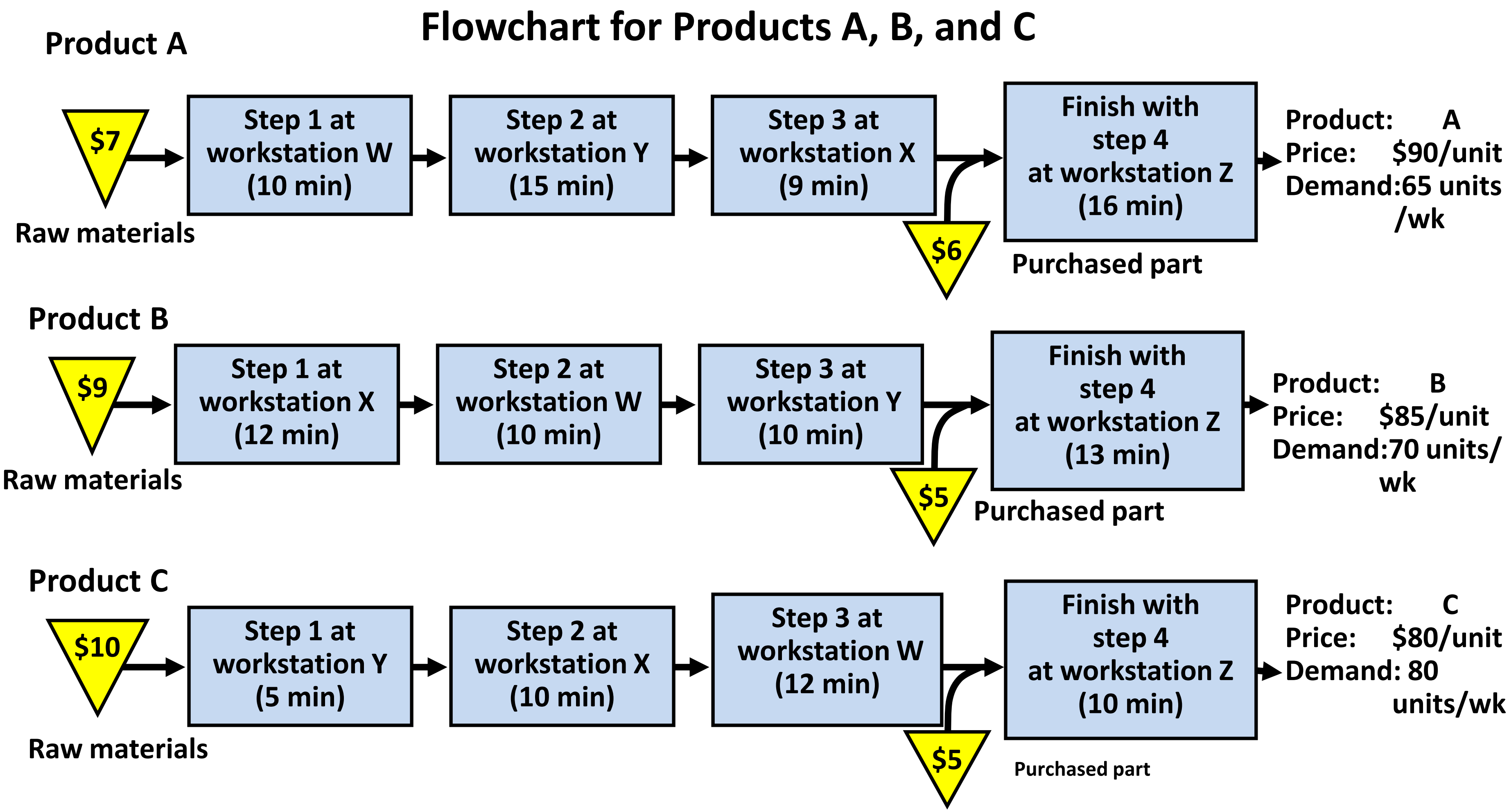
Profits			
Revenue	(60 × \$75) + (70 × \$72) + (80 × \$45) + (100 × \$38)	=	\$16,940
Materials	(60 × \$10) + (70 × \$5) + (80 × \$5) + (100 × \$10)	=	–\$2,350
Labor	(5 workers) × (8 hours/day) × (5 days/week) × (\$18/hour)	=	–\$3,600
Overhead		=	–\$8,500
Profit		=	\$2,490

Manufacturing the product mix of 60 A, 70 B, 80 C, and 100 D will yield a profit of \$2,490 per week.

Application 5.1

- O’Neill Enterprises manufactures three unique products (A, B, C) that are fabricated and assembled in four different workstations (W, X, Y, Z) using a small batch process.
- Each of the products visits every one of the four workstations, though not necessarily in the same order.
- Batch setup times are negligible.
- O’Neill can make and sell up to the limit of its demand per week, and there are no penalties for not being able to meet all the demand.
- Each workstation is staffed by a worker dedicated to work on that workstation alone, and is paid $12 per hour.
- Variable overhead costs are $8000/week. The plant operates one 8-hour shift per day, or 40 hours/week.
- Which of the four workstations W, X, Y, or Z has the highest total workload, and thus serves as the bottleneck for O’Neill Enterprises?

Application 5.1



Application 5.1

Identify the bottleneck by computing total workload at each workstation. The firm wants to satisfy as much of the product demand in a week as it can. Each week consists of 2400 minutes of available production time. Multiplying the processing time at each station for a given product with the number of units demanded per week yields the capacity load. These loads are summed across all products going through that workstation and then compared with the existing capacity of 2400 minutes.

Application 5.1

Work Station	Load from Product A	Load from Product B	Load from Product C	Total Load (minutes)
W	(65x10)=650	(70x10)=700	(80x12)=960	2310
X	(65x9)=585	(70x12)=840	(80x10)=800	2225
Y	(65x15)=975	(70x10)=700	(80x5)=400	2075
Z	(65x16)=1040	(70x13)=910	(80x10)=800	2750

These calculations show that workstation Z is the bottleneck, because the aggregate work load at Z exceeds the available capacity of 2400 minutes per week.

Application 5.2

- The senior management at O'Neill wants to improve the profitability of the firm by accepting the right set of orders.
- Currently, decisions are made to accept as much of the highest contribution margin product as possible (up to the limit of its demand), followed by the next highest contribution margin product, and so on until no more capacity is available.
- Since the firm cannot satisfy all the demand, the product mix must be chosen carefully.
- Jane Hathaway, the newly hired production supervisor, is knowledgeable about the Theory of Constraints and bottleneck based scheduling. She believes that profitability can indeed be approved if bottleneck resources were exploited to determine the product mix.

Application 5.2

Decision rule 1: Traditional method

Step 1: Calculate the profit margin per unit of each product as shown below

	A	B	C
Price	$90.00	$85.00	$80.00
Raw Material & Purchased Parts	–13.00	–14.00	–15.00
= Contribution Profit Margin	$77.00	$71.00	$65.00

When ordering from highest to lowest, the profit margin per unit order of these products is ABC.

Application 5.2

Step 2: Allocate resources W, X, Y, and Z to the products in the order decided in step 1. Satisfy each demand until the bottleneck resource (workstation Z) is encountered. Subtract minutes away from 2400 minutes available for each week at each stage.

Work Center	Starting	After 65 A	After 70 B	Can Only Make 45 C
W	2400	1750	1050	510
X	2400	1815	975	525
Y	2400	1425	725	500
Z	2400	1360	450	0

The best product mix is 65 A, 70 B, and 45 C

Application 5.2

Step 3: Compute profitability for the selected product mix.

	Profits
Revenue	$15400
Materials	–$2500
Overhead	–$8000
Labor	–$1920
Profit	$2980

Manufacturing the product mix of 65 A, 70 B, and 45 C will yield a profit of $2980.

Application 5.2

Decision rule 2: Bottleneck-based approach

Step 1: Calculate the contribution/minute of processing time at bottleneck workstation Z:

	Product A	Product B	Product C
Contribution Margin	$77.00	$71.00	$65.00
Time at Bottleneck	16 minutes	13 minutes	10 minutes
Contribution Margin per minute	4.81	5.46	6.50

When ordering from highest to lowest contribution margin/minute at the bottleneck, the manufacturing sequence of these products is CBA, which is reverse of the traditional method order.

Application 5.2

Step 2: **Allocate resources W, X, Y, and Z to the products in the order decided in step 1. Satisfy each demand until the bottleneck resource (workstation Z) is encountered. Subtract minutes away from 2400 minutes available for each week at each stage.**

Work Center	Starting	After 80 C	After 70 B	Can Only Make 43 A
W	2,400	1,440	740	310
X	2,400	1,600	760	373
Y	2,400	2,000	1300	655
Z	2,400	1,600	690	2

The best product mix is 43A, 70B, and 80C

Application 5.2

Step 3: Compute profitability for the selected product mix. The new profitability figures are shown below based on the new production quantities of 43A, 70B, and 80C.

	Profits
Revenue	$16220
Materials	–$2739
Overhead	–$8000
Labor	–$1920
Profit	$3561

Manufacturing the product mix of 43 A, 70 B, and 80 C will yield a profit of $3561.

Managing Constraints in a Line Process

- **Line Balancing**
  - The assignment of work to stations in a line so as to achieve the desired output rate with the smallest number of workstations

- **Precedence Diagram**
  - A diagram that allows one to visualize immediate predecessors better

Example 5.4

Green Grass, Inc., a manufacturer of lawn and garden equipment, is designing an assembly line to produce a new fertilizer spreader, the Big Broadcaster. Using the following information on the production process, construct a precedence diagram for the Big Broadcaster.

Work Element	Description	Time (sec)	Immediate Predecessor(s)
A	Bolt leg frame to hopper	40	None
B	Insert impeller shaft	30	A
C	Attach axle	50	A
D	Attach agitator	40	B
E	Attach drive wheel	6	B
F	Attach free wheel	25	C
G	Mount lower post	15	C
H	Attach controls	20	D, E
I	Mount nameplate	18	F, G
		Total 244	

Example 5.4

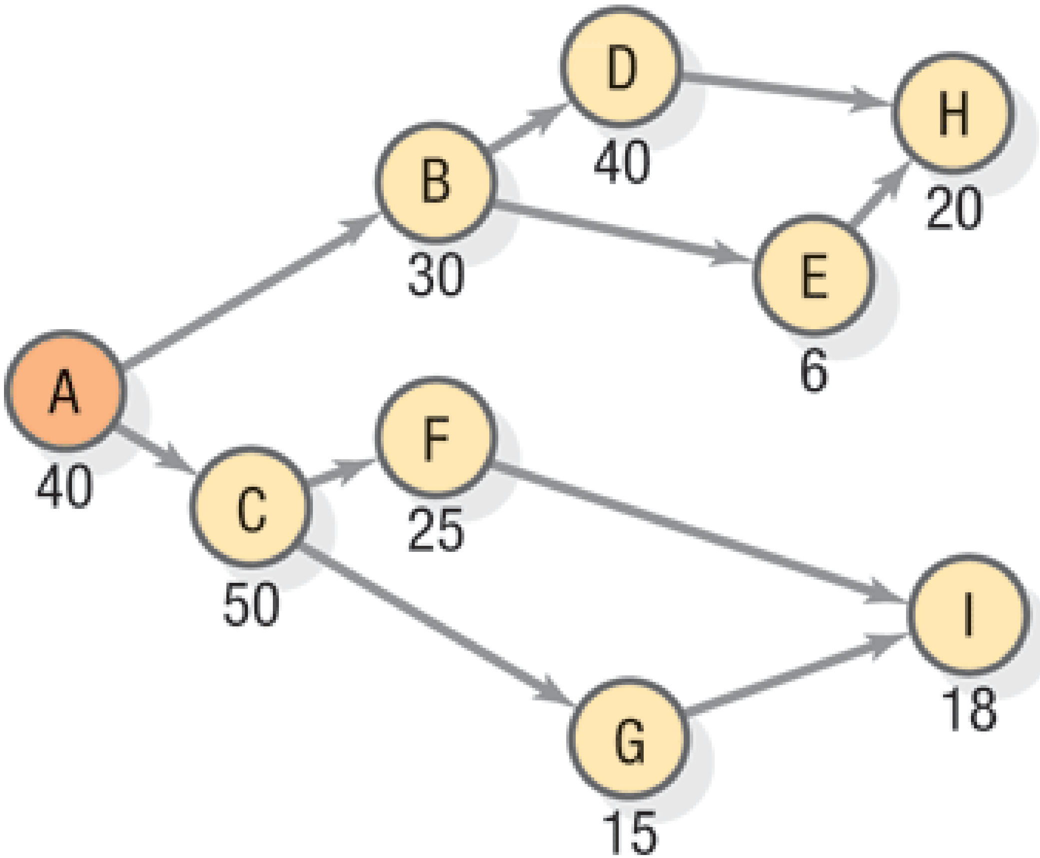


Figure 5.5

Managing Constraints in a Line Process

- **Desired output rate**
  - **Ideally is matched to the staffing or production plan**

- **Cycle time**
  - **Maximum time allowed for work a unit at each station**

$$c = \frac{1}{r}$$

where

c = cycle time in hours
r = desired output rate

Managing Constraints in a Line Process

- **Theoretical Minimum (TM)**
  - A benchmark or goal for the smallest number of stations possible

$$TM = \frac{\Sigma t}{c}$$

where

Σt = total time required to assemble each unit

c = cycle time

Managing Constraints in a Line Process

- **Idle time**
  - The total unproductive time for all stations in the assembly of each unit

$$\text{Idle time} = nc - \Sigma t$$

where

n = number of stations

c = cycle time

Σt = total time required to assemble each unit

Managing Constraints in a Line Process

- **Efficiency**
  - The ratio of productive time to total time, expressed as a percent

$$\text{Efficiency (\%)} = \frac{\Sigma t}{nc}(100)$$

- **Balance Delay**
  - The amount by which efficiency falls short of 100 percent

$$\text{Balance delay (\%)} = 100 - \text{Efficiency}$$

Example 5.5

Green Grass's plant manager just received marketing's latest forecasts of Big Broadcaster sales for the next year. She wants its production line to be designed to make 2,400 spreaders per week for at least the next 3 months. The plant will operate 40 hours per week.

a. What should be the line's cycle time?
b. What is the smallest number of workstations that she could hope for in designing the line for this cycle time?
c. Suppose that she finds a solution that requires only five stations. What would be the line's efficiency?

Example 5.5

a. First convert the desired output rate (2,400 units per week) to an hourly rate by dividing the weekly output rate by 40 hours per week to get units per hour. Then the cycle time is

$$c = 1/r = 1/60 \text{ (hr/unit)} = 1 \text{ minute/unit} = 60 \text{ seconds/unit}$$

b. Now calculate the theoretical minimum for the number of stations by dividing the total time, Σt, by the cycle time, c = 60 seconds. Assuming perfect balance, we have

$$\text{TM} = \frac{\Sigma t}{c} = \frac{244 \text{ seconds}}{60 \text{ seconds}} = 4.067 \text{ or } 5 \text{ stations}$$

Example 5.5

c. Now calculate the efficiency of a five-station solution, assuming for now that one can be found:

$$\text{Efficiency} = \frac{\Sigma t}{nc}(100) = \frac{244}{5(60)}(100) = 81.3\%$$

Managing Constraints in a Line Process

- Finding a Solution
  - The goal is to cluster the work elements into workstations so that:
    - The number of workstations required is minimized
    - The precedence and cycle-time requirements are not violated

Managing Constraints in a Line Process

Create one station at a time. For the station now being created, identify the unassigned work elements that qualify for assignment: They are candidates if 1. All of their predecessors have been assigned to this station or stations already created. 2. Adding them to the workstation being created will not create a workload that exceeds the cycle time.	
Decision Rule	**Logic**
Longest work element	Picking the candidate with the longest time to complete is an effort to fit in the most difficult elements first, leaving the ones with short times to "fill out" the station.
Shortest work element	This rule is the opposite of the longest work element rule because it gives preference in workstation assignments to those work elements that are quicker. It can be tried because no single rule guarantees the best solution. It might provide another solution for the planner to consider.
Most followers	When picking the next work element to assign to a station being created, choose the element that has the most *followers* (due to precedence requirements). In Figure 5.5, item C has three followers (F, G, and I) whereas item D has only one follower (H). This rule seeks to maintain flexibility so that good choices remain for creating the last few workstations at the end of the line.
Fewest followers	Picking the candidate with the fewest followers is the opposite of the most followers rule.

Table 5.3

Managing Constraints in a Line Process

The theoretical minimum number of workstations is 5 and the cycle time is 60 seconds, so this represents an optimal solution to the problem.

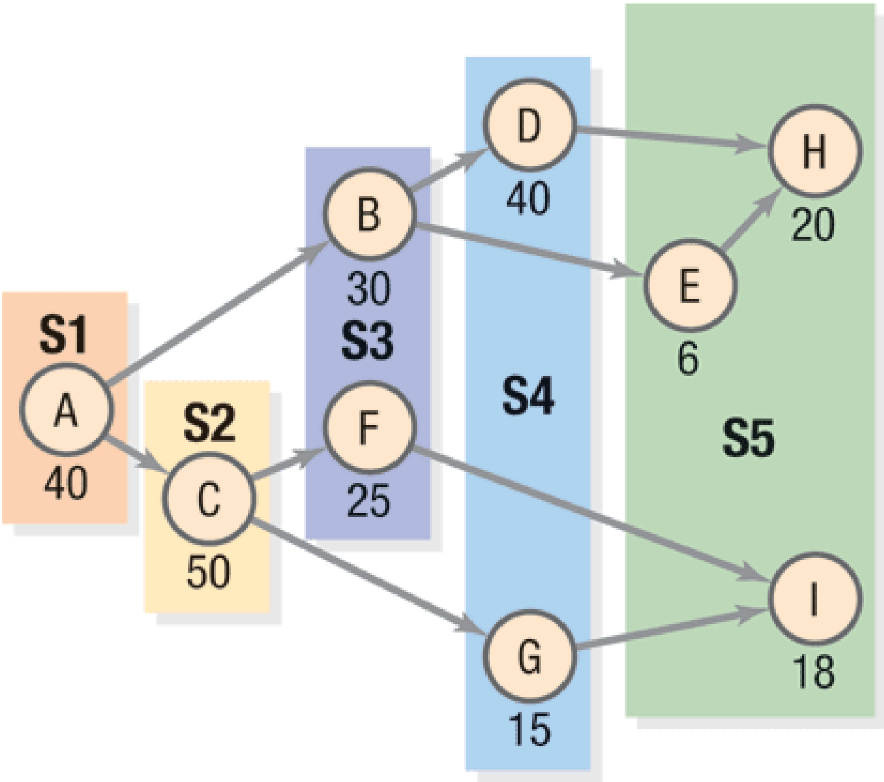


Figure 5.6

Application 5.3

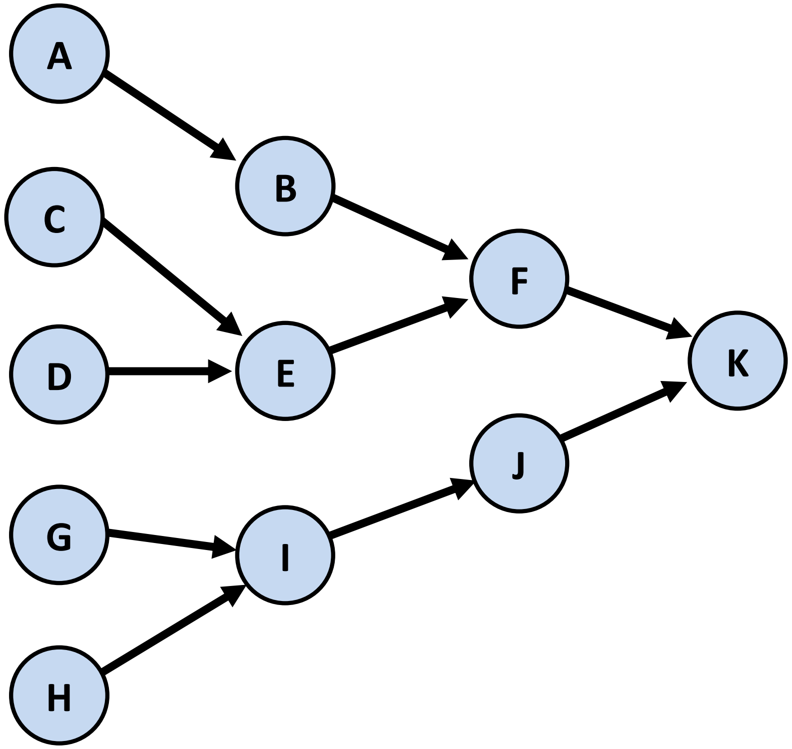
A plant manager needs a design for an assembly line to assembly a new product that is being introduced. The time requirements and immediate predecessors for the work elements are as follows:

Work Element	Time (sec)	Immediate Predecessor
A	12	—
B	60	A
C	36	—
D	24	—
E	38	C, D
F	72	B, E
G	14	—
H	72	—
I	35	G, H
J	60	I
K	12	F, J
Total =	435	

Application 5.3

Draw a precedence diagram, complete I, F, J, and K

Work Element	Time (sec)	Immediate Predecessor
A	12	—
B	60	A
C	36	—
D	24	—
E	38	C, D
F	72	B, E
G	14	—
H	72	—
I	35	G, H
J	60	I
K	12	F, J
Total =	435	



Application 5.3

If the desired output rate is 30 units per hour, what are the cycle time and theoretical minimum?

$$c = \frac{1}{r} = \frac{1}{30}(3600) = 120 \text{ sec/unit}$$

$$\text{TM} = \frac{\Sigma t}{c} = \frac{435}{120} = 3.6 \text{ or } 4 \text{ stations}$$

Application 5.3

Suppose that we are fortunate enough to find a solution with just four stations. What is the idle time per unit, efficiency, and the balance delay for this solution?

Idle time = $nc - \Sigma t$ = 4(120) – 435 = **45 seconds**

$$\text{Efficiency (\%)} = \frac{\Sigma t}{nc}(100) = \frac{435}{480}(100) = 90.6\%$$

Balance delay (%) = 100 – Efficiency = 100 – 90.6 = **9.4%**

Application 5.3

Using trial and error, one possible solution is shown below.

Station	Work Elements Assigned	Cumulative Time	Idle Time (c = 120)
1	H, C, A	120	0
2	B, D, G	98	22
3	E, F	110	10
4	I, J, K	107	13
5	A fifth station is not needed		

Rebalancing the Assembly Line

- Managerial Considerations
  - Pacing is the movement of product from one station to the next as soon as the cycle time has elapsed
  - Behavioral factors such as absenteeism, turnover, and grievances can increase after installing production lines.
  - The number of models produced complicates scheduling and necessitates good communication.
  - Cycle times are dependent on the desired output rate or sometimes on the maximum workstations allowed.

Solved Problem 1

Bill's Car Wash offers two types of washes: Standard and Deluxe. The process flow for both types of customers is shown in the following chart. Both wash types are first processed through steps A1 and A2. The Standard wash then goes through steps A3 and A4 while the Deluxe is processed through steps A5, A6, and A7. Both offerings finish at the drying station (A8). The numbers in parentheses indicate the minutes it takes for that activity to process a customer.

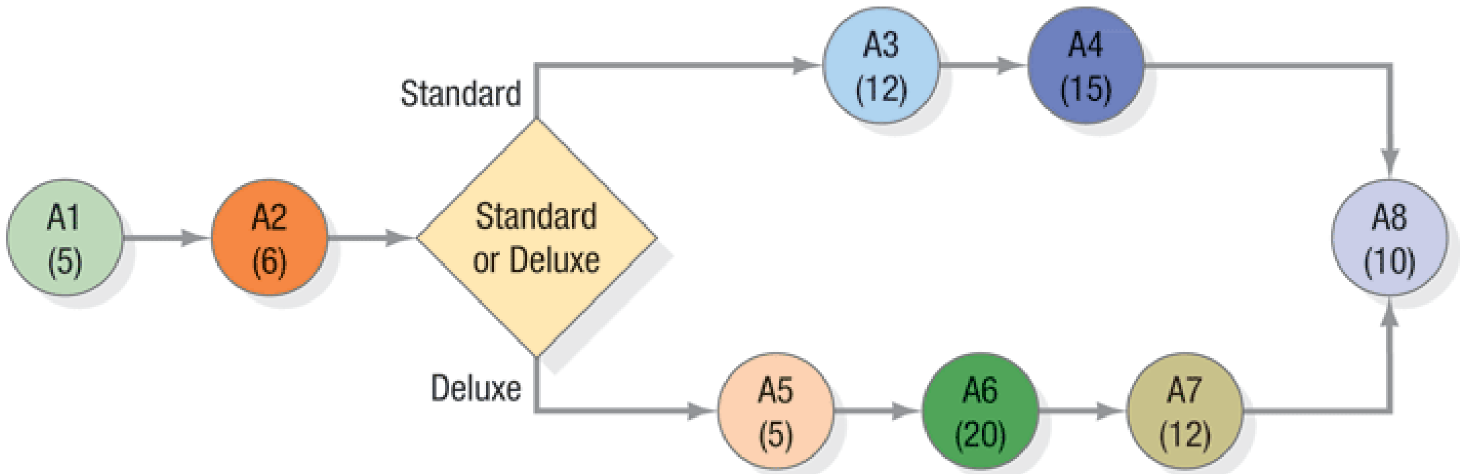


Figure 5.7

Solved Problem 1

a. Which step is the bottleneck for the Standard car wash process? For the Deluxe car wash process?

b. What is the capacity (measured as customers served per hour) of Bill's Car Wash to process Standard and Deluxe customers? Assume that no customers are waiting at step A1, A2, or A8.

c. If 60 percent of the customers are Standard and 40 percent are Deluxe, what is the average capacity of the car wash in customers per hour?

d. Where would you expect Standard wash customers to experience waiting lines, assuming that new customers are always entering the shop and that no Deluxe customers are in the shop? Where would the Deluxe customers have to wait, assuming no Standard customers?

Solved Problem 1

a. Step A4 is the bottleneck for the Standard car wash process, and Step A6 is the bottleneck for the Deluxe car wash process, because these steps take the longest time in the flow.

b. The capacity for Standard washes is 4 customers per hour because the bottleneck step A4 can process 1 customer every 15 minutes (60/15). The capacity for Deluxe car washes is 3 customers per hour (60/20). These capacities are derived by translating the "minutes per customer" of each bottleneck activity to "customers per hour."

c. The average capacity of the car wash is
$(0.60 \times 4) + (0.40 \times 3) =$ 3.6 customers per hour.

Solved Problem 1

d. **Standard wash customers would wait before steps A1, A2, A3, and A4 because the activities that immediately precede them have a higher rate of output (i.e., smaller processing times). Deluxe wash customers would experience a wait in front of steps A1, A2, and A6 for the same reasons. A1 is included for both types of washes because the arrival rate of customers could always exceed the capacity of A1.**

Solved Problem 2

A company is setting up an assembly line to produce 192 units per 8-hour shift. The following table identifies the work elements, times, and immediate predecessors:

Work Element	Time (sec)	Immediate Predecessor(s)
A	40	None
B	80	A
C	30	D, E, F
D	25	B
E	20	B
F	15	B
G	120	A
H	145	G
I	130	H
J	115	C, I
	Total 720	

Solved Problem 2

a. What is the desired cycle time (in seconds)?

b. What is the theoretical minimum number of stations?

c. Use trial and error to work out a solution, and show your solution on a precedence diagram.

d. What are the efficiency and balance delay of the solution found?

Solved Problem 2

a. Substituting in the cycle-time formula, we get

$$c = \frac{1}{r} = \frac{8 \text{ hours}}{192 \text{ units}} (3{,}600 \text{ sec/hr}) = 150 \text{ sec/unit}$$

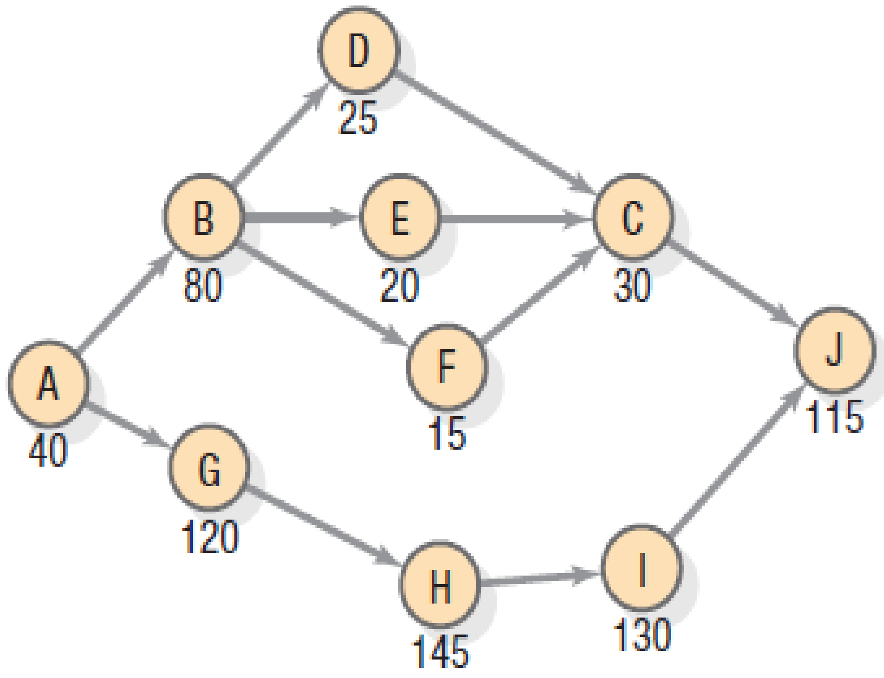
b. The sum of the work-element times is 720 seconds, so

$$TM = \frac{\Sigma t}{c} = \frac{720 \text{ sec/unit}}{150 \text{ sec/unit-station}} = 4.8 \quad \text{or} \quad 5 \text{ stations}$$

which may not be achievable.

Solved Problem 2

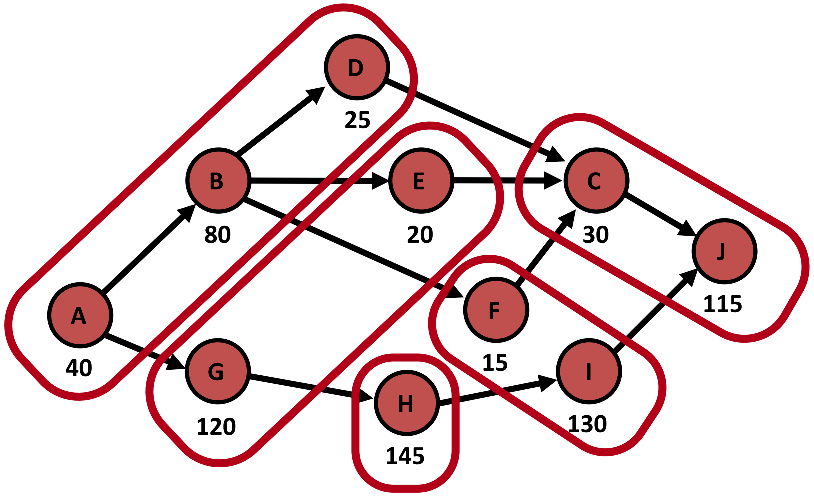
c. Precedence Diagram



Work Element	Immediate Predecessor(s)
A	None
B	A
C	D, E, F
D	B
E	B
F	B
G	A
H	G
I	H
J	C, I

Figure 5.8

Solved Problem 2



Station	Candidate(s)	Choice	Work-Element Time (sec)	Cumulative Time (sec)	Idle Time (c= 150 sec)
S1	A	A	40	40	110
	B	B	80	120	30
	D, E, F	D	25	145	5
S2	E, F, G	G	120	120	30
	E, F	E	20	140	10
S3	F, H	H	145	145	5
S4	F, I	I	130	130	20
	F	F	15	145	5
S5	C	C	30	30	120
	J	J	115	145	5

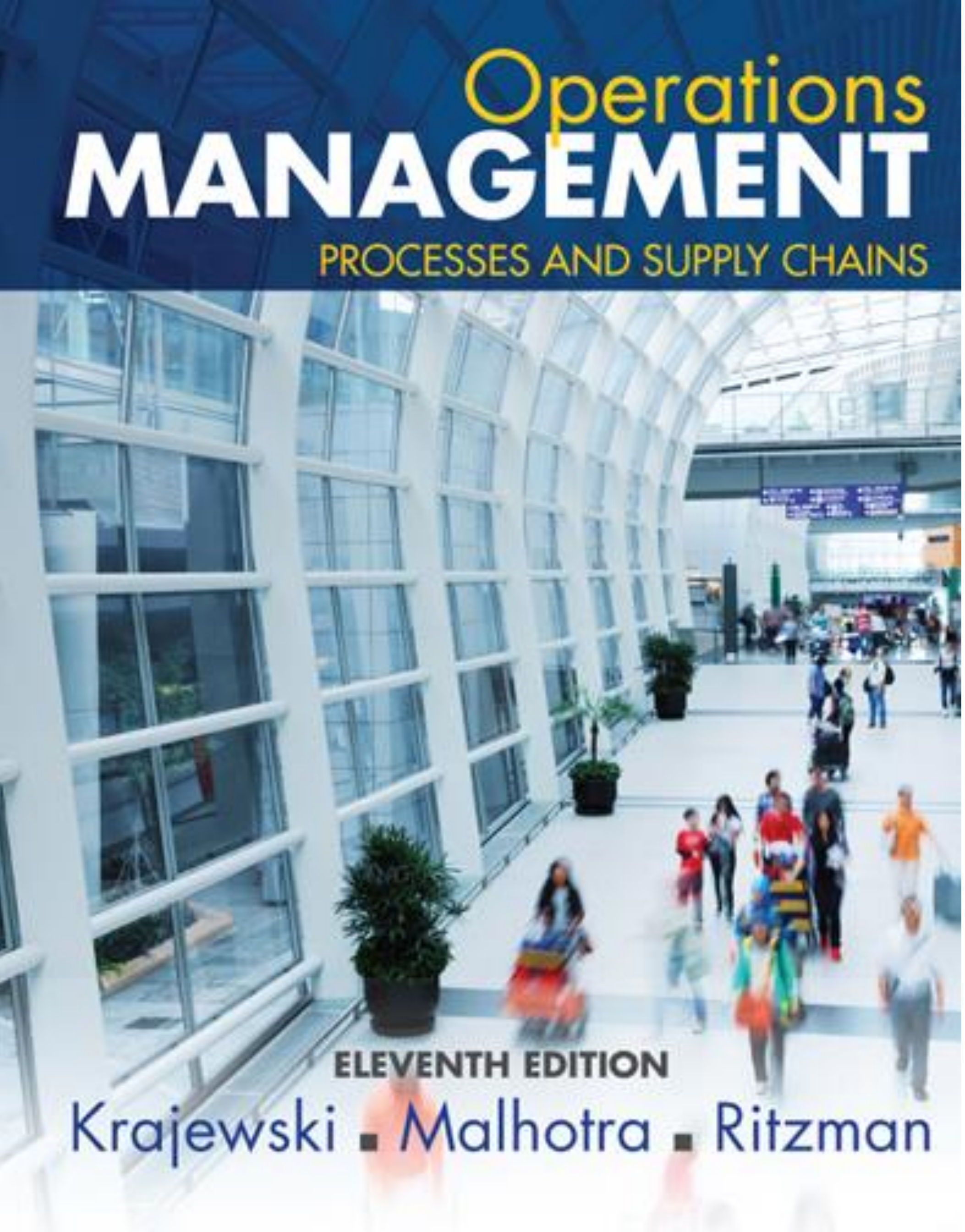
Solved Problem 2

d. Calculating the efficiency, we get

$$\text{Efficiency (\%)} = \frac{\Sigma t}{nc}(100) = \frac{\text{720 sec/unit}}{\text{5(150 sec/unit)}}(100)$$

$$= 96\%$$

Thus, the balance delay is only 4 percent (100–96).



Forecasting

Chapter 8

What is a Forecast?

Forecast

A prediction of
future events used
for planning
purposes.

Demand Patterns

- A *time series* is the repeated observations of demand for a service or product in their order of occurrence
- There are five basic time series patterns
  - Horizontal
  - Trend
  - Seasonal
  - Cyclical
  - Random

Demand Patterns

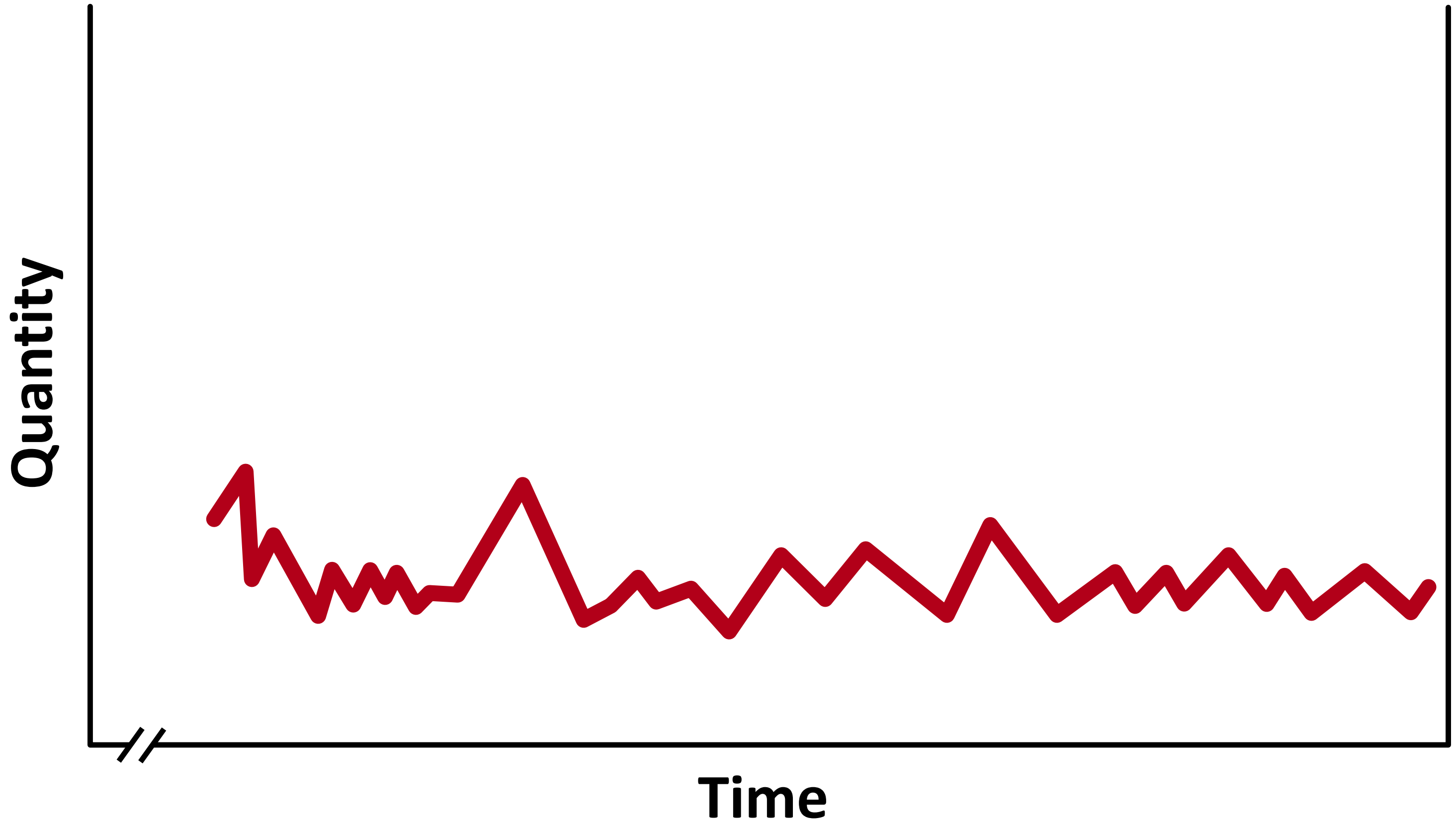


Figure 8.1

(a) Horizontal: Data cluster about a horizontal line

Demand Patterns

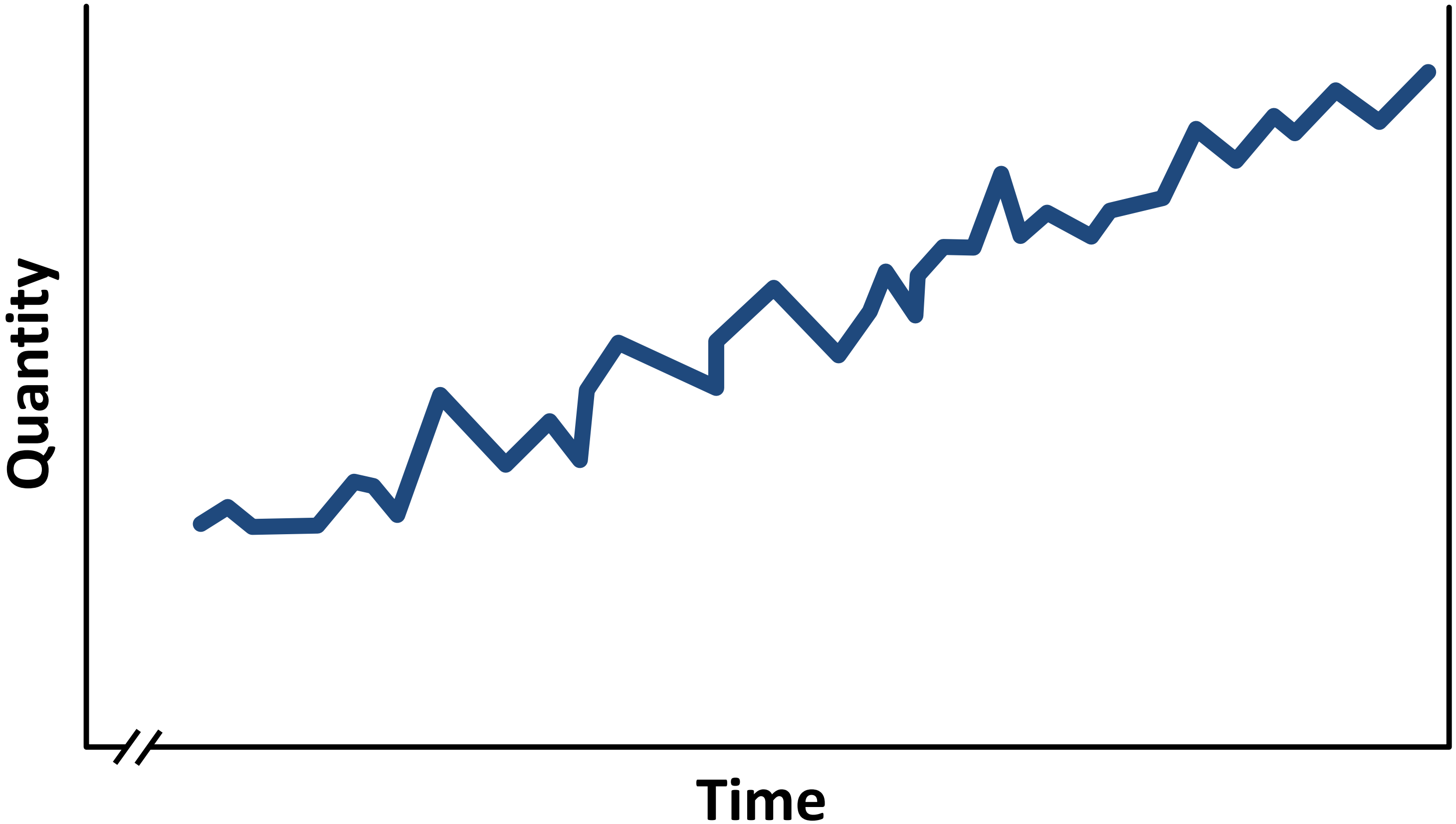


Figure 8.1

(b) Trend: Data consistently increase or decrease

Demand Patterns

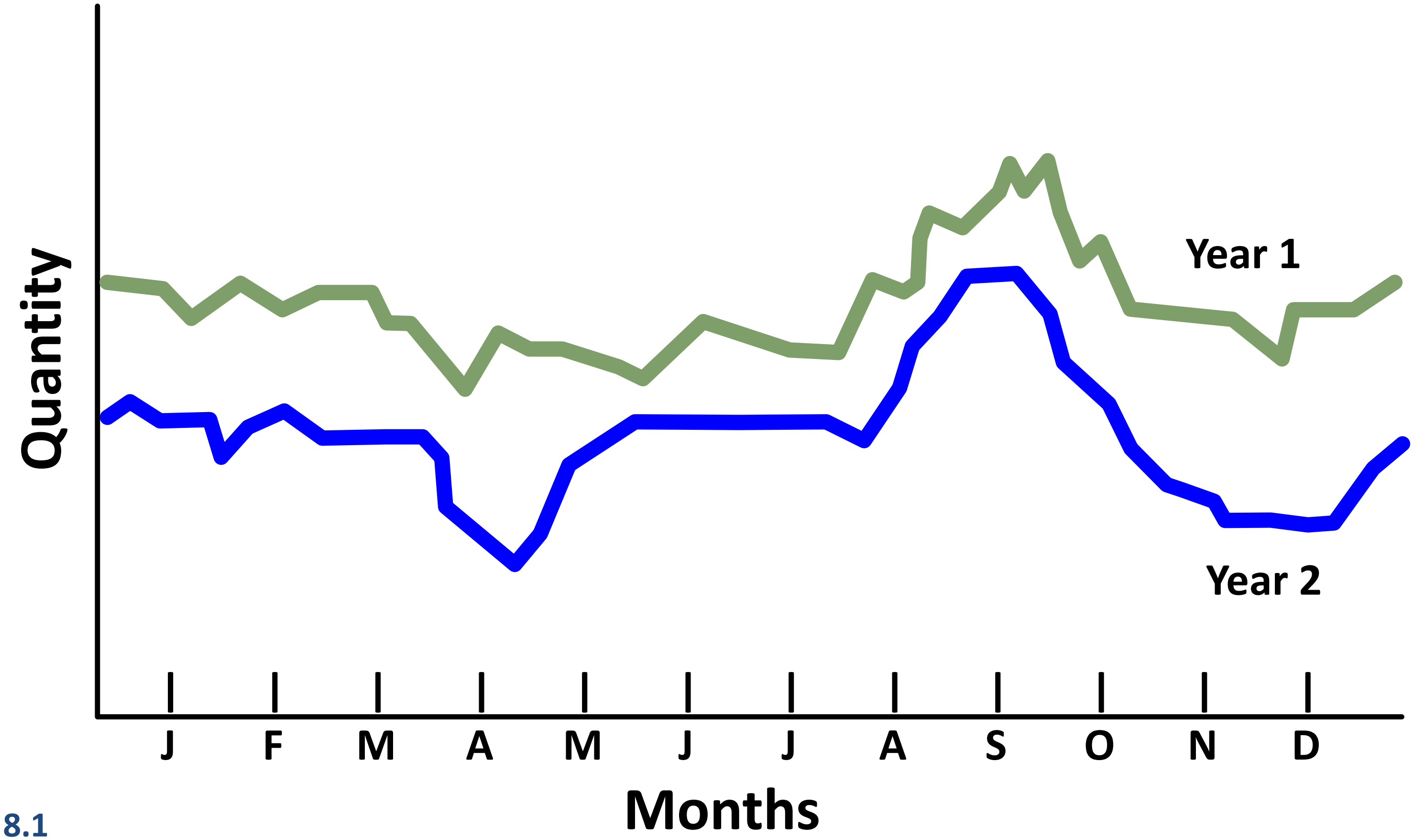


Figure 8.1

(c) Seasonal: Data consistently show peaks and valleys

Demand Patterns

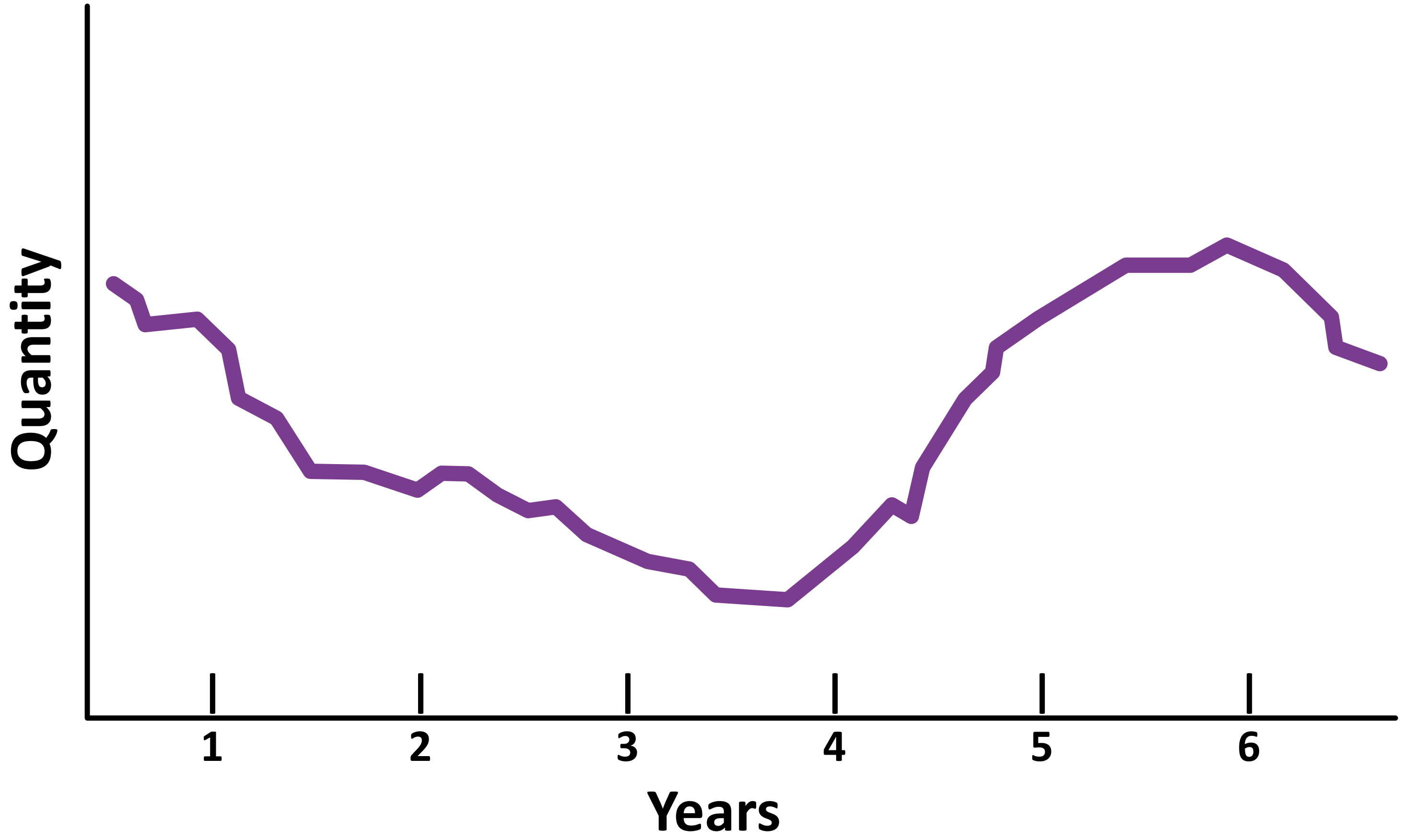


Figure 8.1

(d) Cyclical: Data reveal gradual increases and decreases over extended periods

Demand Management Options

- **Demand Management**
  - **The process of changing demand patterns using one or more demand options**

Demand Management Options

- Complementary Products
- Promotional Pricing
- Prescheduled Appointments
- Reservations
- Revenue Management
- Backlogs
- Backorders and Stockouts

Key Decisions on Making Forecasts

- **Deciding What to Forecast**
  - **Level of aggregation**
  - **Units of measurement**

- **Choosing the Type of Forecasting Technique**
  - **Judgment methods**
  - **Causal methods**
  - **Time-series analysis**
  - **Trend projection using regression**

Forecast Error

- For any forecasting method, it is important to measure the accuracy of its forecasts.

- Forecast error is simply the difference found by subtracting the forecast from actual demand for a given period, or

$$E_t = D_t - F_t$$

where

E_t = forecast error for period t

D_t = actual demand in period t

F_t = forecast for period t

Measures of Forecast Error

Cumulative sum of forecast errors (*Bias*)

$$\text{CFE} = \sum E_t$$

Standard deviation

$$\sigma = \sqrt{\frac{\sum (E_t - \bar{E})^2}{n-1}}$$

Average forecast error

$$\bar{E} = \frac{\text{CFE}}{n}$$

Mean Absolute Deviation

$$\text{MAD} = \frac{\sum |E_t|}{n}$$

Mean Squared Error

$$\text{MSE} = \frac{\sum E_t^2}{n}$$

Mean Absolute Percent Error

$$\text{MAPE} = \frac{(\sum |E_t|/D_t)(100)}{n}$$

Example 8.1

The following table shows the actual sales of upholstered chairs for a furniture manufacturer and the forecasts made for each of the last eight months.

