

Chapter

1 Using Operations to Compete

DISCUSSION QUESTIONS

1. Answering this question demonstrates that processes underlie all of our jobs. What might be surprising is how many students would put their job in the category of “other,” suggesting that many jobs do not fall neatly into any one functional area. Perhaps many in the “other” category might best be called “operations” on further reflection. Customers, both internal and external, are part of each process, and the goal is to manage the processes to add the most value for them.
2. Amazon.com offers a very broad range of services and products at competitive prices. Its competitive priorities would include fast delivery time, on-time delivery, customization, variety and low-cost operations. As a business, Amazon.com is actually assembling a customized basket of goods that must be delivered in a short window of time in a dependable fashion. Low-cost operations are needed to remain competitive. To remain in business, Amazon.com needs to maintain high volumes of traffic. Operations strategy must focus on stock availability and quick, economical, and dependable delivery.
3. The hospital’s commitment *to provide attention to patients arriving to the emergency unit in less than 15 minutes and never to turn away patients who need to be hospitalized* implies that the facility must be designed to have extra capacity in both beds and emergency room facilities. It must plan on having extra personnel in the emergency room and also plan on having additional emergency personnel on call to take care of unprecedented heavy loads. In line with the mission statement, maximum utilization of the facilities (i.e., beds and emergency room personnel) would not be one of the performance objectives for the hospital.
4. FedEx traditionally has competed on the basis of fast, dependable delivery. Before the boom in Internet applications, many businesses relied on FedEx to get things to other businesses overnight. Now, this need is beginning to diminish as sophisticated systems are being installed to assist companies in planning operations better. And, the internet based companies are adding more demands for low cost ground deliveries to specific customer doors. FedEx, in order to remain competitive with companies such as UPS, has moved into the door-to-door delivery business, perhaps through acquisition. Nonetheless, it will require changes to this company’s competitive priorities.
5. Technology Management. To identify a market segment, we need to determine answers to questions such as: Which colleges and departments currently offer the subject? What do instructors desire in the way of textbook support? Is there a trend toward Technology Management courses? Are there other Technology Management

texts? Some needs assessment can be accomplished by survey, but the response rate may be low. A high-investment strategy would be to ask or hire instructors to review and critique a list of topics, then an outline, then a draft. Explicit services include supplying information about the subject in the form of a textbook and instructor support in the form of ancillary publications.

6. It is often not a good idea for a company to try to excel in all of the competitive priorities because it is generally impossible to do so. Mediocrity is a predictable result. The choice and the minimum level of one or more of the competitive priorities are set by the order qualifiers for the particular product or service. The choice of the competitive priorities that the company should emphasize is usually governed by the company's strategy driven by its mission statement and the core competencies that the company wants to harness to seek the best competitive advantage.
7. Core processes should link to a firm's core competencies. Core processes are those processes that provide the firm the best competitive advantage. Essential to the definition a firm's core processes is the concept of "interaction costs." These costs include the time and money that are expended whenever people and companies exchange services, products, or ideas. If the transaction costs are higher to retain a process within the firm's organization than to outsource the process, the process should be outsourced.
8. Wendy's assembles hamburgers to order. When materials are held at the stage just before final assembly, they can be used to complete a wide variety of different sandwiches. Because no finished-goods stock exists, when customers say, "Hold the sauce," there is no delay or waste of materials. Service clerks specialize. One clerk takes orders and payment. Others fill portions of the order. Orders are processed in single file. Throughput is normally restricted by transactions at the cash register. At busy times, throughput is increased by splitting the bottleneck operation. One clerk takes customer orders, another receives payment. The Wendy's operation has some characteristics of assembly. Therefore, the impact of new menu items on the production operations must be carefully considered.
9. Grandmother's Chicken.
 - a. Kathryn Shoemaker's strategic plans include the following:
 - ☐ Product and service plans: Should the new location offer a new mix?
 - ☐ Competitive priorities: If the product mix and service mix are different at the new location, the thrust could be on low volumes and high quality.
 - ☐ Quality management: Should the goal be reliability or top quality?
 - ☐ Process strategy: What processes will be needed to make chicken dinners in the addition or new facility?
 - ☐ New technologies: Is it time to automate? Is this why there is a problem in service times?
 - ☐ Capacity: How large should the addition or new facility be?
 - ☐ Location: Should we locate in Uniontown or expand in Middlesburg?

- b. Attitudes toward nutrition could change the demand for chicken. Competitors such as Boston Market may be planning to move to Uniontown or even Middlesburg. There may be a trend toward demands for ever-faster service, which cannot be supported by the processes specified in the “unique recipe.” The economy of Uniontown might not be supportive of restaurant services. Shoemaker should also consider the