Calculate CFE, MSE, σ, MAD, and MAPE for this product.

Month t	Demand D_t	Forecast F_t	Error E_t	Error[2] E_t^2	Absolute Error $\lvert E_t \rvert$	Absolute % Error $(\lvert E_t \rvert / D_t)(100)$
1	200	225	–25			
2	240	220	20			
3	300	285	15			
4	270	290	–20			
5	230	250	–20	400	20	8.7
6	260	240	20	400	20	7.7
7	210	250	–40	1,600	40	19.0
8	275	240	35	1,225	35	12.7
		Total	–15	5,275	195	81.3%

Example 8.1

The following table shows the actual sales of upholstered chairs for a furniture manufacturer and the forecasts made for each of the last eight months.

Calculate CFE, MSE, σ, MAD, and MAPE for this product.

Month t	Demand D_t	Forecast F_t	Error E_t	Error² E_t^2	Absolute Error $\|E_t\|$	Absolute % Error $(\|E_t\|/D_t)(100)$
1	200	225	–25	625	25	12.5%
2	240	220	20	400	20	8.3
3	300	285	15	225	15	5.0
4	270	290	–20	400	20	7.4
5	230	250	–20	400	20	8.7
6	260	240	20	400	20	7.7
7	210	250	–40	1,600	40	19.0
8	275	240	35	1,225	35	12.7
		Total	–15	5,275	195	81.3%

Example 8.1

Using the formulas for the measures, we get:

Cumulative forecast error (mean bias)

$$\text{CFE} = -15$$

Average forecast error (mean bias):

$$\bar{E} = \frac{\text{CFE}}{n} = \frac{15}{8} = -1.875$$

Mean squared error:

$$\text{MSE} = \frac{\Sigma E_t^2}{n} = \frac{5{,}275}{8} = 659.4$$

Example 8.1

Standard deviation:

$$\sigma = \sqrt{\frac{\Sigma[E_t - (-1.875)]^2}{n-1}} = 27.4$$

Mean absolute deviation:

$$\text{MAD} = \frac{\Sigma|E_t|}{n} = \frac{195}{8} = 24.4$$

Mean absolute percent error:

$$\text{MAPE} = \frac{(\Sigma|E_t|/D_t)(100)}{n} = \frac{81.3\%}{8} = 10.2\%$$

Example 8.1

- A CFE of –15 indicates that the forecast has a slight bias to overestimate demand.
- The MSE, σ, and MAD statistics provide measures of forecast error variability.
- A MAD of 24.4 means that the average forecast error was 24.4 units in absolute value.
- The value of σ, 27.4, indicates that the sample distribution of forecast errors has a standard deviation of 27.4 units.
- A MAPE of 10.2 percent implies that, on average, the forecast error was about 10 percent of actual demand.

These measures become more reliable as the number of periods of data increases.

Judgment Methods

- Other methods (casual, time-series, and trend projection using regression) require an adequate history file, which might not be available.
- Judgmental forecasts use contextual knowledge gained through experience.
  - Salesforce estimates
  - Executive opinion
  - Market research
  - Delphi method

Causal Methods: Linear Regression

- A dependent variable is related to one or more independent variables by a linear equation
- The independent variables are assumed to "cause" the results observed in the past
- Simple linear regression model is a straight line

$$Y = a + bX$$

where

Y = dependent variable
X = independent variable
a = Y-intercept of the line
b = slope of the line

Linear Regression

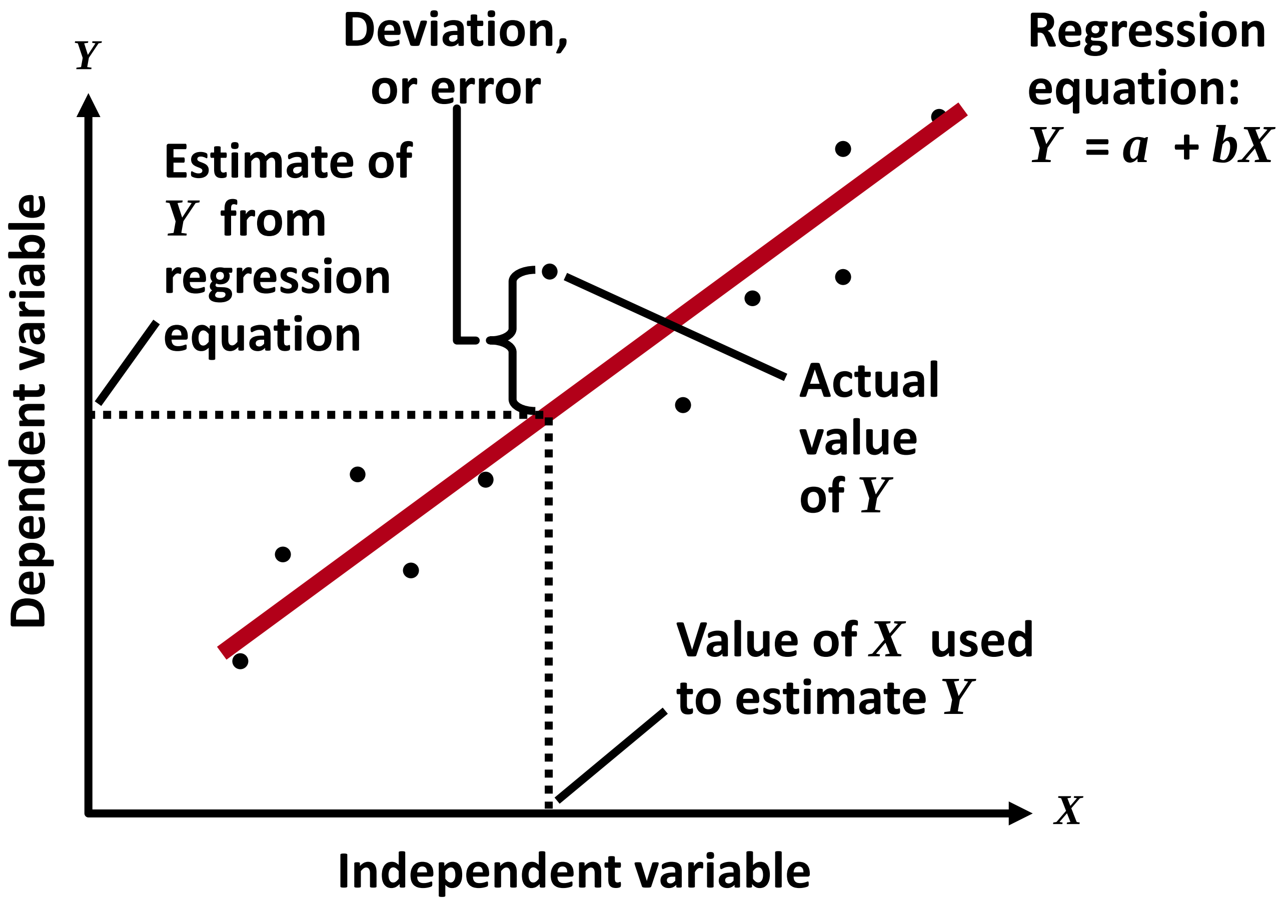


Figure 8.3

Linear Regression

- The sample correlation coefficient, r
  - Measures the direction and strength of the relationship between the independent variable and the dependent variable.
  - The value of r can range from $-1.00 \leq r \leq 1.00$
- The sample coefficient of determination, r^2
  - Measures the amount of variation in the dependent variable about its mean that is explained by the regression line
  - The values of r^2 range from $0.00 \leq r^2 \leq 1.00$
- The standard error of the estimate, s_{yx}
  - Measures how closely the data on the dependent variable cluster around the regression line

Example 8.2

The supply chain manager seeks a better way to forecast the demand for door hinges and believes that the demand is related to advertising expenditures. The following are sales and advertising data for the past 5 months:

Month	Sales (thousands of units)	Advertising (thousands of $)
1	264	2.5
2	116	1.3
3	165	1.4
4	101	1.0
5	209	2.0

The company will spend $1,750 next month on advertising for the product. Use linear regression to develop an equation and a forecast for this product.

Example 8.2

We used POM for Windows to determine the best values of *a*, *b*, the correlation coefficient, the coefficient of determination, and the standard error of the estimate

$$a = -8.135$$
$$b = 109.229X$$
$$r = 0.980$$
$$r^2 = 0.960$$
$$s_{yx} = 15.603$$

The regression equation is

$$Y = -8.135 + 109.229X$$

Example 8.2

The *r* of 0.98 suggests an unusually strong positive relationship between sales and advertising expenditures. The coefficient of determination, r^2, implies that 96 percent of the variation in sales is explained by advertising expenditures.

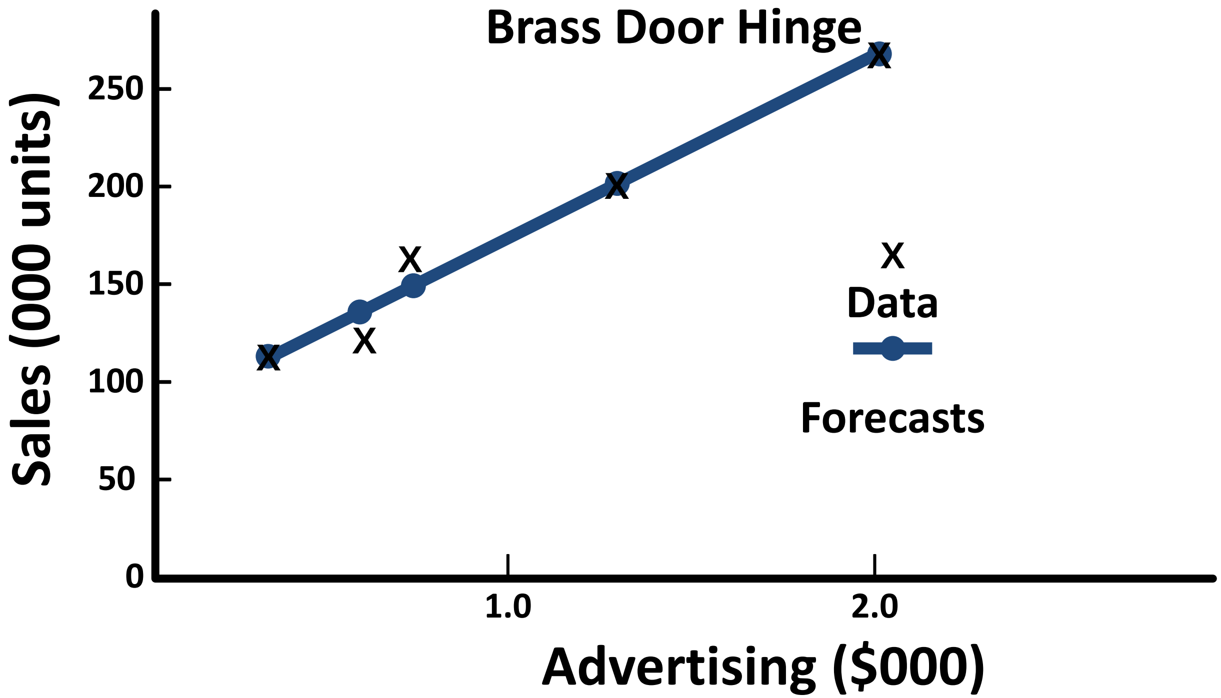


Figure 8.4

Example 8.2

- **Forecast for month 6:**

$$Y = -8.135 + 109.229X$$

$$Y = -8.135 + 109.229(1.75)$$

$$Y = 183.016 \text{ or } 183{,}016 \text{ units}$$

Time Series Methods

- **Naïve forecast**
  - The forecast for the next period equals the demand for the current period (Forecast = D_t)
- **Horizontal Patterns: Estimating the average**
  - Simple moving average
  - Weighted moving average
  - Exponential smoothing

Simple Moving Averages

- Specifically, the forecast for period $t + 1$ can be calculated at the end of period t (after the actual demand for period t is known) as

$$F_{t+1} = \frac{\text{Sum of last } n \text{ demands}}{n} = \frac{D_t + D_{t-1} + D_{t-2} + \ldots + D_{t-n+1}}{n}$$

where

D_t = actual demand in period t

n = total number of periods in the average

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

Example 8.3

a. Compute a three-week moving average forecast for the arrival of medical clinic patients in week 4. The numbers of arrivals for the past three weeks were as follows:

Week	Patient Arrivals
1	400
2	380
3	411

b. If the actual number of patient arrivals in week 4 is 415, what is the forecast error for week 4?

c. What is the forecast for week 5?

Example 8.3

Week	Patient Arrivals
1	400
2	380
3	411

a. The moving average forecast at the end of week 3 is:

$$F_4 = \frac{411 + 380 + 400}{3} = 397.0$$

b. The forecast error for week 4 is

$$E_4 = D_4 - F_4 \quad = 415 - 397 = 18$$

c. The forecast for week 5 requires the actual arrivals from weeks 2 through 4, the three most recent weeks of data

$$F_5 = \frac{415 + 411 + 380}{3} = 402.0$$

Application 8.1

Estimating with Simple Moving Average using the following customer-arrival data:

Month	Customer arrival
1	800
2	740
3	810
4	790

Use a three-month moving average to forecast customer arrivals for month 5

$$F_5 = \frac{D_4 + D_3 + D_2}{3} = \frac{790 + 810 + 740}{3} = 780$$

Forecast for month 5 is 780 customer arrivals

Application 8.1

If the actual number of arrivals in month 5 is 805, what is the forecast for month 6?

Month	Customer arrival
1	800
2	740
3	810
4	790

$$F_6 = \frac{D_5 + D_4 + D_3}{3} = \frac{805 + 790 + 810}{3} = 801.667$$

Forecast for month 6 is 802 customer arrivals

Application 8.1

Forecast error is simply the difference found by subtracting the forecast from actual demand for a given period, or

$$E_t = D_t - F_t$$

Given the three-month moving average forecast for month 5, and the number of patients that actually arrived (805), what is the forecast error?

$$E_5 = 805 - 780 = 25$$

Forecast error for month 5 is 25

Weighted Moving Averages

In the weighted moving average method, each historical demand in the average can have its own weight, provided that the sum of the weights equals 1.0.

The average is obtained by multiplying the weight of each period by the actual demand for that period, and then adding the products together

$$F_{t+1} = W_1 D_1 + W_2 D_2 + \ldots + W_n D_{t-n+1}$$

Application 8.2

Using the customer arrival data in Application 14.1, let $W_1 = 0.50$, $W_2 = 0.30$, and $W_3 = 0.20$. Use the weighted moving average method to forecast arrivals for month 5.

$$F_5 = W_1 D_4 + W_2 D_3 + W_3 D_2$$

$$= 0.50(790) + 0.30(810) + 0.20(740) = 786$$

Forecast for month 5 is 786 customer arrivals.

Given the number of customers that actually arrived (805), what is the forecast error?

$$E_5 = 805 - 786 = 19$$

Forecast error for month 5 is 19.

Application 8.2

If the actual number of arrivals in month 5 is 805, compute the forecast for month 6:

$$F_6 = W_1D_5 + W_2D_4 + W_3D_3$$

$$= 0.50(805) + 0.30(790) + 0.20(810)$$

$$= 801.5$$

Forecast for month 6 is 802 customer arrivals.

Exponential Smoothing

- A sophisticated weighted moving average that calculates the average of a time series by implicitly giving recent demands more weight than earlier demands
- Requires only three items of data
  - The last period's forecast
  - The demand for this period
  - A smoothing parameter, alpha (α), where $0 \le \alpha \le 1.0$
- The equation for the forecast is

F_{t+1} = α(Demand this period) + (1 – α)(Forecast calculated last period)

$$= \alpha D_t + (1 - \alpha)F_t$$

Exponential Smoothing

- The emphasis given to the most recent demand levels can be adjusted by changing the smoothing parameter.
- Larger α values emphasize recent levels of demand and result in forecasts more responsive to changes in the underlying average.
- Smaller α values treat past demand more uniformly and result in more stable forecasts.

Example 8.4

a. Reconsider the patient arrival data in Example 14.3. It is now the end of week 3 so the actual arrivals is known to be 411 patients. Using α = 0.10, calculate the exponential smoothing forecast for week 4.

b. What was the forecast error for week 4 if the actual demand turned out to be 415?

c. What is the forecast for week 5?

Example 8.4

a. To obtain the forecast for week 4, using exponential smoothing with and the initial forecast of 390*, we calculate the average at the end of week 3 as:

$$F_4 = 0.10(411) + 0.90(390) = 392.1$$

Thus, the forecast for week 4 would be 392 patients.

** Here the initial forecast of 390 is the average of the first two weeks of demand. POM for Windows and OM Explorer, on the other hand, simply use the actual demand for the first week as the default setting for the initial forecast for period 1, and do not begin tracking forecast errors until the second period.*

Example 8.4

b. The forecast error for week 4 is

$$E_4 = 415 - 392 = 23$$

c. The new forecast for week 5 would be

$$F_5 = 0.10(415) + 0.90(392.1) = 394.4$$

or 394 patients.

Application 8.3

Suppose that there were 790 arrivals in month 4 (D_t), whereas the forecast (F_t) was for 783 arrivals. Use exponential smoothing with α = 0.20 to compute the forecast for month 5.

$$F_{t+1} = F_t + \alpha(D_t - F_t) \qquad 783 + 0.20(790 - 783) = 784.4$$

Forecast for month 5 is 784 customer arrivals

Given the number of patients that actually arrived (805), what is the forecast error?

$$E_5 = 805 - 784 = 21$$

Forecast error for month 5 is 21

Application 8.3

Given the actual number of arrivals in month 5, what is the forecast for month 6?

$$F_{t+1} = F_t + \alpha(D_t - F_t) \quad = 784.4 + 0.20(805 - 784.4)$$

$$= 788.52$$

Forecast for month 6 is 789 customer arrivals

Trend Patterns: Using Regression

- A trend in a time series is a systematic increase or decrease in the average of the series over time
- The forecast can be improved by calculating an estimate of the trend
- Trend Projection with Regression accounts for the trend with simple regression analysis.

Example 8.5

- Medanalysis, Inc., provides medical laboratory services
- Managers are interested in forecasting the number of blood analysis requests per week
- There has been a national increase in requests for standard blood tests.
- The arrivals over the next 16 weeks are given in Table 8.1.
- What is the forecasted demand for the next three periods?

Example 8.5

Arrivals at Medanalysis, Inc.

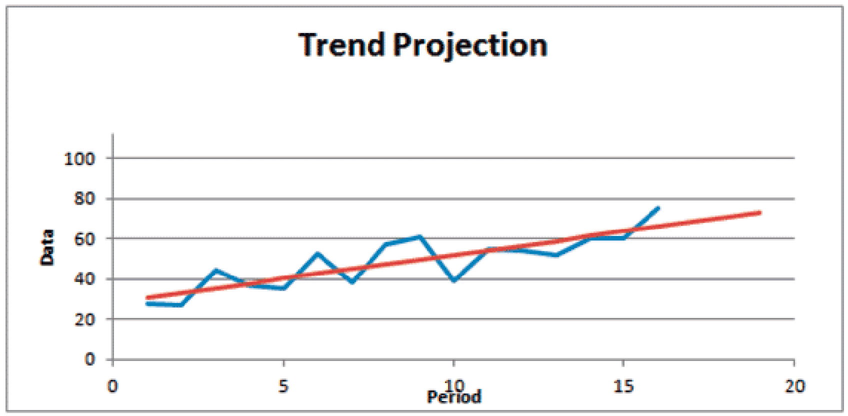
Week	Arrivals	Week	Arrivals
1	28	9	61
2	27	10	39
3	44	11	55
4	37	12	54
5	35	13	52
6	53	14	60
7	38	15	60
8	57	16	75

Table 8.1

Example 8.5

Solver - Trend Projection with Regression

Regression begins in period	1
Error analysis begins in period	1
Number of future forecasts	3



a (Y intercept)	28.50
b (slope or trend)	2.35
r2	0.69
CFE	0.00
MAD	6.21
MSE	52.96
MAPE	13.53%

Forecast for period 17	68.375
Forecast for period 18	70.72059
Forecast for period 19	73.06618

Figure 8.6(a)

Example 8.5

				CFE	Averages		
					MSE	MAD	MAPE
				0.000	52.958	6.210	13.53%
Period #	Actual Demand	Forecast	Error	Running CFE	Error Squared	Absolute Error	Abs % error
1	28	31	-2.846	-2.846	8.097	2.846	10.16%
2	27	33	-6.191	-9.037	38.331	6.191	22.93%
3	44	36	8.463	-0.574	71.626	8.463	19.23%
4	37	38	-0.882	-1.456	0.779	0.882	2.38%
5	35	40	-5.228	-6.684	27.331	5.228	14.94%
6	53	43	10.426	3.743	108.711	10.426	19.67%
7	38	45	-6.919	-3.176	47.874	6.919	18.21%
8	57	47	9.735	6.559	94.776	9.735	17.08%
9	61	50	11.390	17.949	129.725	11.390	18.67%
10	39	52	-12.956	4.993	167.855	12.956	33.22%
11	55	54	0.699	5.691	0.488	0.699	1.27%
12	54	57	-2.647	3.044	7.007	2.647	4.90%
13	52	59	-6.993	-3.949	48.897	6.993	13.45%
14	60	61	-1.338	-5.287	1.791	1.338	2.23%
15	60	64	-3.684	-8.971	13.571	3.684	6.14%
16	75	66	8.971	0.000	80.471	8.971	11.96%

Figure 8.6(b)

Application 8.4

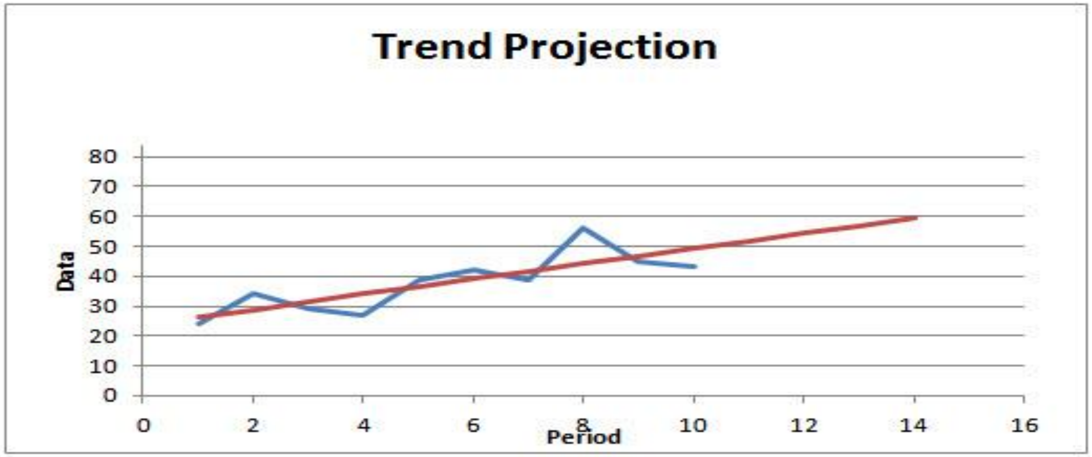
- Use *OM Explorer* to project the following weekly demand data using trend projection with regression.
- What is the forecasted demand for periods 11-14?

Week	Demand	Week	Demand
1	24	6	42
2	34	7	39
3	29	8	56
4	27	9	45
5	39	10	43

Application 8.4

Solver - Trend Projection with Regression

Regression begins in period	1	check scrollbar
Error analysis begins in period	1	
Number of future forecasts	4	



a (Y intercept)	23.733
b (slope or trend)	2.558
r^2	0.650
CFE	0.000
MAD	4.472
MSE	28.995
MAPE	11.85%

Forecast for period 11	51.867
Forecast for period 12	54.424
Forecast for period 13	56.982
Forecast for period 14	59.539

Application 8.4

Worksheet

Solver - Time-Series Forecasting

				CFE	Averages		
					MSE	MAD	MAPE
				0.000	**28.995**	**4.472**	**11.85%**
Period #	Actual Demand	Forecast	Error	Running CFE	Error Squared	Absolute Error	Abs % error
1	24	26	-2.291	-2.291	5.248	2.291	9.55%
2	34	29	5.152	2.861	26.538	5.152	15.15%
3	29	31	-2.406	0.455	5.789	2.406	8.30%
4	27	34	-6.964	-6.509	48.492	6.964	25.79%
5	39	37	2.479	-4.030	6.144	2.479	6.36%
6	42	39	2.921	-1.109	8.533	2.921	6.96%
7	39	42	-2.636	-3.745	6.950	2.636	6.76%
8	56	44	11.806	8.061	139.383	11.806	21.08%
9	45	47	-1.752	6.309	3.068	1.752	3.89%
10	43	49	-6.309	0.000	39.805	6.309	14.67%

Seasonal Patterns: Using Seasonal Factors

Multiplicative seasonal method

A method whereby seasonal factors are multiplied by an estimate of average demand to arrive at a seasonal forecast.

Additive seasonal method

A method in which seasonal forecasts are generated by adding a constant to the estimate of average demand per season.

Multiplicative Seasonal Method

Multiplicative seasonal method

1. For each year, calculate the average demand for each season by dividing annual demand by the number of seasons per year.
2. For each year, divide the actual demand for each season by the average demand per season, resulting in a seasonal factor for each season.
3. Calculate the average seasonal factor for each season using the results from Step 2.
4. Calculate each season's forecast for next year.

Example 8.6

The manager of the Stanley Steemer carpet cleaning company needs a quarterly forecast of the number of customers expected next year. The carpet cleaning business is seasonal, with a peak in the third quarter and a trough in the first quarter. Following are the quarterly demand data from the past 4 years:

The manager wants to forecast customer demand for each quarter of year 5, based on an estimate of total year 5 demand of 2,600 customers.

Example 8.6

	YEAR 1		YEAR 2	
Q	Demand	Seasonal Factor (1)	Demand	Seasonal Factor (2)
1	45	45/250 = 0.18	70	70/300 = 0.23
2	335	335/250 = 1.34	370	370/300 = 1.23
3	520	520/250 = 2.08	590	590/300 = 1.97
4	100	100/250 = 0.40	170	170/300 = 0.57
Total	1,000		1,200	
Average	1,000/4 = 250		1,200/4 = 300	

Example 8.6

	YEAR 3		YEAR 4	
Q	Demand	Seasonal Factor (3)	Demand	Seasonal Factor (4)
1	100	100/450 = 0.22	100	100/550 = 0.18
2	585	585/450 = 1.30	725	725/550 = 1.32
3	830	830/450 = 1.84	1160	1160/550 = 2.11
4	285	285/450 = 0.63	215	215/550 = 0.39
Total	1,800		2,200	
Average	1,800/4 = 450		2,200/4 = 550	

Example 8.6

Average Seasonal Factor

Quarter	Average Seasonal Factor
1	0.2043
2	1.2979
3	2.0001
4	0.4977

Quarterly Forecasts

Quarter	Forecast
1	650 x 0.2043 = 132.795
2	650 x 1.2979 = 843.635
3	650 x 2.001 = 1,300.06
4	650 x 0.4977 = 323.505

Example 8.6

Period	Quarters		
Starting Year	1	Years	4
Computed Forecast Demand for Year 5			2600
User-supplied Forecast Demand for Year 5			2600

Quarter	Year 1	Year 2	Year 3	Year 4
1	45	70	100	100
2	335	370	585	725
3	520	590	830	1160
4	100	170	285	215

(a) Inputs sheet

Quarter	Seasonal Index	Forecast
1	0.2043	132.795
2	1.2979	843.635
3	2.0001	1300.065
4	0.4977	323.505

Figure 8.7

(b) Results

Application 8.5

Suppose the multiplicative seasonal method is being used to forecast customer demand. The actual demand and seasonal indices are shown below.

	Year 1		Year 2		Average
Quarter	Demand	Index	Demand	Index	Index
1	100	0.40	192	0.64	0.52
2	400	1.60	408	1.36	1.48
3	300	1.20	384	1.28	1.24
4	200	0.80	216	0.72	0.76
Average	250		300		

Application 8.5

If the projected demand for Year 3 is 1320 units, what is the forecast for each quarter of that year?

Quarter	Average Index
1	0.52
2	1.48
3	1.24
4	0.76

1320 units ÷ 4 quarters = 330 units

Forecast for Quarter 1 = 0.52(330) ≈ 172 units

Forecast for Quarter 2 = 1.48(330) ≈ 488 units

Forecast for Quarter 3 = 1.24(330) ≈ 409 units

Forecast for Quarter 4 = 0.76(330) ≈ 251 units

Criteria for Selecting Time-Series Method

- Criteria:
  - Minimizing bias (CFE)
  - Minimizing MAPE, MAD, or MSE
  - Maximizing r^2 for trend projections using regression
  - Using a holdout sample analysis
  - Using a tracking signal
  - Meeting managerial expectations of changes in the components of demand.
  - Minimizing the forecast errors in recent periods.

Choosing a Time-Series Method

- **Using Statistical Criteria:**
  - For more stable demand patterns, use lower α values or larger *n* values to emphasize historical experience.
  - For more dynamic demand patters, use higher α values or smaller *n* values.

Choosing a Time-Series Method

- **Holdout sample**
  - **Actual demands from the more recent time periods in the time series that are set aside to test different models developed from the earlier time periods.**

Tracking Signals

- A measure that indicates whether a method of forecasting is accurately predicting actual changes in demand.

$$\text{Tracking signal} = \frac{\text{CFE}}{\text{MAD}} \quad \text{or} \quad \frac{\text{CFE}}{\text{MAD}_t}$$

Each period, the CFE and MAD are updated to reflect current error, and the tracking signal is compared to some predetermined limits.

Tracking Signals

- The MAD can be calculated as the simple average of all absolute errors or as a weighted average determined by the exponential smoothing method

$$\text{MAD}_t = \alpha|E_t| + (1 - \alpha)\text{MAD}_{t-1}$$

If forecast errors are normally distributed with a mean of 0, the relationship between σ and MAD is simple

$$\sigma = (\sqrt{\pi/2})(\text{MAD}) \cong 1.25(\text{MAD})$$

$$\text{MAD} = 0.7978\sigma \cong 0.8\sigma \quad \text{where } \pi = 3.1416$$

Tracking Signals

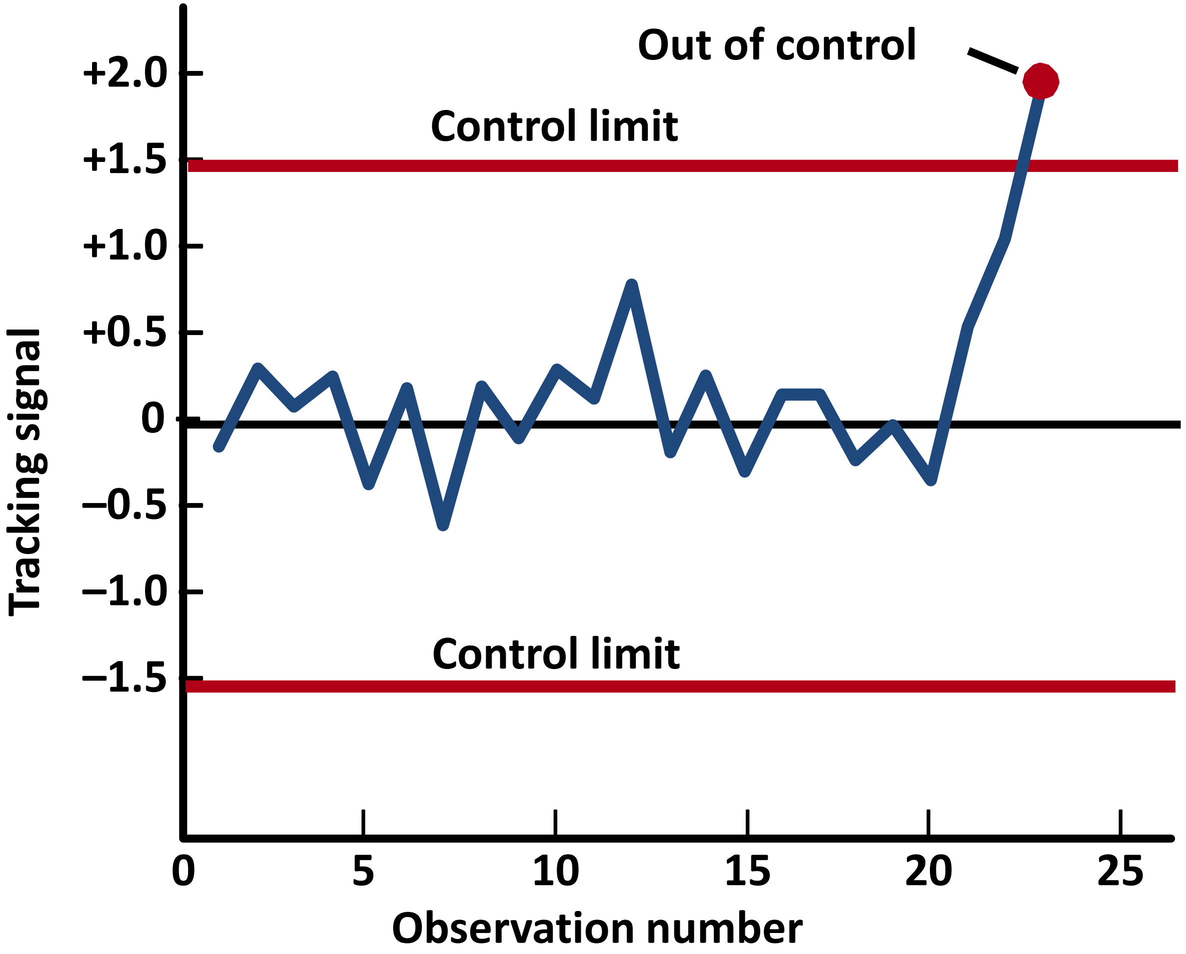
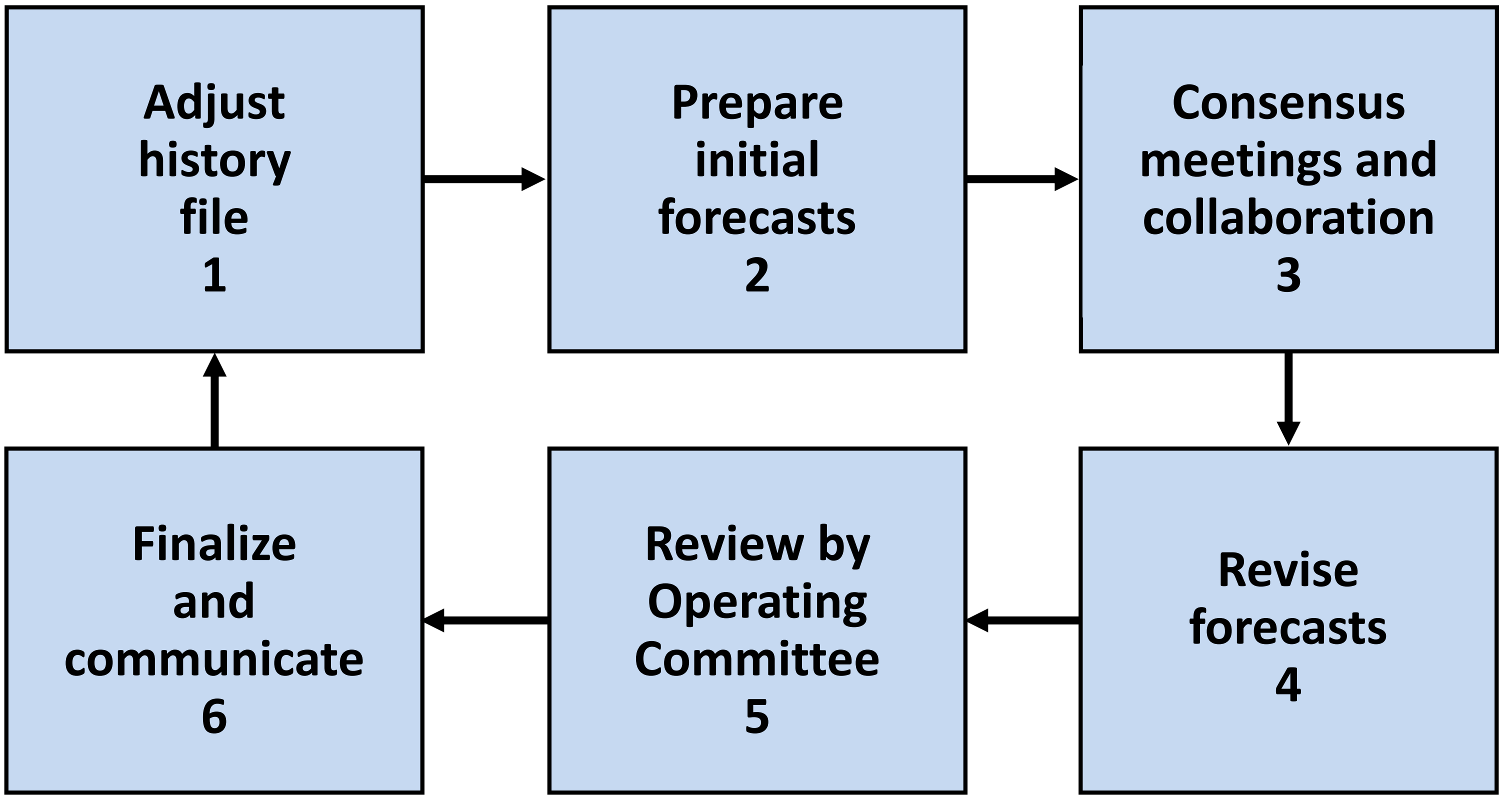


Figure 8.8

Forecasting as a Process



Using Multiple Forecasting Methods

- Combination forecasts
- Judgmental adjustments
- Focus forecasting

Forecasting Principles

SOME PRINCIPLES FOR THE FORECASTING PROCESS
▪ Better processes yield better forecasts
▪ Demand forecasting is being done in virtually every company, either formally or informally. The challenge is to do it well—better than the competition
▪ Better forecasts result in better customer service and lower costs, as well as better relationships with suppliers and customers
▪ The forecast can and must make sense based on the big picture, economic outlook, market share, and so on
▪ The best way to improve forecast accuracy is to focus on reducing forecast error
▪ Bias is the worst kind of forecast error; strive for zero bias
▪ Whenever possible, forecast at more aggregate levels. Forecast in detail only where necessary
▪ Far more can be gained by people collaborating and communicating well than by using the most advanced forecasting technique or model

Table 8.2

Solved Problem 1

Chicken Palace periodically offers carryout five-piece chicken dinners at special prices. Let Y be the number of dinners sold and X be the price. Based on the historical observations and calculations in the following table, determine the regression equation, correlation coefficient, and coefficient of determination. How many dinners can Chicken Palace expect to sell at $3.00 each?

Observation	Price (*X*)	Dinners Sold (*Y*)
1	$2.70	760
2	$3.50	510
3	$2.00	980
4	$4.20	250
5	$3.10	320
6	$4.05	480
Total	$19.55	3,300
Average	$ 3.26	550

Solved Problem 1

We use the computer to calculate the best values of *a*, *b*, the correlation coefficient, and the coefficient of determination

$$a = 1{,}454.60$$
$$b = -277.63$$
$$r = -0.84$$
$$r^2 = 0.71$$

The regression line is

$$Y = a + bX = 1{,}454.60 - 277.63X$$

For an estimated sales price of $3.00 per dinner

$$Y = a + bX = 1{,}454.60 - 277.63(3.00)$$

$$= 621.71 \text{ or } 622 \text{ dinners}$$

Solved Problem 2

The Polish General's Pizza Parlor is a small restaurant catering to patrons with a taste for European pizza. One of its specialties is Polish Prize pizza. The manager must forecast weekly demand for these special pizzas so that he can order pizza shells weekly. Recently, demand has been as follows:

Week	Pizzas	Week	Pizzas
June 2	50	June 23	56
June 9	65	June 30	55
June 16	52	July 7	60

a. Forecast the demand for pizza for June 23 to July 14 by using the simple moving average method with n = 3 then using the weighted moving average method with and weights of 0.50, 0.30, and 0.20, with 0.50.

b. Calculate the MAD for each method.

Solved Problem 2

a. The simple moving average method and the weighted moving average method give the following results:

Current Week	Simple Moving Average Forecast for Next Week	Weighted Moving Average Forecast for Next Week
June 16	$\frac{52 + 65 + 50}{3} = 55.7$ or 56	$[(0.5 \times 52) + (0.3 \times 65) + (0.2 \times 50)] = 55.5$ or 56
June 23	$\frac{56 + 52 + 65}{3} = 57.7$ or 58	$[(0.5 \times 56) + (0.3 \times 52) + (0.2 \times 65)] = 56.6$ or 57
June 30	$\frac{55 + 56 + 52}{3} = 54.3$ or 54	$[(0.5 \times 55) + (0.3 \times 56) + (0.2 \times 52)] = 54.7$ or 55
July 7	$\frac{60 + 55 + 56}{3} = 57.0$ or 57	$[(0.5 \times 60) + (0.3 \times 55) + (0.2 \times 56)] = 57.7$ or 58

Solved Problem 2

b. The mean absolute deviation is calculated as follows:

		Simple Moving Average		Weighted Moving Average	
Week	Actual Demand	Forecast for This Week	Absolute Errors $\lvert E_t \rvert$	Forecast for This Week	Absolute Errors $\lvert E_t \rvert$
June 23	56	56	$\lvert 56 - 56 \rvert = 0$	56	$\lvert 56 - 56 \rvert = 0$
June 30	55	58	$\lvert 55 - 58 \rvert = 3$	57	$\lvert 55 - 57 \rvert = 2$
July 7	60	54	$\lvert 60 - 54 \rvert = 6$	55	$\lvert 60 - 55 \rvert = 5$
			$\text{MAD} = \frac{0 + 3 + 6}{3} = 3$		$\text{MAD} = \frac{0 + 2 + 2}{3} = 2.3$

For this limited set of data, the weighted moving average method resulted in a slightly lower mean absolute deviation. However, final conclusions can be made only after analyzing much more data.

Solved Problem 3

The monthly demand for units manufactured by the Acme Rocket Company has been as follows:

Month	Units	Month	Units
May	100	September	105
June	80	October	110
July	110	November	125
August	115	December	120

a. Use the exponential smoothing method to forecast June to January. The initial forecast for May was 105 units; $\alpha = 0.2$.

b. Calculate the absolute percentage error for each month from June through December and the MAD and MAPE of forecast error as of the end of December.

c. Calculate the tracking signal as of the end of December. What can you say about the performance of your forecasting method?

Solved Problem 3

a.

Current Month, t	Calculating Forecast for Next Month $F_{t+1} = \alpha D_t + (1 - \alpha)F_t$	Forecast for Month $t + 1$
May	0.2(100) + 0.8(105) = 104.0 or 104	June
June	0.2(80) + 0.8(104.0) = 99.2 or 99	July
July	0.2(110) + 0.8(99.2) = 101.4 or 101	August
August	0.2(115) + 0.8(101.4) = 104.1 or 104	September
September	0.2(105) + 0.8(104.1) = 104.3 or 104	October
October	0.2(110) + 0.8(104.3) = 105.4 or 105	November
November	0.2(125) + 0.8(105.4) = 109.3 or 109	December
December	0.2(120) + 0.8(109.3) = 111.4 or 111	January

Solved Problem 3

b.

Month, t	Actual Demand, D_t	Forecast, F_t	Error, $E_t = D_t - F_t$	Absolute Error, $\lvert E_t \rvert$	Absolute Percent Error, $(\lvert E_t \rvert / D_t)(100)$
June	80	104	–24	24	30.0%
July	110	99	11	11	10.0
August	115	101	14	14	12.0
September	105	104	1	1	1.0
October	110	104	6	6	5.5
November	125	105	20	20	16.0
December	120	109	11	11	9.2
Total	765		39	87	83.7%

$$\text{MAD} = \frac{\Sigma \lvert E_t \rvert}{n} = \frac{87}{7} = 12.4 \qquad \text{MAPE} = \frac{(\Sigma \lvert E_t \rvert / D_t)(100)}{n} = \frac{83.7\%}{7} = 11.96\%$$

Solved Problem 3

c. As of the end of December, the cumulative sum of forecast errors (CFE) is 39. Using the mean absolute deviation calculated in part (b), we calculate the tracking signal:

$$\text{Tracking signal} = \frac{\text{CFE}}{\text{MAD}} = \frac{39}{12.4} = 3.14$$

The probability that a tracking signal value of 3.14 could be generated completely by chance is small. Consequently, we should revise our approach. The long string of forecasts lower than actual demand suggests use of a trend method.

Solved Problem 4

The Northville Post Office experiences a seasonal pattern of daily mail volume every week. The following data for two representative weeks are expressed in thousands of pieces of mail:

Day	Week 1	Week 2
Sunday	5	8
Monday	20	15
Tuesday	30	32
Wednesday	35	30
Thursday	49	45
Friday	70	70
Saturday	15	10
Total	224	210

a. Calculate a seasonal factor for each day of the week.

b. If the postmaster estimates 230,000 pieces of mail to be sorted next week, forecast the volume for each day.

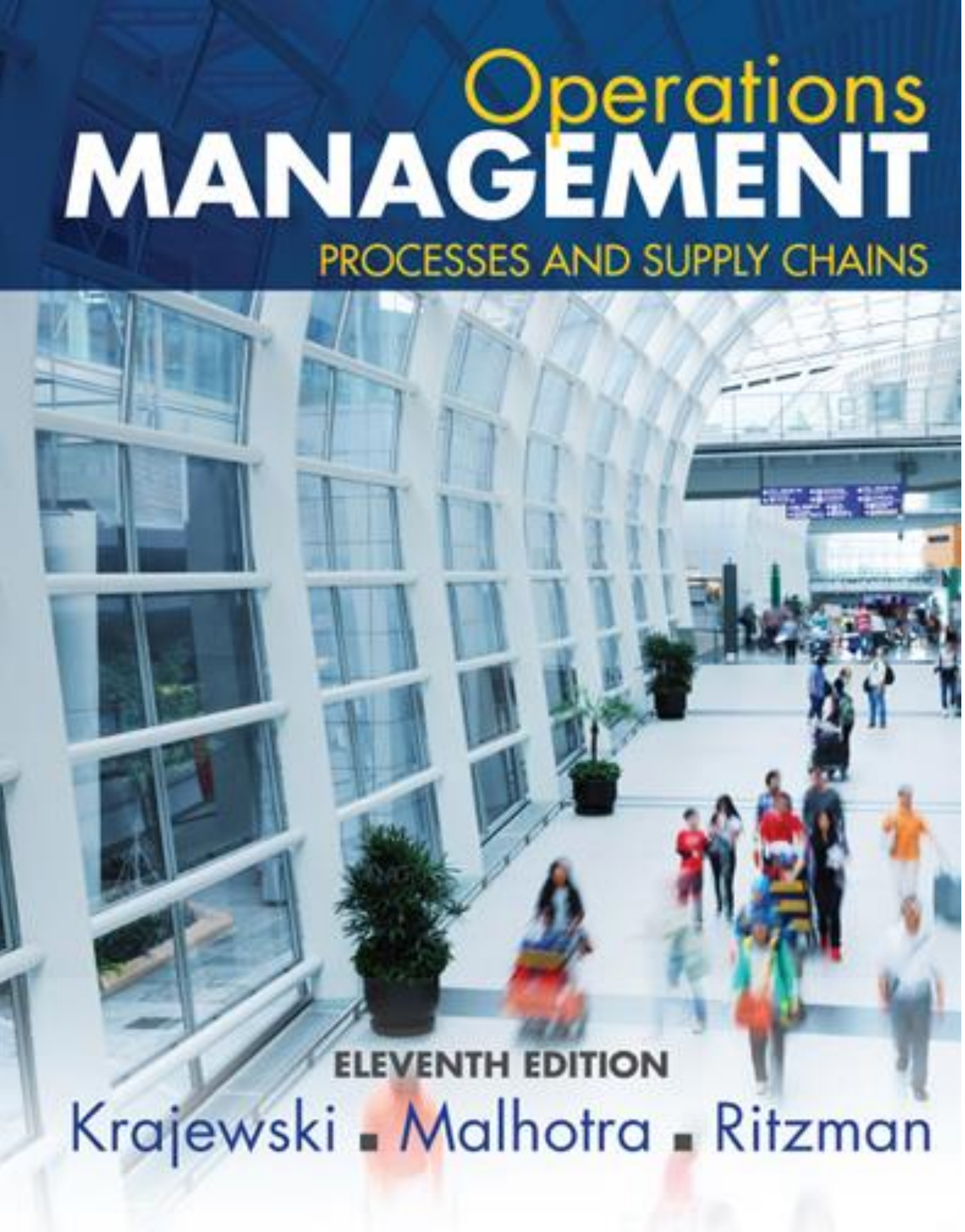
Solved Problem 4

	Week 1		Week 2		
Day	Mail Volume	Seasonal Factor (1)	Mail Volume	Seasonal Factor (2)	Average Seasonal Factor [(1) + (2)]/2
Sunday	5	5/32 = 0.15625	8	8/30 = 0.26667	0.21146
Monday	20	20/32 = 0.62500	15	15/30 = 0.50000	0.56250
Tuesday	30	30/32 = 0.93750	32	32/30 = 1.06667	1.00209
Wednesday	35	35/32 = 1.09375	30	30/30 = 1.00000	1.04688
Thursday	49	49/32 = 1.53125	45	45/30 = 1.50000	1.51563
Friday	70	70/32 = 2.18750	70	70/30 = 2.33333	2.26042
Saturday	15	15/32 = 0.46875	10	10/30 = 0.33333	0.40104
Total	224		210		
Average	224/7 = 32		210/7 = 30		

Solved Problem 4

b. The average daily mail volume is expected to be 230,000/7 = 32,857 pieces of mail. Using the average seasonal factors calculated in part (a), we obtain the following forecasts:

Day	Calculations	Forecast
Sunday	0.21146(32,857) =	6,948
Monday	0.56250(32,857) =	18,482
Tuesday	1.00209(32,857) =	32,926
Wednesday	1.04688(32,857) =	34,397
Thursday	1.51563(32,857) =	49,799
Friday	2.26042(32,857) =	74,271
Saturday	0.40104(32,857) =	13,177
	Total	230,000



Inventory Management

Chapter 9

What is a Inventory Management?

Inventory Management

The planning and controlling of inventories to meet the competitive priorities of the organization.

What is Inventory?

Inventory

A stock of materials used to satisfy customer demand or to support the production of services or goods.

Inventory Trade-Offs

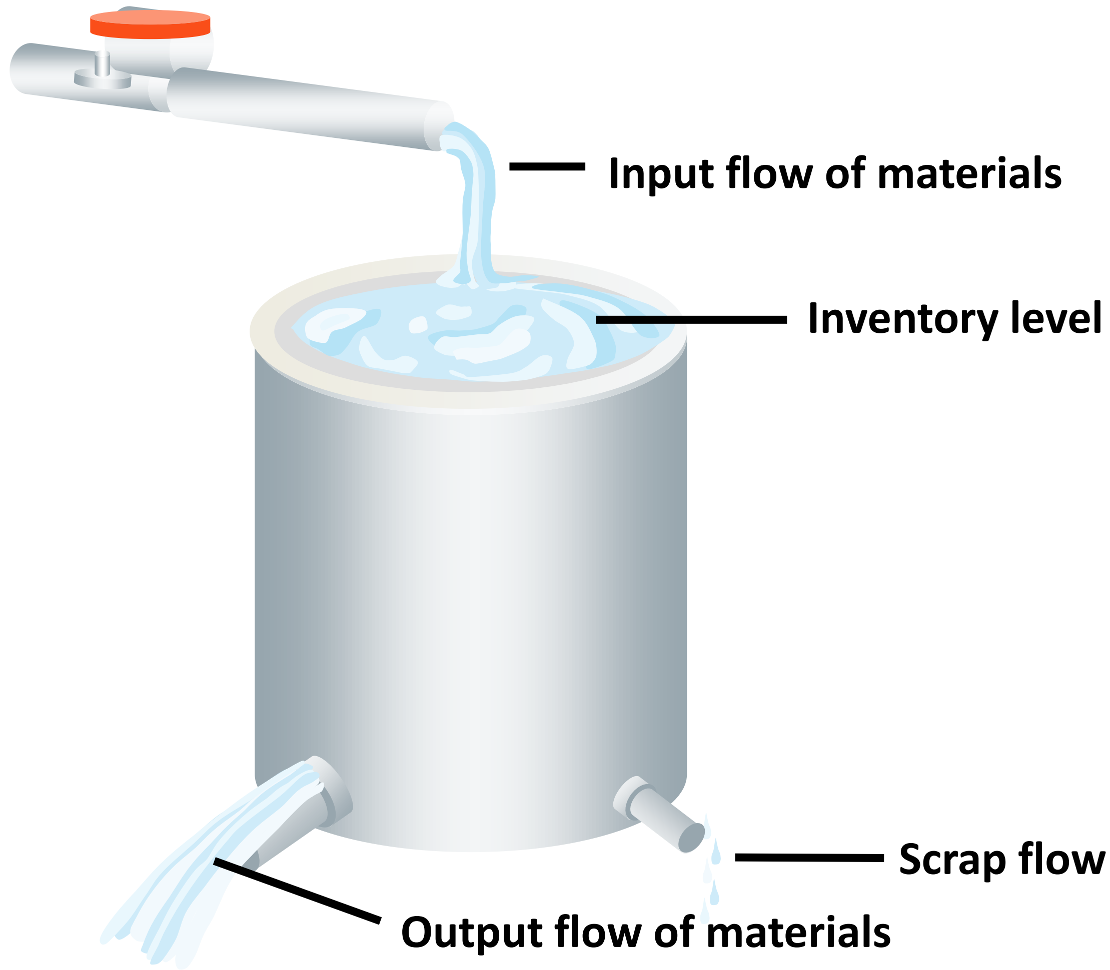


Figure 9.1

Pressures for Small Inventories

- Inventory holding cost
- Cost of capital
- Storage and handling costs
- Taxes
- Insurance
- Shrinkage
  - Pilferage
  - Obsolescence
  - Deterioration

Pressures for Large Inventories

- Customer service
- Ordering cost
- Setup cost
- Labor and equipment utilization
- Transportation cost
- Payments to suppliers

Types of Inventory

- **Accounting Inventories**
  - **Raw materials**
  - **Work-in-process**
  - **Finished goods**

Types of Inventory

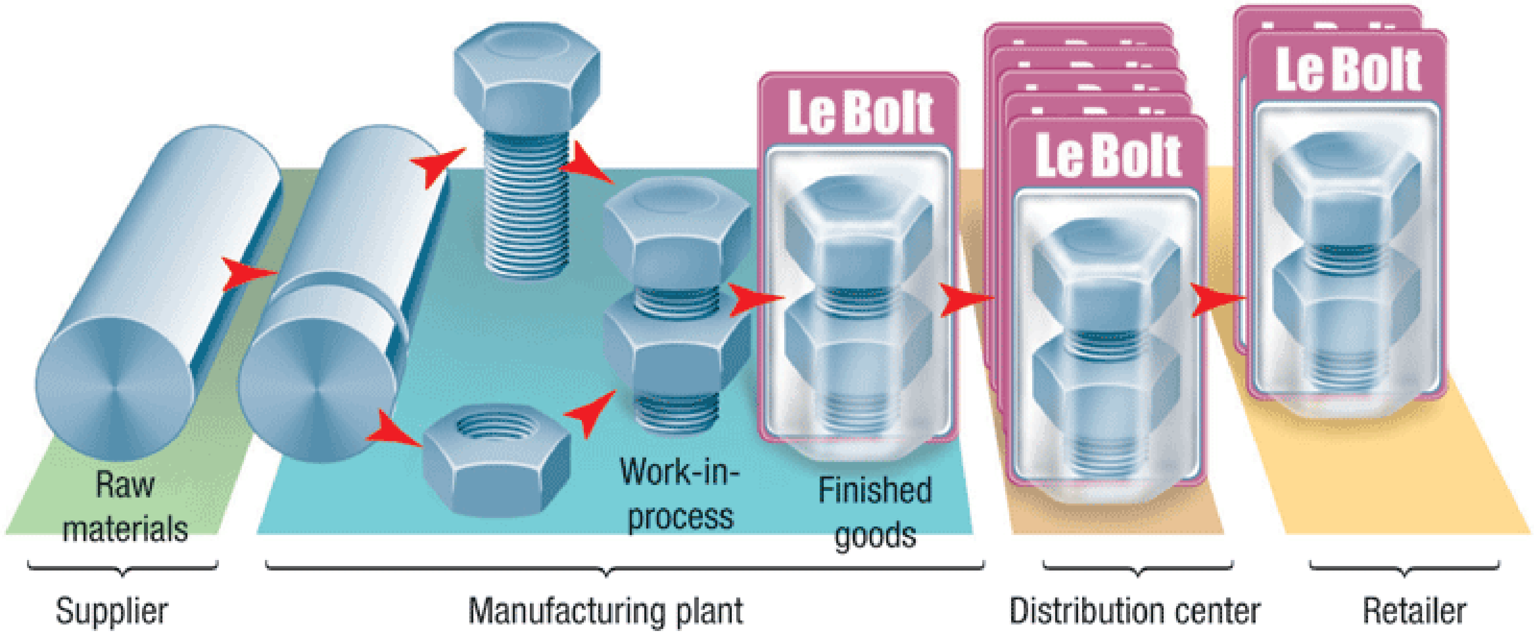


Figure 9.2

Types of Inventory

- **Operational Inventories**
  - **Cycle Inventory**
  - **Safety Stock Inventory**
  - **Anticipation Inventory**
  - **Pipeline Inventory**

Cycle Inventory

Lot sizing principles

1. The lot size, Q, varies directly with the elapsed time (or cycle) between orders.
2. The longer the time between orders for a given item, the greater the cycle inventory must be.

$$\text{Average cycle inventory} = \frac{Q + 0}{2} = \frac{Q}{2}$$

Pipeline Inventory

Average demand during lead time = $\bar{D}_L$

Average demand per period = $\bar{d}$

Number of periods in the item's lead time = L

Pipeline inventory = $\bar{D}_L = \bar{d}L$

Example 9.1

A plant makes monthly shipments of electric drills to a wholesaler in average lot sizes of 280 drills. The wholesaler's average demand is 70 drills a week, and the lead time from the plant is 3 weeks. The wholesaler must pay for the inventory from the moment the plant makes a shipment. If the wholesaler is willing to increase its purchase quantity to 350 units, the plant will give priority to the wholesaler and guarantee a lead time of only 2 weeks. What is the effect on the wholesaler's cycle and pipeline inventories?

Example 9.1

The wholesaler's current cycle and pipeline inventories are

$$\text{Cycle inventory} = \frac{Q}{2} = \textbf{140 drills}$$

$$\text{Pipeline inventory} = \bar{D}_L = \bar{d}L = (70 \text{ drills/week})(3 \text{ weeks})$$

$$= \textbf{210 drills}$$

Example 9.1

The wholesaler's cycle and pipeline inventories if they accept the new proposal

$$\text{Cycle inventory} = \frac{Q}{2} = \textbf{175 drills}$$

$$\text{Pipeline inventory} = \overline{D}_L = \overline{d}L = (70 \text{ drills/week})(2 \text{ weeks})$$

$$= \textbf{140 drills}$$

Inventory Reduction Tactics

- **Cycle inventory**
  - **Reduce the lot size**
    - Reduce ordering and setup costs and allow Q to be reduced
    - Increase repeatability to eliminate the need for changeovers
- **Safety stock inventory**
  - **Place orders closer to the time when they must be received**
    - Improve demand forecasts
    - Cut lead times
    - Reduce supply uncertainties
    - Rely more on equipment and labor buffers

Inventory Reduction Tactics

- **Anticipation inventory**
  - **Match demand rate with production rates**
    - **Add new products with different demand cycles**
    - **Provide off-season promotional campaigns**
    - **Offer seasonal pricing plans**
- **Pipeline inventory**
  - **Reduce lead times**
    - **Find more responsive suppliers and select new carriers**
    - **Change Q in those cases where the lead time depends on the lot size**

What is an ABC Analysis?

ABC Analysis

The process of dividing SKUs into three classes, according to their dollar usage, so that managers can focus on items that have the highest dollar value.

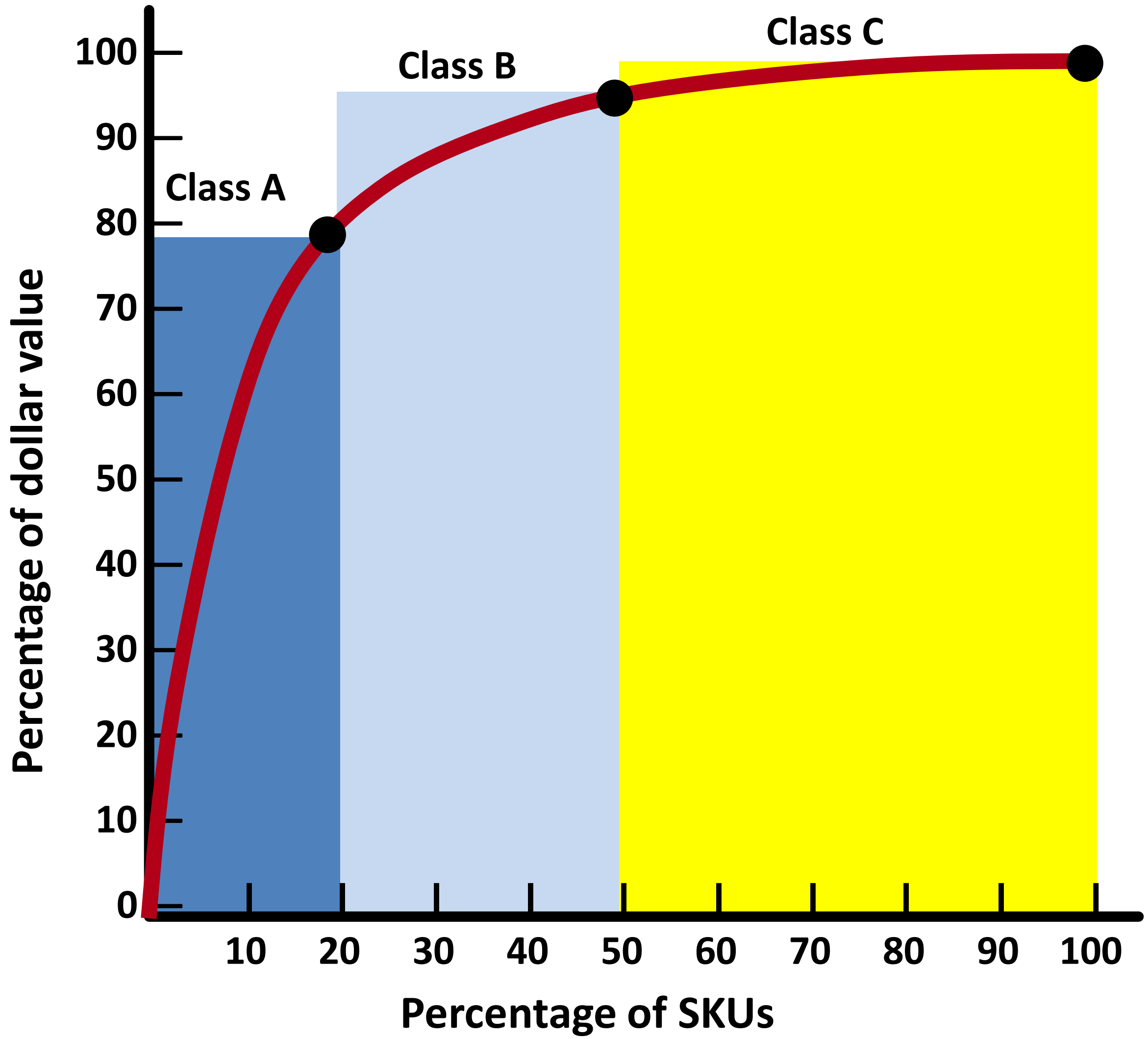


Figure 9.4

Economic Order Quantity

- The lot size, *Q*, that minimizes total annual inventory holding and ordering costs

- Five assumptions
  1. Demand rate is constant and known with certainty.
  2. No constraints are placed on the size of each lot.
  3. The only two relevant costs are the inventory holding cost and the fixed cost per lot for ordering or setup.
  4. Decisions for one item can be made independently of decisions for other items.
  5. The lead time is constant and known with certainty.

Economic Order Quantity

- Don’t use the EOQ
  - Make-to-order strategy
  - Order size is constrained
- Modify the EOQ
  - Quantity discounts
  - Replenishment not instantaneous
- Use the EOQ
  - Make-to-stock strategy with relatively stable demand.
  - Carrying and setup costs are known and relatively stable

Calculating EOQ

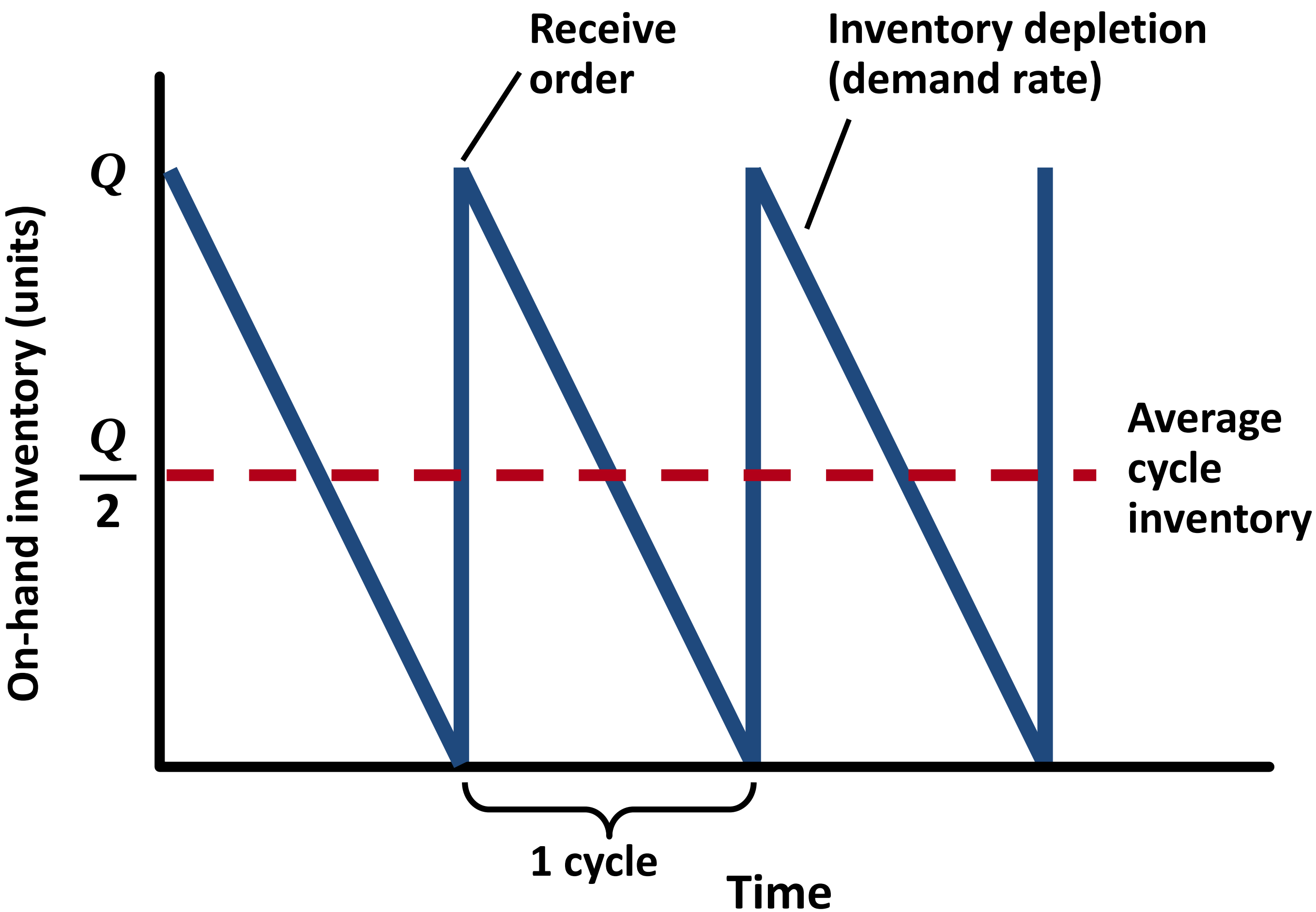


Figure 9.5

Calculating EOQ

- **Annual holding cost**

Annual holding cost = (Average cycle inventory)
× (Unit holding cost)

- **Annual ordering cost**

Annual ordering cost = (Number of orders/Year)
× (Ordering or setup costs)

- **Total annual cycle inventory cost**

Total costs = Annual holding cost
+ Annual ordering or setup cost

Calculating EOQ

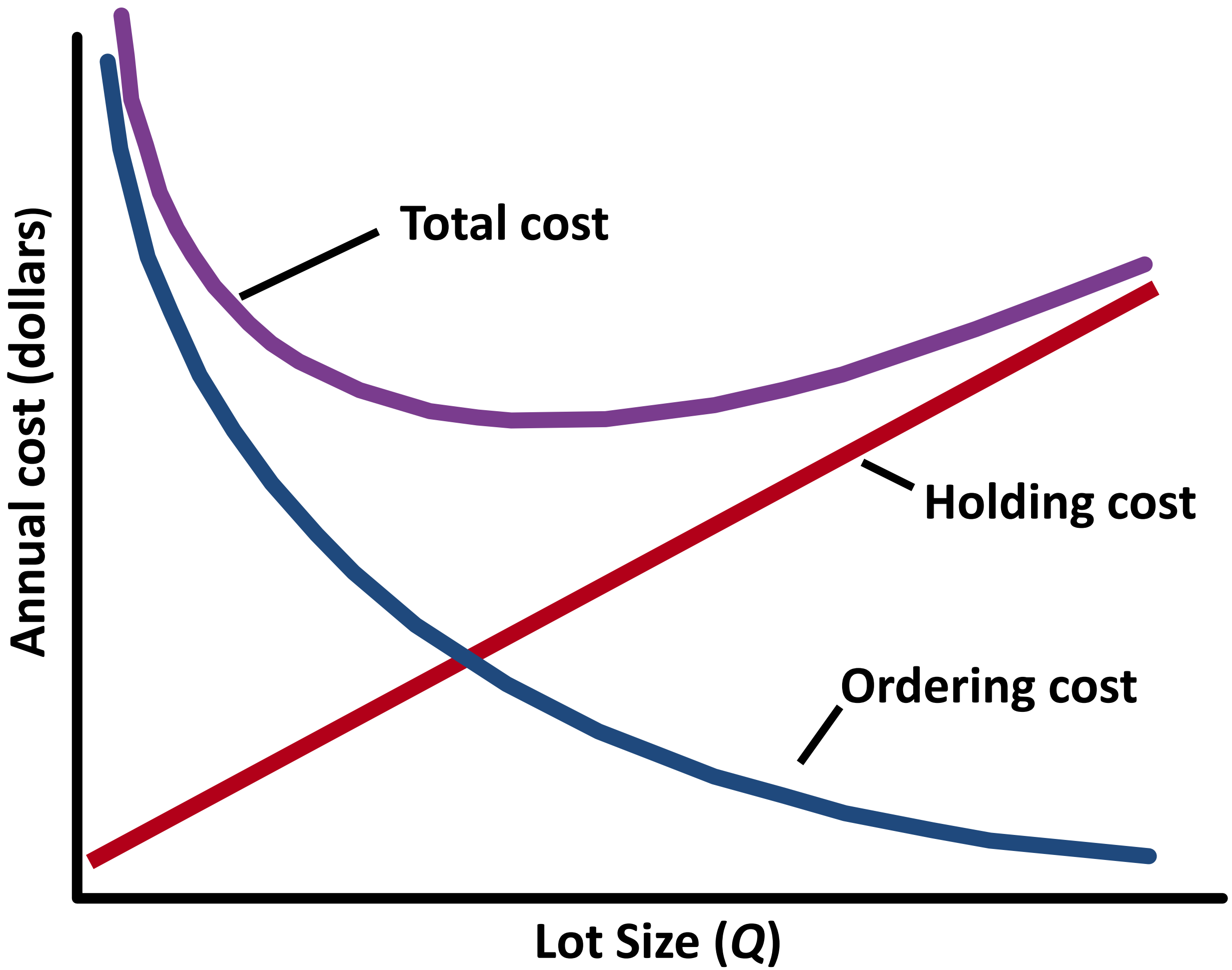


Figure 9.6

Calculating EOQ

- Total annual cycle-inventory cost

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S)$$

where

C = total annual cycle-inventory cost
Q = lot size (in units)
H = holding cost per unit per year
D = annual demand (in units)
S = ordering or setup costs per lot

Example 9.2

- A museum of natural history opened a gift shop which operates 52 weeks per year.
- Top-selling SKU is a bird feeder.
- Sales are 18 units per week, the supplier charges $60 per unit.
- Ordering cost is $45.
- Annual holding cost is 25 percent of a feeder's value.
- Management chose a 390-unit lot size.
- What is the annual cycle-inventory cost of the current policy of using a 390-unit lot size?
- Would a lot size of 468 be better?

Example 9.2

We begin by computing the annual demand and holding cost as

$$D = (18 \text{ units/week})(52 \text{ weeks/year}) = 936 \text{ units}$$

$$H = 0.25(\$60/\text{unit}) = \$15$$

The total annual cycle-inventory cost for the current policy is

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) = \frac{390}{2}(\$15) + \frac{936}{390}(\$45)$$

$$= \$2{,}925 + \$108 = \$3{,}033$$

The total annual cycle-inventory cost for the alternative lot size is

$$C = \frac{468}{2}(\$15) + \frac{936}{468}(\$45) = \$3{,}510 + \$90 = \$3{,}600$$

Example 9.2

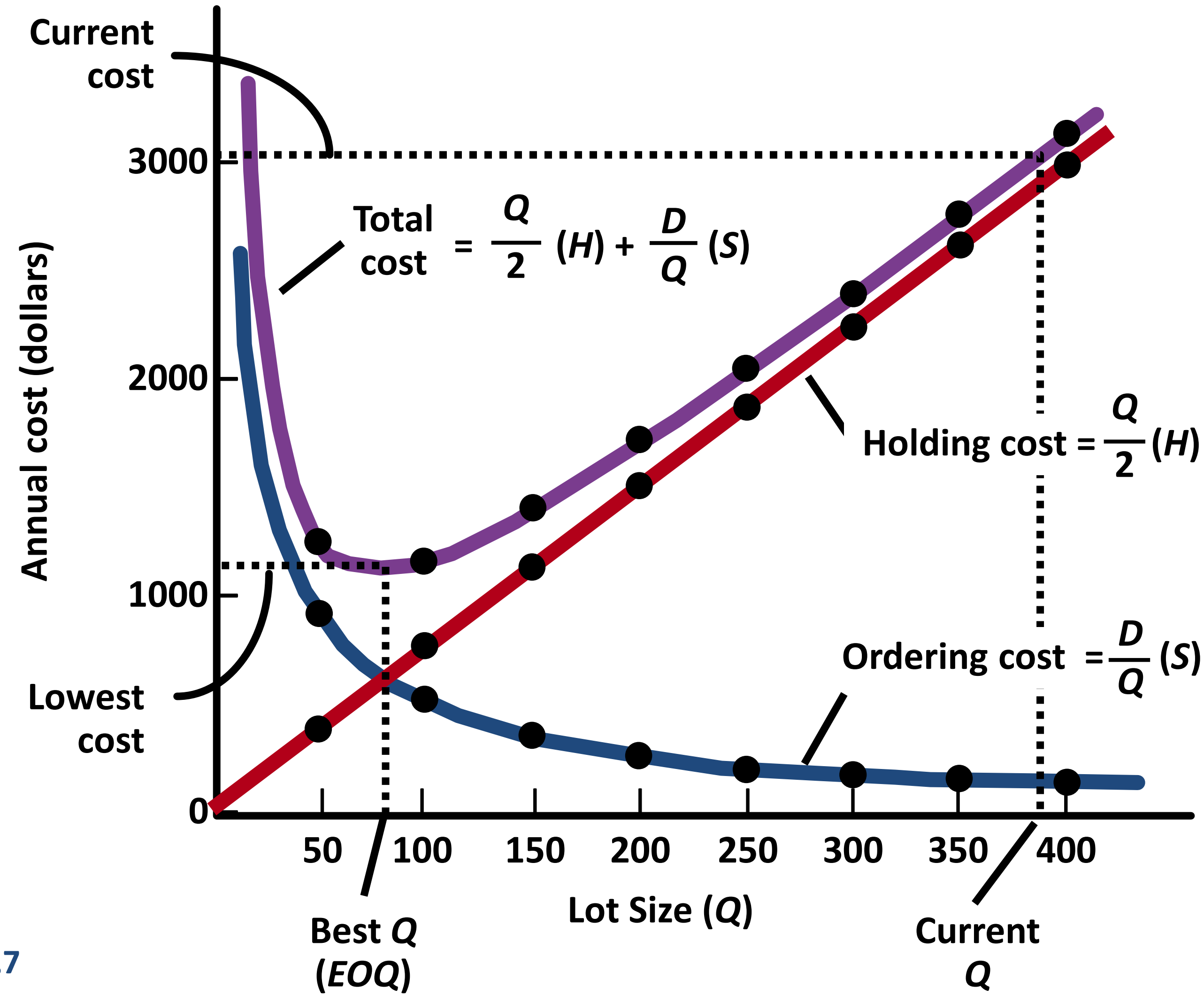


Figure 9.7

Calculating EOQ

- **The EOQ formula:**

$$\text{EOQ} = \sqrt{\frac{2DS}{H}}$$

- **Time Between Orders (TBO):**

$$\text{TBO}_{\text{EOQ}} = \frac{\text{EOQ}}{D}\text{(12 months/year)}$$

Example 9.3

For the bird feeders in Example 9.2, calculate the EOQ and its total annual cycle-inventory cost. How frequently will orders be placed if the EOQ is used?

Using the formulas for EOQ and annual cost, we get

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(936)(45)}{15}} = 74.94 \text{ or } 75 \text{ units}$$

Example 9.3

Below shows that the total annual cost is much less than the $3,033 cost of the current policy of placing 390-unit orders.

Parameters

Current Lot Size (Q)	390
Demand (D)	936
Order Cost (S)	$45
Unit Holding Cost (H)	$15

Economic Order Quantity	75

Annual Costs

Orders per Year	2.4
Annual Ordering Cost	$108.00
Annual Holding Cost	$2,925.00
Annual Inventory Cost	$3,033.00

Annual Costs based on EOQ

Orders per Year	12.48
Annual Ordering Cost	$561.60
Annual Holding Cost	$562.50
Annual Inventory Cost	$1,124.10

Figure 9.8

Example 9.3

When the EOQ is used, the TBO can be expressed in various ways for the same time period.

$$TBO_{EOQ} = \frac{EOQ}{D} = \frac{75}{936} = 0.080 \text{ year}$$

$$TBO_{EOQ} = \frac{EOQ}{D}(12 \text{ months/year}) = \frac{75}{936}(12) = 0.96 \text{ month}$$

$$TBO_{EOQ} = \frac{EOQ}{D}(52 \text{ weeks/year}) = \frac{75}{936}(52) = 4.17 \text{ weeks}$$

$$TBO_{EOQ} = \frac{EOQ}{D}(365 \text{ days/year}) = \frac{75}{936}(365) = 29.25 \text{ days}$$

Application 9.1

Suppose that you are reviewing the inventory policies on an $80 item stocked at a hardware store. The current policy is to replenish inventory by ordering in lots of 360 units. Additional information is:

D = 60 units per week, or 3,120 units per year

S = $30 per order

H = 25% of selling price, or $20 per unit per year

What is the EOQ?

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(3{,}120)(30)}{20}} = 97 \text{ units}$$

Application 9.1

What is the total annual cost of the current policy (*Q* = 360), and how does it compare with the cost with using the EOQ?

Current Policy	EOQ Policy
Q = 360 units	*Q* = 97 units
C = (360/2)(20) + (3,120/360)(30)	*C* = (97/2)(20) + (3,120/97)(30)
C = 3,600 + 260	*C* = 970 + 965
C = $3,860	*C* = $1,935

Application 9.1

What is the time between orders (TBO) for the current policy and the EOQ policy, expressed in weeks?

$$TBO_{360} = \frac{360}{3{,}120}\text{(52 weeks per year)} = \text{6 weeks}$$

$$TBO_{EOQ} = \frac{97}{3{,}120}\text{(52 weeks per year)} = \text{1.6 weeks}$$

Managerial Insights from the EOQ

SENSITIVITY ANALYSIS OF THE EOQ				
Parameter	**EOQ**	**Parameter Change**	**EOQ Change**	**Comments**
Demand	$\sqrt{\dfrac{2DS}{H}}$	↑	↑	Increase in lot size is in proportion to the square root of *D*.
Order/ Setup Costs	$\sqrt{\dfrac{2DS}{H}}$	↓	↓	Weeks of supply decreases and inventory turnover increases because the lot size decreases.
Holding Costs	$\sqrt{\dfrac{2DS}{H}}$	↓	↑	Larger lots are justified when holding costs decrease.

Table 9.1

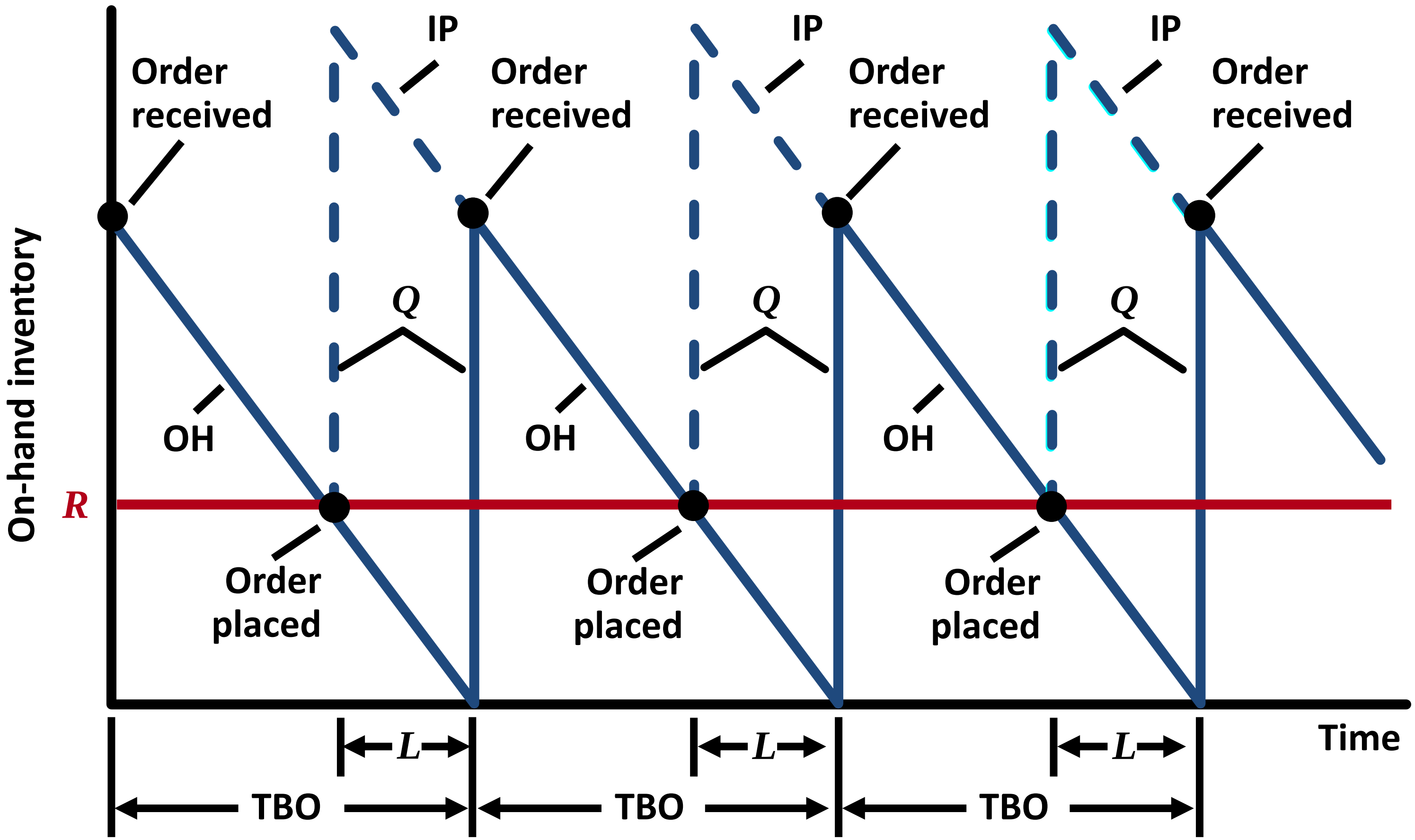
Continuous Review System

- Continuous review (Q) system
  - Reorder point system (ROP) and fixed order quantity system
  - Tracks inventory position (IP)
  - Includes scheduled receipts (SR), on-hand inventory (OH), and back orders (BO)

Inventory position = On-hand inventory + Scheduled receipts – Backorders

$$IP = OH + SR - BO$$

Continuous Review System



Selecting the Reorder Point
When Demand and Lead Time are Constant

Figure 9.9

Example 9.4

Demand for chicken soup at a supermarket is always 25 cases a day and the lead time is always 4 days. The shelves were just restocked with chicken soup, leaving an on-hand inventory of only 10 cases. No backorders currently exist, but there is one open order in the pipeline for 200 cases. What is the inventory position? Should a new order be placed?

R **= Total demand during lead time = (25)(4) = 100 cases**

IP = OH + SR – BO

= 10 + 200 – 0 = 210 cases

Application 9.2

The on-hand inventory is only 10 units, and the reorder point R is 100. There are no backorders and one open order for 200 units. Should a new order be placed?

$$IP = OH + SR - BO = 10 + 200 - 0 = 210$$

$$R = 100$$

Decision: Place NO new order

Continuous Review Systems

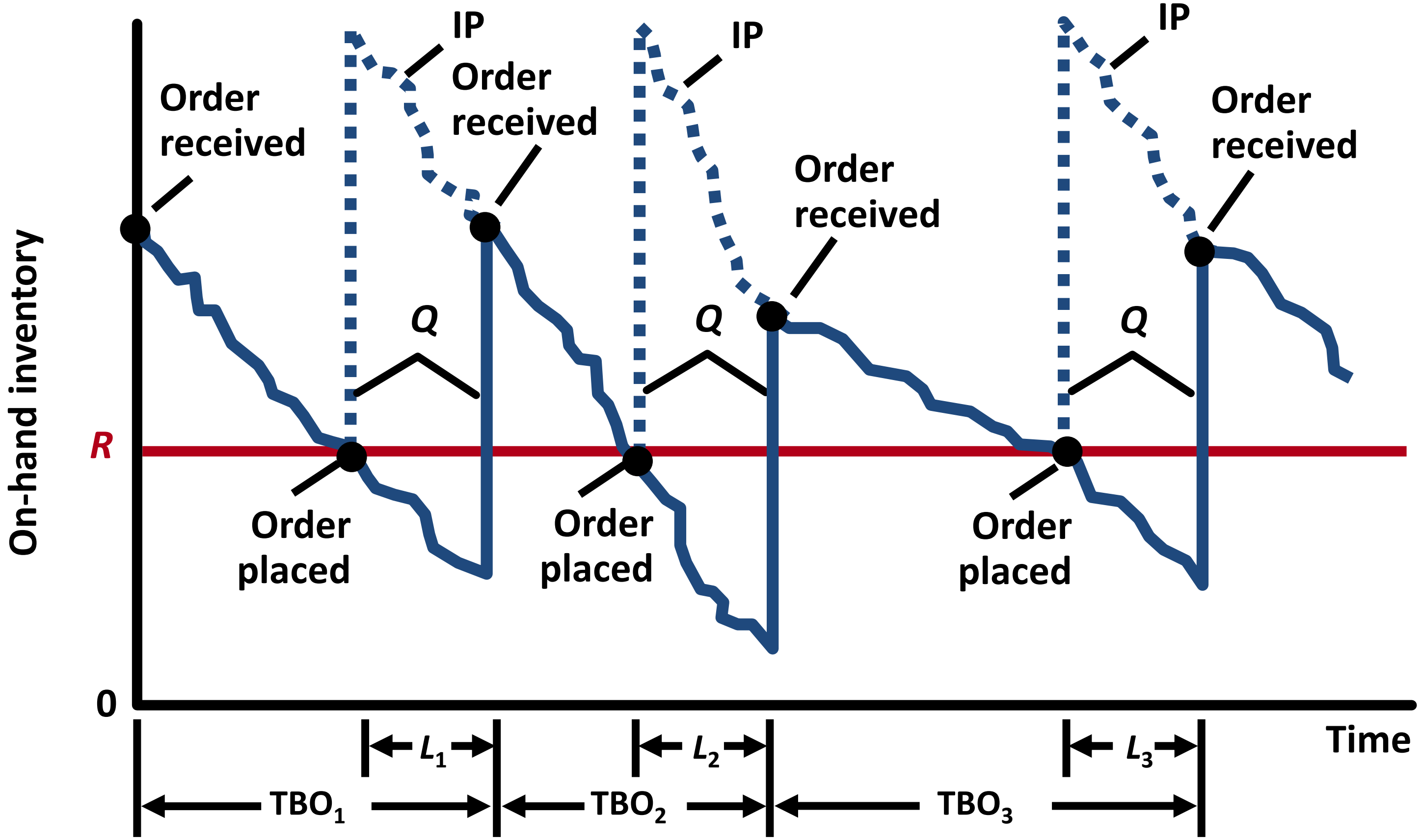


Figure 9.10

Selecting the Reorder Point When Demand is Variable and Lead Time is Constant

Example 9.5

- A distribution center (DC) in Wisconsin stocks Sony plasma TV sets. The center receives its inventory from a mega warehouse in Kansas with a lead time (*L*) of 5 days. The DC uses a reorder point (*R*) of 300 sets and a fixed order quantity (*Q*) of 250 sets. Current on-hand inventory at the end of Day 1 is 400 sets. There are no scheduled receipts (SR) and no backorders (BO). All demands and receipts occur at the end of the day.
- Determine when to order using a *Q* system

Example 9.5

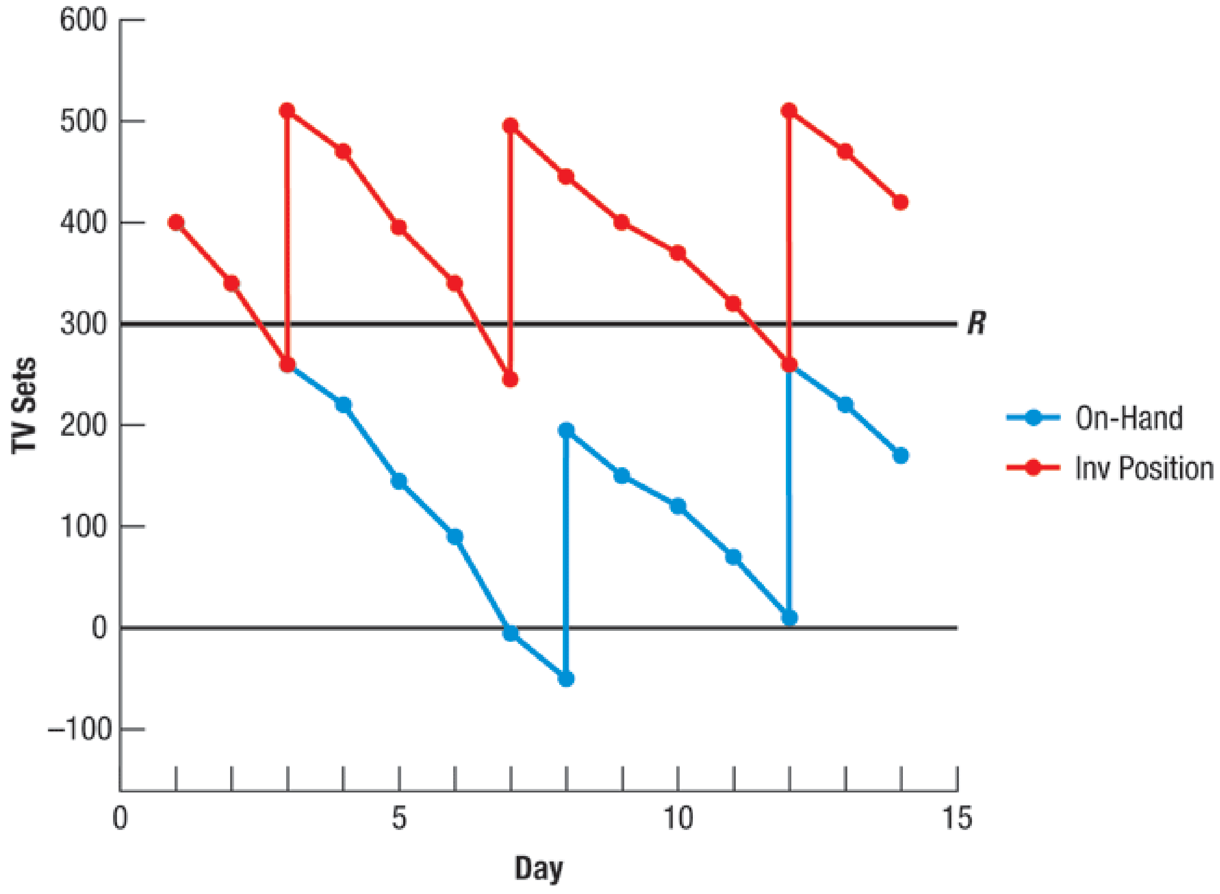
Day	Demand	OH	SR	BO	IP	*Q*
1	50	400			400 + 0 = 400	
2	60	340			340 + 0 = 340	
3	80	260	250 after ordering		260 < *R* before ordering 260 + 250 = 510 after ordering	250 due Day 8
4	40	220	250		220 + 250 = 470	
5	75	145	250		145 + 250 = 395	
6	55	90	250		90 + 250 = 340	
7	95	0	250+ 250 = 500 after ordering	5	0 + 250 – 5 = 245 < *R* before ordering 245 + 250 = 495 after ordering	250 due Day 12

Example 9.5

Day	Demand	OH	SR	BO	IP	*Q*
8	50	0 + 250 – 50 -5 = 195	250		195 + 250 = 445	
9	45	195 – 45 = 150	250		150 + 250 = 400	
10	30	120	250		120 + 250 = 370	
11	50	70	250		70 + 250 = 320	
12	60	70 – 60 + 250 = 260	250 after ordering		260 < *R* before ordering 260 + 250 = 510 after ordering	250 due Day 17
13	40	260 – 40 = 220	250		220 + 250 = 470	
14	50	170	250		170 + 250 = 420	

Example 9.5

The demands at the DC are fairly volatile and cause the reorder point to be breached quite dramatically at times.



Continuous Review Systems

- Selecting the reorder point with variable demand and constant lead time

Reorder point = Average demand during lead time + Safety stock

$= \bar{d}L$ + safety stock

where

$\bar{d}$ = average demand per week (or day or months)

L = constant lead time in weeks (or days or months)

Continuous Review System

- Choosing a Reorder Point
  - Choose an appropriate service-level policy
  - Determine the distribution of demand during lead time
  - Determine the safety stock and reorder point levels

Continuous Review System

- **Step 1: Service Level Policy**
  - **Service Level (Cycle Service Level) – The desired probability of not running out of stock in any one ordering cycle, which begins at the time an order is placed and ends when it arrives in stock.**
  - **Protection Interval – The period over which safety stock must the user from running out of stock.**

Continuous Review System

- Step 2: Distribution of Demand during Lead Time

  - Specify mean and standard deviation
    - Standard deviation of demand during lead time

$$\sigma_{dLT} = \sqrt{\sigma_d^2 L} = \sigma_d \sqrt{L}$$

Continuous Review System

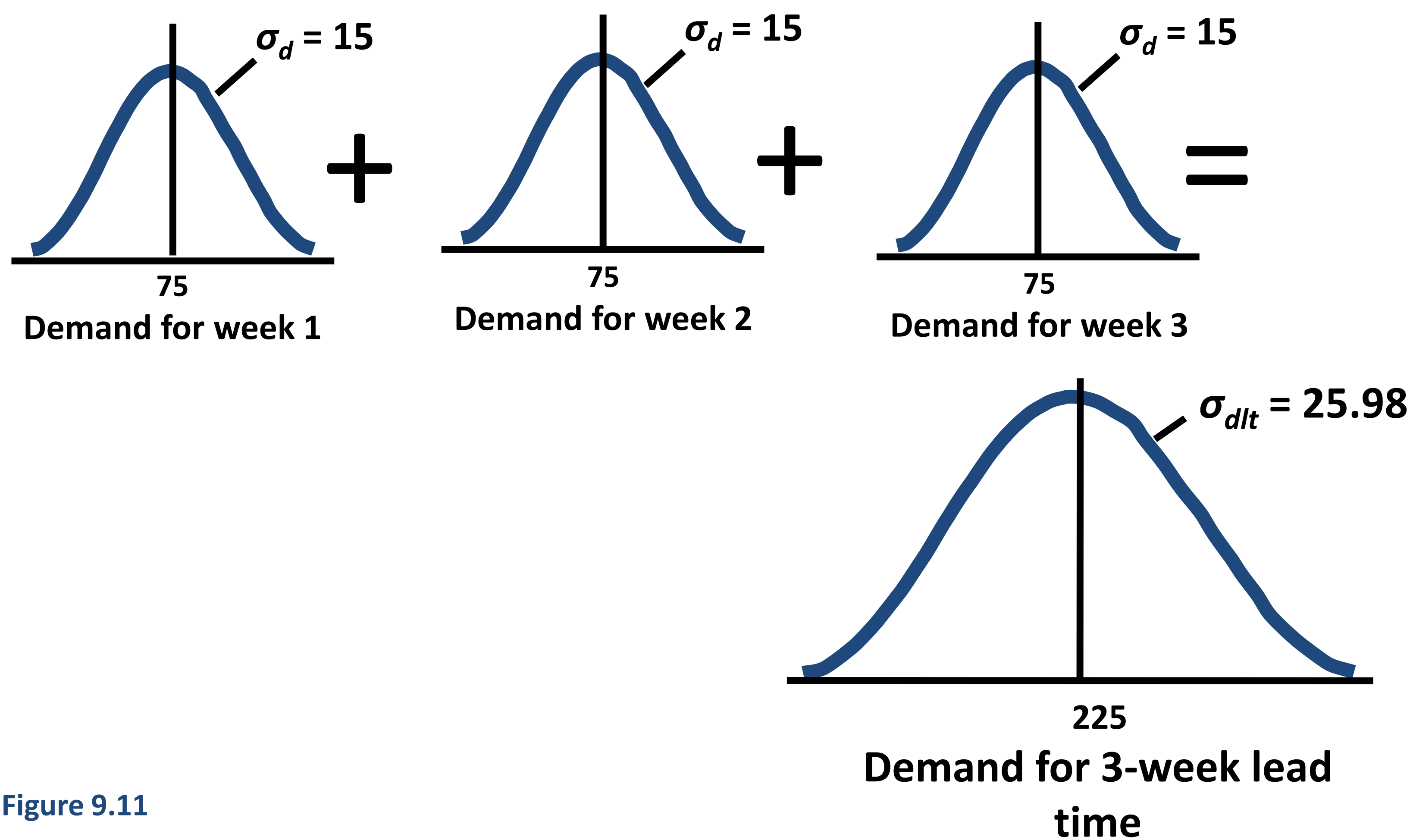


Figure 9.11

Continuous Review System

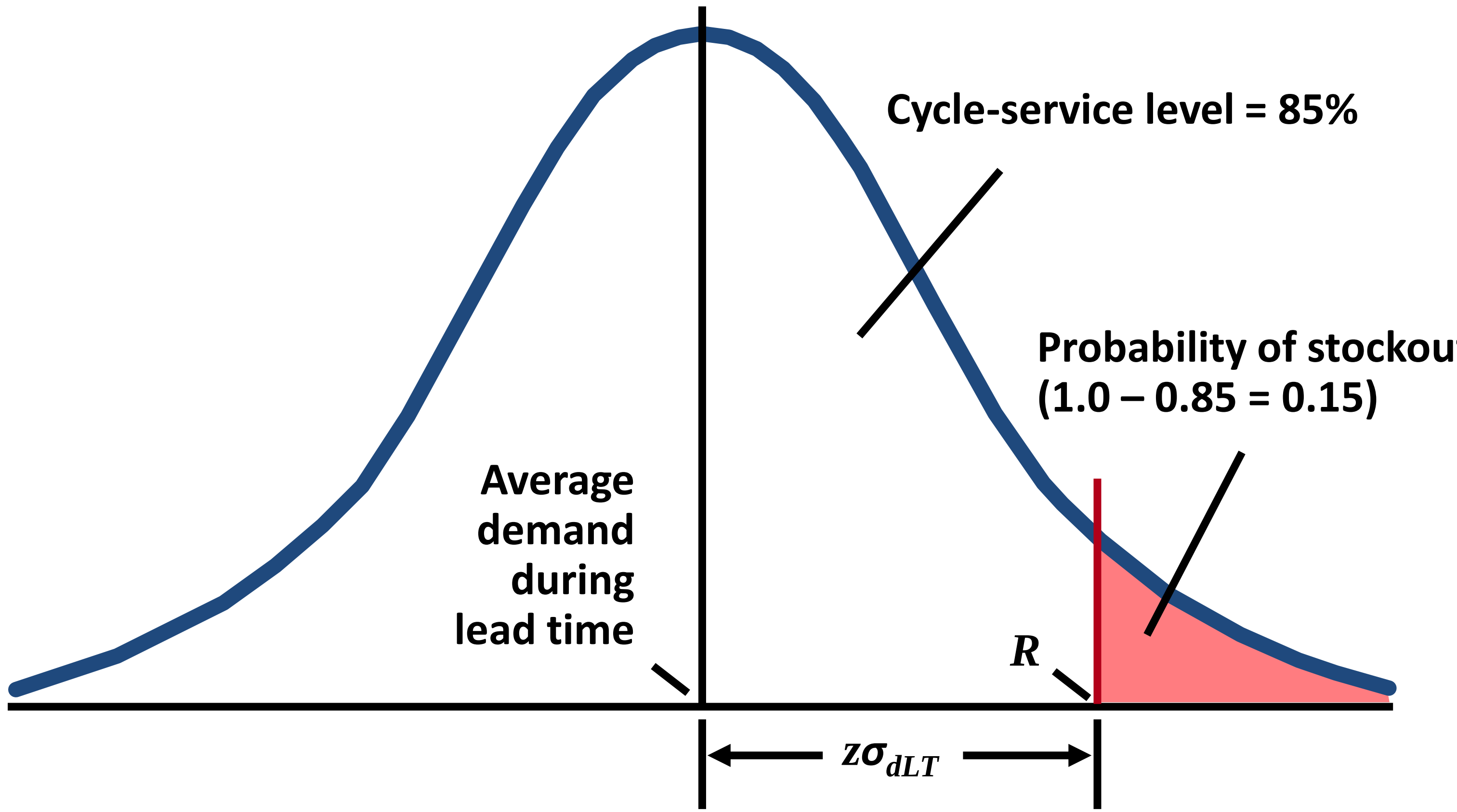


Figure 9.12

Continuous Review System

- Step 3: Safety Stock and Reorder Point

$$\text{Safety stock} = z\sigma_{dLT}$$

where

z = number of standard deviations needed to achieve the cycle-service level

σ_{dLT} = stand deviation of demand during lead time

$$\text{Reorder point} = R = \bar{d}L + \text{safety stock}$$

Example 9.6

- Let us return to the bird feeder in Example 9.3.
- The EOQ is 75 units.
- Suppose that the average demand is 18 units per week with a standard deviation of 5 units.
- The lead time is constant at two weeks.
- Determine the safety stock and reorder point if management wants a 90 percent cycle-service level.

Safety stock = $z\sigma_{dLT}$ = 1.28(7.07) = 9.05 or 9 units

Reorder point = $\bar{d}L$ + Safety stock = 2(18) + 9 = 45 units

Application 9.3

Suppose that the demand during lead time is normally distributed with an average of 85 and $\sigma_{dLT} = 40$. Find the safety stock, and reorder point *R*, for a 95 percent cycle-service level.

Safety stock = $z\sigma_{dLT}$ = 1.645(40) = 65.8 or 66 units

R = Average demand during lead time + Safety stock

R = 85 + 66 = 151 units

Find the safety stock, and reorder point *R*, for an 85 percent cycle-service level.

Safety stock = $z\sigma_{dLT}$ = 1.04(40) = 41.6 or 42 units

R = Average demand during lead time + Safety stock

R = 85 + 42 = 127 units

Continuous Review System

- Selecting the Reorder Point When Demand and Lead Time are Variable

Safety stock = $z\sigma_{dLT}$

R = (Average weekly demand × Average lead time) + Safety stock

= $\bar{d}\,\bar{L}$ + Safety stock

where

$\bar{d}$ = Average weekly (or daily or monthly) demand

$\bar{L}$ = Average lead time

σ_d = Standard deviation of weekly (or daily or monthly)demand

σ_{LT} = Standard deviation of the lead time

$$\sigma_{dLT} = \sqrt{\bar{L}\,\sigma_d^2 + \bar{d}^{\,2}\sigma_{LT}^2}$$

Example 9.7

- The Office Supply Shop estimates that the average demand for a popular ball-point pen is 12,000 pens per week with a standard deviation of 3,000 pens.
- The current inventory policy calls for replenishment orders of 156,000 pens.
- The average lead time from the distributor is 5 weeks, with a standard deviation of 2 weeks.
- If management wants a 95 percent cycle-service level, what should the reorder point be?

Example 9.7

We have $\bar{d}$ = 12,000 pens, σ_d = 3,000 pens, $\bar{L}$ = 5 weeks, and σ_{LT} = 2 weeks

$$\sigma_{dLT} = \sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_{LT}^2} = \sqrt{(5)(3{,}000)^2 + (12{,}000)^2(2)^2}$$

= 24,919.87 pens

Safety stock = $z\sigma_{dLT}$ = (1.65)(24,919.87)

= 41,117.79 or 41,118 pens

Reorder point = $\bar{d}\,\bar{L}$ + Safety stock = (12,000)(5) + 41,118

= 101,118 pens

Continuous Review Systems

- **Two-Bin system**
  - A visual system version of the *Q* system in which a SKU's inventory is stored at two different locations.

- **Calculating Total *Q* System Costs**

Total cost = Annual cycle inventory holding cost
+ Annual ordering cost
+ Annual safety stock holding cost

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) + (H)\ (\text{Safety stock})$$

Continuous Review System

- **Advantages of the *Q* System**
  - The review frequency of each SKU may be individualized.
  - Fixed lot sizes can results in quantity discounts.
  - The system requires low levels of safety stock for the amount of uncertainty in demands during the lead time.

Application 9.5

The Discount Appliance Store uses a continuous review system (Q system). One of the company's items has the following characteristics:

- Demand = 10 units/week (assume 52 weeks per year)
- Ordering or setup cost (S) = \$45/order
- Holding cost (H) = \$12/unit/year
- Lead time (L) = 3 weeks (constant)
- Standard deviation in weekly demand = 8 units
- Cycle-service level = 70%

Application 9.5

What is the EOQ for this item?

$$D = 10/\text{wk} \times 52\ \text{wks/yr} = 520\ \text{units}$$

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(520)(45)}{12}} = 62\ \text{units}$$

What is the desired safety stock?

$$\sigma_{dLT} = \sigma_d\sqrt{L} = 8\sqrt{3} = 14\ \text{units}$$

$$\text{Safety stock} = z\sigma_{dLT} = 0.525(14) = 8\ \text{units}$$

Application 9.5

What is the desired reorder point *R*?

R = Average demand during lead time + Safety stock

R = 3(10) + 8 = 38 units

What is the total annual cost?

$$C = \frac{62}{2}(\$12) + \frac{520}{62}(\$45) + 8(\$12) = \$845.42$$

Application 9.5

Suppose that the current policy is *Q* = 80 and *R* = 150. What will be the changes in average cycle inventory and safety stock if your EOQ and *R* values are implemented?

Reducing *Q* from 80 to 62

Cycle inventory reduction = 40 – 31 = 9 units

Safety stock reduction = 120 – 8 = 112 units

Reducing *R* from 150 to 38

Periodic Review System (P)

- **Fixed interval reorder system or periodic reorder system**
- **Four of the original EOQ assumptions maintained**
  1. **No constraints are placed on lot size**
  2. **Holding and ordering costs**
  3. **Independent demand**
  4. **Lead times are certain and supply is known**

Periodic Review System (P)

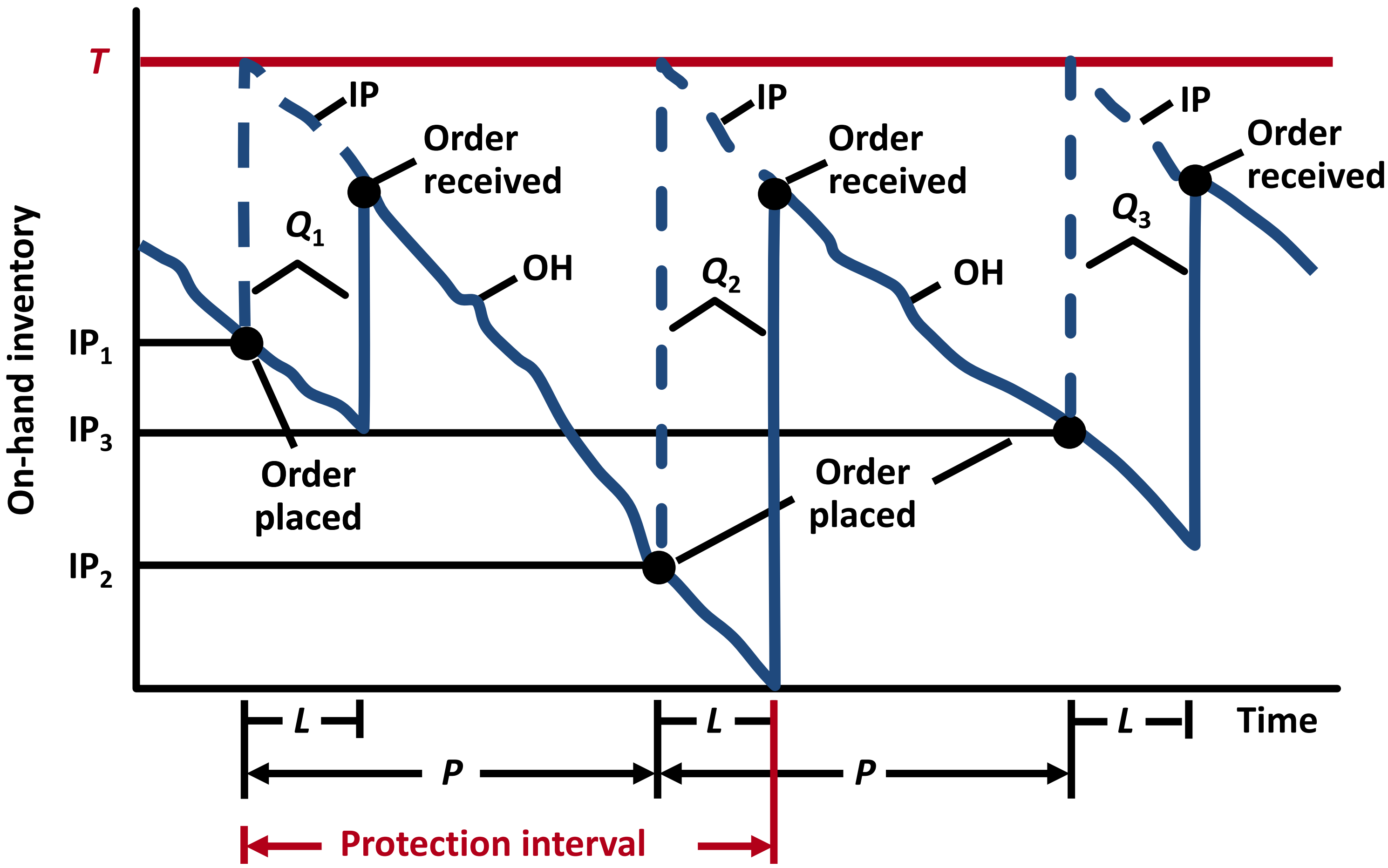


Figure 9.13

Example 9.8

- Refer to Example 9.5
- Suppose that the management want to use a Periodic Review System for the Sony TV sets. The first review is scheduled for the end of Day 2. All demands and receipts occur at the end of the day. Lead time is 5 Days and management has set $T = 620$ and $P = 6$ days.
- Determine how much to order (Q) using a P System.

Example 9.8

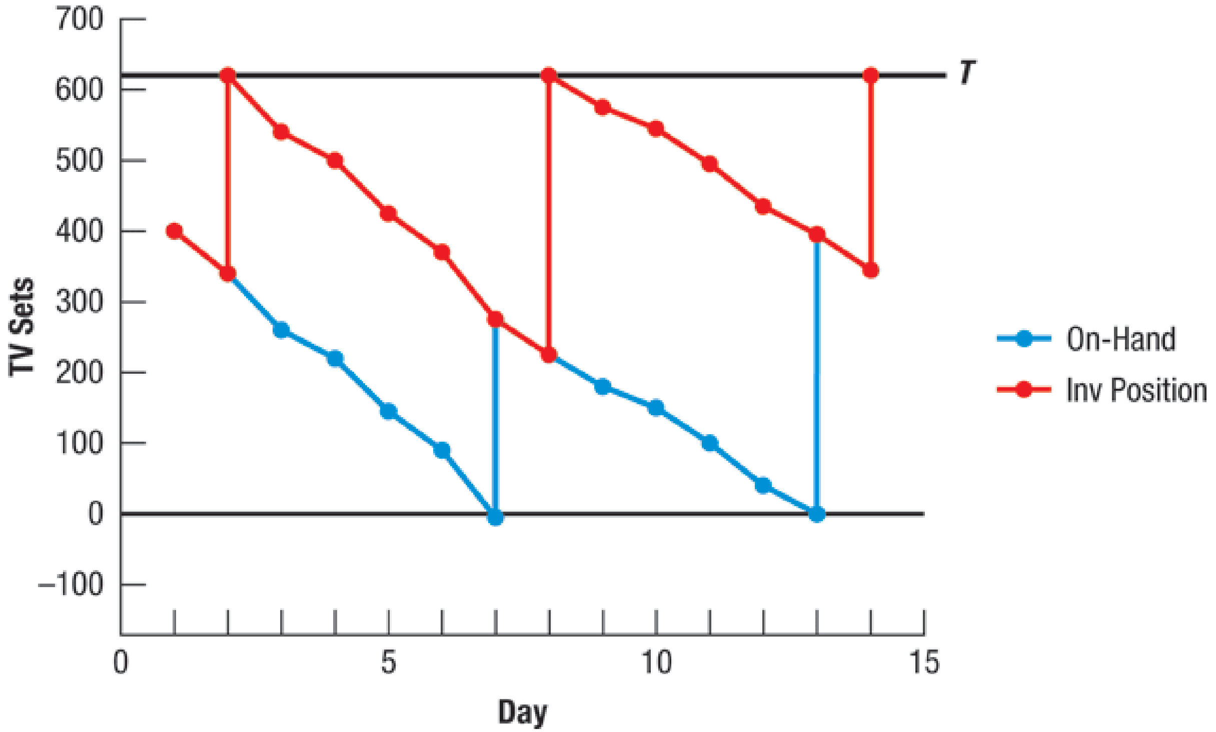
Day	Demand	OH	SR	BO	IP	Q
1	50	400			400	
2	60	340	280 after ordering		340 before ordering 340 + 280 = 620 after ordering	620 – 340 = 280 due Day 7
3	80	260	280		260 + 280 = 540	
4	40	220	280		220 + 280 = 500	
5	75	145	280		145 + 280 = 425	
6	55	90	280		90 + 280 = 370	
7	95	90 + 280 – 95 = 275			270 + 0 = 275	

Example 9.8

Day	Demand	OH	SR	BO	IP	Q
8	50	225	395 after ordering		225 + 0 = 225 before ordering 225 + 395 = 620 after ordering	620 – 225 = 395 due Day 13
9	45	180	395		180 + 395 = 575	
10	30	150	395		150 + 395 = 545	
11	50	100	395		100 + 395 = 495	
12	60	40	395		40 + 395 = 435	
13	40	40 + 395 – 40 = 395			395 + 0 = 395	
14	50	345	275 after ordering		340 + 0 = 340 before ordering 345 + 275 = 620 after ordering	620 – 345 = 275 due Day 19

Example 9.8

The *P* system requires more inventory for the same level of protection against stockouts or backorders.



Periodic Review System

- Selecting the time between reviews, choosing P and T
- Selecting T when demand is variable and lead time is constant
  - *IP* covers demand over a protection interval of $P + L$
  - The average demand during the protection interval is $\bar{d}(P + L)$, or

$$T = \bar{d}(P + L) + \text{safety stock for protection interval}$$

$$\text{Safety stock} = z\sigma_{P+L}, \textit{ where } \sigma_{P+L} = \sigma_d\sqrt{P+L}$$

Example 9.9

- Again, let us return to the bird feeder example.
- Recall that demand for the bird feeder is normally distributed with a mean of 18 units per week and a standard deviation in weekly demand of 5 units.
- The lead time is 2 weeks, and the business operates 52 weeks per year. The Q system called for an EOQ of 75 units and a safety stock of 9 units for a cycle-service level of 90 percent.
- What is the equivalent P system?
- Answers are to be rounded to the nearest integer.

Example 9.9

We first define *D* and then *P*. Here, *P* is the time between reviews, expressed in weeks because the data are expressed as demand per week:

$$D = (18 \text{ units/week})(52 \text{ weeks/year}) = 936 \text{ units}$$

$$P = \frac{\text{EOQ}}{D}(52) = \frac{75}{936}(52) = 4.2 \text{ or } 4 \text{ weeks}$$

With $\bar{d}$= 18 units per week, an alternative approach is to calculate *P* by dividing the EOQ by $\bar{d}$ to get 75/18 = 4.2 or 4 weeks.

Either way, we would review the bird feeder inventory every 4 weeks.

Example 9.9

We now find the standard deviation of demand over the protection interval ($P + L$) = 6:

$$\sigma_{P+L} = \sigma_d\sqrt{P + L} = 5\sqrt{6} = 12.25 \text{ units}$$

For a 90 percent cycle-service level $z = 1.28$:

Safety stock = $z\sigma_{P+L}$ = 1.28(12.25) = 15.68 or 16 units

We now solve for T:

T = Average demand during the protection interval + Safety stock

= $\bar{d}(P + L)$ + safety stock

= (18 units/week)(6 weeks) + 16 units = 124 units

Application 9.6

The on-hand inventory is 10 units, and *T* is 400. There are no back orders, but one scheduled receipt of 200 units. Now is the time to review. How much should be reordered?

$$IP = OH + SR - BO$$

$$= 10 + 200 - 0 = 210$$

$$T - IP = 400 - 210 = 190$$

The decision is to order 190 units

Periodic Review System

- Selecting the Target Inventory Level When Demand and Lead Time are Variable
  - Simulation
- Systems Based on the *P* System
  - Single-Bin System
  - Optional Replenishment System
- Calculating Total *P* System Costs

$$C = \frac{\bar{d}P}{2}(H) + \frac{D}{\bar{d}P}(S) + Hz\sigma_{P+L}$$

Periodic Review System

- Advantages of the *P* System
  1. It is convenient because replenishments are made at fixed intervals.
  2. Orders for multiple items from the same supplier can be combined into a single purchase order.
  3. The inventory position needs to be known only when a review is made (not continuously).

Application 9.7

Return to Discount Appliance Store (Application 9.5), but now use the *P* system for the item.

Previous information:

Demand = 10 units/wk (assume 52 weeks per year) = 520

EOQ = 62 units (with reorder point system)

Lead time (*L*) = 3 weeks

Standard deviation in weekly demand = 8 units

***z* = 0.525 (for cycle-service level of 70%)**

Application 9.7

Reorder interval P, if you make the average lot size using the Periodic Review System approximate the EOQ.

P = (EOQ/D)(52) = (62/520)(52) = 6.2 or 6 weeks

Safety stock

$$\text{Safety Stock} = \sigma_d \sqrt{P + L}$$

$$= (0.525)(8)\sqrt{6+3} = 12.6 \text{ or } 13 \text{ units}$$

Target inventory

$T = \bar{d}(P + L)$ + safety stock for protection interval

T = 10(6 + 3) + 13 = 103 units

Application 9.7

Total cost

$$C = \frac{\bar{d}P}{2}(H) + \frac{D}{\bar{d}P}(S) + Hz\sigma_{P+L}$$

$$= \frac{10(6)}{2}(\$12) + \frac{520}{10(6)}(\$45) + (13)(\$12) = \$906.00$$

Solved Problem 1

- A distribution center experiences an average weekly demand of 50 units for one of its items.
- The product is valued at $650 per unit. Average inbound shipments from the factory warehouse average 350 units.
- Average lead time (including ordering delays and transit time) is 2 weeks.
- The distribution center operates 52 weeks per year; it carries a 1-week supply of inventory as safety stock and no anticipation inventory.
- What is the value of the average aggregate inventory being held by the distribution center?

Solved Problem 1

Type of Inventory	Calculation of Average Inventory
Cycle	$\frac{Q}{2} = \frac{350}{2}$ = 175 units
Safety stock	1-week supply = 50 units
Anticipation	None
Pipeline	$\bar{d}L$ = (50 units/week)(2 weeks) = 100 units
	Average aggregate inventory = 325 units
	Value of aggregate inventory = \$650(325)
	= \$211,250

Solved Problem 2

Booker's Book Bindery divides SKUs into three classes, according to their dollar usage. Calculate the usage values of the following SKUs and determine which is most likely to be classified as class A.

SKU Number	Description	Quantity Used per Year	Unit Value ($)
1	Boxes	500	3.00
2	Cardboard (square feet)	18,000	0.02
3	Cover stock	10,000	0.75
4	Glue (gallons)	75	40.00
5	Inside covers	20,000	0.05
6	Reinforcing tape (meters)	3,000	0.15
7	Signatures	150,000	0.45

Solved Problem 2

SKU Number	Description	Quantity Used per Year		Unit Value ($)		Annual Dollar Usage ($)
1	Boxes	500	×	3.00	=	1,500
2	Cardboard (square feet)	18,000	×	0.02	=	360
3	Cover stock	10,000	×	0.75	=	7,500
4	Glue (gallons)	75	×	40.00	=	3,000
5	Inside covers	20,000	×	0.05	=	1,000
6	Reinforcing tape (meters)	3,000	×	0.15	=	450
7	Signatures	150,000	×	0.45	=	67,500
					Total	81,310

Solved Problem 2

SKU #	Description	Qty Used/Year	Value	Dollar Usage	Pct of Total	Cumulative % of Dollar Value	Cumulative % of SKU	Class
7	Signatures	150,000	$0.45	$67,500	83.0%	83.0%	14.3%	A
3	Cover stock	10,000	$0.75	$7,500	9.2%	92.2%	28.6%	B
4	Glue	75	$40.00	$3,000	3.7%	95.9%	42.9%	B
1	Boxes	500	$3.00	$1,500	1.8%	97.8%	57.1%	C
5	Inside covers	20,000	$0.05	$1,000	1.2%	99.0%	71.4%	C
6	Reinforcing tape	3,000	$0.15	$450	0.6%	99.6%	85.7%	C
2	Cardboard	18,000	$0.02	$360	0.4%	100.0%	100.0%	C
Total				$81,310				

Figure 9.14

Solved Problem 2

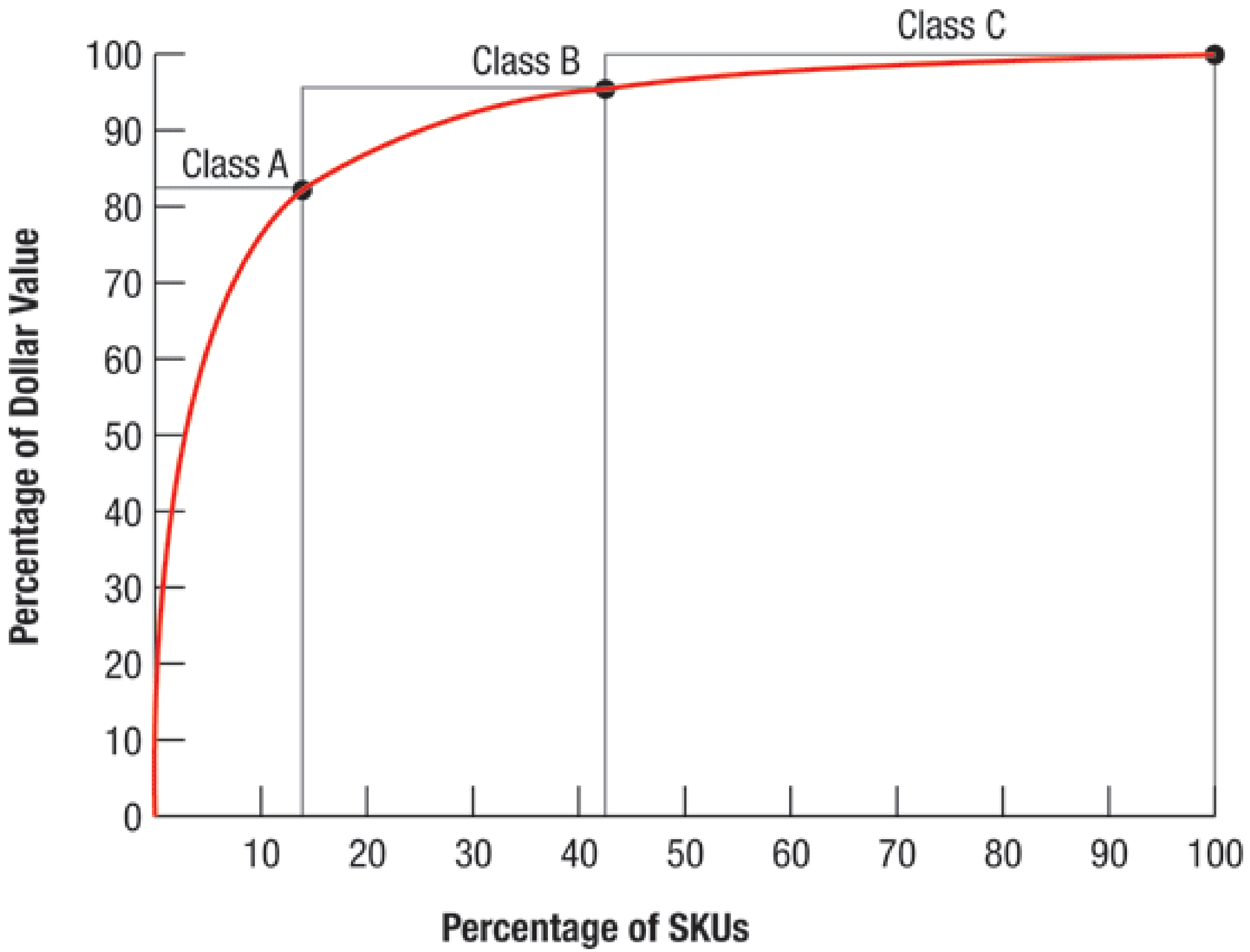


Figure 9.14

Solved Problem 3

Nelson's Hardware Store stocks a 19.2 volt cordless drill that is a popular seller. Annual demand is 5,000 units, the ordering cost is $15, and the inventory holding cost is $4/unit/year.

a. What is the economic order quantity?
b. What is the total annual cost for this inventory item?

a. The order quantity is

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(5{,}000)(\$15)}{\$4}}$$

$$= \sqrt{37{,}500} = 193.65 \text{ or } \textbf{194 drills}$$

b. The total annual cost is

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) = \frac{194}{2}(\$4) + \frac{5{,}000}{194}(\$15) = \textbf{\$774.60}$$

Solved Problem 4

A regional distributor purchases discontinued appliances from various suppliers and then sells them on demand to retailers in the region. The distributor operates 5 days per week, 52 weeks per year. Only when it is open for business can orders be received. The following data are estimated for the countertop mixer:

- Average daily demand ($\bar{d}$) = 100 mixers
- Standard deviation of daily demand (σ_d) = 30 mixers
- Lead time (L) = 3 days
- Holding cost (H) = $9.40/unit/year
- Ordering cost (S) = $35/order
- Cycle-service level = 92 percent
- The distributor uses a continuous review (Q) system

Solved Problem 4

a. What order quantity Q, and reorder point, R, should be used?

b. What is the total annual cost of the system?

c. If on-hand inventory is 40 units, one open order for 440 mixers is pending, and no backorders exist, should a new order be placed?

Solved Problem 4

a. Annual demand is

D = (5 days/week)(52 weeks/year)(100 mixers/day)

= 26,000 mixers/year

The order quantity is

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(26{,}000)(\$35)}{\$9.40}}$$

$$= \sqrt{193{,}167} = 440.02 \text{ or } 440 \text{ mixers}$$

Solved Problem 4

The standard deviation of the demand during lead time distribution is

$$\sigma_{dLT} = \sigma_d \sqrt{L} = 30\sqrt{3} = 51.96$$

A 92 percent cycle-service level corresponds to $z = 1.41$

Safety stock = $z\sigma_{dLT}$ = 1.41(51.96 mixers) = 73.26 or 73 mixers

Average demand during lead time = $\bar{d}\bar{L}$ = 100(3) = 300 mixers

Reorder point (R) = Average demand during lead time + Safety stock

= 300 mixers + 73 mixers = 373 mixers

With a continuous review system, Q = 440 and R = 373

Solved Problem 4

b. The total annual cost for the *Q* systems is

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) + (H)(\text{Safety stock})$$

$$C = \frac{440}{2}(\$9.40) + \frac{26{,}000}{440}(\$35) + (\$9.40)(73) = \$4{,}822.38$$

c. Inventory position = On-hand inventory + Scheduled receipts – Backorders

IP = OH + SR – BO = 40 + 440 – 0 = 480 mixers

Because IP (480) exceeds *R* (373), do not place a new order

Solved Problem 5

Suppose that a periodic review (P) system is used at the distributor in Solved Problem 4, but otherwise the data are the same.

a. Calculate the P (in workdays, rounded to the nearest day) that gives approximately the same number of orders per year as the EOQ.

b. What is the target inventory level, T? Compare the P system to the Q system in Solved Problem 4.

c. What is the total annual cost of the P system?

d. It is time to review the item. On-hand inventory is 40 mixers; receipt of 440 mixers is scheduled, and no backorders exist. How much should be reordered?

Solved Problem 5

a. The time between orders is

$$P = \frac{\text{EOQ}}{D}(260 \text{ days/year}) = \frac{440}{26{,}000}(260) = 4.4 \text{ or } 4 \text{ days}$$

Solved Problem 5

b. The OM Solver data below shows that T = 812 and safety stock = (1.41)(79.37) = 111.91 or about 112 mixers.

The corresponding Q system for the counter-top mixer requires less safety stock.

Continuous Review (Q) System

z	1.41
Safety Stock	73
Reorder Point	373
Annual Cost	$4,822.38

Periodic Review (P) System

Time Between Reviews (P)	4.00	Days
	☑ Enter manually	
Standard Deviation of Demand During Protection Interval	79.37	
Safety Stock	112	
Average Demand During Protection Interval	700	
Target Inventory Level (T)	812	
Annual Cost	$5,207.80	

Figure 9.15

Solved Problem 5

c. The total annual cost of the *P* system is

$$C = \frac{\bar{d}P}{2}(H) + \frac{D}{\bar{d}P}(S) + (H)(\text{Safety stock})$$

$$C = \frac{100(4)}{2}(\$9.40) + \frac{26{,}000}{100(4)}(\$35) + (\$9.40)(1.41)(79.37)$$

$= \$5{,}207.80$

d. Inventory position is the amount on hand plus scheduled receipts minus backorders, or

IP = OH + SR – BO = 40 + 440 – 0 = 480 mixers

The order quantity is the target inventory level minus the inventory position, or

Q = *T* – IP = 812 mixers – 480 mixers = 332 mixers

An order for 332 mixers should be placed.

Solved Problem 6

Grey Wolf Lodge is a popular 500-room hotel in the North Woods. Managers need to keep close tabs on all room service items, including a special pine-scented bar soap. The daily demand for the soap is 275 bars, with a standard deviation of 30 bars. Ordering cost is $10 and the inventory holding cost is $0.30/bar/year. The lead time from the supplier is 5 days, with a standard deviation of 1 day. The lodge is open 365 days a year.

a. What is the economic order quantity for the bar of soap?
b. What should the reorder point be for the bar of soap if management wants to have a 99 percent cycle-service level?
c. What is the total annual cost for the bar of soap, assuming a Q system will be used?

Solved Problem 6

a. We have $D = (275)(365) = 100{,}375$ bars of soap; $S = \$10$; and $H = \$0.30$. The EOQ for the bar of soap is

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(100{,}375)(\$10)}{\$0.30}}$$

$$= \sqrt{6{,}691{,}666.7} = 2{,}586.83 \text{ or } 2{,}587 \text{ bars}$$

Solved Problem 6

b. We have $\bar{d}$ = 275 bars/day, σ_d = 30 bars, $\bar{L}$ = 5 days, and σ_{LT} = 1 day

$$\sigma_{dLT} = \sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_{LT}^2} = \sqrt{(5)(30)^2 + (275)^2(1)^2} = 283.06 \text{ bars}$$

Safety stock = $z\sigma_{dLT}$ = (2.33)(283.06) = 659.53 or 660 bars

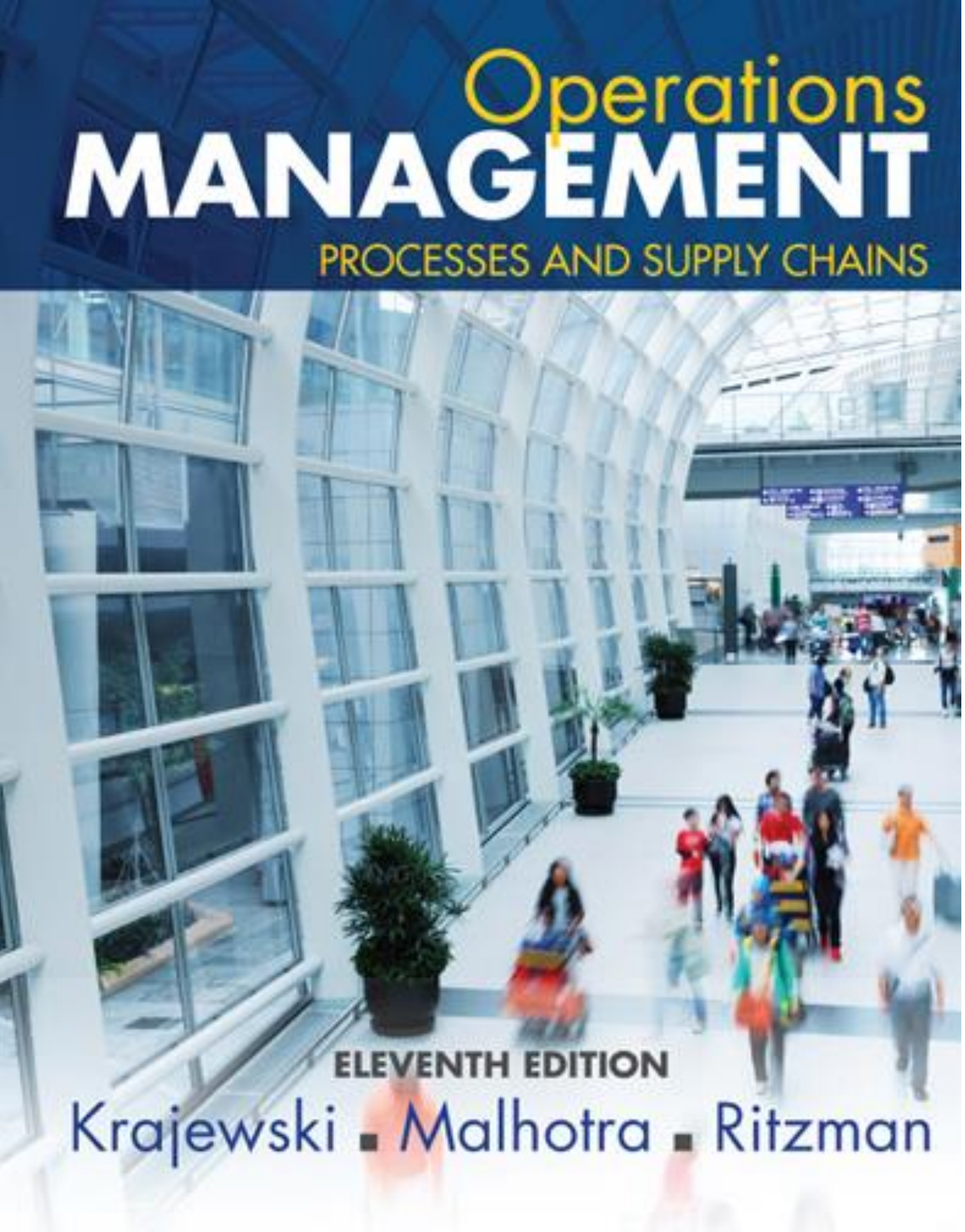
Reorder point = $\bar{d}\bar{L}$ + Safety stock = (275)(5) + 660 = 2,035 bars

Solved Problem 6

c. The total annual cost for the *Q* system is

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) + (H)(\text{Safety stock})$$

$$C = \frac{2{,}587}{2}(\$0.30) + \frac{100{,}375}{2{,}587}(\$10) + (\$0.30)(660) = \$974.05$$



Operations Planning and Scheduling

Chapter 10

What is Operations Planning and Scheduling?

Operations planning and scheduling

The process of balancing supply with demand, from the aggregate level down to the short-term scheduling level

Operations Planning and Scheduling

TYPES OF PLANS WITH OPERATIONS PLANNING AND SCHEDULING	
Term	**Definition**
Sales and operations plan (S&OP)	A time-phased plan of future aggregate resource levels so that supply is in balance with demand
Aggregate plan	Another term for the sales and operations plan
Production plan	A sales and operations plan for a *manufacturing firm* that centers on production rates and inventory holdings
Staffing plan	A sales and operations plan for a *service firm*, which centers on staffing and on other human resource-related factors
Resource plan	An intermediate step in the planning process that lies between S&OP and scheduling
Schedule	A detailed plan that allocates resources over shorter time horizons to accomplish specific tasks

Table 10.1

Levels in Operations Planning and Scheduling

- **Level 1: Sales and Operations Planning**
  - **Aggregation**
    1. Services or products
    2. Workforce
    3. Time
  - **Information inputs**
  - **Relationship to other plans**
    - Business Plan
    - Annual Plan

Levels in Operations Planning and Scheduling

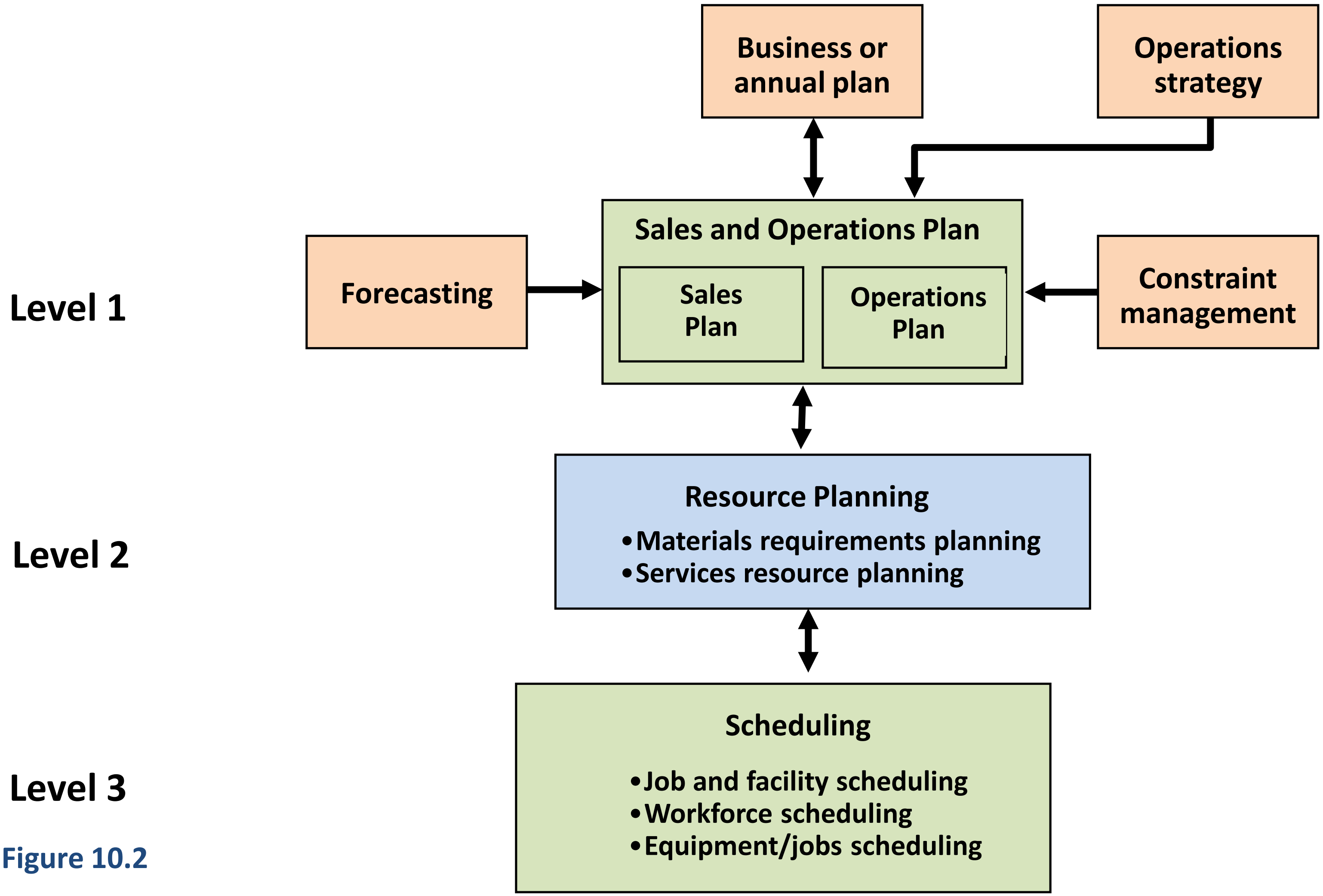


Figure 10.2

Levels in Operations Planning and Scheduling

- **Level 2: Resource Planning**
  - A process that takes sales and operations plans; process time standards, routings, and other information on how services or products are produced; and then plans the timing of capacity and material requirements.
- **Level 3: Scheduling**
  - A process that takes the resource plan and translates it into specific operational tasks on a detailed basis.

S&OP Supply Options

1. Anticipation Inventory
2. Workforce Adjustment
3. Workforce Utilization
4. Part-Time Workers
5. Subcontractors
6. Vacation Schedules

S&OP Strategies

- **Chase Strategy**
  - A strategy that involves hiring and laying off employees to match the demand forecast
- **Level Strategy**
  - A strategy that keeps the workforce constant, but varies its utilization via overtime, undertime, and vacation planning to match the demand forecast
- **Mixed Strategy**
  - A strategy that considers the full range of supply options

S&OP Strategies

TYPES OF COSTS WITH SALES AND OPERATIONS PLANNING	
Cost	**Definition**
Regular time	Regular-time wages plus benefits and pay for vacations
Overtime	Wages paid for work beyond the normal workweek exclusive of fringe benefits
Hiring and layoff	Cost of advertising jobs, interviews, training programs, scrap caused by inexperienced employees, exit interviews, severance pay, and retraining
Inventory holding	Capital, storage and warehousing, pilferage and obsolescence, insurance, and taxes
Backorder and stockout	Costs to expedite past-due orders, potential cost of losing a customer

Table 10.2

S&OP Strategies

Artic Air Company—April Sales and Operations Plan

Family: Medium window units (make-to-stock) — *Unit of measure:* 100 units

	HISTORY									3rd	4th	Mos	Fiscal Year	Business
SALES	J	F	M	A*	M	J	J	A	S	3 Mos**	3 Mos	13–18	Projection ($000)	Plan ($000)
New forecast	45	55	60	70	85	95	130	110	70	150	176	275	$8,700	$8,560
Actual sales	52	40	63											
Diff for month	7	–15	3											
Cum		–8	–5											
OPERATIONS														
New Plan	75	75	75	75	75	85	85	85	75	177	225			
Actual	75	78	76											
Diff for month	0	3	1											
Cum		3	4											
INVENTORY														
Plan	85	105	120	125	115	105	60	35	40	198	321			
Actual	92	130	143											

DEMAND ISSUES AND ASSUMPTIONS

1. New product design to be launched in January of next year.

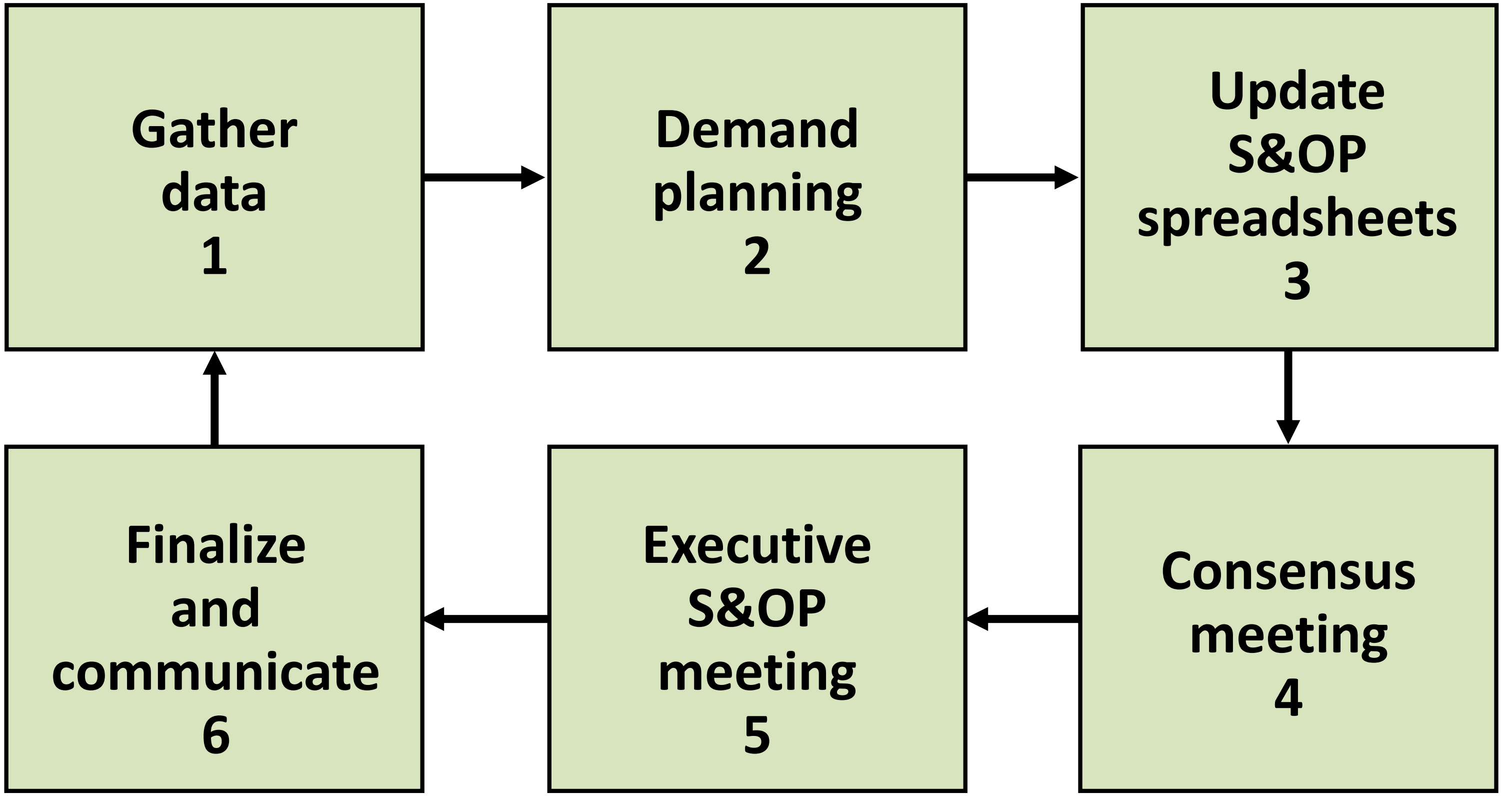
SUPPLY ISSUES

1. Vacations primarily in November and December.
2. Overtime in June–August.

Figure 10.3

S&OP Strategies

Steps in Sales and Operations Planning Process



Spreadsheet for a Manufacturer

	1	2	3	4	5	6	Total
Inputs							
Forecasted demand	24	142	220	180	136	168	870
Workforce level	120	158	158	158	158	158	910
Undertime	6	0	0	0	0	0	6
Overtime	0	0	0	0	0	0	0
Vacation time	20	6	0	0	4	10	40
Subcontracting time	0	0	0	0	0	6	6
Backorders	0	0	0	4	0	0	4
Derived							
Utilized time	94	152	158	158	154	148	864
Inventory	70	80	18	0	14	0	182
Hires	0	38	0	0	0	0	38
Layoffs	0	0	0	0	0	0	0
Calculated							
Utilized time cost	$376,000	$608,000	$632,000	$632,000	$616,000	$592,000	$3,456,000
Undertime cost	$24,000	$0	$0	$0	$0	$0	$24,000
Overtime cost	$0	$0	$0	$0	$0	$0	$0
Vacation time cost	$80,000	$24,000	$0	$0	$16,000	$40,000	$160,000
Inventory cost	$2,800	$3,200	$720	$0	$560	$0	$7,280
Backorders cost	$0	$0	$0	$4,000	$0	$0	$4,000
Hiring cost	$0	$91,200	$0	$0	$0	$0	$91,200
Layoff cost	$0	$0	$0	$0	$0	$0	$0
Subcontracting cost	$0	$0	$0	$0	$0	$43,200	$43,200
Total cost	$482,800	726,400	632,720	636,000	632,560	675,200	$3,785,680

Figure 10.4

Example 10.1

- A large distribution center must develop a staffing plan that minimizes total costs using part-time stockpickers (using chase and level plans)
- For the level strategy, need to meet demand with the minimum use of undertime and not consider vacation scheduling
- Each part-time employee can work a maximum of 20 hours per week on regular time
- Instead of paying undertime, each worker’s day is shortened during slack periods and overtime can be used during peak periods

	1	2	3	4	5	6	Total
Forecasted demand	6	12	18	15	13	14	78

Example 10.1

Currently, 10 part-time clerks are employed. They have not been subtracted from the forecasted demand shown. Constraints and cost information are as follows:

a. The size of training facilities limits the number of new hires in any period to no more than 10.

b. No backorders are permitted; demand must be met each period.

c. Overtime cannot exceed 20 percent of the regular-time capacity in any period. The most that any part-time employee can work is 1.20(20) = 24 hours per week.

d. The following costs can be assigned:

Regular-time wage rate	$2,000/time period at 20 hrs/week
Overtime wages	150% of the regular-time rate
Hires	$1,000 per person
Layoffs	$500 per person

Example 10.1

a. Chase Strategy

- This strategy simply involves adjusting the workforce as needed to meet demand.
- Rows in the spreadsheet that do not apply (such as inventory and vacations) are hidden.
- The workforce level row is identical to the forecasted demand row.
- A large number of hirings and layoffs begin with laying off 4 part-time employees immediately because the current staff is 10 and the staff level required in period 1 is only 6.
- The total cost is **$173,500.**

Example 10.1

	1	2	3	4	5	6	Total
Inputs							
Forecasted demand	6	12	18	15	13	14	78
Workforce level	6	12	18	15	13	14	78
Undertime	0	0	0	0	0	0	0
Overtime	0	0	0	0	0	0	0
Derived							
Utilized time	6	12	18	15	13	14	78
Hires	0	6	6	0	0	1	13
Layoffs	4	0	0	3	2	0	9
Calculated							
Utilized time cost	$12,000	$24,000	$36,000	$30,000	$26,000	$28,000	$156,000
Undertime cost	$0	$0	$0	$0	$0	$0	$0
Hiring cost	$0	$6,000	$6,000	$0	$0	$1,000	$13,000
Layoff cost	$2,000	$0	$0	$1,500	$1,000	$0	$4,500
Total cost	$14,000	30,000	42,000	31,500	27,000	29,000	$173,500

Figure 10.5

Example 10.1

b. Level Strategy

- **In order to minimize undertime, the maximum use of overtime possible must occur in the peak period.**
- **The most overtime that the manager can use is 20 percent of the regular-time capacity, *w*, so**

$$1.20w = 18 \text{ employees required in peak period (period 3)}$$

$$w = \frac{18}{1.20} = 15 \text{ employees}$$

  - **A 15-employee staff size minimizes the amount of undertime for this level strategy.**
  - **Because the staff already includes 10 part-time employees, the manager should immediately hire 5 more.**
  - **The total cost is $164,000.**

Example 10.1

	1	2	3	4	5	6	Total
Inputs							
Forecasted demand	6	12	18	15	13	14	78
Workforce level	15	15	15	15	15	15	90
Undertime	9	3	0	0	2	1	15
Overtime	0	0	3	0	0	0	3
Derived							
Utilized time	6	12	15	15	13	14	75
Hires	5	0	0	0	0	0	5
Layoffs	0	0	0	0	0	0	0
Calculated							
Utilized time cost	$12,000	$24,000	$30,000	$30,000	$26,000	$28,000	$150,000
Undertime cost	$0	$0	$0	$0	$0	$0	$0
Overtime cost	$0	$0	$9,000	$0	$0	$0	$9,000
Hiring cost	$5,000	$0	$0	$0	$0	$0	$5,000
Layoff cost	$0	$0	$0	$0	$0	$0	$0
Total cost	$17,000	24,000	39,000	30,000	26,000	28,000	$164,000

Figure 10.6

Application 10.1

- The Barberton Municipal Division of Road Maintenance is charged with road repair in the city of Barberton and surrounding area.
- Cindy Kramer, road maintenance director, must submit a staffing plan for the next year based on a set schedule for repairs and on the city budget.
- Kramer estimates that the labor hours required for the next four quarters are 6,000, 12,000, 19,000, and 9,000, respectively.
- Each of the 11 workers on the workforce can contribute 520 hours per quarter. Overtime is limited to 20 percent of the regular-time capacity in any quarter. Subcontracting is not permitted.
- Payroll costs are $6,240 in wages per worker for regular time worked up to 520 hours, with an overtime pay rate of $18 for each overtime hour. Although unused overtime capacity has no cost, unused regular time is paid at $12 per hour.
- The cost of hiring a worker is $3,000, and the cost of laying off a worker is $2,000.

Application 10.1

- Use a chase strategy for the Barberton Municipal Division that varies the workforce level without using overtime.
- Undertime should be minimized, except for the minimal amount mandated because the quarterly requirements are not integer multiples of 520 hours.

Application 10.1

	Quarter				
	1	2	3	4	Total
Forecasted demand (hrs)	6,000	12,000	19,000	9,000	46,000
Workforce level (workers)	12	24	37	18	91
Undertime (hours)	240	480	240	360	1,320
Overtime (hours)	0	0	0	0	0
Utilized time (hours)	6,000	12,000	19,000	9,000	46,000
Hires (workers)	1	12	13	0	26
Layoffs (workers)	0	0	0	19	19

Application 10.1

What is the total cost of this plan?

	Costs per Quarter				
	1	2	3	4	Total
Utilized time	$72,000	$144,000	$228,000	$108,000	$552,000
Undertime	2,880	5,760	2,880	4,320	15,840
Overtime	0	0	0	0	0
Hires	3,000	36,000	39,000	0	78,000
Layoffs	0	0	0	38,000	38,000
				Total Cost	$683,840

Application 10.2

- Find a level plan for the Barberton Municipal Division that allows no delay in road repair and minimizes undertime.
- Overtime can be used to its limits in any quarter.
- Given that the demand peaks in quarter 3:

$$1.20w = \frac{19{,}000}{520} = 36.54 \text{ employee-period equivalents}$$

$$w = 30.45 \text{ or } 31 \text{ employees}$$

Application 10.2

	Quarter				
	1	2	3	4	Total
Forecasted demand (hrs)	6,000	12,000	19,000	9,000	46,000
Workforce level (workers)	31	31	31	31	124
Undertime (hours)	10,120	4,120	0	7,120	21,360
Overtime (hours)	0	0	2,880	0	2,880
Utilized time (hours)	6,000	12,000	16,120	9,000	43,120
Hires (workers)	20	0	0	0	20
Layoffs (workers)	0	0	0	0	0

Application 10.2

What is the total cost of this level workforce plan?

	Costs per Quarter				
	1	2	3	4	Total
Utilized time	$72,000	$144,000	$193,440	$108,000	$517,440
Undertime	121,440	49,440	0	85,440	256,320
Overtime	0	0	51,840	0	51,840
Hires	60,000	0	0	0	60,000
Layoffs	0	0	0	0	0
				Total Cost	$885,600

Application 10.3

- A mixed strategy considers and implements a fuller range of reactive alternatives than any one “pure” strategy.
- Now propose a plan of your own for the Barberton Municipal Division.
- Use the chase strategy as a base, but find a way to decrease the cost of hiring and layoffs by selectively using some overtime.

Application 10.3

	Quarter				
	1	2	3	4	Total
Forecasted demand	6,000	12,000	19,000	9,000	46,000
Workforce level	12	24	31	18	85
Undertime (hours)	240	480	0	360	1,080
Overtime (hours)	0	0	2,880	0	2,880
Utilized time (hours)	6,000	12,000	16,120	9,000	43,120
Hires (workers)	1	12	7	0	20
Layoffs (workers)	0	0	0	13	13

- The key idea in this plan is hiring only 7 employees in quarter 3, while using overtime to its maximum limit and eliminating undertime for that quarter.
- Hiring fewer in quarter 3 allows the number of layoffs in quarter 4 to drop to only 13, down from 19.

Application 10.3

What is the cost of your mixed strategy plan?

	Costs per Quarter				
	1	2	3	4	Total
Utilized time	$72,000	$144,000	$193,440	$108,000	$517,440
Undertime	2,880	5,760	0	4,320	12,960
Overtime	0	0	51,840	0	51,840
Hires	3,000	36,000	21,000	0	60,000
Layoffs	0	0	0	26,000	26,000
				Total Cost	$668,240

Scheduling

- **Scheduling**
  - **The function that takes the operations and scheduling process from planning to execution.**

Scheduling

- **Job and Facility Scheduling**
  - **Gantt progress chart**
  - **Gantt workstation chart**

Scheduling

Gantt Progress Chart

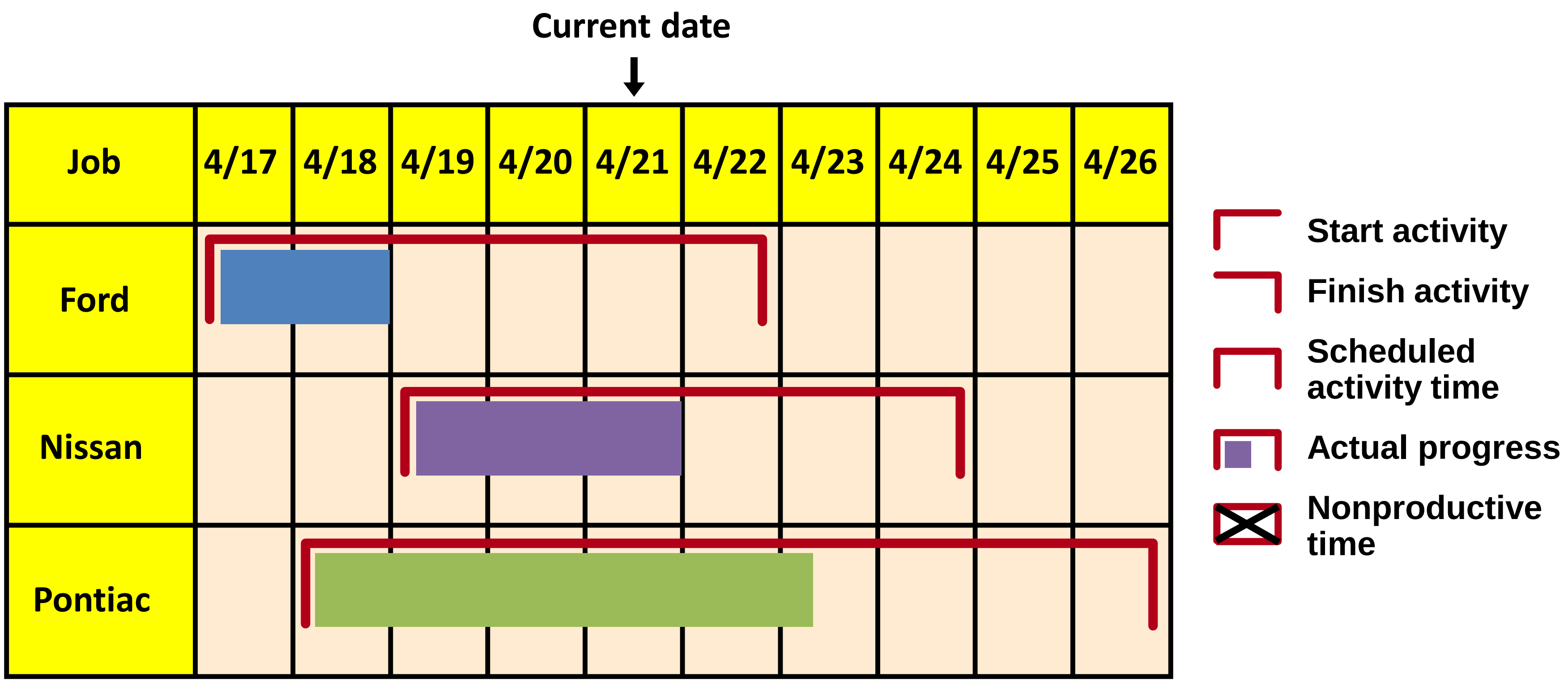


Figure 10.7

Scheduling

Gantt Workstation Chart

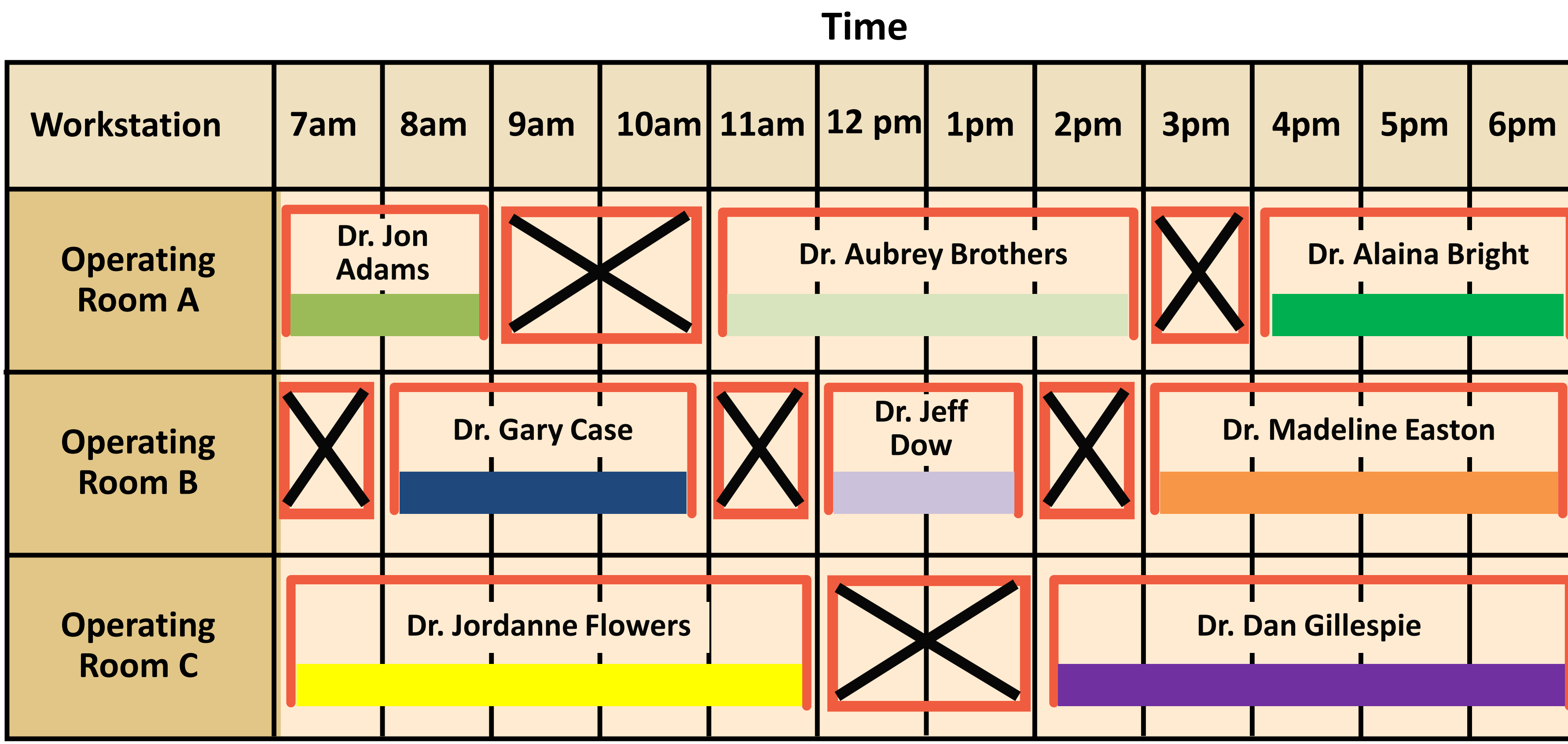


Figure 10.8

Scheduling

- **Workforce Scheduling –**
  - A type of scheduling that determines when employees work
- **Constraints**
  - Technical constraints
  - Legal and behavioral considerations
  - Psychological needs of workers
- **Scheduling Options**
  - Rotating schedule vs Fixed schedule

Scheduling

- Steps in developing a workforce schedule

  Step 1: Find all the pairs of consecutive days

  Step 2: If a tie occurs, choose one of the tied pairs, consistent with the provisions written into the labor agreement

  Step 3: Assign the employee the selected pair of days off

  Step 4: Repeat steps 1 – 3 until all of the requirements have been satisfied

Example 10.2

The Amalgamated Parcel Service is open seven days a week. The schedule of requirements is:

Day	M	T	W	Th	F	S	Su
Required number of employees	6	4	8	9	10	3	2

- The manager needs a workforce schedule that provides two consecutive days off and minimizes the amount of total slack capacity.
- To break ties in the selection of off days, the scheduler gives preference to Saturday and Sunday if it is one of the tied pairs.
- If not, she selects one of the tied pairs arbitrarily.

Example 10.2

- Friday contains the maximum requirements, and the pair S – Su has the lowest total requirements. Therefore, Employee 1 is scheduled to work Monday through Friday.
- Note that Friday still has the maximum requirements and that the requirements for the S – Su pair are carried forward because these are Employee 1's days off.
- These updated requirements are the ones the scheduler uses for the next employee.

Example 10.2

Scheduling Days Off								
M	T	W	Th	F	S	Su	Employee	Comments
6	4	8	9	10	3	2	1	The S–Su pair has the lowest total requirements. Assign Employee 1 to a M-F schedule.
5	3	7	8	9	3	2	2	The S–Su pair has the lowest total requirements. Assign Employee 2 to a M-F schedule.
4	2	6	7	8	3	2	3	The S–Su pair has the lowest total requirements. Assign Employee 3 to a M-F schedule.
3	1	5	6	7	3	2	4	The M–T pair has the lowest total requirements. Assign Employee 4 to a W-Su schedule.
3	1	4	5	6	2	1	5	The S–Su pair has the lowest total requirements. Assign Employee 5 to a M-F schedule.
2	0	3	4	5	2	1	6	The M–T pair has the lowest total requirements. Assign Employee 6 to a W-Su schedule.
2	0	2	3	4	1	0	7	The S–Su pair has the lowest total requirements. Assign Employee 7 to a M-F schedule.
1	0	1	2	3	1	0	8	Four pairs have the minimum requirement and the lowest total. Choose the S–Su pair according to the tie-breaking rule. Assign Employee 8 to a M-F schedule.
0	0	0	1	2	1	0	9	Arbitrarily choose the Su–M pair to break ties because the S–Su pair does not have the lowest total requirements. Assign Employee 9 to a T-S schedule.
0	0	0	0	1	0	0	10	Choose the S–Su pair according to the tie-breaking rule. Assign Employee 10 to a M-F schedule.

Example 10.2

In this example, Friday always has the maximum requirements and should be avoided as a day off.

The final schedule for the employees is shown in the following table.

Final Schedule								
Employee	M	T	W	Th	F	S	Su	Total
1	X	X	X	X	X	off	off	
2	X	X	X	X	X	off	off	
3	X	X	X	X	X	off	off	
4	off	off	X	X	X	X	X	
5	X	X	X	X	X	off	off	
6	off	off	X	X	X	X	X	
7	X	X	X	X	X	off	off	
8	X	X	X	X	X	off	off	
9	off	X	X	X	X	X	off	
10	X	X	X	X	X	off	off	
Capacity, C	7	8	10	10	10	3	2	50
Requirements, R	6	4	8	9	10	3	2	42
Slack, C – R	1	4	2	1	0	0	0	8

Sequencing Jobs at a Workstation

- Priority Sequencing Rules
  - First-come, first-served (FCFS)
  - Earliest due date (EDD)

- Performance Measures
  - Flow Time
    - Flow time = Finish time + Time since job arrived at workstation
  - Past Due (Tardiness)

Example 10.3

- Currently a consulting company has five jobs in its backlog.
- Determine the schedule by using the FCFS rule, and calculate the average days past due and flow time.
- How can the schedule be improved, if average flow time is the most critical?

Customer	Time Since Order Arrived (days ago)	Processing Time (days)	Due Date (days from now)
A	15	25	29
B	12	16	27
C	5	14	68
D	10	10	48
E	0	12	80

Example 10.3

a. The FCFS rule states that Customer A should be the first one in the sequence, because that order arrived earliest—15 days ago.

Customer E's order arrived today, so it is processed last.

The sequence is shown in the following table, along with the days past due and flow times.

Customer Sequence	Start Time (days)		Processing Time (days)		Finish Time (days)	Due Date	Days Past Due	Days Ago Since Order Arrived	Flow Time (days)
A	0	+	25	=	25	29	0	15	40
B	25	+	16	=	41	27	14	12	53
D	41	+	10	=	51	48	3	10	61
C	51	+	14	=	65	68	0	5	70
E	65	+	12	=	77	80	0	0	77

Example 10.3

The *finish time* for a job is its start time plus the processing time. Its finish time becomes the start time for the next job in the sequence, assuming that the next job is available for immediate processing. The days past due for a job is zero (0) if its due date is equal to or exceeds the finish time. Otherwise it equals the shortfall. The flow time for each job equals its finish time plus the number of days ago since the order first arrived at the workstation. The days past due and average flow time performance measures for the FCFS schedule are

$$\text{Average days past due} = \frac{0 + 14 + 3 + 0 + 0}{5} = 3.4 \text{ days}$$

$$\text{Average flow time} = \frac{40 + 53 + 61 + 70 + 77}{5} = 60.2 \text{ days}$$

Example 10.3

b. Using the STP rule, the average flow time can be reduced with this new sequence.

Customer Sequence	Start Time (days)		Processing Time (days)		Finish Time (days)	Due Date	Days Past Due	Days Ago Since Order Arrived	Flow Time (days)
D	0	+	10	=	10	48	0	10	20
E	10	+	12	=	22	80	0	0	22
C	22	+	14	=	36	68	0	5	41
B	36	+	16	=	52	27	25	12	64
A	52	+	25	=	77	29	48	15	92

$$\text{Average days past due} = \frac{0 + 0 + 0 + 25 + 48}{5} = 14.6 \text{ days}$$

$$\text{Average flow time} = \frac{20 + 22 + 41 + 64 + 92}{5} = 47.8 \text{ days}$$

Application 10.4

A consulting company has five jobs in its backlog. A schedule was created using the FCFS rule and the average days past due was 3.4 days and the average flow time was 60.2 days. Create a new schedule using the EDD rule, calculating the average days past due and flow time. In this case, does EDD outperform the FCFS rule?

Customer	Time Since Order Arrived (days ago)	Processing Time (days)	Due Date (days from now)
A	15	25	29
B	12	16	27
C	5	14	68
D	10	10	48
E	0	12	80

Application 10.4

Customer Sequence	Start Time (days)		Processing Time (days)		Finish Time (days)	Due Date	Days Past Due	Days Ago Since Order Arrived	Flow Time (days)
B	0	+	16	=	16	27	0	12	28
A	16	+	25	=	41	29	12	15	56
D	41	+	10	=	51	48	3	10	61
C	51	+	14	=	65	68	0	5	70
E	65	+	12	=	77	80	0	0	77

Application 10.4

The days past due and average flow time performance measures for the EDD schedule are:

$$\text{Average days past due} = \frac{0 + 12 + 3 + 0 + 0}{5} = 3.0 \text{ days}$$

$$\text{Average flow time} = \frac{28 + 56 + 61 + 70 + 77}{5} = 58.4 \text{ days}$$

By both measures, EDD outperforms the FCFS.

However, the solution found in Example 15.3 still has the best average flow time of only 47.8 days

Software Support

- Computerized scheduling systems are available to cope with the complexity of workforce scheduling.
- Software is also available for sequencing jobs at workstations.
- Advance planning and scheduling (APS) systems seek to optimize resources across the supply chain and align daily operations with strategic goals.

Solved Problem 1

- The Cranston Telephone Company employs workers who lay telephone cables and perform various other construction tasks.
- The company prides itself on good service and strives to complete all service orders within the planning period in which they are received.
- Each worker puts in 600 hours of regular time per planning period and can work as many as an additional 100 hours of overtime.
- The operations department has estimated the following workforce requirements for such services over the next four planning periods:

Planning Period	1	2	3	4
Demand (hours)	21,000	18,000	30,000	12,000

Solved Problem 1

Cranston pays regular-time wages of $6,000 per employee per period for any time worked up to 600 hours (including undertime). The overtime pay rate is $15 per hour over 600 hours. Hiring, training, and outfitting a new employee costs $8,000. Layoff costs are $2,000 per employee. Currently, 40 employees work for Cranston in this capacity. No delays in service, or backorders, are allowed.

a. Prepare a chase strategy using only hiring and layoffs. What are the total numbers of employees hired and laid off?

b. Develop a workforce plan that uses the level strategy, relaying only on overtime and undertime. Maximize the use of overtime during the peak period so as to minimize the workforce level and amount of undertime.

c. Propose an effective mixed-strategy plan.

d. Compare the total costs of the three plans.

Solved Problem 1

a. Chase Strategy

	1	2	3	4	Total
Inputs					
Forecasted demand	35	30	50	20	135
Workforce level	35	30	50	20	135
Undertime	0	0	0	0	0
Overtime	0	0	0	0	0
Derived					
Utilized time	35	30	50	20	135
Hires	0	0	20	0	20
Layoffs	5	5	0	30	40
Calculated					
Utilized time cost	$210,000	$180,000	$300,000	$120,000	$810,000
Undertime cost	$0	$0	$0	$0	$0
Overtime cost	$0	$0	$0	$0	$0
Hiring cost	$0	$0	$160,000	$0	$160,000
Layoff cost	$10,000	$10,000	$0	$60,000	$80,000
Total cost	$220,000	190,000	460,000	180,000	$1,050,000

Figure 10.9

Solved Problem 1

b. Level Strategy

	1	2	3	4	Total
Inputs					
Forecasted demand	35	30	50	20	135
Workforce level	43	43	43	43	172
Undertime	8	13	0	23	44
Overtime	0	0	7	0	7
Derived					
Utilized time	35	30	43	20	128
Hires	3	0	0	0	3
Layoffs	0	0	0	0	0
Calculated					
Utilized time cost	$210,000	$180,000	$258,000	$120,000	$768,000
Undertime cost	$48,000	$78,000	$0	$138,000	$264,000
Overtime cost	$0	$0	$63,000	$0	$63,000
Hiring cost	$24,000	$0	$0	$0	$24,000
Layoff cost	$0	$0	$0	$0	$0
Total cost	$282,000	258,000	321,000	258,000	$1,119,000

Figure 10.10

Solved Problem 1

c. Mixed Strategy

	1	2	3	4	Total
Inputs					
Forecasted demand	35	30	50	20	135
Workforce level	35	35	43	30	143
Undertime	0	5	0	10	15
Overtime	0	0	7	0	7
Derived					
Utilized time	35	30	43	20	128
Hires	0	0	8	0	8
Layoffs	5	0	0	13	18
Calculated					
Utilized time cost	$210,000	$180,000	$258,000	$120,000	$768,000
Undertime cost	$0	$30,000	$0	$60,000	$90,000
Overtime cost	$0	$0	$63,000	$0	$63,000
Hiring cost	$0	$0	$64,000	$0	$64,000
Layoff cost	$10,000	$0	$0	$26,000	$36,000
Total cost	$220.000	210,000	385,000	206,000	$1,021,000

Figure 10.11

Solved Problem 1

d. Total Cost of Plans

CHASE = **$1,050,000**

LEVEL = **$1,119,000**

MIXED = **$1,021,000**

Solved Problem 2

- The Food Bin grocery store operates 24 hours per day, 7 days per week.
- Fred Bulger, the store manager, has been analyzing the efficiency and productivity of store operations recently. Bulger decided to observe the need for checkout clerks on the first shift for a one-month period.
- At the end of the month, he calculated the average number of checkout registers that should be open during the first shift each day.
- His results showed peak needs on Saturdays and Sundays.

Day	M	T	W	Th	F	S	Su
Number of Clerks Required	3	4	5	5	4	7	8

Solved Problem 2

Bulger now has to come up with a workforce schedule that guarantees each checkout clerk two consecutive days off but still covers all requirements.

a. Develop a workforce schedule that covers all requirements while giving two consecutive days off to each clerk. How many clerks are needed? Assume that the clerks have no preference regarding which days they have off.

b. Plans can be made to use the clerks for other duties if slack or idle time resulting from this schedule can be determined. How much idle time will result from this schedule, and on what days?

Solved Problem 2

a. We use the method demonstrated in Example 15.2 to determine the number of clerks needed.

The minimum number of clerks is eight.

	Day						
	M	T	W	Th	F	S	Su
Requirements	3	4	5	5	4	7	8
Clerk 1	off	off	X	X	X	X	X
Requirements	3	4	4	4	3	6	7
Clerk 2	off	off	X	X	X	X	X
Requirements	3	4	3	3	2	5	6
Clerk 3	X	X	X	off	off	X	X
Requirements	2	3	2	3	2	4	5
Clerk 4	X	X	X	off	off	X	X

Solved Problem 2

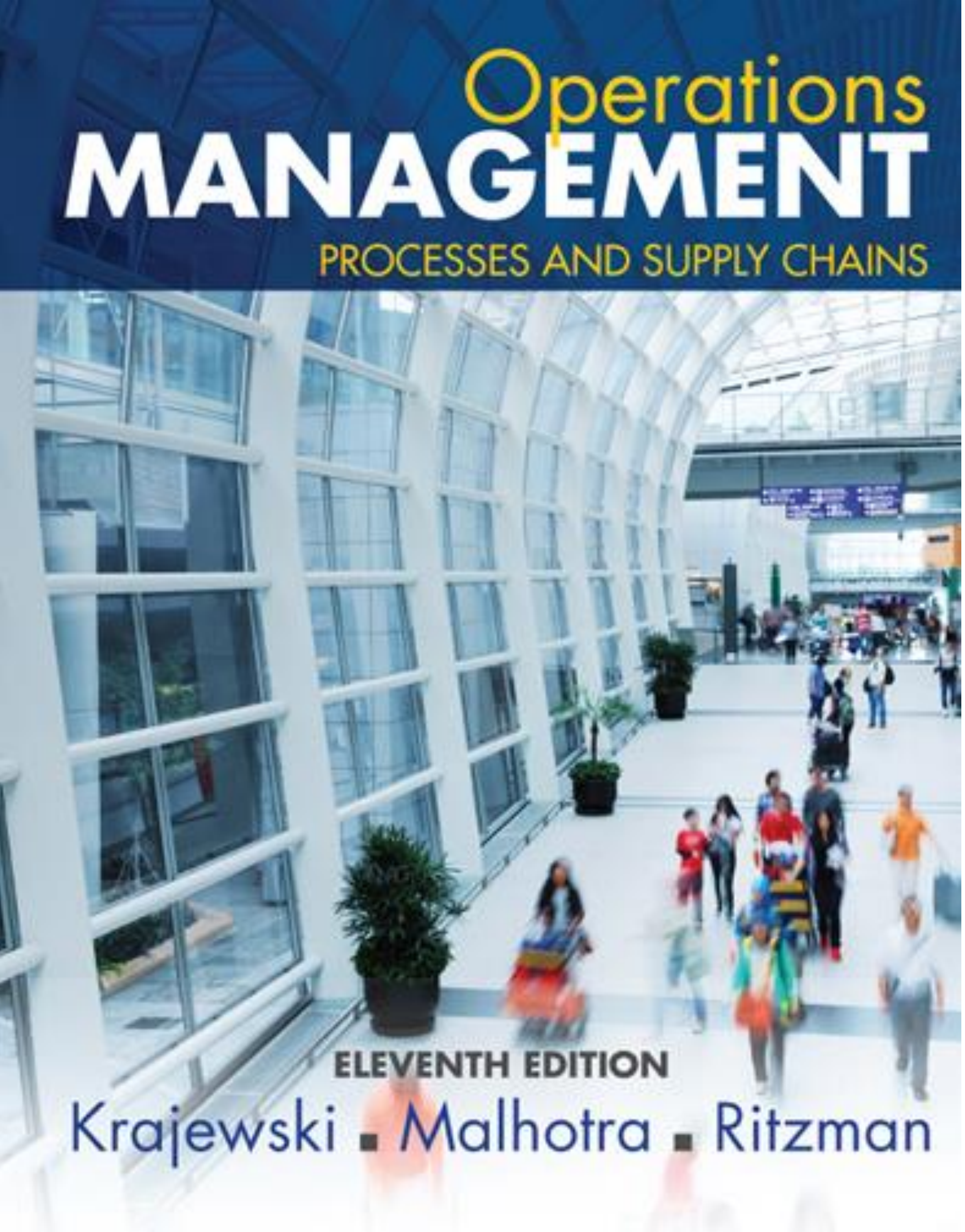
	Day						
	M	T	W	Th	F	S	Su
Requirements	1	2	1	3	2	3	4
Clerk 5	X	off	off	X	X	X	X
Requirements	0	2	1	2	1	2	3
Clerk 6	off	off	X	X	X	X	X
Requirements	0	2	0	1	0	1	2
Clerk 7	X	X	off	off	X	X	X
Requirements	0	1	0	1	0	0	1
Clerk 8	X	X	X	X	off	off	X
Requirements	0	0	0	0	0	0	0

Solved Problem 2

b. Based on the results in part (a), the number of clerks on duty minus the requirements is the number of idle clerks available for other duties:

	M	T	W	Th	F	S	Su
Number on duty	5	4	6	5	5	7	8
Requirements	3	4	5	5	4	7	8
Idle clerks	2	0	1	0	1	0	0

- The slack in this schedule would indicate to Bulger the number of employees he might ask to work part time (fewer than 5 days per week).
- For example, Clerk 7 might work Tuesday, Saturday, and Sunday and Clerk 8 might work Tuesday, Thursday, and Sunday.
- That would eliminate slack from the schedule.



Resource Planning

Chapter 11

What is Resource Planning?

Resource Planning

A process that takes sales and operations plans; processes information in the way of time standards, routings, and other information on how services or products are produced; and then plans the input requirements

Materials Requirements Planning

- **Material Requirements Planning (MRP)**
  - A computerized information developed specifically to help manufacturers manage dependent demand inventory and schedule replenishment orders

- **MRP Explosion**
  - A process that converts the requirements of various final products into a material requirements plan that specifies the replenishment schedules of all the subassemblies, components, and raw materials needed to produce final products

MRP Inputs

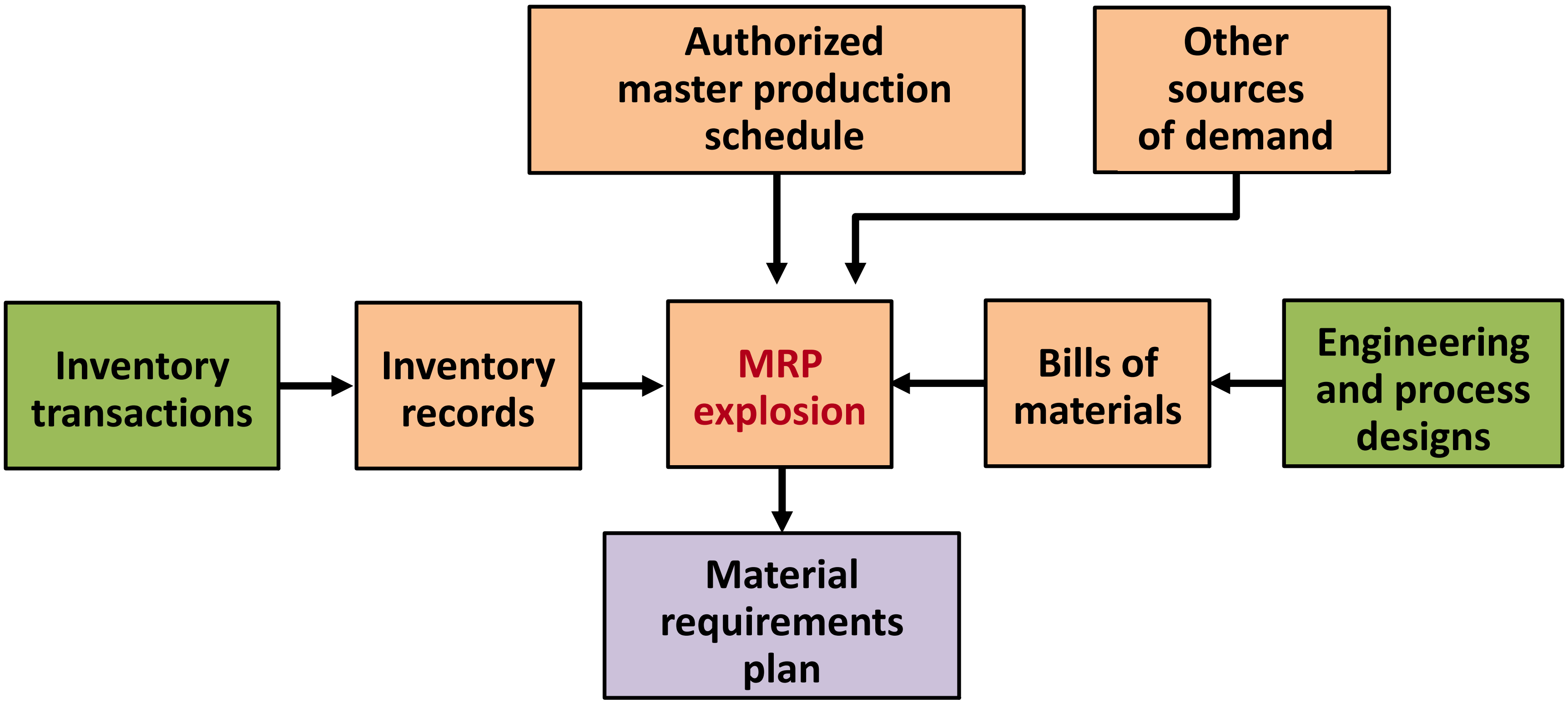
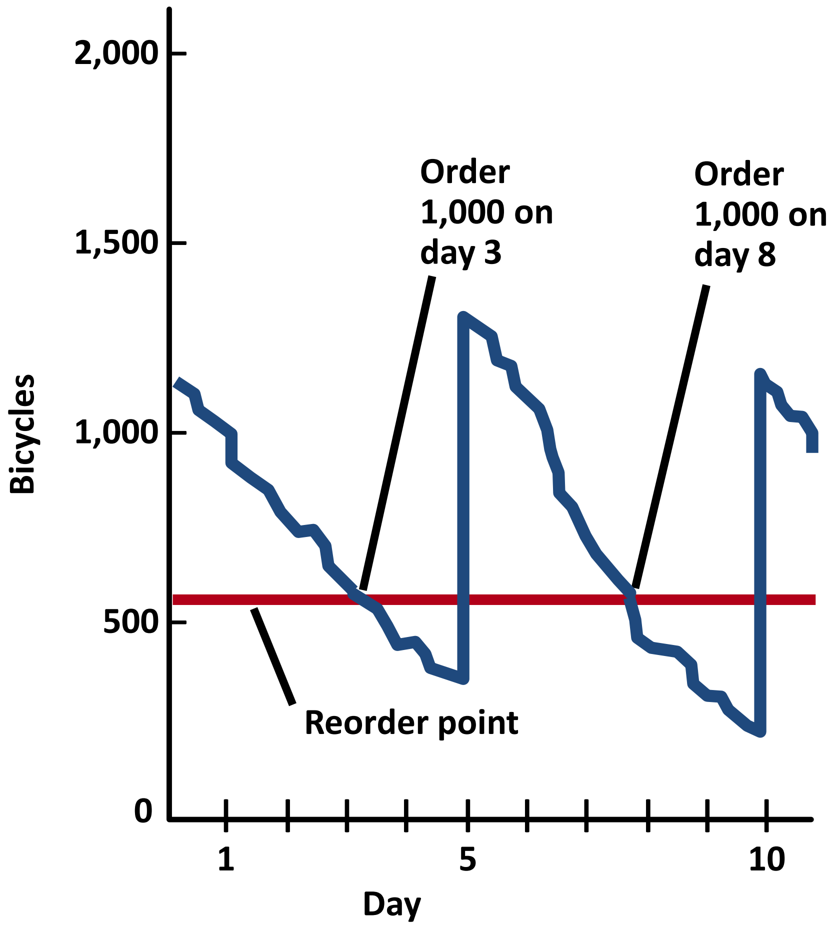


Figure 11.1

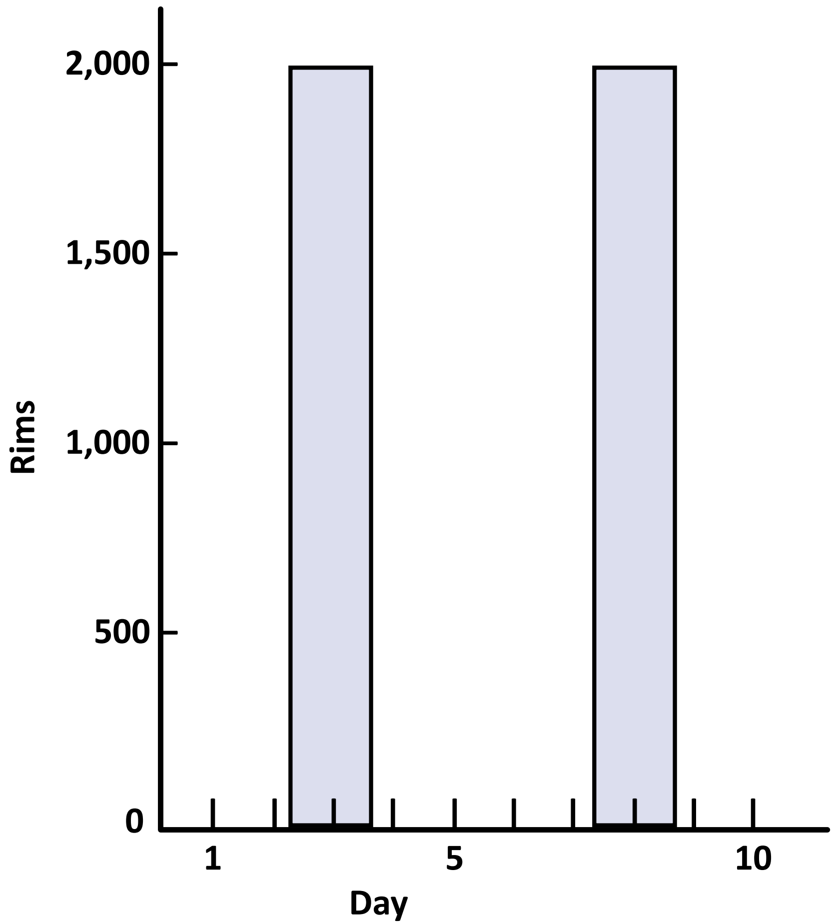
Material Requirements Planning

- Dependent demand
  - The demand for an item that occurs because the quantity required varies with the production plans for other items held in the firm's inventory
- Parent
  - An product that is manufactured from one or more components
- Component
  - An item that goes through one or more operations to be transformed into or become part of one or more parents

Material Requirements Planning



(a) Parent inventory



(b) Component demand

Figure 11.2

Master Production Scheduling

- **Master Production Schedule (MPS)**
  - A part of the material requirements plan that details how many end items will be produced within specified periods of time

- **In a Master Production Schedule:**
  - Sums of quantities must equal sales and operations plan.
  - Production quantities must be allocated efficiently over time.
  - Capacity limitations and bottlenecks may determine the timing and size of MPS quantities.

Master Production Scheduling

	April				May			
	1	2	3	4	5	6	7	8
Ladder-back chair	150					150		
Kitchen chair				120			120	
Desk chair		200	200		200			200
Aggregate production plans for chair family	670				670			

Figure 11.3

Master Production Scheduling

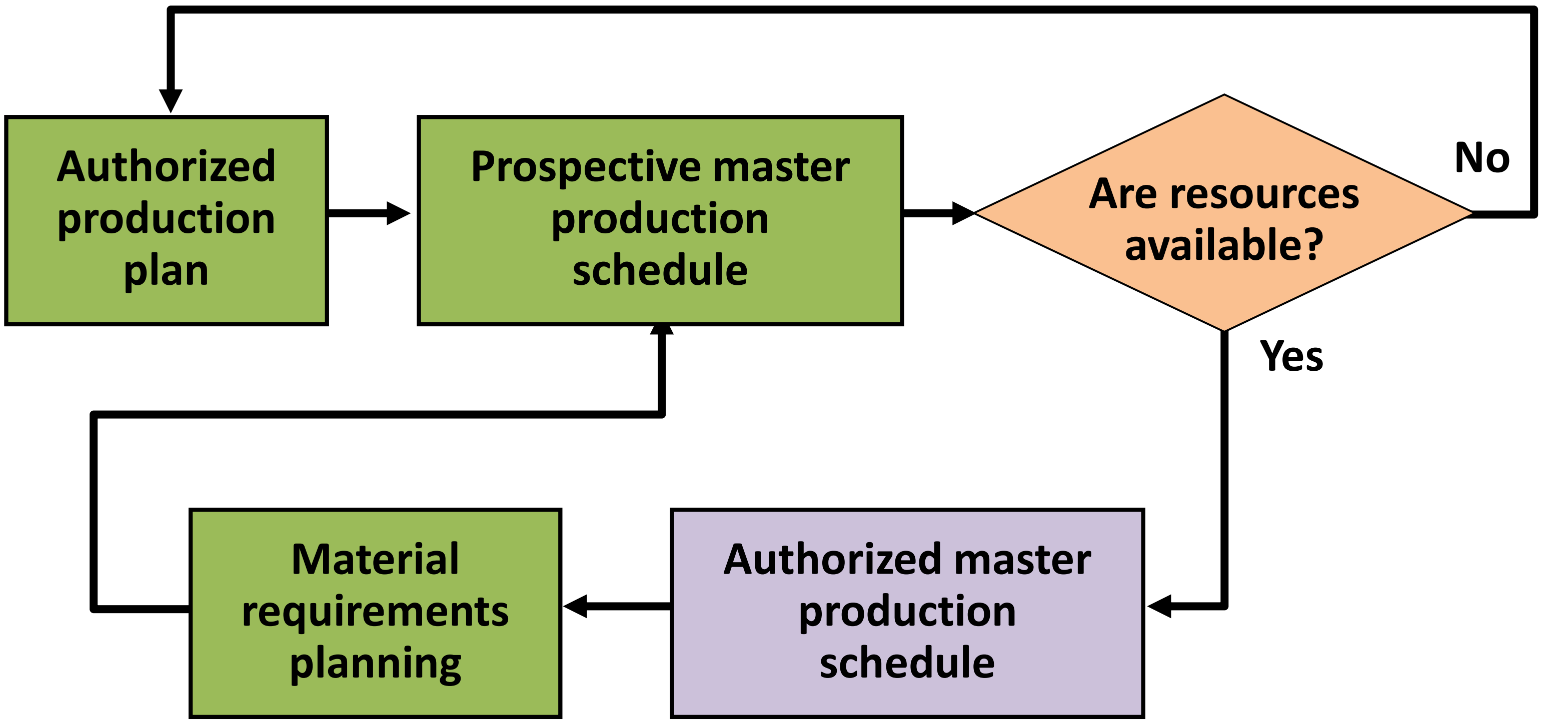


Figure 11.4

Master Production Scheduling

Developing a Master Production Schedule

Step 1: Calculate projected on-hand inventories

$$\begin{pmatrix}\text{Projected on-hand} \\ \text{inventory at end} \\ \text{of this week}\end{pmatrix} = \begin{pmatrix}\text{On-hand} \\ \text{inventory at} \\ \text{end of last week}\end{pmatrix} + \begin{pmatrix}\text{MPS quantity} \\ \text{due at start} \\ \text{of this week}\end{pmatrix} - \begin{pmatrix}\text{Projected} \\ \text{requirements} \\ \text{this week}\end{pmatrix}$$

where:

Projected requirements = Max(Forecast, Customer Orders Booked)

$$\text{Inventory} = \begin{pmatrix}\text{55 chairs} \\ \text{currently} \\ \text{in stock}\end{pmatrix} + \begin{pmatrix}\text{MPS quantity} \\ \text{(0 for week 1)}\end{pmatrix} - \begin{pmatrix}\text{38 chairs already} \\ \text{promised for} \\ \text{delivery in week 1}\end{pmatrix}$$

= **17 chairs**

Master Production Scheduling

Item: Ladder-back chair

Quantity on Hand: 55	April 1	April 2
Forecast	30	30
Customer orders (booked)	38	27
Projected on-hand inventory	17	–13
MPS quantity	0	0
MPS start		

Explanation:
Forecast is less than booked orders in week 1; projected on-hand inventory balance = 55 + 0 – 38 = 17.

Explanation:
Forecast exceeds booked orders in week 2; projected on-hand inventory balance = 17 + 0 – 30 = –13. The shortage signals a need to schedule an MPS quantity for completion in week 2.

Figure 11.6

Master Production Scheduling

Developing a Master Production Schedule

Step 2: Determine the timing and size of MPS quantities

- The goal is to maintain a nonnegative projected on-hand inventory balance
- As shortages in inventory are detected, MPS quantities should be scheduled to cover them

$$\text{Inventory} = \left(\begin{array}{c}\text{17 chairs in}\\ \text{inventory at the}\\ \text{end of week 1}\end{array}\right) + \left(\begin{array}{c}\text{MPS quantity}\\ \text{of 150 chairs}\end{array}\right) - \left(\begin{array}{c}\text{Forecast of}\\ \text{30 chairs}\end{array}\right)$$

$$= \text{137 chairs}$$

Master Production Schedule (MPS)

Item: Ladder-back chair							Order Policy: 150 units Lead Time: 1 week	
	April				May			
Quantity on Hand: 55	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	35	35	35	35
Customer orders booked	38	27	24	8	0	0	0	0
Projected on-hand inventory	17	137	107	77	42	7	122	87
MPS quantity	0	150	0	0	0	0	150	0
MPS start	150	0	0	0	0	150	0	0

Explanation:
The time needed to assemble 150 chairs is 1 week. The assembly department must start assembling chairs in week 1 to have them ready by week 2.

Explanation:
On-hand inventory balance = 17 + 150 – 30 = 137. The MPS quantity is needed to avoid a shortage of 30 – 17 = 13 chairs in week 2.

Figure 11.7

Master Production Scheduling

- **Available-to-promise (ATP) inventory**
  - The quantity of end items that marketing can promise to deliver on specific dates
  - It is the difference between the customer orders already booked and the quantity that operations is planning to produce
- **Freezing the MPS**
  - Disallow changes to the near-term portion of the MPS
- **Reconciling the MPS with Sales and Operations Plans**

Master Production Schedule (MPS)

Item: Ladder-back chair								Order Policy: 150 units Lead Time: 1 week
	April				May			
Quantity on Hand: 55	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	35	35	35	35
Customer orders booked	38	27	24	8	0	0	0	0
Projected on-hand inventory	17	137	107	77	42	7	122	87
MPS quantity	0	150	0	0	0	0	150	0
MPS start	150	0	0	0	0	150	0	0
Available-to-promise (ATP) inventory	17	91					150	

Figure 11.8

Explanation:
The total of customer orders booked until the next MPS receipt is 38 units. The ATP = 55 (on-hand) + 0 (MPS quantity) – 38 = 17.

Explanation:
The total of customer orders booked until the next MPS receipt is 27 + 24 + 8 = 59 units. The ATP = 150 (MPS quantity) – 59 = 91 units..

Application 11.1

- Determine the MPS for Product A that has a 50-unit policy and 55 units on hand.

- The demand forecast and booked orders are shown in the partially completed plan.

- The lead time is one week.

Application 11.1

Item: Product A										Order Policy: 50 units Lead Time: 1 week
Quantity on Hand 55	1	2	3	4	5	6	7	8	9	10
Forecast	20	10	40	10	0	0	30	20	40	20
Customer orders (booked)	30	20	5	8	0	2	0	0	0	0
Projected on-hand inventory	25	5	15	5	5	3	23	3	13	43
MPS quantity			50				50		50	50
MPS start		50				50		50	50	
Available-to-promise (ATP) inventory	5		35				50		50	50

MRP Explosion

- Bill of Materials
  - A record of all the components of an item, the parent-component relationships, and the usage quantities derived from engineering and process designs
- End items
- Intermediate items
- Subassemblies
- Purchased items
- Part commonality (sometimes called standardization of parts or modularity)

MRP Explosion

Bill of Materials for a Ladder-Back Chair

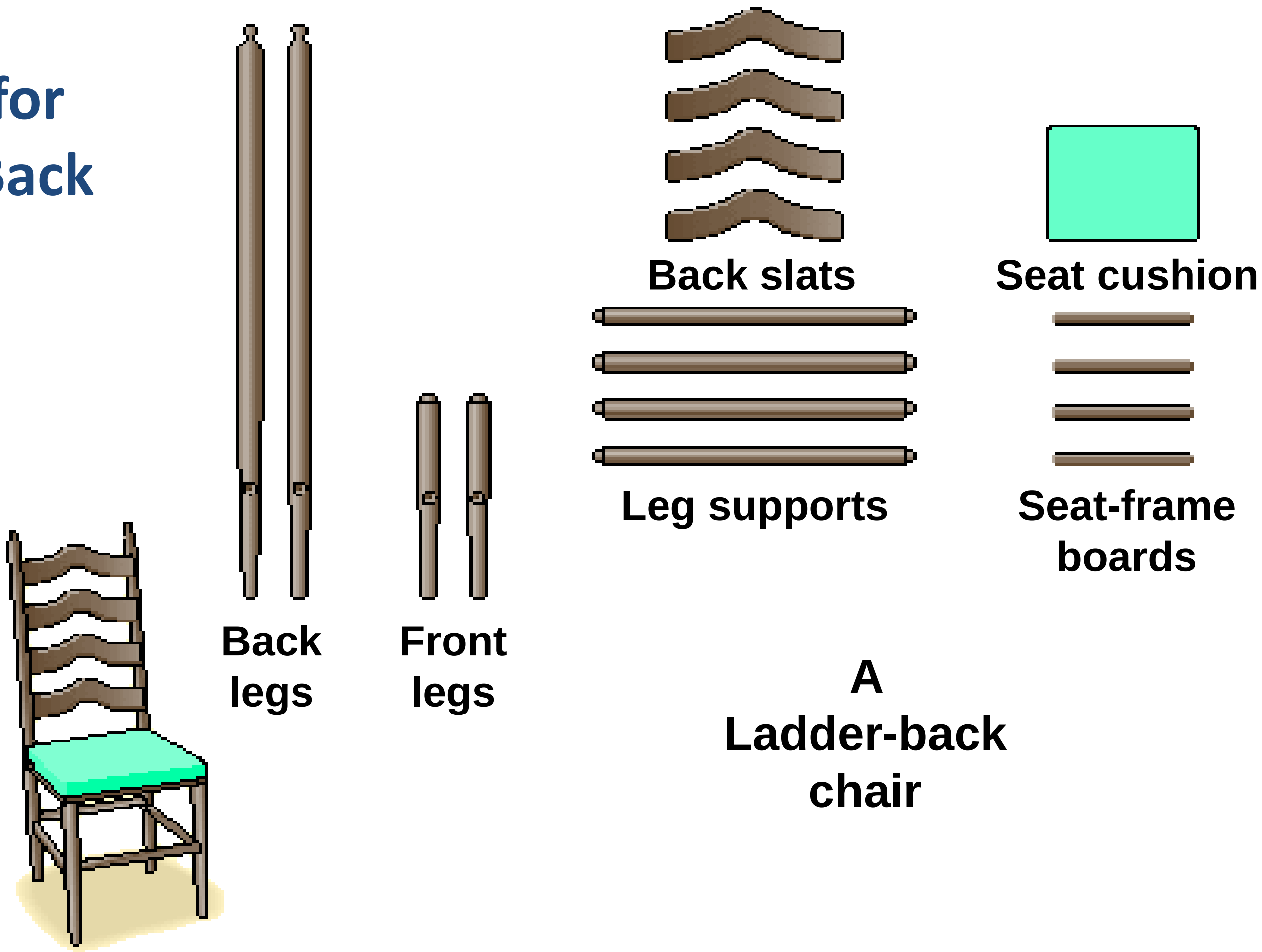


Figure 11.10

MRP Explosion

Bill of Materials for a Ladder-Back Chair

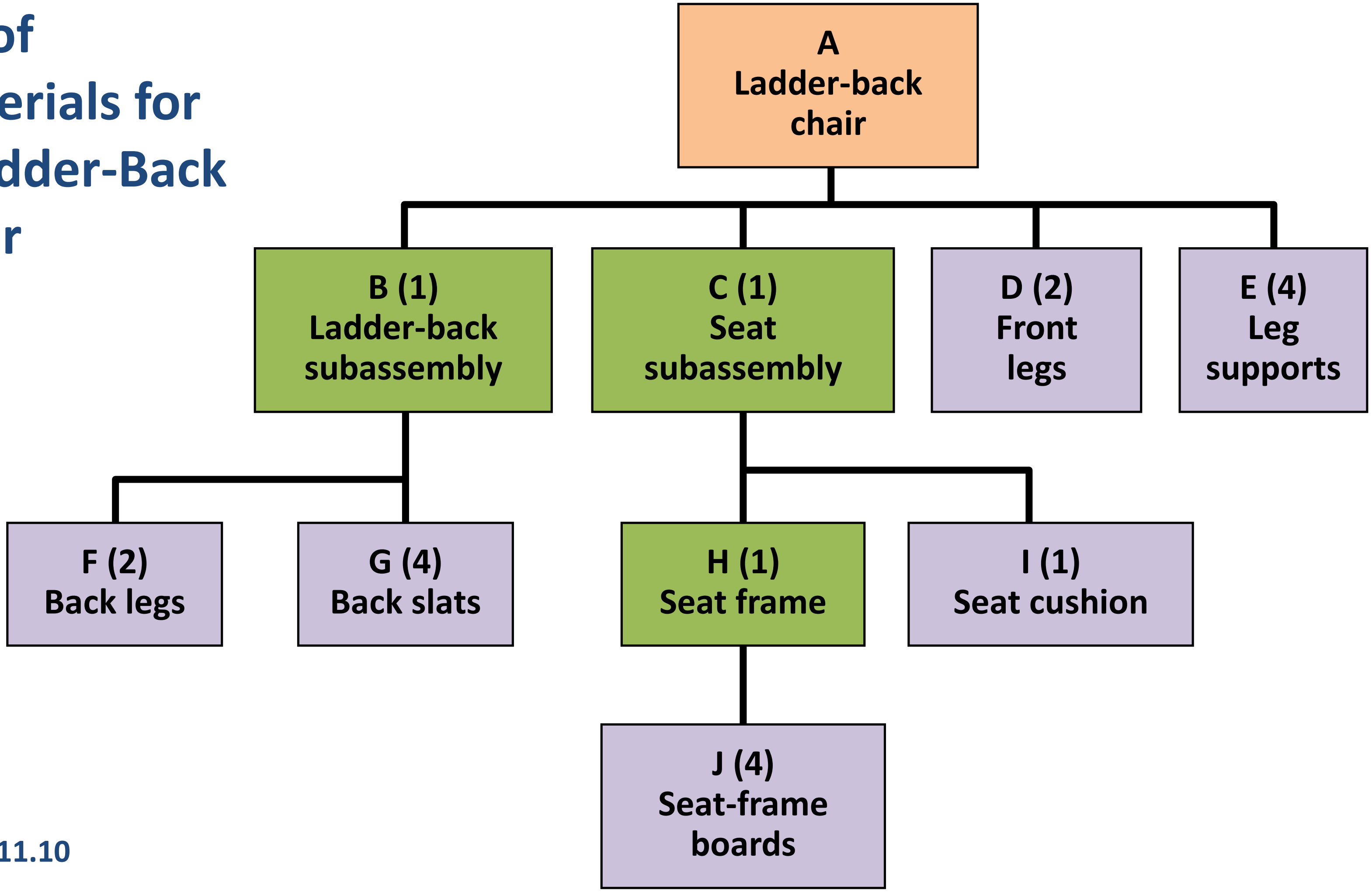


Figure 11.10

MRP Explosion

- **Inventory record**
  - **A record that shows an item's lot-size policy, lead time, and various time-phased data.**

MRP Explosion

- The time-phase information contained in the inventory record consists of:
  - Gross requirements
  - Scheduled receipts
  - Projected on-hand inventory

$$\begin{pmatrix}\text{Projected on-hand}\\ \text{inventory balance}\\ \text{at end of week } t\end{pmatrix} = \begin{pmatrix}\text{Inventory on}\\ \text{hand at end of}\\ \text{week } t\text{–}1\end{pmatrix} + \begin{pmatrix}\text{Scheduled or}\\ \text{planned receipts}\\ \text{in week } t\end{pmatrix} - \begin{pmatrix}\text{Gross}\\ \text{requirements}\\ \text{in week } t\end{pmatrix}$$

  - Planned receipts
  - Planned order releases

MRP Explosion

- The on-hand inventory calculations for each week in the following slide are as follows

Week 1:	37 + 230 – 150 =	117
Weeks 2 and 3:	117 + 0 – 0 =	117
Week 4:	117 + 0 – 120 =	–3
Week 5:	–3 + 0 – 0 =	–3
Week 6:	–3 + 0 – 150 =	–153
Week 7:	–153 + 0 – 120 =	–273
Week 8:	–273 + 0 – 0 =	–273

MRP Explosion

Item: C Description: Seat subassembly							Lot Size: 230 units Lead Time: 2 weeks	
	Week							
	1	2	3	4	5	6	7	8
Gross requirements	150	0	0	120	0	150	120	0
Scheduled receipts	230	0	0	0	0	0	0	0
Projected on-hand inventory 37	117	117	117	–3	–3	–153	–273	–273
Planned receipts								
Planned order releases								

Figure 11.11

Explanation:
Gross requirements are the total demand for the two chairs. Projected on-hand inventory in week 1 is 37 + 230 – 150 = 117 units.

MRP Explosion

Item: C Description: Seat subassembly								Lot Size: 230 units Lead Time: 2 weeks
	Week							
	1	2	3	4	5	6	7	8
Gross requirements	150	0	0	120	0	150	120	0
Scheduled receipts	230	0	0	0	0	0	0	0
Projected on-hand inventory 37	117	117	117	227	227	77	187	187
Planned receipts				230			230	
Planned order releases		230			230			

Figure 11.12

Without a planned receipt in week 4, a shortage of 3 units will occur: 117 + 0 + 0 – 120 = –3 units. Adding the planned receipt brings the balance to 117 + 0 + 230 – 120 = 227 units.

The first planned receipt lasts until week 7, when projected inventory would drop to 77 + 0 + 0 – 120 = –43 units. Adding the second planned receipt brings the balance to 77 + 0 + 230 – 120 = 187 units.

Planning Factors

- Planning lead time
  - An estimate of the time between placing an order and receiving the item in inventory.
- Planning lead time consists of estimates for:
  - Setup time
  - Processing time
  - Materials handling time between operations
  - Waiting time

Planning Factors

- **Lot-sizing rules**
  - **Fixed order quantity (FQO) rule maintains the same order quantity each time an order is issued**
    - **Could be determined by quantity discounts, truckload capacity, minimum purchases, or EOQ**

Planning Factors

- **Lot-sizing rules**
  - **Periodic order quantity (POQ) rule allows a different order quantity for each order issued but issues the order for predetermined time intervals**

$$\begin{pmatrix}\text{POQ lot size}\\ \text{to arrive in}\\ \text{week } t\end{pmatrix} = \begin{pmatrix}\text{Total gross requirements}\\ \text{for } P \text{ week, including}\\ \text{week } t\end{pmatrix} - \begin{pmatrix}\text{Projected on-hand}\\ \text{inventory balance at}\\ \text{end of week } t\text{–}1\end{pmatrix}$$

Planning Factors

Using $P = 3$:

$$(\text{POQ lot size}) = \begin{pmatrix}\text{Gross requirements} \\ \text{for weeks} \\ \text{4, 5, and 6}\end{pmatrix} - \begin{pmatrix}\text{Inventory at} \\ \text{end of week 3}\end{pmatrix}$$

(POQ lot size) = (120 + 0 + 150) – 117 = **153 units**

Planning Factors

Using POQ Rule

Periods	8								
Item	Seat Assembly			Period (P) for POQ	3	Lot Size (FOQ)			
Description						Lead Time			2
POQ Rule									
		1	2	3	4	5	6	7	8
Gross requirements		150			120		150	120	
Scheduled receipts		230							
Projected on-hand inventory	37	117	117	117	150	150			
Planned receipts					153			120	
Planned order releases			153			120			

Figure 11.13

Planning Factors

- Lot-sizing rules
  - Lot-for-lot (L4L) rule under which the lot size ordered covers the gross requirements of a single week

$$\left(\begin{array}{c}\text{L4L lot size}\\ \text{to arrive in}\\ \text{week } t\end{array}\right) = \left(\begin{array}{c}\text{Gross requirements}\\ \text{for week } t\end{array}\right) - \left(\begin{array}{c}\text{Projected on-hand}\\ \text{inventory balance at}\\ \text{end of week } t-1\end{array}\right)$$

$$(\text{L4L lot size}) = \left(\begin{array}{c}\text{Gross requirements}\\ \text{in week 4}\end{array}\right) - \left(\begin{array}{c}\text{Inventory balance}\\ \text{at end of week 3}\end{array}\right)$$

$$(\text{L4L lot size}) = 120 - 117 = 3 \text{ units}$$

Planning Factors

Item: Ladder-back chair									
Order Policy: L4L **Lead Time:** 2 weeks									
		Week							
		1	2	3	4	5	6	7	8
Gross requirements		150			120		150	120	
Scheduled receipts		230							
Projected on-hand inventory	37	117	117	117					
Planned receipts					3		150	120	
Planned order releases			3		150	120			

Figure 11.14

Application 11.2

Item H10-A is a produced item (not purchased) with an order quantity of 80 units. Complete the rest of its MRP record using the fixed order quantity (FOQ) rule

Item: H10-A Description: Chair seat assembly									Lot Size: FOQ = 80 units Lead Time: 4 weeks	
	Week									
	31	32	33	34	35	36	37	38	39	40
Gross requirements		60				35		45		60
Scheduled receipts		80								
Projected on-hand inventory 20	20	40	40	40	40	5	5	40	40	60
Planned receipts								80		80
Planned order releases				80		80				

Application 11.3

Now complete the H10-A record using a POQ rule. The P should give an average lot size of 80 units.

Assume the average weekly requirements are 20 units.

$$P = \frac{80}{20} = \textbf{4 weeks}$$

Application 11.3

Item: H10-A
Description: Chair seat assembly

Lot Size: POQ = 4
Lead Time: 4 weeks

	Week									
	31	32	33	34	35	36	37	38	39	40
Gross requirements		60				35		45		60
Scheduled receipts		80								
Projected on-hand inventory 20	20	40	40	40	40	5	5	60	60	0
Planned receipts								100		
Planned order releases				100						

Application 11.4

Revise the H10-A record using the lot-for-lot (L4L) Rule. (Complete the highlighted section)

Item: H10-A Description: Chair seat assembly								Lot Size: L4L Lead Time: 4 weeks		
	Week									
	31	32	33	34	35	36	37	38	39	40
Gross requirements		60				35		45		60
Scheduled receipts		80								
Projected on-hand inventory 20	20	40	40	40	40	5	5	0	0	0
Planned receipts								40		60
Planned order releases				40		60				

Planning Factors

- Comparing lot-sizing rules

$$\text{FOQ:} \quad \frac{227 + 227 + 77 + 187 + 187}{5} = 181 \text{ units}$$

$$\text{POQ:} \quad \frac{150 + 150 + 0 + 0 + 0}{5} = 60 \text{ units}$$

$$\text{L4L:} \quad \frac{0 + 0 + 0 + 0 + 0}{5} = 0 \text{ units}$$

Planning Factors

- **Lot sizes affect inventory, setup, and ordering costs**

1. **The FOQ rule generates a high level of average inventory because it creates inventory *remnants*.**

2. **The POQ rule reduces the amount of average on-hand inventory because it does a better job of matching order quantity to requirements.**

3. **The L4L rule minimizes inventory investment, but it also maximizes the number of orders placed.**

Planning Factors

- Safety stock for dependent demand items with lumpy demand (gross requirements) is helpful only when future gross requirements, the timing or size of scheduled receipts, and the amount of scrap that will be produced are uncertain.
  - Used for end items and purchased items to protect against fluctuating customer orders and unreliable suppliers of components but avoid using it as much as possible for intermediate items.

Planning Factors

Safety Stock

FOQ Rule		Lot Size: 230 units Lead Time: 2 weeks Safety Stock: 80 units							
		Week							
		1	2	3	4	5	6	7	8
Gross requirements		150			120		150	120	
Scheduled receipts		230							
Projected on-hand inventory	37	117	117	117	227	227	307	187	187
Planned receipts					230		230		
Planned order releases			230		230				

Figure 11.15

Outputs from MRP

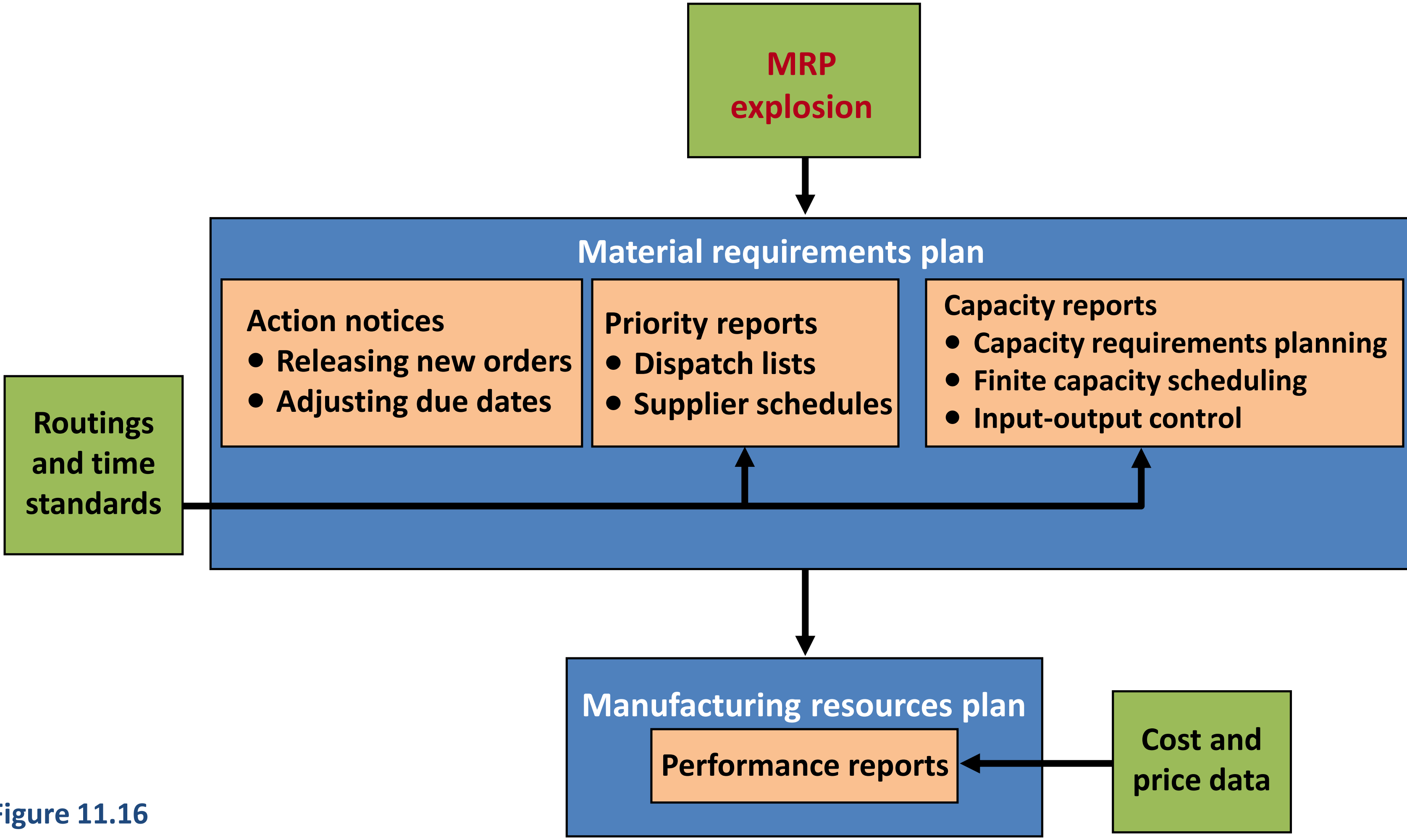
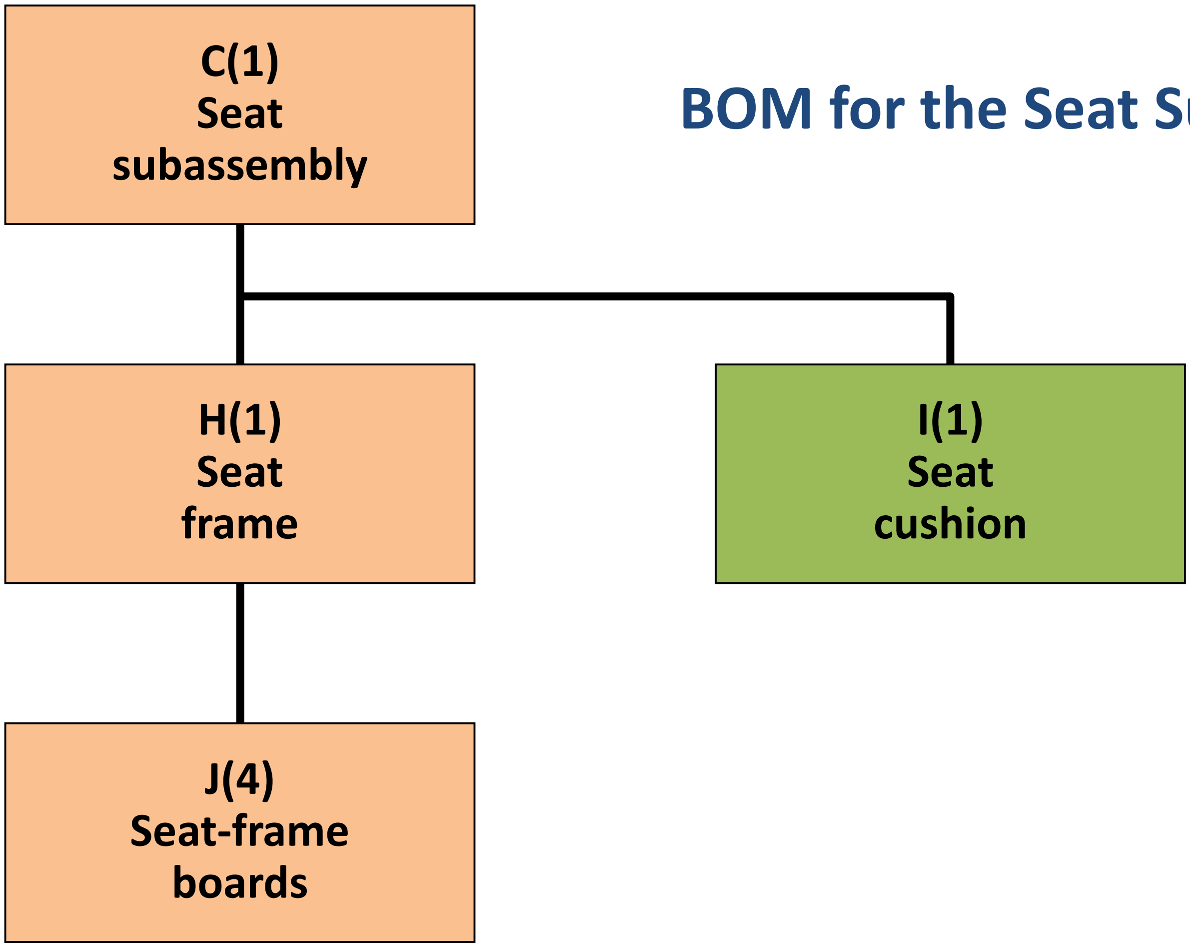


Figure 11.16

Outputs from MRP

- **Material Requirements**
  - **An item's gross requirements are derived from three sources:**
    - The MPS for immediate parents that are end items
    - The planned order releases for immediate parents below the MPS level
    - Any other requirements not originating in the MPS, such as the demand for replacement parts

Outputs from MRP



BOM for the Seat Subassembly

Figure 11.17

Outputs from MRP

Item: Seat subassembly Lot size: 230 units Lead time: 2 weeks	Week							
	1	2	3	4	5	6	7	8
Gross requirements	150	0	0	120	0	150	120	0
Scheduled receipts	230	0	0	0	0	0	0	0
Projected on-hand inventory 37	117	117	117	227	227	77	187	187
Planned receipts				230			230	
Planned order releases		230			230			

Figure 11.18

Outputs from MRP

Item: Seat subassembly
Lot size: 230 units
Lead time: 2 weeks

Week	1	2	3	4	5	6	7	8
Gross requirements	150	0	0	120	0	150	120	0
Planned receipts				230			230	
Planned order releases		230			230			

Usage quantity: 1

Usage quantity: 1

Item: Seat frames
Lot size: 300 units
Lead time: 1 week

Week	1	2	3	4	5	6	7	8
Gross requirements	0	230	0	0	230			
Scheduled receipts	0	300	0	0	0	0	0	0
Projected on-hand inventory 40								
Planned receipts								
Planned order releases								

Item: Seat cushion
Lot size: L4L
Lead time: 1 week

Week	1	2	3	4	5	6	7	8
Gross requirements	0	230	0	0	230			
Scheduled receipts	0	0	0	0	0	0	0	0
Projected on-hand inventory 0								
Planned receipts								
Planned order releases								

Figure 11.18

Outputs from MRP

Item: Seat subassembly Lot size: 230 units Lead time: 2 weeks	Week 1	2	3	4	5	6	7	8
Gross requirements	150	0	0	120	0	150	120	0
Planned receipts				230			230	
Planned order releases		230			230			

Item: Seat frames Lot size: 300 units Lead time: 1 week		Week 1	2	3	4	5	6	7	8
Gross requirements		0	230	0	0	230	0	0	0
Scheduled receipts		0	300	0	0	0	0	0	0
Projected on-hand inventory	40	40	110	110	110	180	180	180	180
Planned receipts						300			
Planned order releases					300				

Item: Seat cushion Lot size: L4L Lead time: 1 week		Week 1	2	3	4	5	6	7	8
Gross requirements		0	230	0	0	230	0	0	0
Scheduled receipts		0	0	0	0	0	0	0	0
Projected on-hand inventory	0	0	0	0	0	0	0	0	0
Planned receipts			230			230			
Planned order releases		230			230				

Figure 11.18

Outputs from MRP

Item: Seat frames Lot size: 300 units Lead time: 1 week	Week							
	1	2	3	4	5	6	7	8
Gross requirements	0	230	0	0	230	0	0	0
Planned receipts					300			
Planned order releases				300				

Item: Seat cushion Lot size: L4L Lead time: 1 week	Week							
	1	2	3	4	5	6	7	8
Gross requirements	0	230	0	0	230	0	0	0
Planned receipts		230			230			
Planned order releases	230			230				

Usage quantity: 4

Item: Seat-frame boards Lot size: 1500 units Lead time: 1 week		Week							
		1	2	3	4	5	6	7	8
Gross requirements					1200				
Scheduled receipts		0	0	0	0	0	0	0	0
Projected on-hand inventory	200	200	200	200	500	500	500	500	500
Planned receipts					1500				
Planned order releases				1500					

Figure 11.18

Application 11.5

A firm makes a product (Item A) from three components (intermediate Items B and D, and purchased item C).

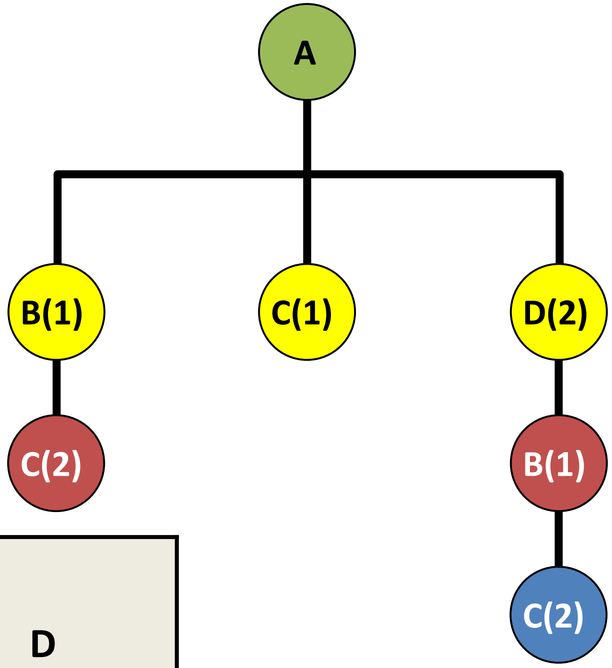
The latest MPS for product A calls for completion of a 250-unit order in week 8, and its lead time is 2 weeks.

The master schedule and bill of material for Product A are on the following slides:

Item: End Item A								Lead Time: 2 wks
	Week							
	1	2	3	4	5	6	7	8
MPS quantity								250
MPS start						250		

Application 11.5

Develop a material requirements plan for items B, C, and D, given the following inventory data.



Data Category	Item B	Item C	Item D
Lot-sizing rule	POQ (*P* = 5)	FOQ = 1000	L4L
Lead time	2 weeks	1 week	3 weeks
Scheduled receipts	None	1000 (week 1)	None
Beginning inventory	0	800	0

Application 11.5

An item's gross requirements cannot be derived until all of its immediate parents are processed.

Thus we must begin with Item D. Its only immediate parent is item A, and its planned "production plan" is shown by the MPS start row.

Item: D Description:	Lot Size: L4L Lead Time: 3 weeks							
	Week							
	1	2	3	4	5	6	7	8
Gross requirements						500		
Scheduled receipts								
Projected on-hand inventory 0	0	0	0	0	0	0	0	0
Planned receipts						500		
Planned order releases			500					

Application 11.5

We can do item B next, because the planned "production quantities" for its two immediate parents (A and D) are known.

Item C cannot be done yet, because one of its parents is item B, and its PORs are still unknown.

Item: B Description:				Lot Size: POQ = 5 Lead Time: 2 weeks				
	Week							
	1	2	3	4	5	6	7	8
Gross requirements			500			250		
Scheduled receipts								
Projected on-hand inventory 0	0	0	250	250	250	0	0	0
Planned receipts			750					
Planned order releases	750							

Application 11.5

Finally we can do Item C, because we now know the planned "production quantities" of both of its immediate parents (A and B).

Item: C Description:	Lot Size: 1000 Lead Time: 1 week							
	Week							
	1	2	3	4	5	6	7	8
Gross requirements	1500					250		
Scheduled receipts	1000							
Projected on-hand inventory 800	300	300	300	300	300	50	50	50
Planned receipts								
Planned order releases								

Outputs from MRP

- Action notices
  - A computer-generated memo alerting planners about releasing new orders and adjusting the due dates of scheduled receipts.
- Resource Requirement Reports
  - Theory of constraints principles
  - Capacity requirements planning (CRP)
- Performance Reports
  - Manufacturing resource planning (MRP II)

MRP and the Environment

- Consumer and government concern about the deterioration of the natural environment has driven manufacturers to reengineer their processes to become more environmentally friendly.

- Companies can modify their MRP systems to help track these waste and plans for their disposal.

MRP, Core Processes, and Supply Chain Linkages

- The MRP system interacts with the four core processes of an organization
  - Supplier relationship process
  - New service/product development process
  - Order fulfillment process
  - Customer relationship process

MRP, Core Processes, and Supply Chain Linkages

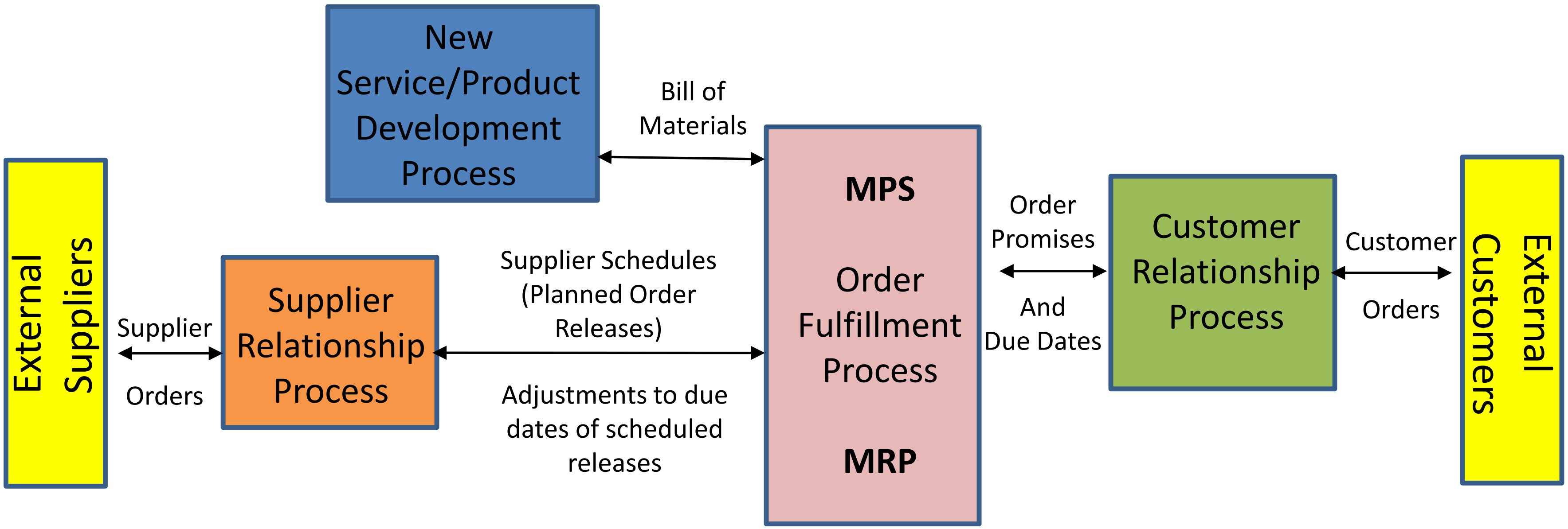


Figure 11.19

Enterprise Resource Planning

- **Enterprise process**
  - A companywide process that cuts across functional areas, business units, geographic regions, product lines, suppliers, and customers
- **Enterprise resource planning (ERP) systems**
  - Large, integrated information systems that support many enterprise processes and data storage needs

Enterprise Resource Planning

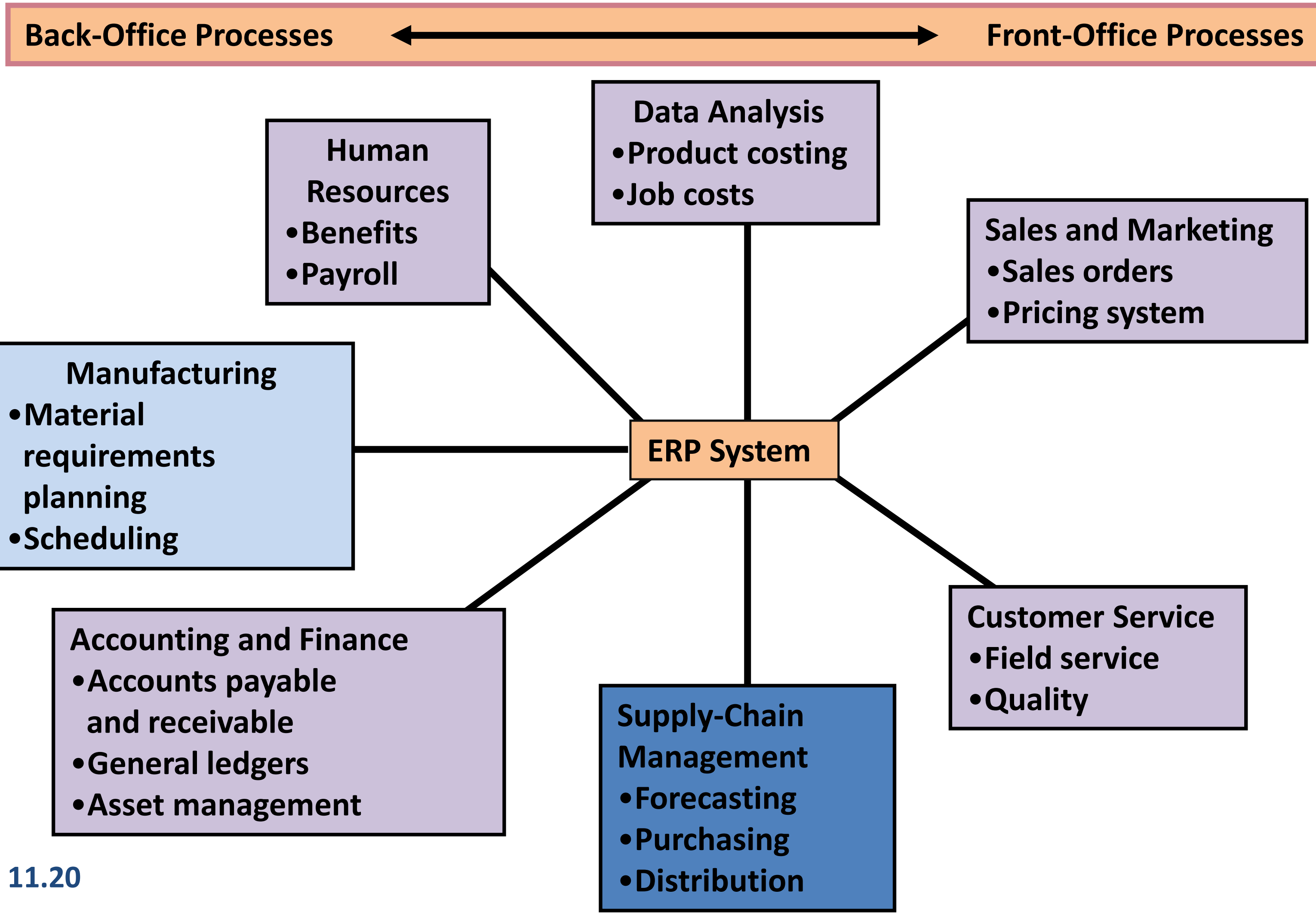


Figure 11.20

Resource Planning for Service Providers

- Dependent demand for services
  - Restaurants
  - Airlines
  - Hospitals
  - Hotels

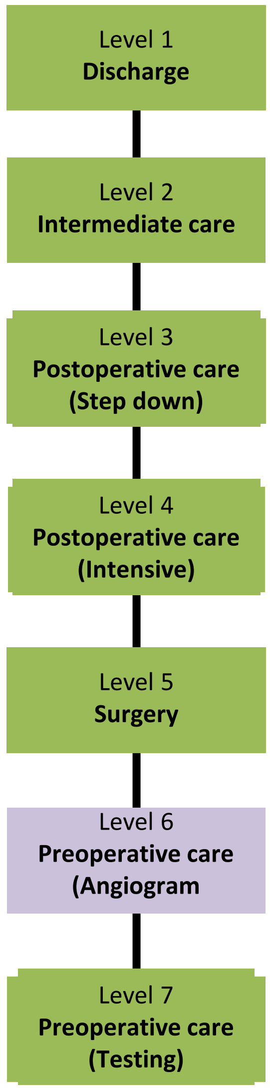
- Bill of Resources (BOR)
  - A record of a service firm's parent-component relationships and all of the materials, equipment time, staff, and other resources associated with them, including usage quantities.

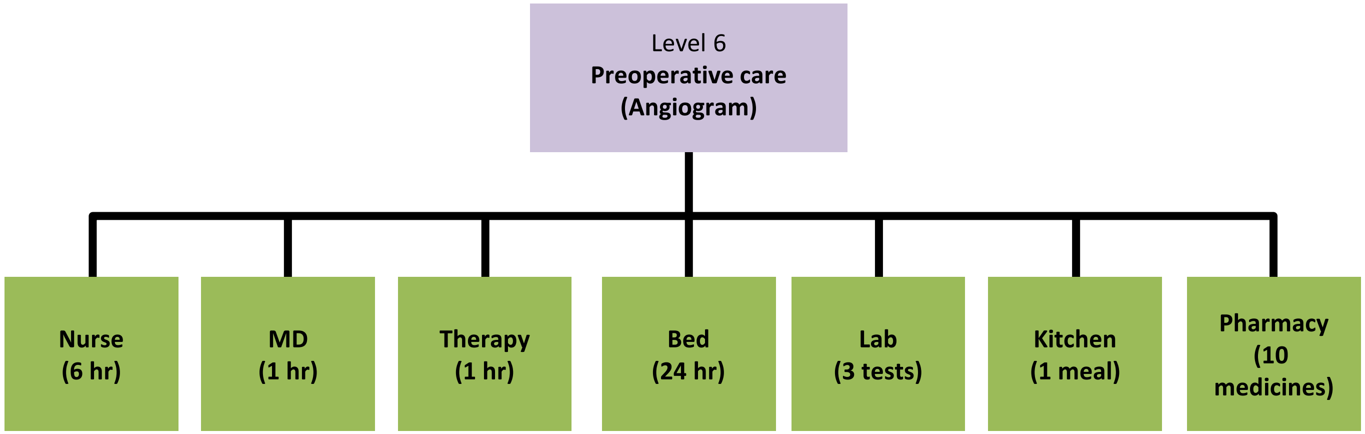
Bill of Resources

- Consider a regional hospital that among many other procedures performs aneurysm treatments. The BOR (Figure 11.21) for treatment has 7 levels.

- The hospital is interested in understanding how much of each critical resource of nurses, beds and lab tests will be needed if the projected patient departures from the aneurysm treatment process over the next 15 days are as shown in Table 11.1

Bill of Resources





Cumulative lead time, or the patient stay time at the hospital, across all seven levels for the entire duration of the aneurysm treatment is 10 days.

Figure 11.21

Bill of Resources

Day of the Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aneurysm Patient	1	2	1	3	2	3	0	1	2	1	2	2	2	2	2

The first 10 days of the projected departures represent actual patients who have started the process while the last 5 days are forecasts based on historical records.

Table 11.1

Bill of Resources

Resources Required for Each Aneurysm Patient	Nurse Hours Required Per Day Per Patient	Beds Required Per Day Per Patient	Lab Tests Required Per Day Per Patient
Level 1	0	0	0
Level 2	6	0	0
Level 3	16	1	4
Level 4	12	1	6
Level 5	22	1	2
Level 6	6	1	3
Level 7	1	0	0

Table 11.2

Use the information above to calculate the daily resource requirements for treating aneurysm patients (similar to the gross requirements in a MRP record). Begin by calculating the number of patients that will be at each level (or stage) of treatment each day.

Bill of Resources

As shown below, the aneurysm patient departures become the Master Schedule for Level 1 and these departures drive the need for resources at each level of the process.

Day of the Month		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aneurysm Patient Departures		1	2	1	3	2	3	0	1	2	1	2	2	2	2	2
Number of Patients at Level 1 (LT = 1 Day)		1	2	1	3	2	3	0	1	2	1	2	2	2	2	2
Number of Patients at Level 2 (LT = 1 Day)		2	1	3	2	3	0	1	2	1	2	2	2	2	2	
Number of Patients at Level 3 (LT = 3 Days)	Advancing to Level 2	1	3	2	3	0	1	2	1	2	2	2	2	2		
	In Progress Second Day	3	2	3	0	1	2	1	2	2	2	2	2			
	In Progress First Day	2	3	0	1	2	1	2	2	2	2	2	_	_		
	Total	6	8	5	4	3	4	5	5	6	6	6	4	2		
Number of Patients at Level 4 (LT = 2 Days)	Advancing to Level 3	3	0	1	2	1	2	2	2	2	2					
	In Progress First Day	0	1	2	1	2	2	2	2	2	_					
	Total	3	1	3	3	3	4	4	4	4	2					
Number of Patients at Level 5 (LT = 1 Day)		1	2	1	2	2	2	2	2							
Number of Patients at Level 6 (LT = 1 Day)		2	1	2	2	2	2	2								
Number of Patients at Level 7 (LT = 1 Day)		1	2	2	2	2	2									

Figure 11.22

Bill of Resources

Once we know how many patients will need each level of treatment on each day, we can multiply this demand by the amount of each resource required to treat them.

Example:

Total Number of Lab Tests Projected for Day 5

$$= [0(2) + 0(3) + 4(3) + 6(3) + 2(2) + 3(2) + 0(2)]$$

$$= 40$$

Bill of Resources

Day of the Month	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Nursing Hours Required	179	198	170	170	160	170	190	184	150	132	108	76	44	12	0
Beds required	12	12	11	11	10	12	13	11	10	8	6	4	2	0	0
Lab Tests Required	50	45	46	44	40	50	54	48	48	36	24	16	8	0	0

The above table shows how much of each critical resource is required in total to treat aneurysm patients for the 15-day master schedule.

This table shows the resources needed from Day 1 to Day 15 for the current schedule.

Table 11.3

Solved Problem 1

Refer to the bill of materials for product A shown below.

If there is no existing inventory and no scheduled receipts, how many units of items G, E, and D must be purchased to produce 5 units of end item A?

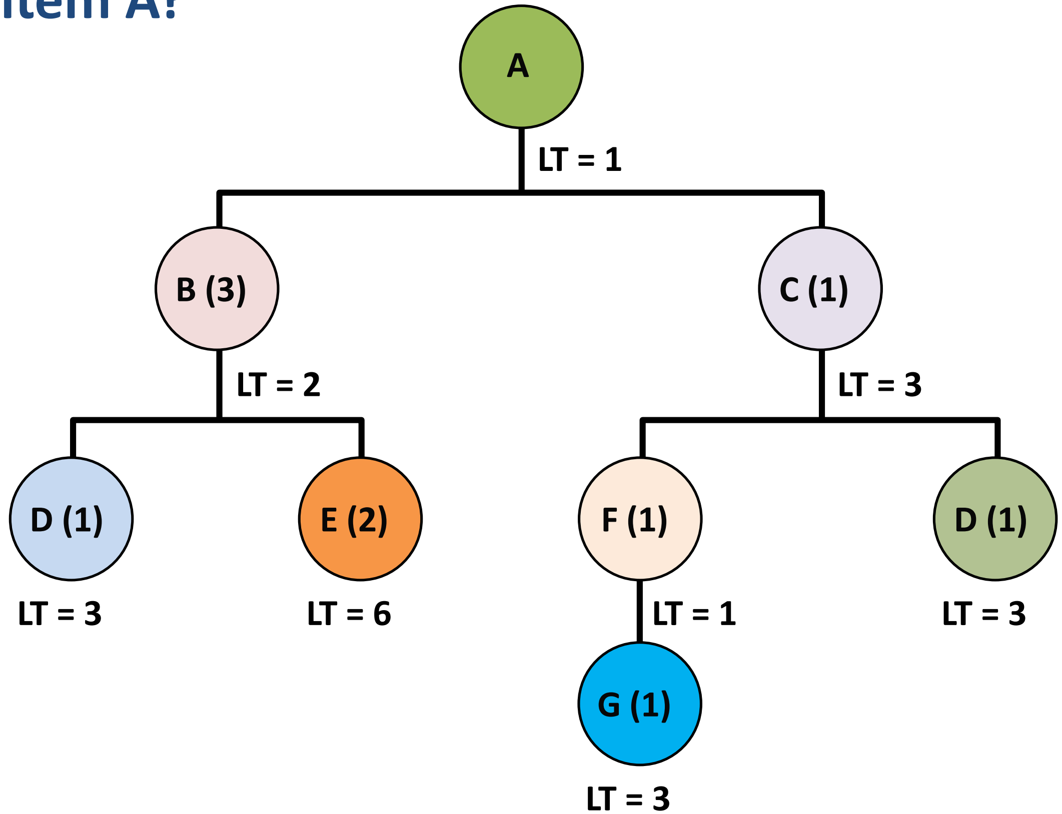


Figure 11.23

Solved Problem 1

- Five units of item G, 30 units of item E, and 20 units of item D must be purchased to make 5 units of A.
- The usage quantities indicate that 2 units of E are needed to make 1 unit of B and that 3 units of B are needed to make 1 unit of A; therefore, 5 units of A require 30 units of E ($2 \times 3 \times 5 = 30$).
- One unit of D is consumed to make 1 unit of B, and 3 units of B per unit of A result in 15 units of D ($1 \times 3 \times 5 = 15$)
- One unit of D in each unit of C and 1 unit of C per unit of A result in another 5 units of D ($1 \times 1 \times 5 = 5$).
- The total requirements to make 5 units of A are 20 units of D($15 + 5$).
- The calculation of requirements for G is simply $1 \times 1 \times 1 \times 5 = 5$ units.

Solved Problem 2

- The order policy is to produce end item A in lots of 50 units.
- Complete the projected on-hand inventory and MPS quantity rows.
- Complete the MPS start row by offsetting the MPS quantities for the final assembly lead time.
- Compute the available-to-promise inventory for item A.

Solved Problem 2

- Assess the following customer requests for new orders.
- Assume that these orders arrive consecutively and their affect on ATP is cumulative.
- Which of these orders can be satisfied without altering the MPS Start quantities?
  - Customer A requests 30 units in week 1
  - Customer B requests 30 units in week 4
  - Customer C requests 10 units in week 3
  - Customer D requests 50 units in week 5

Solved Problem 2

Item: A										Order Policy: 50 units Lead Time: 1 week
Quantity on Hand 5	Week									
	1	2	3	4	5	6	7	8	9	10
Forecast	20	10	40	10	0	0	30	20	40	20
Customer orders (booked)	30	20	5	8	0	2	0	0	0	0
Projected on-hand inventory	25									
MPS quantity	50									
MPS start										
Available-to-promise (ATP) inventory										

Figure 11.24

Solved Problem 2

The projected on-hand inventory for the second week is

$$\begin{pmatrix}\text{Projected on-hand}\\ \text{inventory at end}\\ \text{of week 2}\end{pmatrix} = \begin{pmatrix}\text{On-hand}\\ \text{inventory in}\\ \text{week 1}\end{pmatrix} + \begin{pmatrix}\text{MPS quantity}\\ \text{due in week 2}\end{pmatrix} - \begin{pmatrix}\text{Requirements}\\ \text{in week 2}\end{pmatrix}$$

= 25 + 0 – 20 = 5 units

where requirements are the larger of the forecast or actual customer orders booked for shipment during this period. No MPS quantity is required.

Without an MPS quantity in the third period, a shortage of item A will occur: 5 + 0 – 40 = –35.

Therefore, an MPS quantity equal to the lot size of 50 must be scheduled for completion in the third period. Then the projected on-hand inventory for the third week will be 5 + 50 – 40 = 15.

Solved Problem 2

The MPS start row is completed by simply shifting a copy of the MPS quantity row to the left by one column to account for the 1-week final assembly lead time. Also shown are the available-to-promise quantities. In week 1, the ATP is

$$\begin{pmatrix}\text{Available-to-}\\ \text{promise in}\\ \text{week 1}\end{pmatrix} = \begin{pmatrix}\text{On-hand}\\ \text{quantity in}\\ \text{week 1}\end{pmatrix} + \begin{pmatrix}\text{MPS quantity}\\ \text{in week 1}\end{pmatrix} - \begin{pmatrix}\text{Orders booked up}\\ \text{to week 3 when the}\\ \text{next MPS arrives}\end{pmatrix}$$

$$= 5 + 50 - (30 + 20) = \textbf{5 units}$$

Solved Problem 2

The ATP for the MPS quantity in week 3 is

$$\begin{pmatrix}\text{Available-to-}\\ \text{promise in}\\ \text{week 3}\end{pmatrix} = \begin{pmatrix}\text{MPS quantity}\\ \text{in week 3}\end{pmatrix} - \begin{pmatrix}\text{Orders booked up}\\ \text{to week 7 when the}\\ \text{next MPS arrives}\end{pmatrix}$$

$$= 50 - (5 + 8 + 0 + 2) = \textbf{35 units}$$

Solved Problem 2

Lot Size: 50 units
Lead Time: 1 week

Quantity on Hand: 5	Week 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Forecast	20	10	40	10			30	20	40	20					
Customer orders (booked)	30	20	5	8		2									
Projected on-hand inventory	25	5	15	5	5	3	23	3	13	43					
MPS quantity	50		50				50		50	50					
MPS start		50				50		50	50						
Available-to-promise (ATP) inventory	5		35				50		50	50					

Figure 11.25

Solved Problem 3

The MPS start quantities for product A calls for the assembly department to begin final assembly according to the following schedule:

- 100 units in week 2; 200 units in week 4
- 120 units in week 6; 180 units in week 7
- 60 units in week 8.
- Develop a material requirements plan for the next 8 weeks for items B, C, and D.

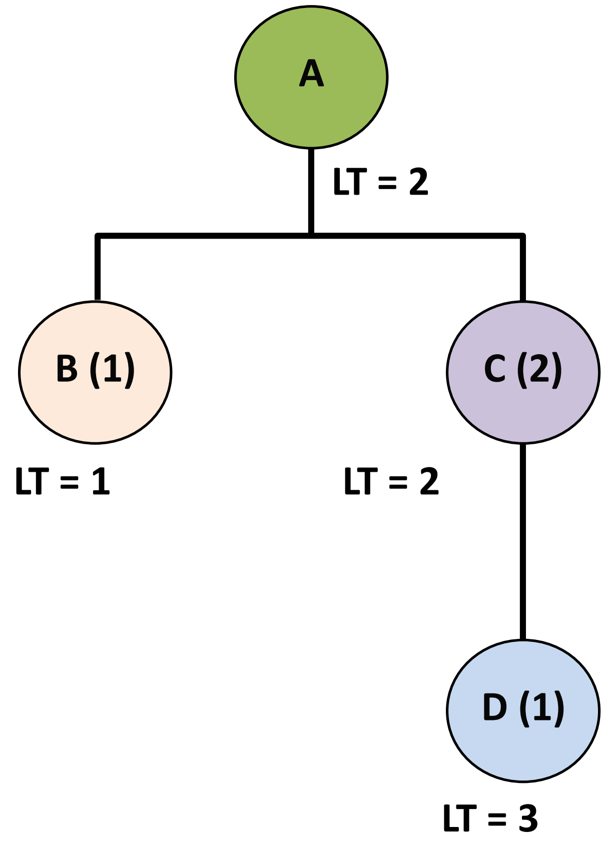


Figure 11.26

Solved Problem 3

INVENTORY RECORD DATA			
	Item		
Data Category	B	C	D
Lot-sizing rule	POQ *(P =3)*	L4L	FOQ = 500 units
Lead time	1 week	2 weeks	3 weeks
Scheduled receipts	None	200 (week 1)	None
Beginning (on-hand) inventory	20	0	425

Solved Problem 3

Item: B										Lot Size: POQ (*P = 3*) Lead Time: 1 week
	Week									
	1	2	3	4	5	6	7	8	9	10
Gross requirements		100		200		120	180	60		
Scheduled receipts										
Projected on-hand inventory 20	20	200	200	0	0	240	60	0	0	0
Planned receipts		280				360				
Planned order releases	280				360					

Figure 11.27

Solved Problem 3

Item: C									Lot Size: L4L Lead Time: 2 weeks	
	Week									
	1	2	3	4	5	6	7	8	9	10
Gross requirements		200		400		240	360	120		
Scheduled receipts	200									
Projected on-hand inventory 0	200	0	0	0	0	0	0	0	0	0
Planned receipts				400		240	360	120		
Planned order releases		400		240	360	120				

Figure 11.27

Solved Problem 3

Item: D										Lot Size: FOQ = 500 units Lead Time: 1 week
	Week									
	1	2	3	4	5	6	7	8	9	10
Gross requirements		400		240	360	120				
Scheduled receipts										
Projected on-hand inventory 425	425	25	25	285	425	305	305	305	305	305
Planned receipts				500	500					
Planned order releases	500	500								

Figure 11.27

Solved Problem 4

- The Pet Training Academy offers a 5-day training program for troubled dogs. As seen below, the training process requires 5 days, beginning with the dog's arrival at 8 A.M. on day one, and departure after a shampoo and trim, at 5 P.M. on day five.

Pet Training Academy Process	Lead Time in Days
Level 1: Departure Day	1
Level 2: 3rd Day	1
Level 3: 2nd Day	2
Level 4: Arrival Day	1
Total	5

Table 11.5

Solved Problem 4

- To adequately train a dog, the Academy requires Training Coaches, Dog Groomers, a Dog Dietician, Care Assistants, and Boarding Kennels where the dogs rest.
- The time required by each employee and resource classifications by process level is given below:

Pet Training Academy Process Resources Required	Training Coach (Hours)	Dog Dietician (Hours)	Care Assistant (Hours)	Boarding Kennel (Hours)
Level 1: Departure Day	**2**	**1**	**1**	**12**
Level 2: 3rd Day	**3**	**1**	**2**	**24**
Level 3: 2nd Day	**3**	**1**	**2**	**24**
Level 4: Arrival Day	**2**	**1**	**1**	**12**

Table 11.6

Solved Problem 4

- **The master schedule for the trained dogs is shown below, noting that departures for trained dogs are actual departures for days 1-5 and forecasted departures for days 6-12.**

Day of the month	1	2	3	4	5	6	7	8	9	10	11	12
Master Schedule of Trained Dogs	5	2	2	8	3	0	1	8	4	3	6	0

Solved Problem 4

a. Use the above information to calculate the daily resource requirements in hours for employees in each category, and the hours of boarding room needed to train the dogs.
b. Assuming that each boarding kennel is available for 24 hours in a day, how many kennels will be required each day?
c. Assuming that each employee is able to work only eight hours per day, how many people in each employee category will be required each day?

Solved Problem 4

Day of the Month		1	2	3	4	5	6	7	8	9	10	11	12
Trained Dog Departures		5	2	2	8	3	0	1	8	4	3	6	0
Number of Dogs at Level 1 (LT = 1 Day)		5	2	2	8	3	0	1	8	4	3	6	0
Number of Dogs at Level 2 (LT = 1 Day)		2	2	8	3	0	1	8	4	3	6	0	
Number of Dogs at Level 3 (LT = 2 Days)	Advancing to Level 2	2	8	3	0	1	8	4	3	6	0		
	In Progress First Day	8	3	0	1	8	4	3	6	0	–		
	Total	**10**	**11**	**3**	**1**	**9**	**12**	**7**	**9**	**6**	**0**		
Number of Dogs at Level 4 (LT = 1 Day)		3	0	1	8	4	3	6	0				

Figure 11.28

Solved Problem 4

The previous table shows the number of dogs at each level during their stay at the Pet Training Academy.

The top row of each level shows the number of dogs who will advance to the next level at the end of the day.

The daily resource requirements for each resource required to train the departing dogs are shown in the following slide.

Total number of CA hours Projected for Day 2

[1(2) + 2(2) + 2(11) +1(0)] = 28 hours

Solved Problem 4

Day of the Month	1	2	3	4	5	6	7	8	9	10	11	12
Training Coach Hours required	52	43	39	44	41	45	59	55	35	24	12	0
Dog Dietician hours required	20	15	14	20	16	16	22	21	13	9	6	0
Care Assistant hours required	32	28	25	24	25	29	37	34	22	15	6	0
Boarding kennels hours required	384	336	300	288	300	348	444	408	264	180	72	0
Number of Boarding Kennels required	16	14	13	12	13	15	19	17	11	8	3	0

Table 11.7

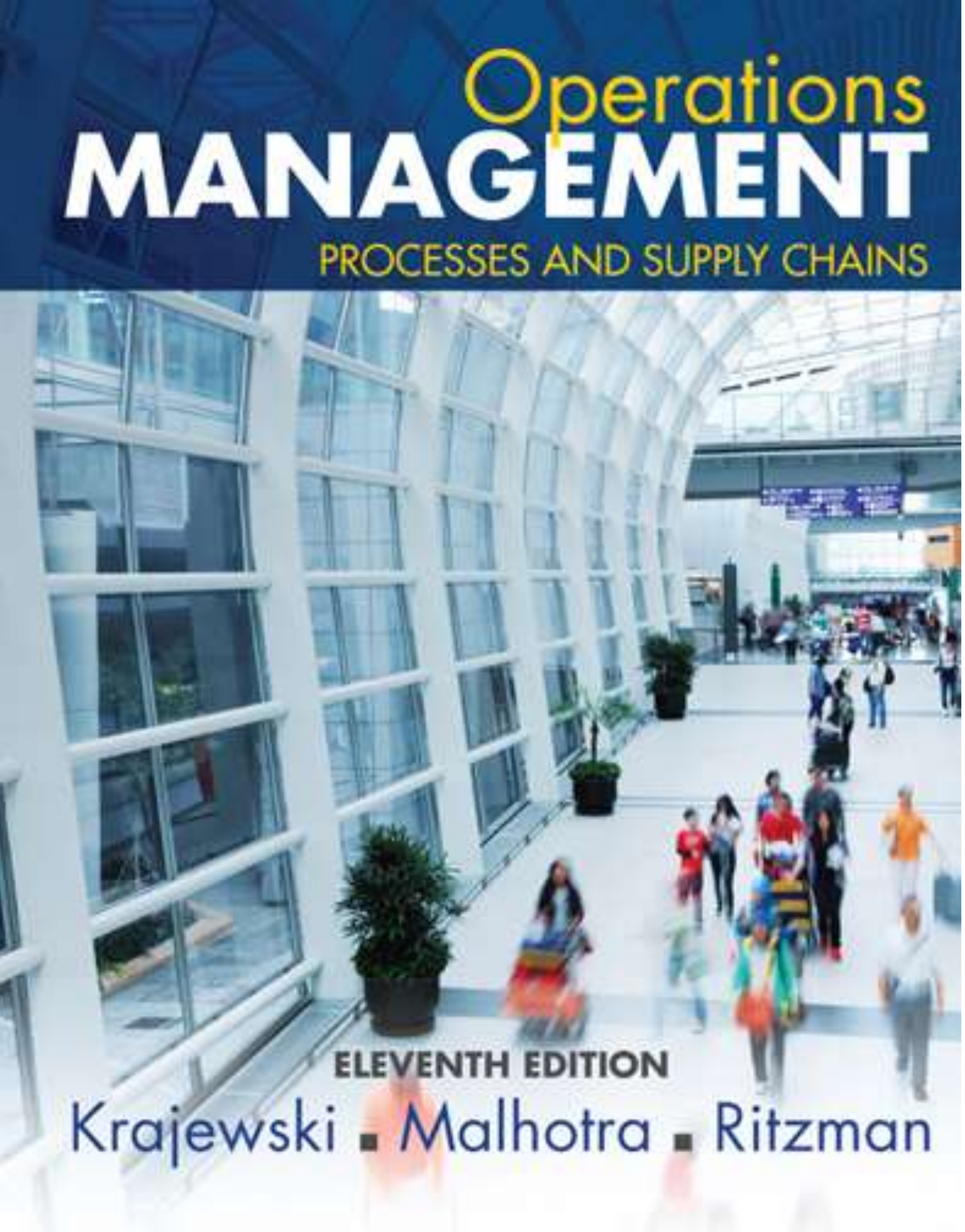
Solved Problem 4

b. **The number of boarding kennels required per day (note all fractional kennels are rounded to the next higher integer) are obtained by dividing the total number of hours needed for boarding kennels by 24, and are shown in the last row of the previous slide.**

Solved Problem 4

c. The number of people required per day in each employee category are obtained by dividing the resource requirements by working hours in each day. They are shown below. Note that all fractional employees are rounded to the next higher integer.

Number of Employee Required per Day	1	2	3	4	5	6	7	8	9	10	11	12
Training Coaches	7	6	5	6	6	6	8	7	5	3	2	0
Dog Dieticians	3	2	2	3	2	2	3	3	2	2	1	0
Care Assistants	4	4	4	3	4	4	5	5	3	2	1	0



Supplement C

Special Inventory Models

Non instantaneous Replenishment

- **Maximum cycle inventory less than Q**
- **Item can be used or sold as it is produced**
- **Production rate, p, exceeds the demand rate, d, so there is a buildup of $(p - d)$ units per time period**
- **Both p and d expressed in same time interval**
- **Buildup continues for Q/p days**

Non instantaneous Replenishment

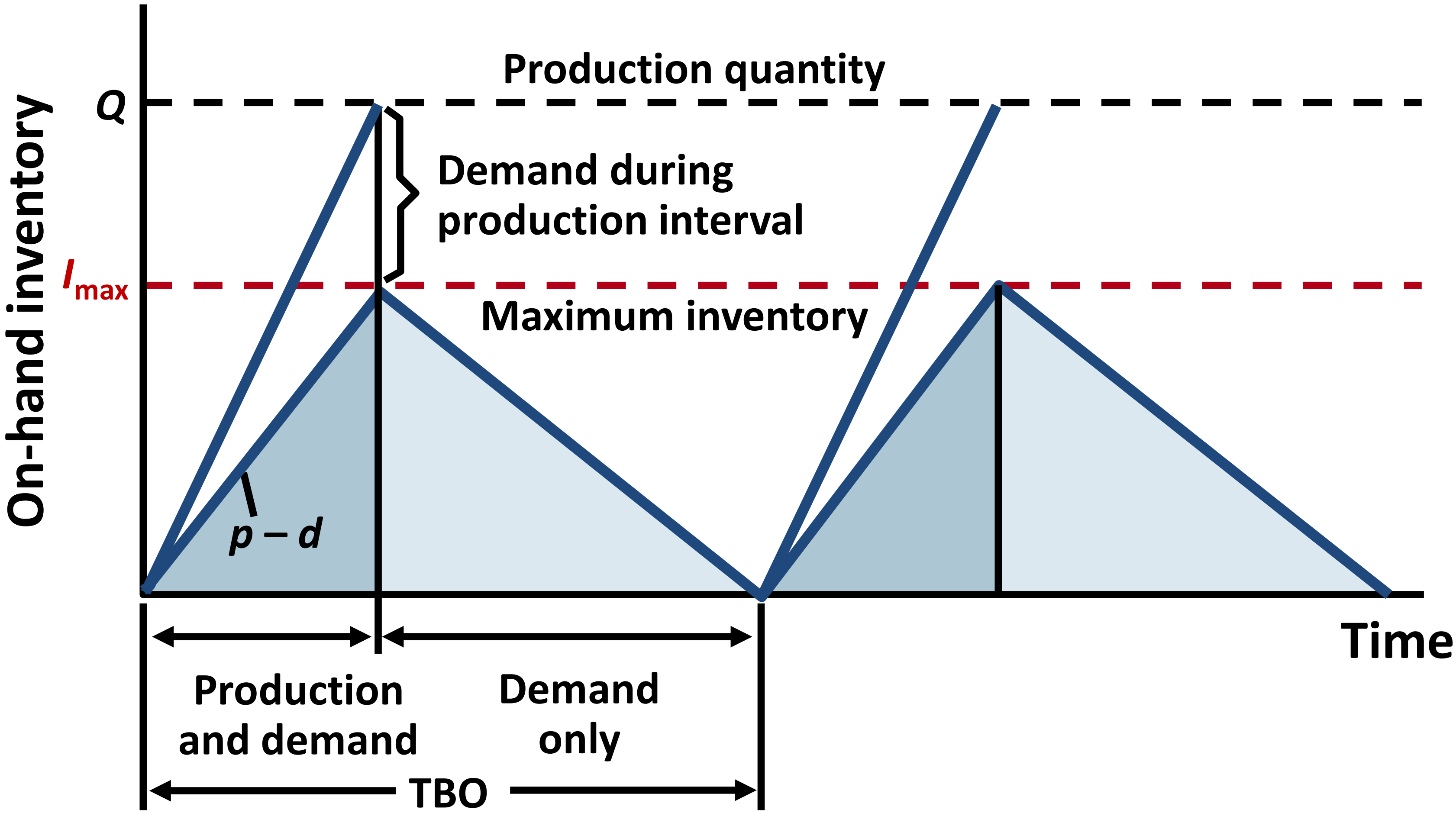


Figure C.1

Non instantaneous Replenishment

Maximum cycle inventory is:

$$I_{\max} = \frac{Q}{p}(p-d) = Q\left(\frac{p-d}{p}\right)$$

where

p = production rate

d = demand rate

Q = lot size

Cycle inventory is no longer $Q/2$, it is $I_{\max}/2$

Non instantaneous Replenishment

Total annual cost =
Annual holding cost + Annual ordering or setup cost

D is annual demand and Q is lot size

d is daily demand; p is daily production rate

$$C = \frac{I_{\max}}{2}(H) + \frac{D}{Q}(S) = \frac{Q}{2}\left(\frac{p-d}{p}\right)(H) + \frac{D}{Q}(S)$$

Noninstantaneous Replenishment

Economic Production Lot Size (ELS): optimal lot size

Because the second term is greater than 1, the ELS results in a larger lot size than the EOQ

$$\text{ELS} = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-d}}$$

Example C.1

A plant manager of a chemical plant must determine the lot size for a particular chemical that has a steady demand of 30 barrels per day. The production rate is 190 barrels per day, annual demand is 10,500 barrels, setup cost is $200, annual holding cost is $0.21 per barrel, and the plant operates 350 days per year.

a. Determine the economic production lot size (ELS)
b. Determine the total annual setup and inventory holding cost for this item
c. Determine the time between orders (TBO), or cycle length, for the ELS
d. Determine the production time per lot

What are the advantages of reducing the setup time by 10 percent?

Example C.1

a. **Solving first for the ELS, we get**

$$\text{ELS} = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-d}} = \sqrt{\frac{2(10,500)(\$200)}{\$0.21}}\sqrt{\frac{190}{190-30}} = 4,873.4 \text{ barrels}$$

b. **The total annual cost with the ELS is**

$$C = \frac{Q}{2}\left(\frac{p-d}{p}\right)(H) + \frac{D}{Q}(S)$$

$$= \frac{4,873.4}{2}\left(\frac{190-30}{190}\right)(\$0.21) + \frac{10,500}{4,873.4}(\$200)$$

$$= \$430.91 + \$430.91 = \$861.82$$

Example C.1

c. Applying the TBO formula to the ELS, we get

$$\text{TBO}_{\text{ELS}} = \frac{\text{ELS}}{D}\left(350 \text{ days/year}\right) = \frac{4{,}873.4}{10{,}500}(350)$$

$$= 162.4 \text{ or } \color{red}{162 \text{ days}}$$

d. The production time during each cycle is the lot size divided by the production rate:

$$\frac{\text{ELS}}{p} = \frac{4{,}873.4}{190} = 25.6 \text{ or } \color{red}{26 \text{ days}}$$

Example C.1

Period Used in Calculations	Day
Demand per Day	30
Production Rate/Day	190
Annual Demand	10,500
Setup Cost	$180
Annual Holding Cost ($)	$0.21
Operating Days per Year	350
Economic Lot Size (ELS)	4,623
Annual Total Cost	$817.60
Time Between Orders (days)	154.1
Production Time	24.3

◉ Enter Holding Cost Manually ○ Holding Cost As % of Value

Figure C.2

Application C.1

A domestic automobile manufacturer schedules 12 two-person teams to assemble 4.6 liter DOHC V-8 engines per work day. Each team can assemble 5 engines per day. The automobile final assembly line creates an annual demand for the DOHC engine at 10,080 units per year. The engine and automobile assembly plants operate 6 days per week, 48 weeks per year. The engine assembly line also produces SOHC V-8 engines. The cost to switch the production line from one type of engine to the other is $100,000. It costs $2,000 to store one DOHC V-8 for one year.

Application C.1

a. What is the economic lot size?
b. How long is the production run?
c. What is the average quantity in inventory?
d. What is the total annual cost?

Application C.1

a. Economic Lot Size

Demand per day = d = 10,080/[(48)(6)] = 35

$$\text{ELS} = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-d}} = \sqrt{\frac{2(10{,}080)(100{,}000)}{2{,}000}}\sqrt{\frac{60}{60-35}} = 1{,}555.38$$

or 1,555 engines

b. The production run

$$\frac{Q}{p} = \frac{1{,}555}{60} = 25.91 \text{ or } 26 \text{ production days}$$

Application C.1

c. **Average inventory**

$$\frac{I_{\max}}{2} = \frac{Q}{2}\left(\frac{p-d}{p}\right) = \frac{1,555}{2}\left(\frac{60-35}{60}\right) = 324 \text{ engines}$$

d. **Total annual cost**

$$C = \frac{I_{\max}}{2}(H) + \frac{D}{Q}(S) = \frac{Q}{2}\left(\frac{p-d}{p}\right)(H) + \frac{D}{Q}(S)$$

$$= \frac{1,555}{2}\left(\frac{60-35}{60}\right)(\$2,000) + \frac{10,080}{1,555}(\$100,000)$$

$$= \$647,917 + \$648,231$$

$$= \$1,296,148$$

Quantity Discounts

Total annual cost = Annual holding cost
+ Annual ordering or setup cost
+ Annual cost of materials

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) + PD$$

where P = price per unit

Quantity Discounts

- Price incentives to purchase large quantities create pressure to maintain a large inventory
- Item's price is no longer fixed
  - If the order quantity is increased enough, then the price per unit is discounted
  - A new approach is needed to find the best lot size that balances:
    - Advantages of lower prices for purchased materials and fewer orders
    - Disadvantages of the increased cost of holding more inventory

Quantity Discounts

- Unit holding cost (H) is usually expressed as a percentage of unit price

- The lower the unit price (P) is, the lower the unit holding cost (H) is

Quantity Discounts

- The total cost equation yields U-shape total cost curves
  - There are cost curves for each price level
  - The feasible total cost begins with the top curve, then drops down, curve by curve, at the price breaks
  - EOQs do not necessarily produce the best lot size
    - The EOQ at a particular price level may not be feasible
    - The EOQ at a particular price level may be feasible but may not be the best lot size

Quantity Discounts

Two-Step Solution Procedure

Step 1. Beginning with lowest price, calculate the EOQ for each price level until a feasible EOQ is found. It is feasible if it lies in the range corresponding to its price. Each subsequent EOQ is smaller than the previous one, because P, and thus H, gets larger and because the larger H is in the denominator of the EOQ formula.

Quantity Discounts

Step 2. If the first feasible EOQ found is for the lowest price level, this quantity is the best lot size. Otherwise, calculate the total cost for the first feasible EOQ and for the larger price break quantity at each lower price level. The quantity with the lowest total cost is optimal.

Quantity Discounts

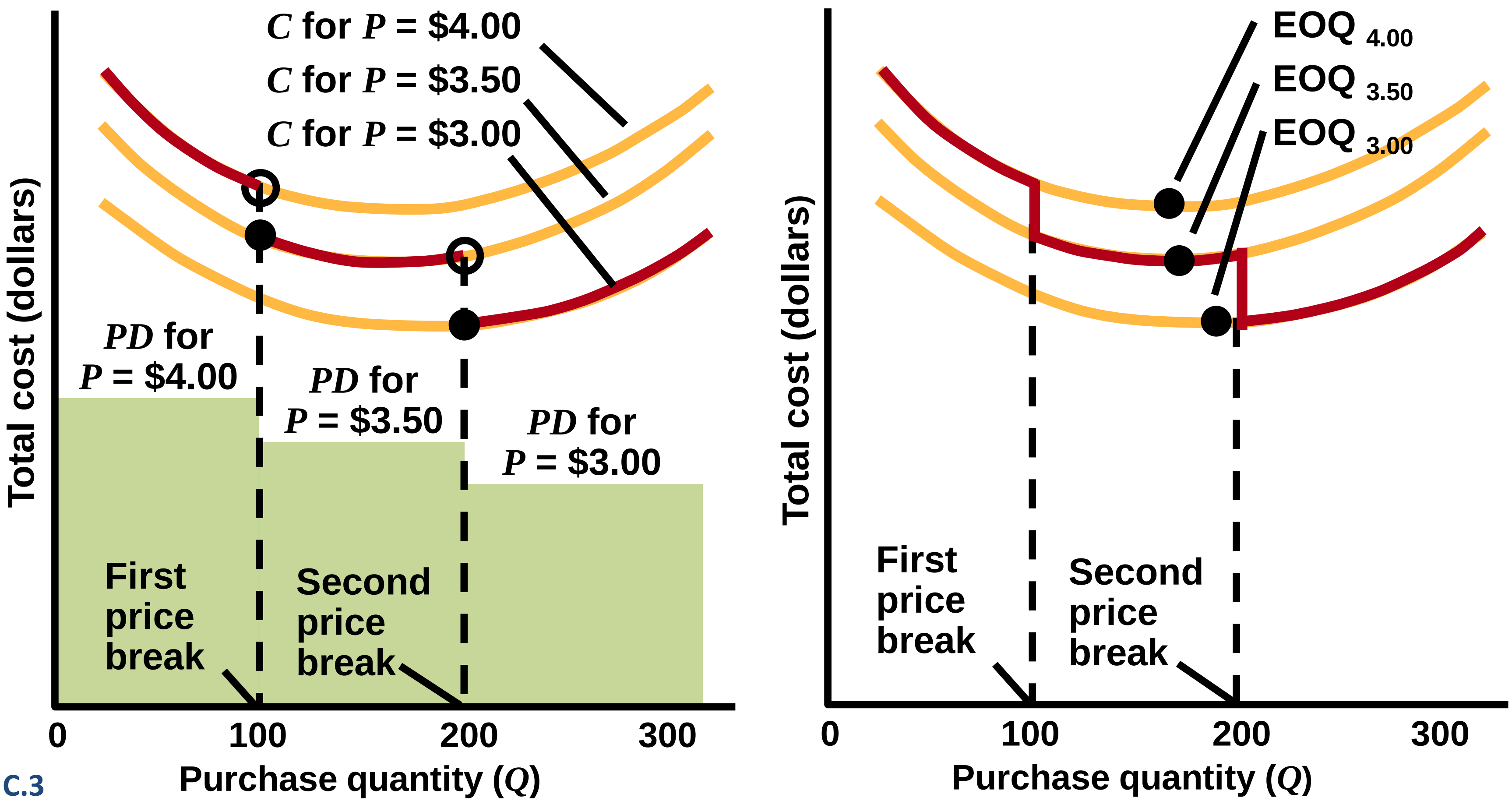


Figure C.3

(a) Total cost curves with purchased materials added

(b) EOQs and price break quantities

Example C.2

A supplier for St. LeRoy Hospital has introduced quantity discounts to encourage larger order quantities of a special catheter. The price schedule is

Order Quantity	Price per Unit
0 to 299	$60.00
300 to 499	$58.80
500 or more	$57.00

The hospital estimates that its annual demand for this item is 936 units, its ordering cost is $45.00 per order, and its annual holding cost is 25 percent of the catheter's unit price. What quantity of this catheter should the hospital order to minimize total costs? Suppose the price for quantities between 300 and 499 is reduced to $58.00. Should the order quantity change?

Example C.2

Step 1: Find the first feasible EOQ, starting with the lowest price level:

$$\text{EOQ}_{57.00} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(936)(\$45.00)}{0.25(\$57.00)}} = 77 \text{ units}$$

A 77-unit order actually costs \$60.00 per unit, instead of the \$57.00 per unit used in the EOQ calculation, so this EOQ is infeasible. Now try the \$58.80 level:

$$\text{EOQ}_{58.80} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(936)(\$45.00)}{0.25(\$58.80)}} = 76 \text{ units}$$

This quantity also is infeasible because a 76-unit order is too small to qualify for the \$58.80 price.

Example C.2

Try the highest price level:

$$\text{EOQ}_{60.00} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(936)(\$45.00)}{0.25(\$60.00)}} = 75 \text{ units}$$

This quantity is feasible because it lies in the range corresponding to its price, P = $60.00

Step 2: The first feasible EOQ of 75 does not correspond to the lowest price level. Hence, we must compare its total cost with the price break quantities (300 and 500 units) at the lower price levels ($58.80 and $57.00):

Example C.2

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) + PD$$

$$C_{75} = \frac{75}{2}\left[(0.25)(\$60.00)\right] + \frac{936}{75}(\$45.00) + \$60.00(936) = \$57,284$$

$$C_{300} = \frac{300}{2}\left[(0.25)(\$58.80)\right] + \frac{936}{300}(\$45.00) + \$58.80(936) = \$57,382$$

$$C_{500} = \frac{500}{2}\left[(0.25)(\$57.00)\right] + \frac{936}{500}(\$45.00) + \$57.00(936) = \$56,999$$

The best purchase quantity is 500 units, which qualifies for the deepest discount.

Example C.2

More	Fewer	

Min. Amount Req'd for Price Point	Lot Sizes	Price/Unit
	0–299	$60.00
300	300–499	$58.00
500	500 or more	$57.00

Annual Demand	936
Order Cost	$45
Holding Cost (% or price)	25%

Best Order Quantity	300

	Price Point	EOQ or Req'd Order for Price Point	Inventory Cost	Order Cost	Purchase Cost	Total Cost	
	$60.00	75	$562.50	$561.60	$56,160	$57,284	
>>	$58.00	300	$2,175	$140.40	$54,288	$56,603	<<
	$57.00	500	$3,563	$84.24	$53,352	$56,999	

Figure C.4

Application C.2

A supplier's price schedule is:

Order Quantity	Price per Unit
0–99	$50
100 or more	$45

If ordering cost is $16 per order, annual holding cost is 20 percent of the purchase price, and annual demand is 1,800 units, what is the best order quantity?

Application C.2

Step 1:

$$EOQ_{45.00} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(1{,}800)(16)}{(45)(0.2)}} = 80 \text{ units (infeasible)}$$

$$EOQ_{50.00} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(1{,}800)(16)}{(50)(0.2)}} = 76 \text{ units (feasible)}$$

Step 2:

$$C_{76} = \frac{76}{2}(50 \cdot 0.2) + \frac{1{,}800}{76}(16) + 50(1{,}800) = \$90{,}759$$

$$C_{100} = \frac{100}{2}(45 \cdot 0.2) + \frac{1{,}800}{100}(16) + 45(1{,}800) = \$81{,}738$$

The best order quantity is 100 units

One-Period Decisions

- Seasonal goods are a dilemma facing many retailers.
- Newsboy problem

Step 1: List the demand levels and probabilities.

Step 2: Develop a payoff table that shows the profit for each purchase quantity, Q, at each assumed demand level, D.

Each row represents a different order quantity and each column represents a different demand.

The payoff depends on whether all units are sold at the regular profit margin which results in two possible cases.

One-Period Decisions

a. If demand is high enough ($Q \leq D$), then all of the units are sold at the full profit margin, p, during the regular season

Payoff = (Profit per unit)(Purchase quantity) = pQ

b. If the purchase quantity exceeds the eventual demand ($Q > D$), only D units are sold at the full profit margin, and the remaining units purchased must be disposed of at a loss, l, after the season

$$\text{Payoff} = \begin{pmatrix}\text{Profit per}\\ \text{unit sold}\\ \text{during}\\ \text{season}\end{pmatrix}(\text{Demand}) - \begin{pmatrix}\text{Loss}\\ \text{per}\\ \text{unit}\end{pmatrix}\begin{pmatrix}\text{Amount}\\ \text{disposed}\\ \text{of after}\\ \text{season}\end{pmatrix}$$

$$= pD - l(Q - D)$$

One-Period Decisions

Step 3: **Calculate the expected payoff of each Q by using the expected value decision rule. For a specific Q, first multiply each payoff by its demand probability, and then add the products.**

Step 4: **Choose the order quantity Q with the highest expected payoff.**

Example C.3

One of many items sold at a museum of natural history is a Christmas ornament carved from wood. The gift shop makes a **$10 profit per unit** sold during the season, but it takes a **$5 loss per unit** after the season is over. The following discrete probability distribution for the season's demand has been identified:

Demand	10	20	30	40	50
Demand Probability	0.2	0.3	0.3	0.1	0.1

How many ornaments should the museum's buyer order?

Example C.3

Each demand level is a candidate for best order quantity, so the payoff table should have five rows. For the first row, where Q = 10, demand is at least as great as the purchase quantity. Thus, all five payoffs in this row are

$$\text{Payoff} = pQ = (\$10)(10) = \$100$$

This formula can be used in other rows but only for those quantity–demand combinations where all units are sold during the season. These combinations lie in the upper-right portion of the payoff table, where $Q \leq D$. For example, the payoff when Q = 40 and D = 50 is

$$\text{Payoff} = pQ = (\$10)(40) = \$400$$

Example C.3

The payoffs in the lower-left portion of the table represent quantity–demand combinations where some units must be disposed of after the season ($Q > D$). For this case, the payoff must be calculated with the second formula. For example, when $Q = 40$ and $D = 30$,

Payoff = $pD - l(Q - D)$ = (\$10)(30) – (\$5)(40 – 30) = **\$250**

Now we calculate the expected payoff for each Q by multiplying the payoff for each demand quantity by the probability of that demand and then adding the results. For example, for $Q = 30$,

Payoff = 0.2(\$0) + 0.3(\$150) + 0.3(\$300) + 0.1(\$300) + 0.1(\$300)
= **\$195**

Example C.3

Profit	$10.00	(if sold during preferred period)
Loss	$5.00	(if sold after preferred period)

Enter the possible demands along with the probability of each occurring. Use the buttons to increase or decrease the number of allowable demand forecasts. NOTE: Be sure to enter demand forecasts and probabilities in all tinted cells, and be sure probabilities add up to 1.

< >

Demand	10	20	30	40	50
Profitability	0.2	0.3	0.3	0.1	0.1

Payoff Table

		Demand				
		10	20	30	40	50
Quantity	10	100	100	100	100	100
	20	50	200	200	200	200
	30	0	150	300	300	300
	40	–50	100	250	400	400
	50	–100	50	200	350	500

Figure C.5

Example C.3

Weighted Payoffs

Order Quantity	Expected Payoff
10	100
20	170
30	195
40	175
50	140

Greatest Expected Payoff	195
Associated with Order Quantity	30

Figure C.6

Application C.3

Swell Productions is sponsoring an outdoor conclave for owners of collectible and classic Fords. The concession stand in the T-Bird area will sell clothing such as T-shirts and official Thunderbird racing jerseys. Jerseys are purchased from Columbia Products for **$40 each** and are sold during the event for **$75 each**. If any jerseys are left over, they can be returned to Columbia for a refund of **$30 each**. Jersey sales depend on the weather, attendance, and other variables. The following table shows the probability of various sales quantities. How many jerseys should Swell Productions order from Columbia for this one-time event?

Sales Quantity	Probability	Quantity Sales	Probability
100	0.05	400	0.34
200	0.11	500	0.11
300	0.34	600	0.05

Application C.3

PAYOFFS							
	Demand, *D*						
Q	100	200	300	400	500	600	Expected Payoff
100							
200							
300							
400							
500							
600							

Application C.3

Payoff = $(p - c)Q$ = ($75 - $40)100 = $3,500 for Q = 100 and $D \geq 100$

PAYOFFS							
	Demand, *D*						
Q	100	200	300	400	500	600	Expected Payoff
100	$3,500	$3,500	$3,500	$3,500	$3,500	$3,500	$3,500
200	$2,500	$7,000	$7,000	$7,000	$7,000	$7,000	$6,775
300	$1,500	$6,000	$10,500	$10,500	$10,500	$10,500	$9,555
400	$500	$5,000	$9,500	$14,000	$14,000	$14,000	$10,805
500	($500)	$4,000	$8,500	$13,000	$17,500	$17,500	$10,525
600	($1,500)	$3,000	$7,500	$12,000	$16,500	$21,000	$9,750

Application C.3

When the order quantity is 500 and the demand is 200,

Payoff = $pD - l(Q - D)$ **=**

(\$75 - \$40)200 – (\$40 – \$30)(500 – 200)

= \$4,000

The highest expected payoff occurs when 400 jerseys are ordered:

Expected payoff$_{400}$ **=**

(\$500 × 0.05) + (\$5,000 × 0.11)
+ (\$9,500 × 0.34) + (\$14,000 × 0.34)
+ (\$14,000 × 0.11) + (\$14,000 × 0.05)

= \$10,805

Solved Problem 1

Peachy Keen, Inc., makes mohair sweaters, blouses with Peter Pan collars, pedal pushers, poodle skirts, and other popular clothing styles of the 1950s. The average demand for mohair sweaters is 100 per week. Peachy's production facility has the capacity to sew 400 sweaters per week. Setup cost is $351. The value of finished goods inventory is $40 per sweater. The annual per-unit inventory holding cost is 20 percent of the item's value.

a. What is the economic production lot size (ELS)?
b. What is the average time between orders (TBO)?
c. What is the total of the annual holding cost and setup cost?

Solved Problem 1

a. The production lot size that minimizes total cost is

$$\text{ELS} = \sqrt{\frac{2DS}{H}}\sqrt{\frac{p}{p-d}} = \sqrt{\frac{2(100 \times 52)(\$351)}{0.20(\$40)}}\sqrt{\frac{400}{400-100}}$$

$$= \sqrt{456{,}300}\sqrt{\frac{4}{3}} = 780 \text{ sweaters}$$

b. The average time between orders is

$$\text{TBO}_{\text{ELS}} = \frac{\text{ELS}}{D} = \frac{780}{5{,}200} = 0.15 \text{ year}$$

Converting to weeks, we get

$$\text{TBO}_{\text{ELS}} = (0.15 \text{ year})(52 \text{ weeks/year}) = 7.8 \text{ weeks}$$

Solved Problem 1

c. The minimum total of setup and holding costs is

$$C = \frac{Q}{2}\left(\frac{p-d}{p}\right)(H) + \frac{D}{Q}(S)$$

$$= \frac{780}{2}\left(\frac{400-100}{400}\right)(0.20 \times \$40) + \frac{5,200}{780}(\$351)$$

$$= \$2,340/\text{year} + \$2,340/\text{year} = \$4,680/\text{year}$$

Solved Problem 2

This solution is **infeasible** because, according to the price schedule, we cannot purchase 80 packages at a price of \$49.00 each. Therefore, we calculate the EOQ at the next lowest price (\$50.25):

$$\text{EOQ}_{50.25} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(490)(\$64.00)}{0.20(\$50.25)}} = \sqrt{6,241} = 79 \text{ packages}$$

- This EOQ is **feasible**, but \$50.25 per package is not the lowest price.
- Determine whether total costs can be reduced by purchasing 200 units and thereby obtaining a quantity discount.

Solved Problem 2

A hospital buys disposable surgical packages from Pfisher, Inc. Pfisher's price schedule is **$50.25 per package** on orders of 1 to 199 packages and **$49.00 per package** on orders of 200 or more packages. Ordering cost is **$64 per order**, and annual holding cost is **20 percent of the per unit purchase price**. Annual demand is **490 packages**. What is the best purchase quantity?

We first calculate the EOQ at the lowest price:

$$\text{EOQ}_{49.00} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(490)(\$64.00)}{0.20(\$49.00)}} = \sqrt{6,400} = 80 \text{ packages}$$

Solved Problem 2

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) + PD$$

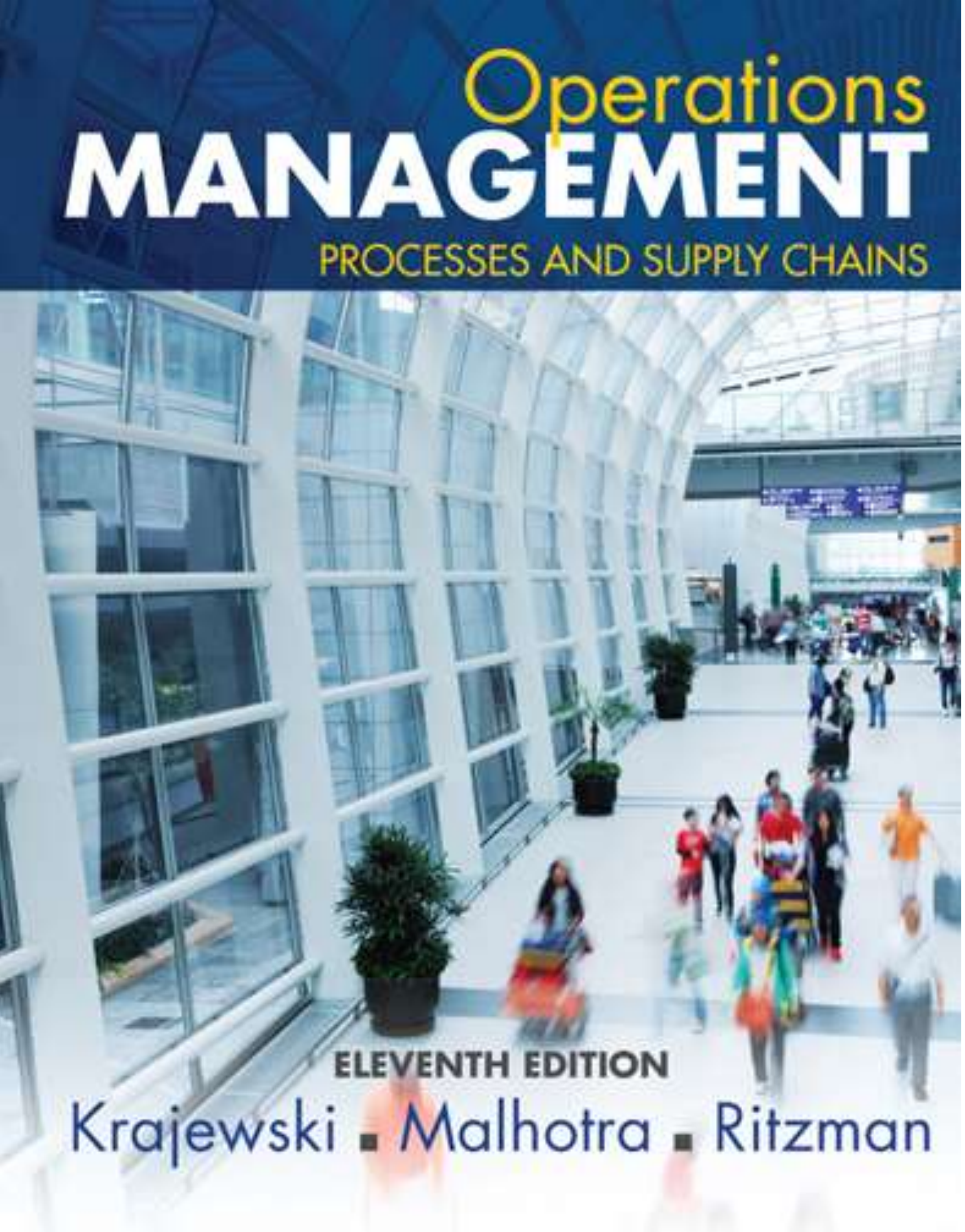
$$C_{79} = \frac{79}{2}(0.20 \times \$50.25) + \frac{490}{79}(\$64.00) + \$50.25(490)$$

$$= \$396.98/\text{year} + \$396.68/\text{year} + \$24{,}622.50 = \$25{,}416.44/\text{year}$$

$$C_{200} = \frac{200}{2}(0.20 \times \$49.00) + \frac{490}{200}(\$64.00) + \$49.00(490)$$

$$= \$980.00/\text{year} + \$156.80/\text{year} + \$24{,}010.00 = \$25{,}146.80/\text{year}$$

Purchasing 200 units per order will save \$269.64/year, compared to buying 79 units at a time.



Lean Systems

Chapter 6

What is a Lean System?

Lean Systems

Operations systems that maximize the value added by each of a company's activities by removing waste and delays from them.

Continuous Improvement Using a Lean Systems Approach

- **Just-in-time (JIT) philosophy**
  - **The belief that waste can be eliminated by cutting unnecessary capacity or inventory and removing non-value-added activities in operations.**

Eight Types of Waste or Muda

1. Overproduction
2. Inappropriate Processing
3. Waiting
4. Transportation
5. Motion
6. Inventory
7. Defects
8. Underutilization of Employees

Table 6.1

Continuous Improvement with Lean Systems

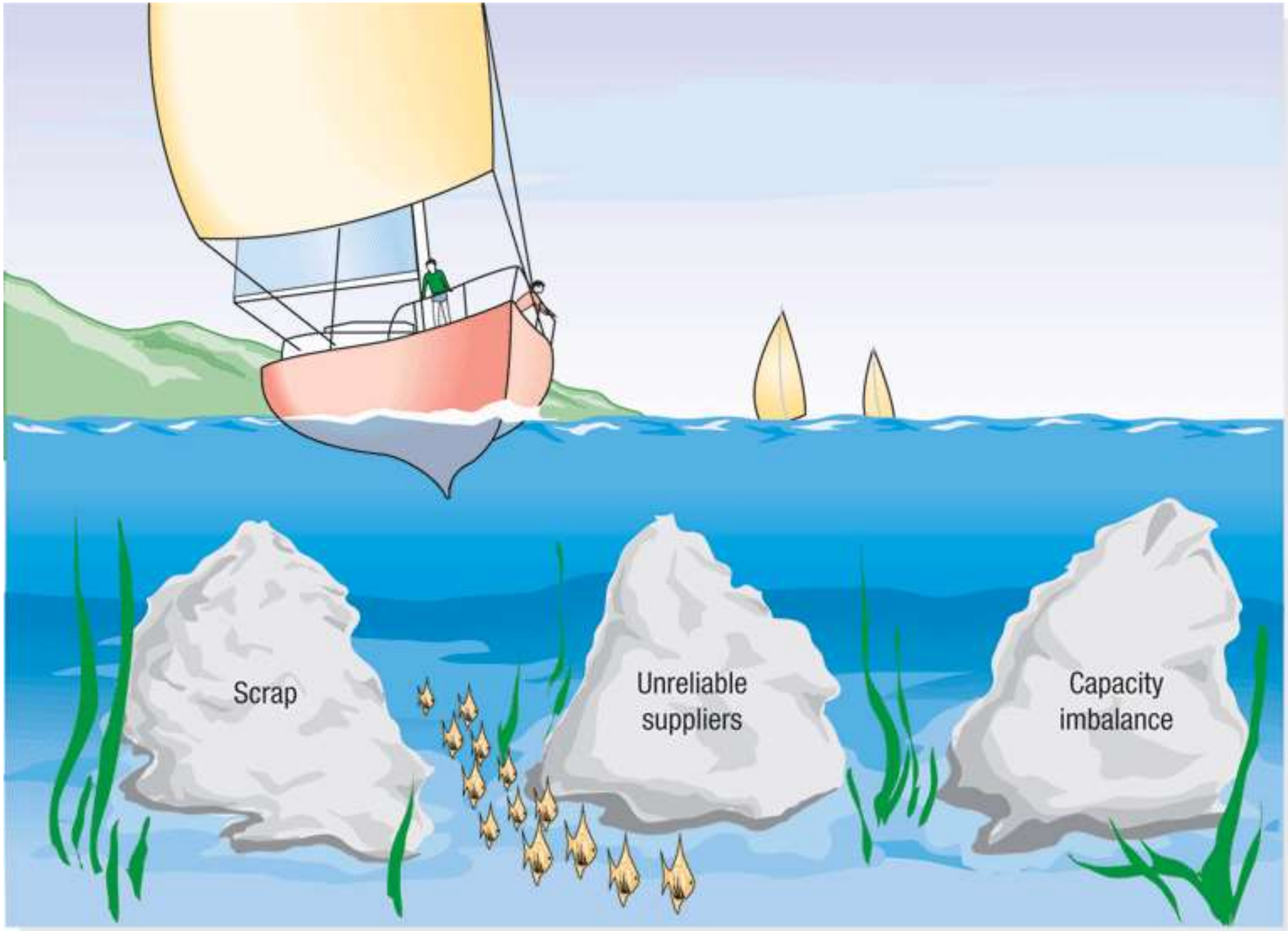


Figure 6.1

Supply Chain Considerations in Lean Systems

- **Close Supplier Ties**

- **Small Lot Sizes**
  - **Single-digit setup**

Process Considerations in Lean Systems

Pull Method of Workflow (LEAN)

A method in which customer demand activates the production of the service or item.

Push Method of Workflow (NOT LEAN)

A method in which production of the item begins in advance of customer needs.

Process Considerations in Lean Systems

- **Quality at the Source**
  - **Jidoka**
    - Automatically stopping the process when something is wrong and then fixing the problems on the line itself as they occur.
  - **Poka-Yoke**
    - Mistake-proofing methods aimed at designing fail-safe systems that minimize human error.

Process Considerations in Lean Systems

- Uniform Workstation Loads
  - Takt time
  - Heijunka
  - Mixed-model assembly
- Standardized Components and Work Methods

Process Considerations in Lean Systems

- Flexible Workforce
- Automation
- 5S
- Total Preventative Maintenance

5S

5S Term	Definition
1. Sort	Separate needed items from unneeded items (including tools, parts, materials, and paperwork), and discard the unneeded.
2. Straighten	Neatly arrange what is left, with a place for everything and everything in its place. Organize the work area so that it is easy to find what is needed.
3. Shine	Clean and wash the work area and make it shine.
4. Standardize	Establish schedules and methods of performing the cleaning and sorting. Formalize the cleanliness that results from regularly doing the first three S practices so that perpetual cleanliness and a state of readiness are maintained.
5. Sustain	Create discipline to perform the first four S practices, whereby everyone understands, obeys, and practices the rules when in the plant. Implement mechanisms to sustain the gains by involving people and recognizing them through a performance measurement system.

Table 6.2

Toyota Production System

- All work must be completely specified as to content, sequence, timing, and outcome.
- All customer-supplier connections should be direct and unambiguous.
- All pathways should be simple and direct.
- All improvements should be made under the guidance of a teacher using the scientific method.

House of Toyota

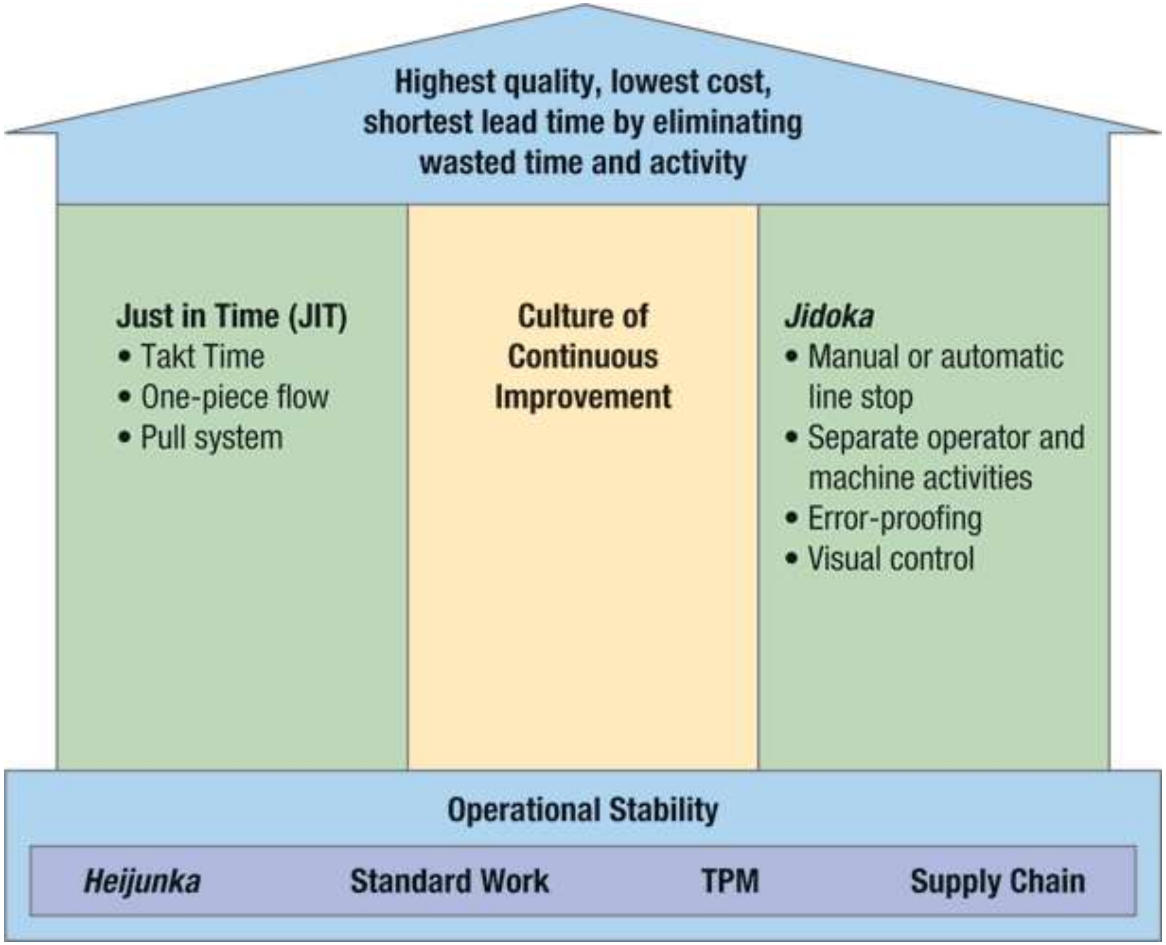


Figure 6.3

One-Worker, Multiple Machines

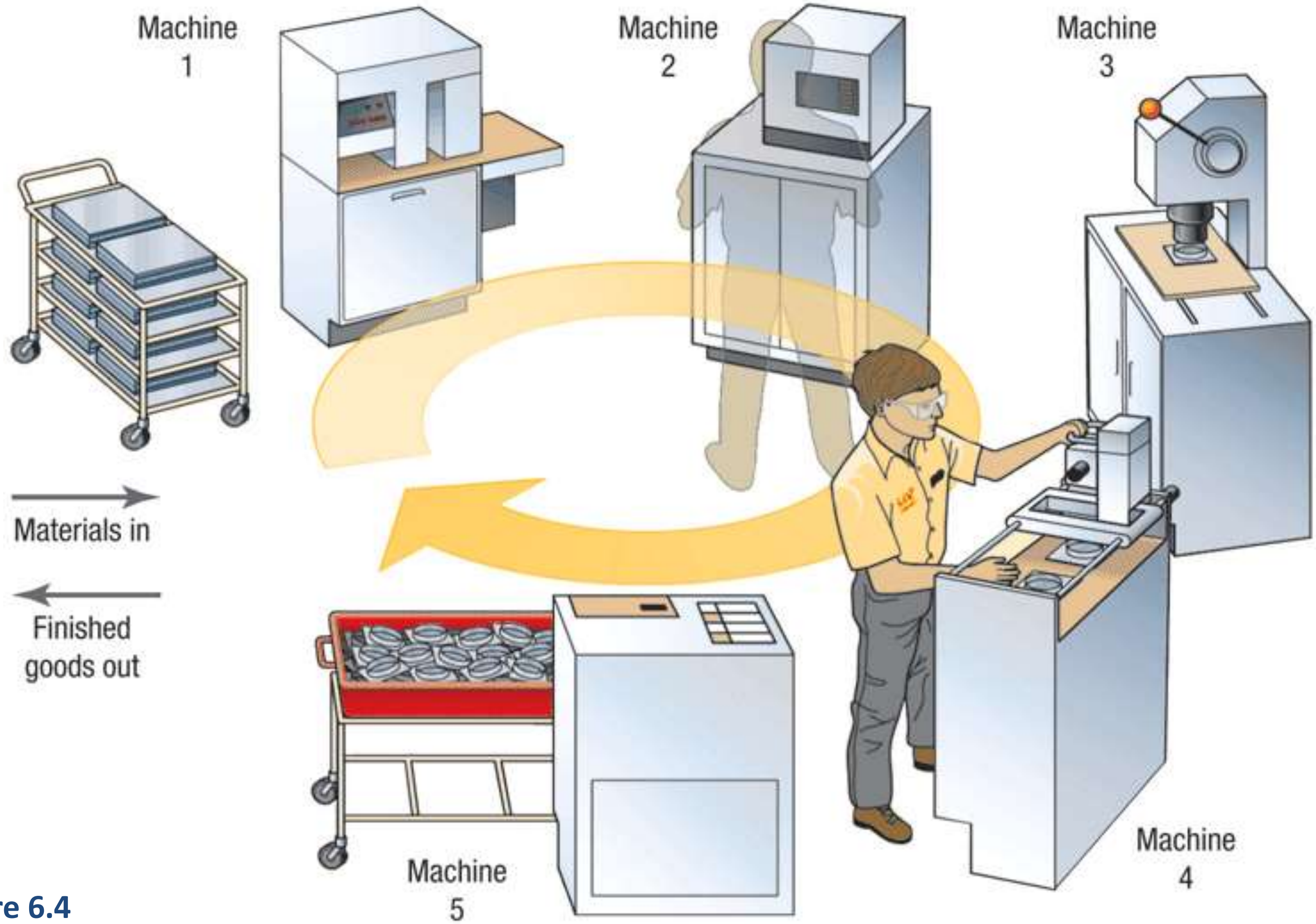
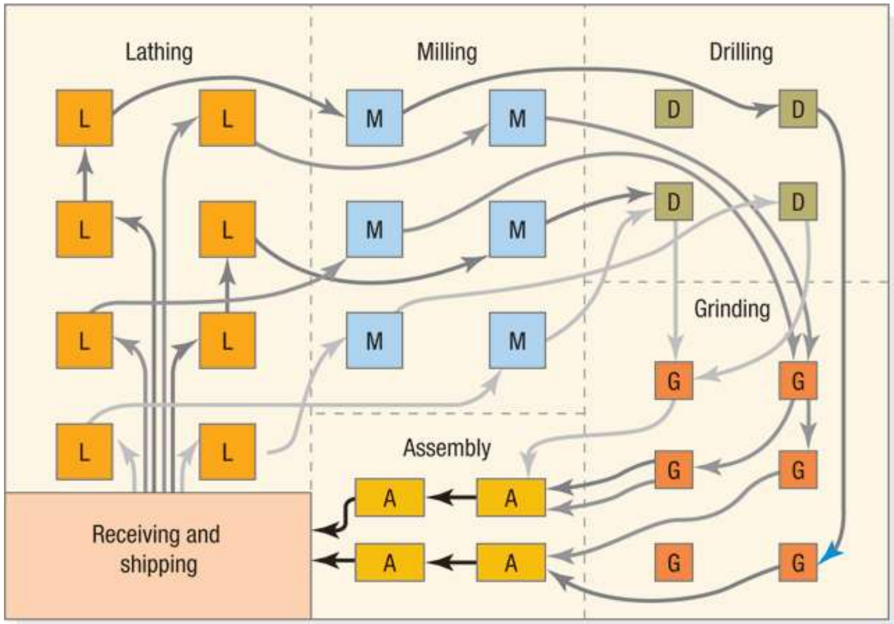


Figure 6.4

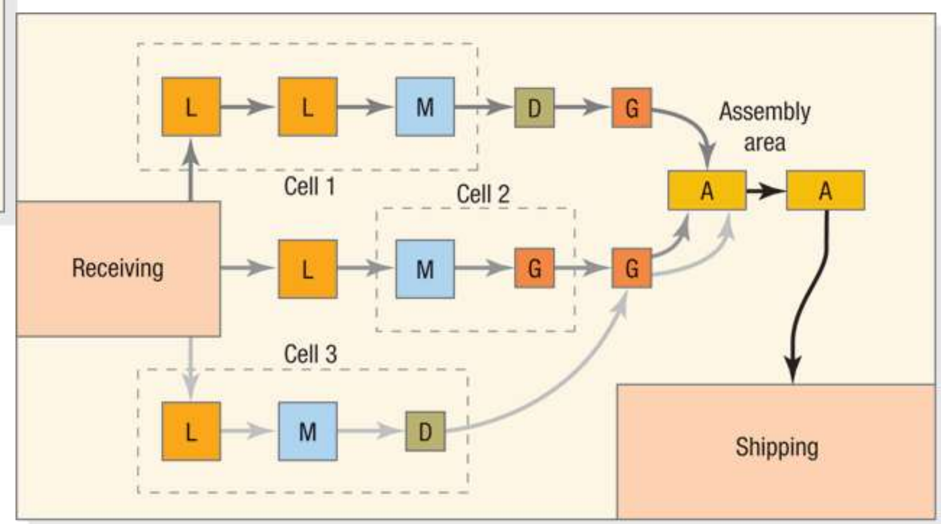
Group Technology



(a) Jumbled flows in a job shop without GT cells

Jumbled Flows without GT

Lines Flows with 3 GT cells



(b) Line flows in a job shop with three GT cells

Figure 6.5

What is a Value Stream Mapping?

Value Stream Mapping

A widely used qualitative lean tool aimed at eliminating waste or *muda.*

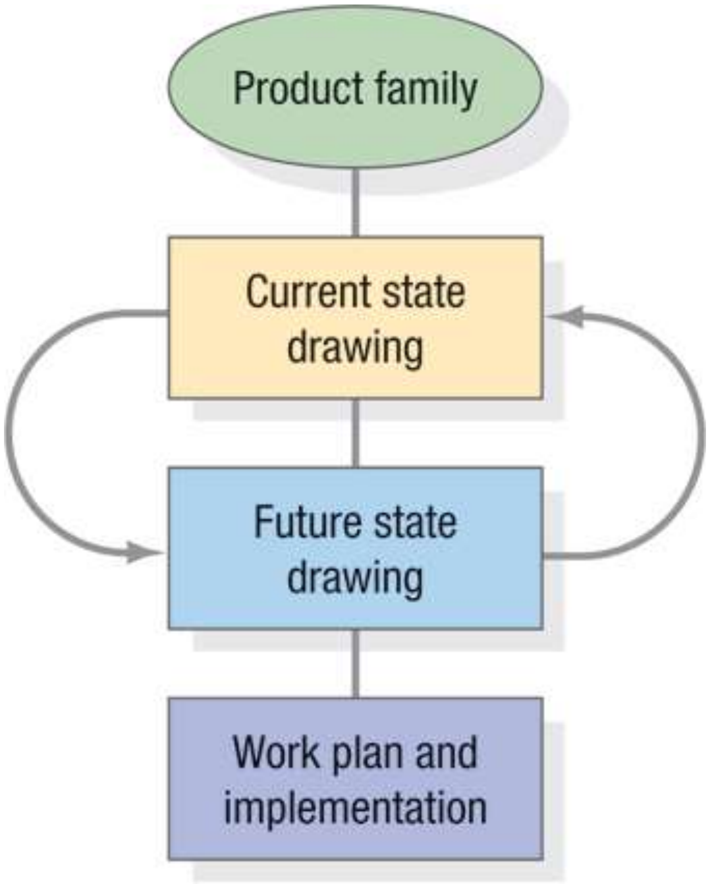


Figure 6.6

VSM Icons

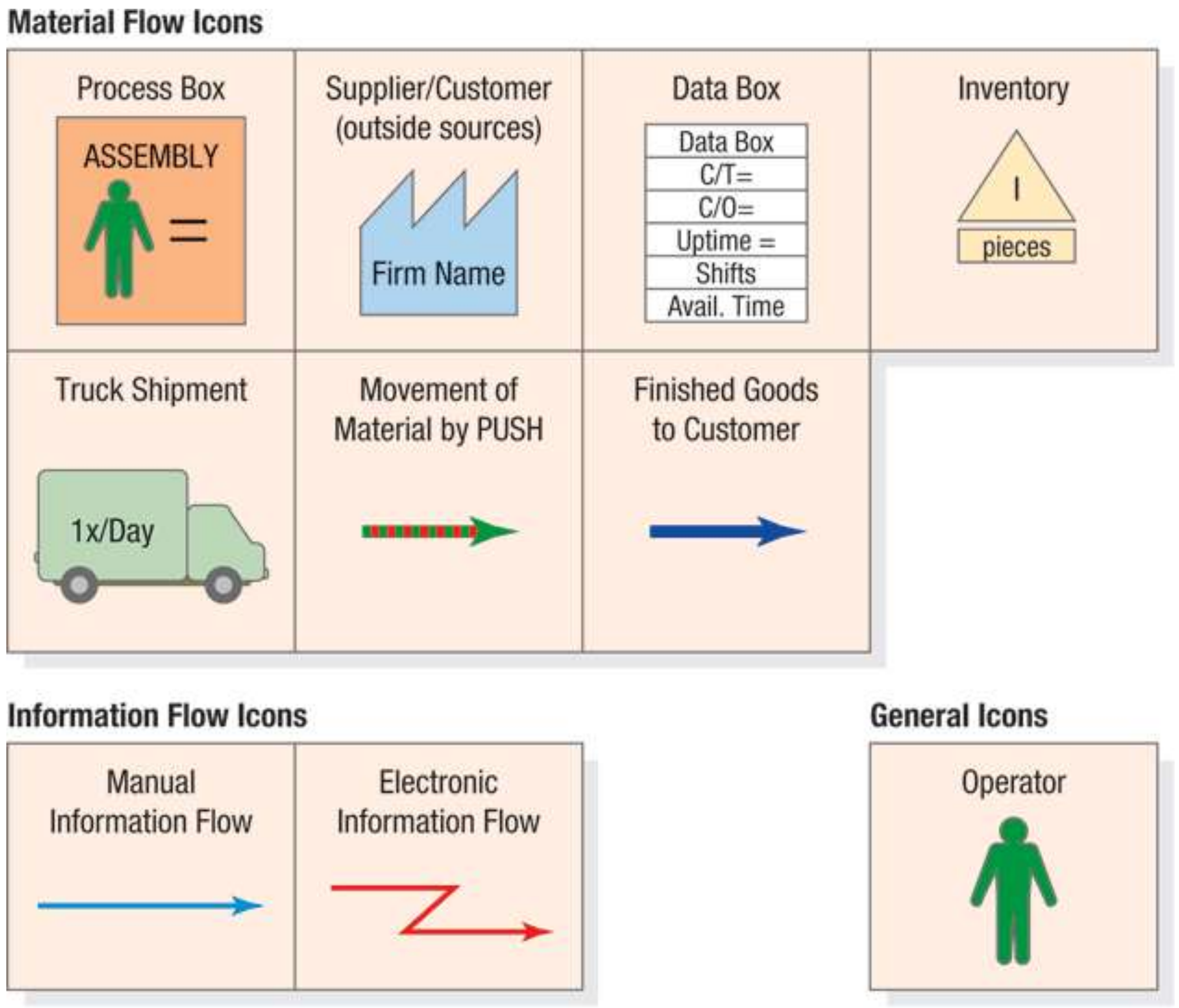


Figure 6.7

VSM Metrics

- Takt Time
  - Daily Availability/Daily Demand
- Cycle Time
- Setup Time
- Per Unit Processing Time
  - Cycle Time + Setup Time
- Capacity
  - Availability/Time at bottleneck

Example 6.1

- Jensen Bearings, Inc makes two types of retainers that are packaged and shipped in returnable trays with 40 retainers in each tray. The operations data is on the following slides.

  a. Create a VSM for Jensen Bearings
  b. What is the takt time?
  c. What is the lead time at each cell?
  d. What is the total processing time?
  e. What is the capacity?

Example 6.1

Overall Process Attributes	Average demand: 3,200/week (1,000 “L”; 2,200 “S”) Batch size: 40 Number of shifts per day: 1 Availability: 8 hours per shift with two 30-minute lunch breaks	
Process Step 1	Press	Cycle time = 12 seconds Setup time = 10 min Up time = 100% Operators = 1 WIP = 5 days of sheets (Before Press)
Process Step 2	Pierce & Form	Cycle time = 34 seconds Setup time = 3 minutes Up time = 100% Operators = 1 WIP = 1,000 “L,” 1,250 “S” (Before Pierce & Form)
Process Step 3	Finish Grind	Cycle time = 35 seconds Setup time = 0 minutes Up time = 100% Operators = 1 WIP = 1,050 “L,” 2,300 “S” (Before Finish Grind)
Process Step 4	Shipping	WIP = 500 “L,” 975 “S” (After Finish Grind)

Table 6.3

Example 6.1

Overall Process Attributes	**Average demand: 3,200/week (1,000 "L"; 2,200 "S")** **Batch size: 40** **Number of shifts per day: 1** **Availability: 8 hours per shift with two 30-minute lunch breaks**
Customer Shipments	One shipment of 3,200 units each week in trays of 40 pieces
Information Flow	All communications from customer are electronic: 180/90/60/30/day Forecasts Daily Order All communications to supplier are electronic 4-Week Forecast Weekly Fax There is a weekly schedule manually delivered to Press, Pierce & Form, and Finish Grind and a Daily Ship Schedule manually delivered to Shipping All material is pushed

Table 6.3

Example 6.1

a.

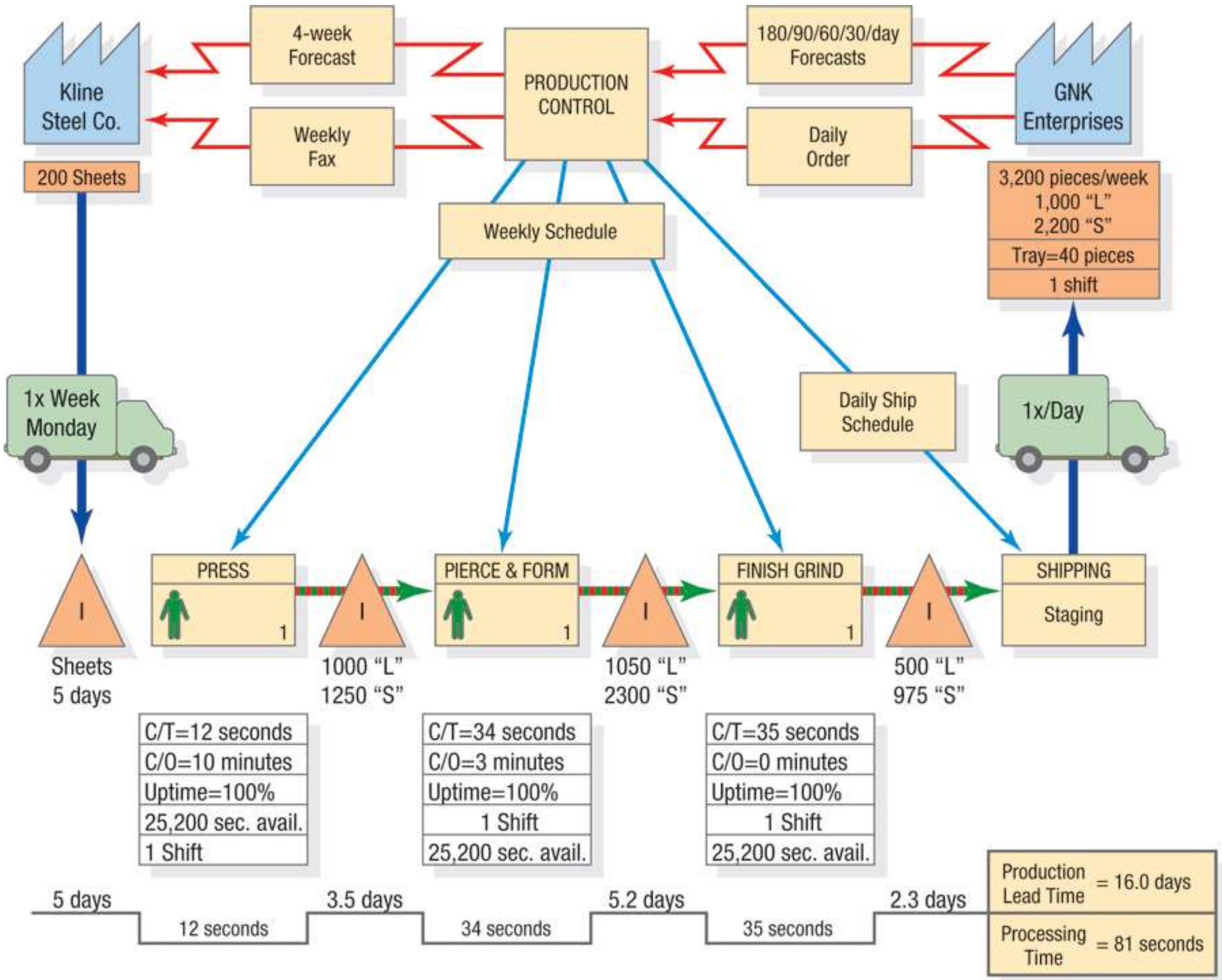


Figure 6.8

Example 6.1

b. Daily Demand

[(1,000 + 2,200) pieces /week]/5 days =

640 pieces per day

Daily Availability

(7 hours/day) x (3,600 seconds per hour) =

25,200 seconds per day

Takt Time = Daily availability/Daily Demand =

25,200/640 =

39.375 seconds per piece

Example 6.1

c. Production Lead time = Inventory/Daily Demand

Raw Material Lead Time - 5 days

WIP between Press and Pierce/Form =
(2,250/640) = 3.5 days

WIP between Pierce/Form and Finish/Grind =
(3,350/640) = 5.2 days

WIP between Finish/Grind and Shipping=
(1,475/640) = 2.3 days

Total Production Lead Time =
(5 + 3.5 + 5.2 + 2.3) = 16 days

d. Total Processing Time = Sum of the Cycle Times
(12 + 34 + 35) = 81 seconds

Example 6.1

e.

Capacity at Press	Capacity at Pierce & Form	Capacity at Finish Grind
Cycle time = 12 seconds	Cycle time = 34 seconds	Cycle time = 35 seconds
Setup Time = (10 min * 60 seconds per min)/40 units per batch = **15.0 seconds**	Setup Time = (3 minutes * 60 seconds per minute)/40 units per batch = **4.5 seconds**	Setup Time = (0 minutes * 60 seconds per minute)/40 units per batch = **0.0 seconds**
Per Unit Processing Time = (12 + 15) = **27 seconds**	Per Unit Processing Time = (34 + 4.5) = **38.5 seconds**	Per Unit Processing Time = (35 + 0.0) = **35.0 seconds**

Pierce and Form is the bottleneck

Capacity = 25,200/38.5 = 654 units/day

Application 6.1

- **Gilman Inc. makes vending machines. The operations data is on the following slides.**

a. What is the cell's current inventory level?

b. What is the takt time?

c. What is the lead time at each cell?

d. What is the total processing time?

e. What is the capacity?

Application 6.1

Overall Process Attributes	**Average demand: 200/day** **Batch size: 20** **Number of shifts per day: 2** **Availability: 8 hours per shift with a 45-minute break**

Customer Shipments	**One shipment of 1,000 units each week**
Information Flow	**All communications with the customer are electronic** **There is a weekly order release to Cutting** **All material is pushed**

Application 6.1

Processing Step 1	Cut	Cycle time = 160 seconds Setup time = 3 minutes Up time = 100% Operators = 1 WIP = 600 units (Before Cut)
Processing Step 2	Grind	Cycle time = 120 seconds Setup time = 1 minute Up time = 99% Operators = 1 WIP = 800 units (Before Grind)
Processing Step 3	Bend	Cycle time = 240 seconds Setup time = none Up time = 100% Operators = 1 WIP = 400 units (Before Bend) WIP = 600 units (After Bend)

Application 6.1

a. Current Inventory Level
(600 + 800 + 400 + 600) = **2400 units**

b. Daily Demand

200 units per day

Daily Availability
(8 hours/day x 60 min) – 45 minutes = 435 min
435 min x 2 shifts/day=
870 minutes per day

Takt Time = Daily availability/Daily Demand = 870/200 =
4.35 minutes per unit

Application 6.1

c. Production Lead time = Inventory/Daily Demand

Raw Material Lead Time - (600/200) = 3 days

WIP between Cut and Grind =
(800/200)= 4 days

WIP between Grind and Bend =
(400/200) = 2 days

Finished Goods Lead Time after Bend =
(600/200) = 3 days

Total Production Lead Time = (3 + 4 + 2 + 3) = 12 days

Application 6.1

d. Total Processing Time = Sum of the Cycle Times

(160 + 120 + 240) = 520 seconds

e. Bending is the bottleneck

Availability at Bending = 870 min/day

Time at bottleneck = (240 + 0)/240 sec/unit = 4 min/unit

Capacity = 870/4 = 217.5 units/day

What is a Kanban?

Kanban

A Japanese word meaning “card” or “visible record” that refers to cards used to control the flow of production through a factory

The Kanban System

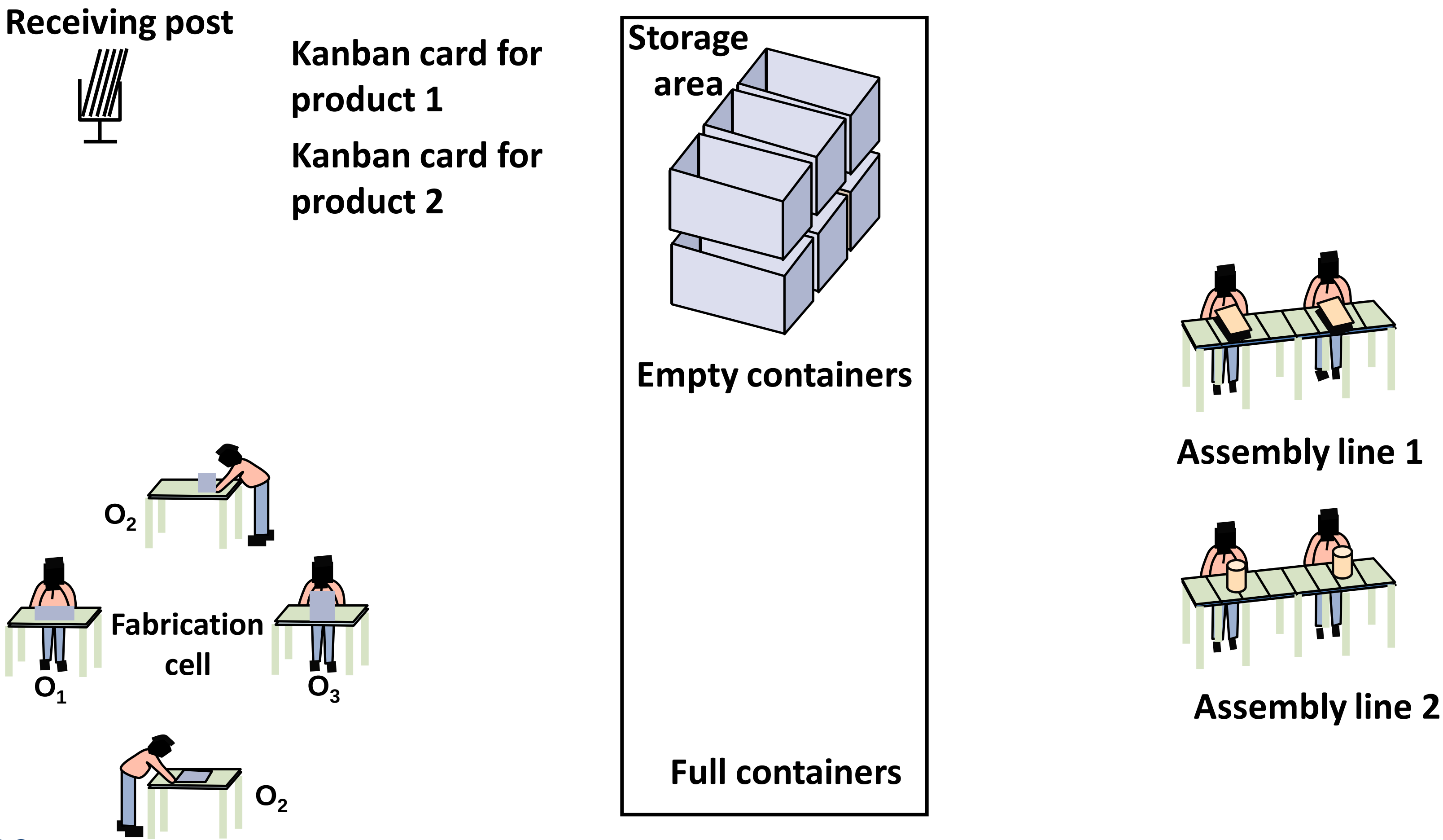


Figure 6.9

The Kanban System

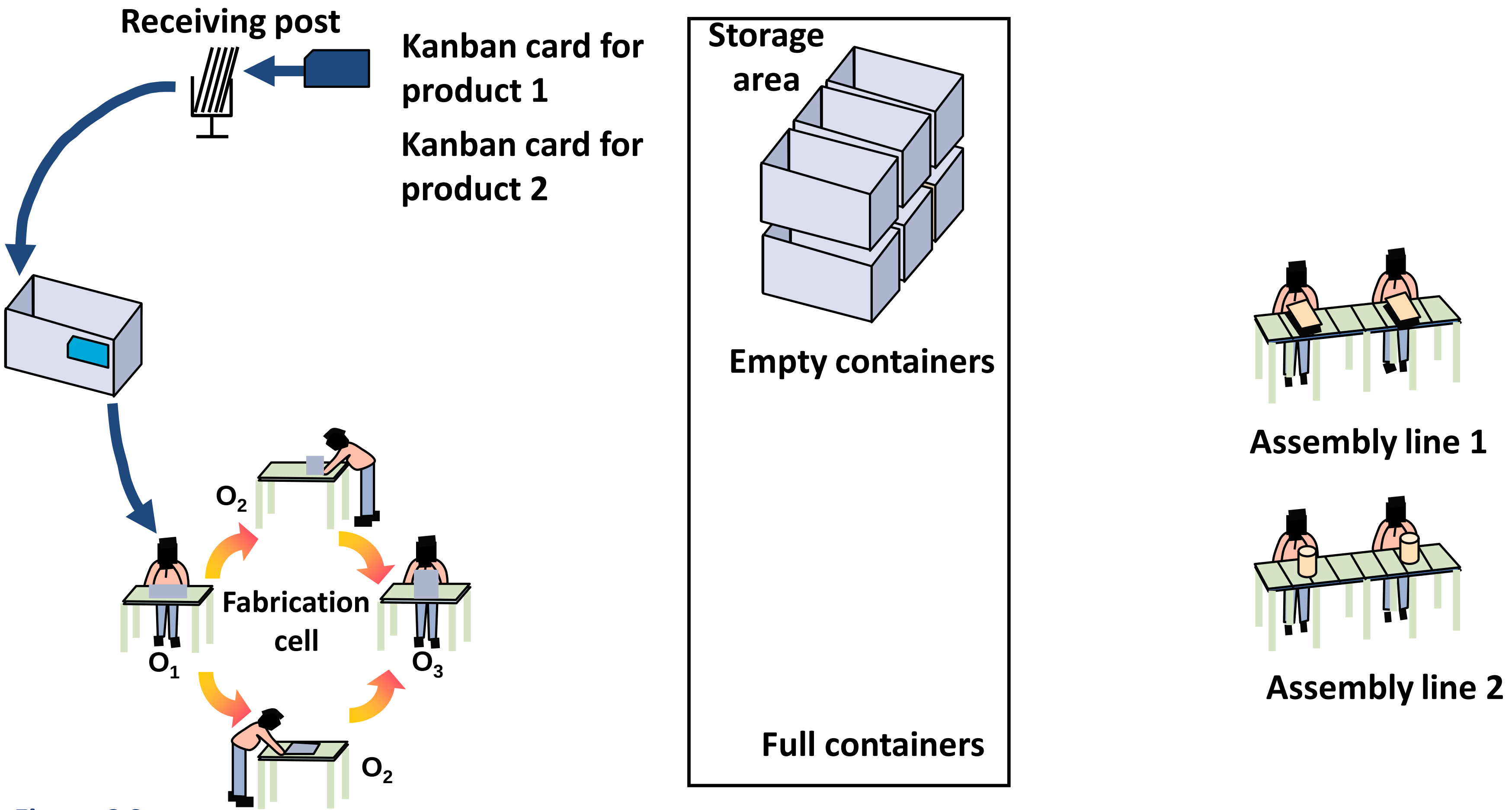


Figure 6.9

The Kanban System

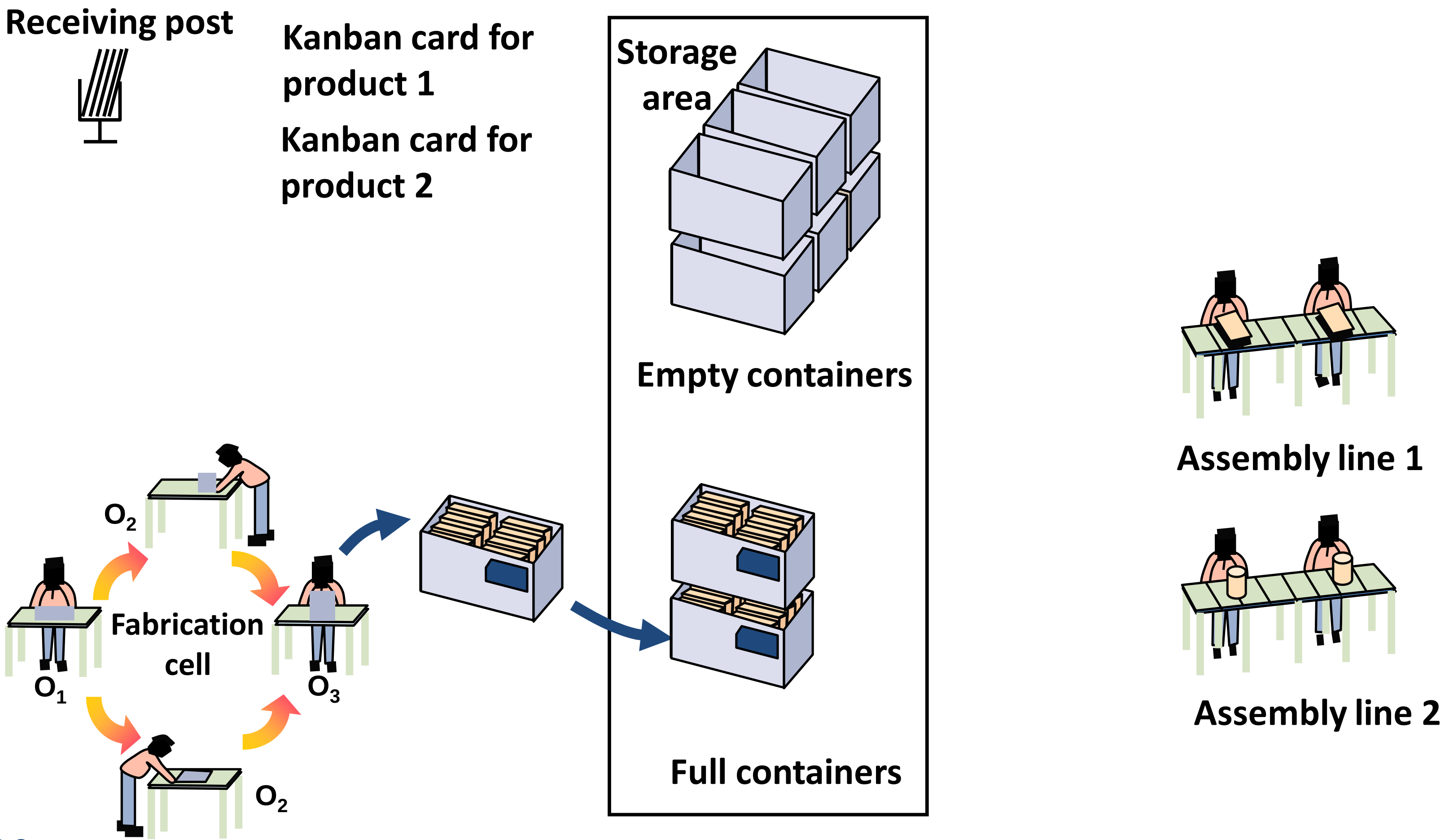


Figure 6.9

The Kanban System

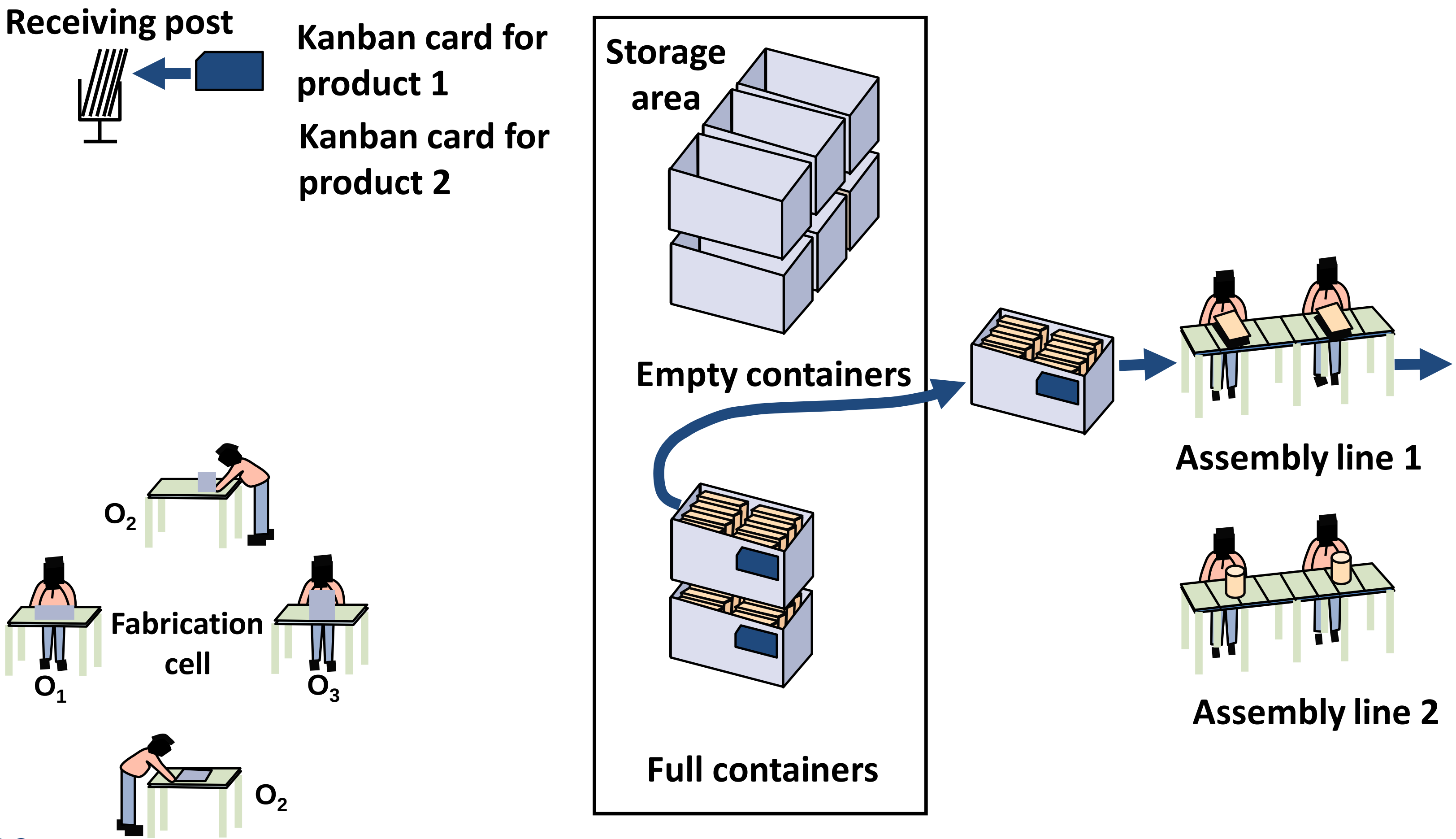


Figure 6.9

The Kanban System

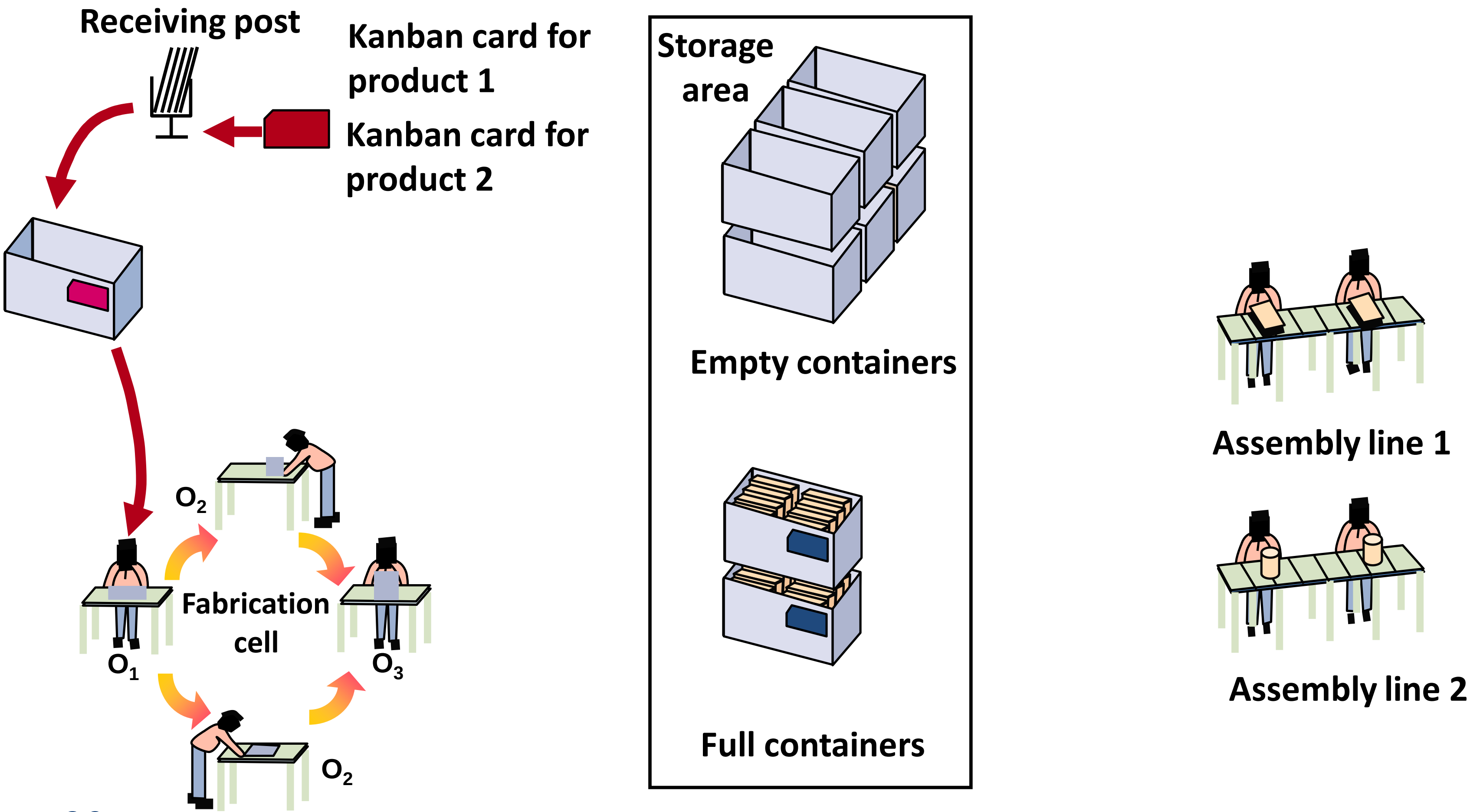


Figure 6.9

The Kanban System

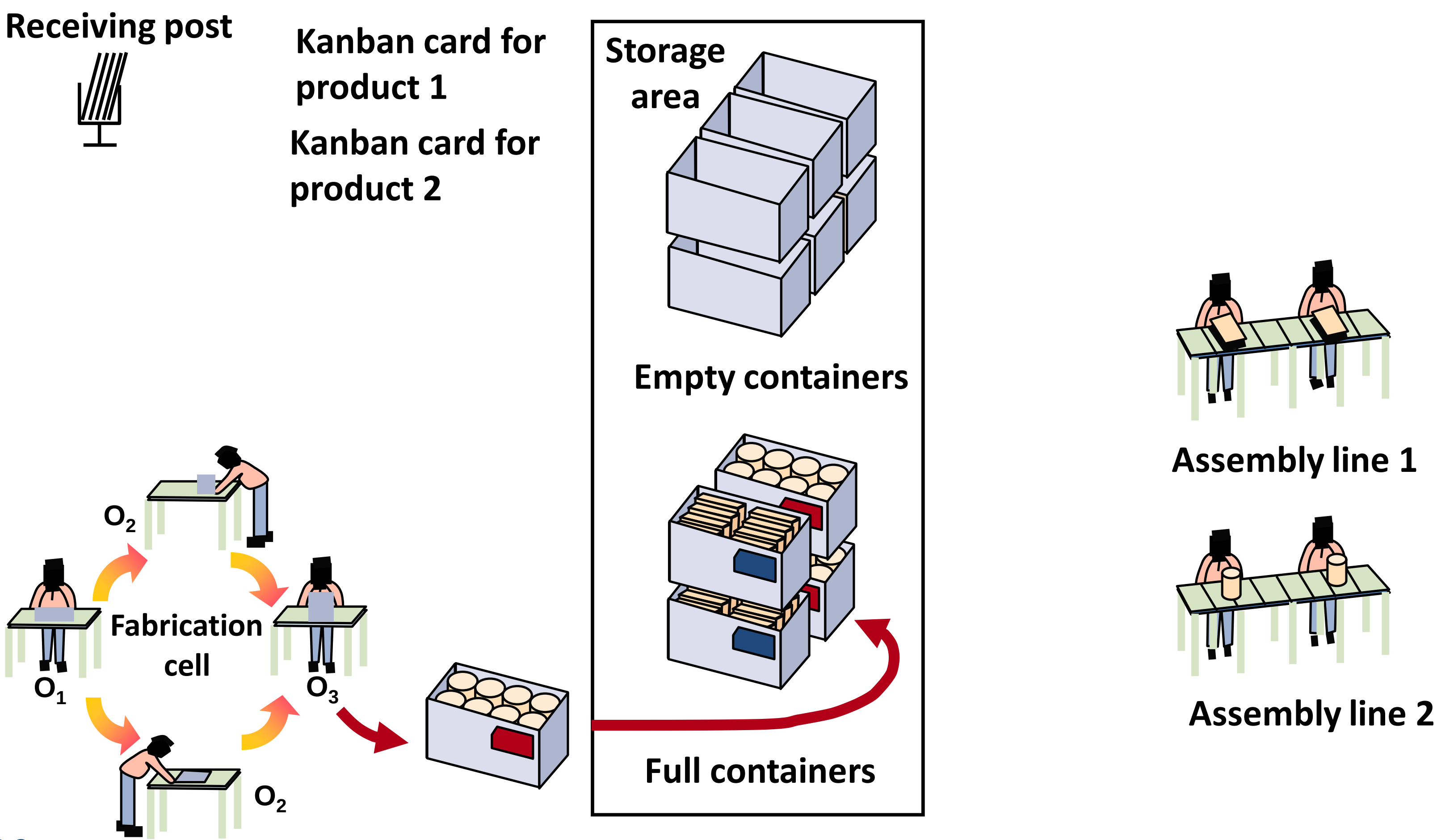


Figure 6.9

The Kanban System

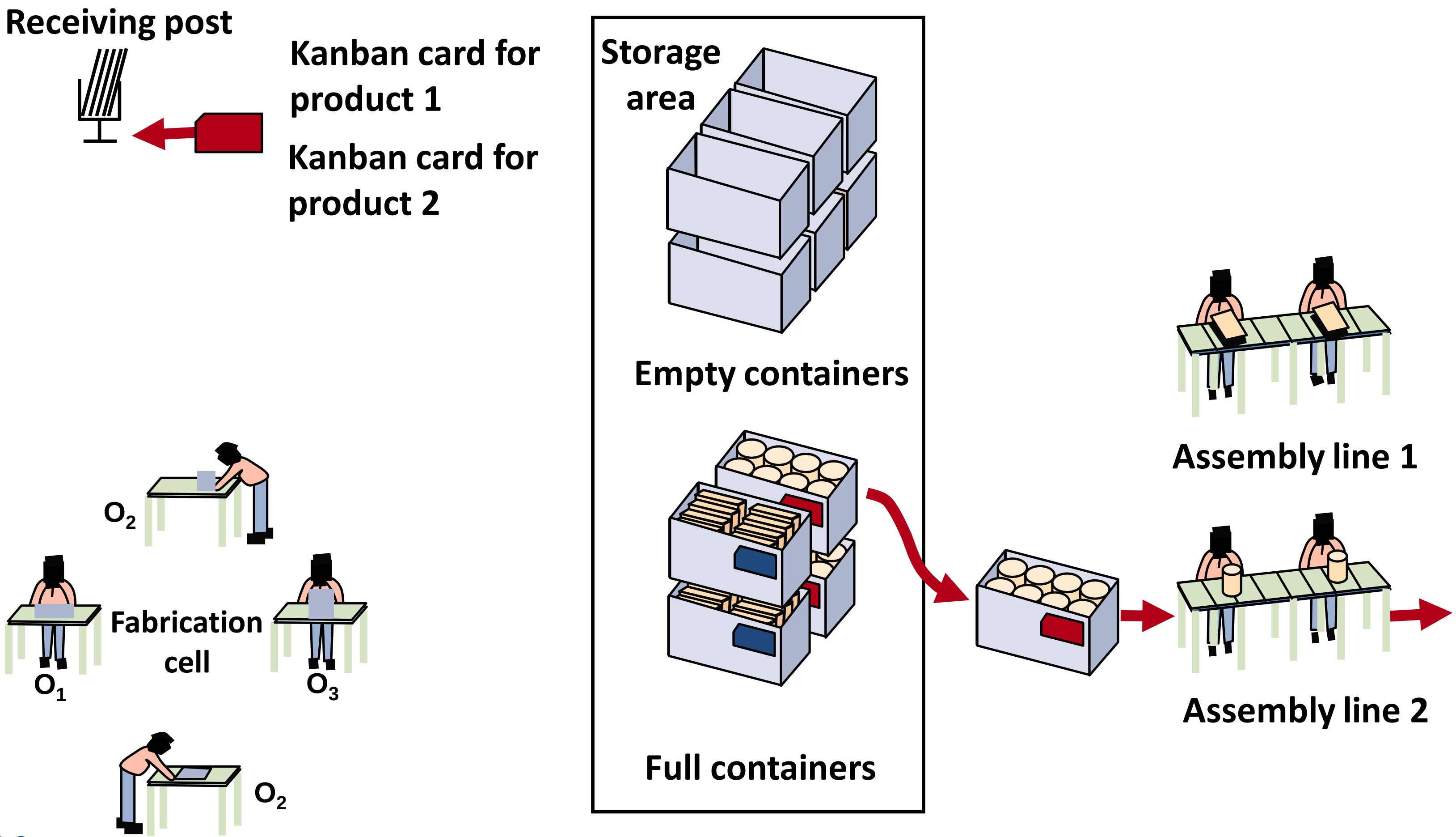


Figure 6.9

General Operating Rules

1. Each container must have a card.
2. Assembly always withdraws from fabrication (pull system).
3. Containers cannot be moved without a kanban.
4. Containers should contain the same number of parts.
5. Only good parts are passed along.
6. Production should not exceed authorization.

Determining the Number of Containers

- Two determinations
  - Number of units to be held by each container
  - Number of containers
  - Little's Law
    - Average work-in-process inventory equals the average demand rate multiplied by the average time a unit spends in the manufacturing process

Determining the Number of Containers

Work in Process (WIP) =
(average demand rate) × (average time a container spends in the manufacturing process) + safety stock

WIP = *kc*

$$kc = \bar{d}(\bar{w} + \bar{p})(1 + \alpha)$$

$$k = \frac{\bar{d}(\bar{w} + \bar{p})(1 + \alpha)}{c}$$

where

- k = number of containers
- $\bar{d}$ = expected daily demand for the part
- $\bar{w}$ = average waiting time
- $\bar{p}$ = average processing time
- c = number of units in each container
- α = policy variable

Example 6.2

- The Westerville Auto Parts Company produces rocker-arm assemblies
- A container of parts spends 0.02 day in processing and 0.08 day in materials handling and waiting
- Daily demand for the part is 2,000 units
- Safety stock equivalent of 10 percent of inventory

a. If each container contains 22 parts, how many containers should be authorized?

b. Suppose that a proposal to revise the plant layout would cut materials handling and waiting time per container to 0.06 day. How many containers would be needed?

Example 6.2

if

$\bar{d}$ = 2,000 units/day,
$\bar{p}$ = 0.02 day,
α = 0.10,
$\bar{w}$ = 0.082 day, and
c = 2,000 units

b. Figure 8.10 from OM Explorer shows that with reduced waiting time, the number of containers drops to 8.

$$k = \frac{2{,}000(0.08 + 0.02)(1.10)}{22}$$

$$= \frac{220}{22} = 10 \text{ containers}$$

Solver-Number of Containers

Enter data in yellow-shaded area.

Daily Expected Demand	2000
Quantity in Standard Container	22
Container Waiting Time (days)	0.06
Processing Time (days)	0.02
Policy Variable	10%
Containers Required	8

Figure 6.10

Application 6.2

Item B52R has an average daily demand of 1,000 units. The average waiting time per container of parts (which holds 100 units) is 0.5 day. The processing time per container is 0.1 day. If the policy variable is set at 10 percent, how many containers are required?

$$k = \frac{\bar{d}(\bar{w} + \bar{p})(1 + \alpha)}{c}$$

$$= \frac{1{,}000(0.5 + 0.1)(1 + 0.1)}{100}$$

= 6.6, or 7 containers

Other Kanban Signals

- Container System
  - Using the container itself as a signal device.
  - Works well with containers specifically designed for parts.
- Containerless System
  - Using visual means in lieu of containers as a signal device.
  - Examples: a painted square on a workbench = one unit.

Organizational Considerations

- The Human Costs of Lean Systems
- Cooperation and Trust
- Reward Systems and Labor Classification

Process Considerations

- **Inventory and Scheduling**
  - **Schedule Stability**
  - **Setups**
  - **Purchasing and Logistics**

Solved Problem 1

- Metcalf, Inc makes brackets for two major automotive customers. The operations data is on the following slides.

  a. Create a VSM for Metcalf Bearings
  b. What is the takt time?
  c. What is the lead time at each cell?
  d. What is the total processing time?
  e. What is the capacity?

Solved Problem 1

Overall Process Attributes	**Average demand: 2700/day** **Batch size: 50** **Number of shifts per day: 2** **Availability: 8 hours per shift with a 30-minute lunch break**	
Process Step 1	Forming	Cycle time = 11 seconds Setup time = 3 minutes Up time = 100% Operators = 1 WIP = 4000 units (Before Forming)
Process Step 2	Drilling	Cycle time = 10 seconds Setup time = 2 minutes Up time = 100% Operators = 1 WIP = 5,000 units (Before Drilling)
Process Step 3	Grinding	Cycle time = 17 seconds Setup time = 0 minutes Up time = 100% Operators = 1 WIP = 2,000 units (Before Grinding)
Process Step 4	Packaging	Cycle time = 15 seconds Setup time = 0 minutes Up time = 100% Operators = 1 WIP = 1,600 units (Before Packaging) WIP = 15,700 units (Before Shipping)
Customer Shipments	One shipment of 13,500 units each week	
Information Flow	All communications with customer are electronic There is a weekly order release to Forming All material is pushed	

Table 6.4

Solved Problem 1

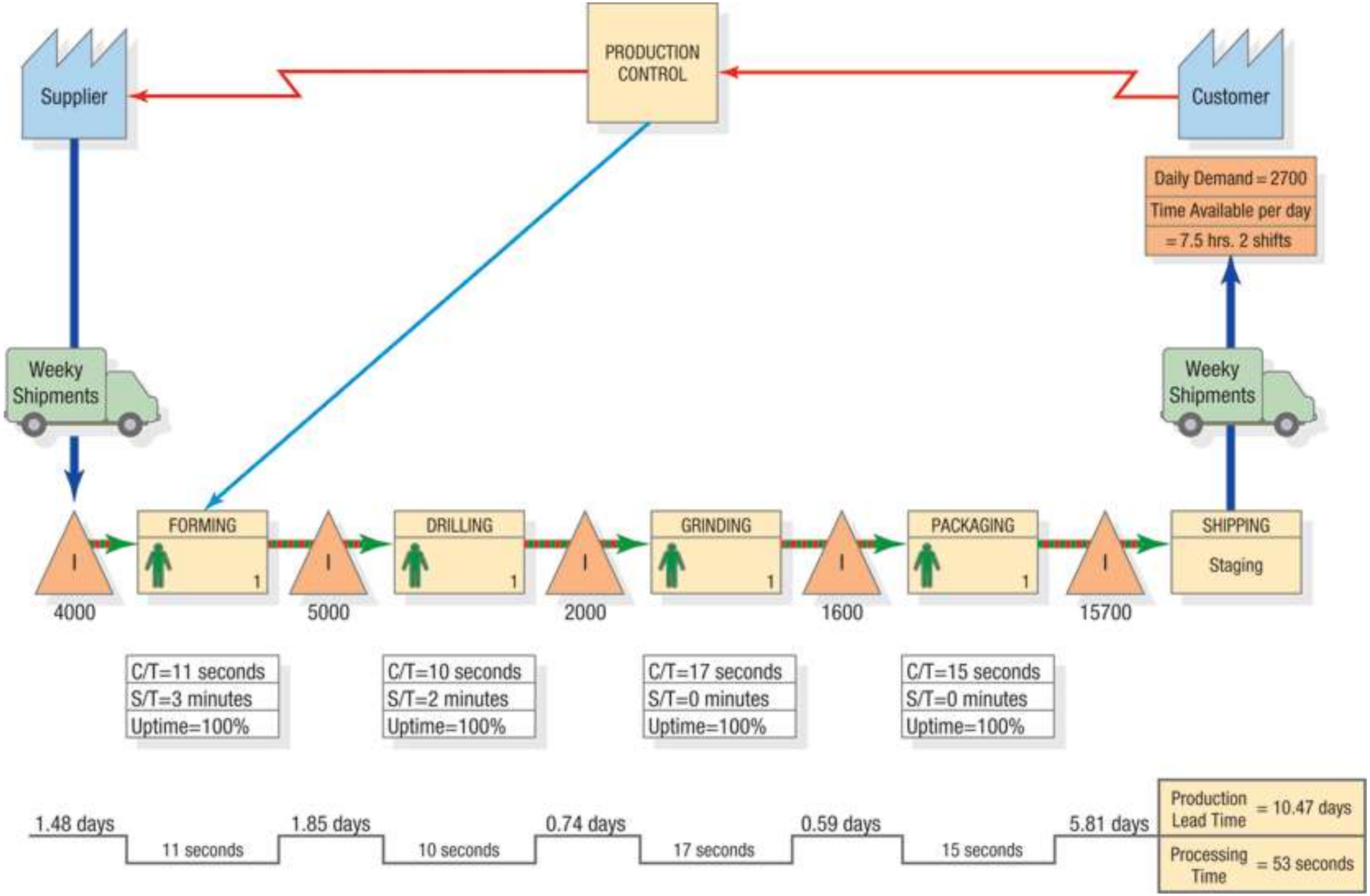


Figure 6.11

Solved Problem 1

b. Daily Demand

2,700 units per day

Daily Availability

(7.5 hours/day) x (3,600 seconds per hour) x (2 shifts/day)=

54,000 seconds per day

Takt Time = Daily availability/Daily Demand =

54,000/2,700 =

20 seconds per unit

Solved Problem 1

c. Production Lead time = Inventory/Daily Demand

Raw Material Lead Time – (4,000/2,700) = **1.48 days**

WIP between Forming and Drilling =
(5,000/2,700)= **1.85 days**

WIP between Drilling and Grinding =
(2,000/2,700) = **.74 day**

WIP between Grinding and Packaging=
(1,600/2,700) = **.59 day**

Finished Goods Lead Time before Shipping =
(15,700/2,700) = **5.81 days**

Total Production Lead Time =
(1.48 + 1.85 + .74 + .59 + 5.81) = **10.47 days**

Solved Problem 1

d. Total Processing Time = Sum of the Cycle Times
(11 + 10 + 17 + 15) = 53 seconds

Capacity at Forming	Capacity at Drilling	Capacity at Grinding	Capacity at Packaging
Cycle time = 11 seconds	Cycle time = 10 seconds	Cycle time = 17 seconds	Cycle time = 15 seconds
Setup Time = (3 minutes * 60 seconds per minute)/ 50 units per batch = **3.6 seconds**	Setup Time = (2 minutes * 60 seconds per minute)/ 50 units per batch = **2.4 seconds**	Setup Time = **zero seconds**	Setup Time = **zero seconds**
Per Unit Processing Time = (11 + 3.6) = **14.6 seconds**	Per Unit Processing Time = (10 + 2.4) = **12.4 seconds**	Per Unit Processing Time = (17 + 0) = **17.0 seconds**	Per Unit Processing Time = (15 + 0) = **15.0 seconds**

Grinding is the bottleneck
Capacity = 54,000/17 = 3,176 units/day

Solved Problem 2

A company using a kanban system has an inefficient machine group. For example, the daily demand for part L105A is 3,000 units. The average waiting time for a container of parts is 0.8 day. The processing time for a container of L105A is 0.2 day, and a container holds 270 units. Currently, 20 containers are used for this item.

a. What is the value of the policy variable, α?
b. What is the total planned inventory (work-in-process and finished goods) for item L105A?
c. Suppose that the policy variable, α, was 0. How many containers would be needed now? What is the effect of the policy variable in this example?

Solved Problem 2

a. We use the equation for the number of containers and then solve for α:

$$k = \frac{\bar{d}(\bar{w} + \bar{p})(1 + \alpha)}{c}$$

$$20 = \frac{3{,}000(0.8 + 0.2)(1 + \alpha)}{270}$$

$$(1 + \alpha) = \frac{20(270)}{3{,}000(0.8 + 0.2)} = 1.8$$

$$\alpha = 1.8 - 1 = 0.8$$

Solved Problem 2

b. With 20 containers in the system and each container holding 270 units, the total planned inventory is

$$20(270) = 5{,}400 \text{ units}$$

c. If $\alpha = 0$

$$k = \frac{3{,}000(0.8 + 0.2)(1 + 0)}{270}$$

$$= 11.11, \text{ or } 12 \text{ containers}$$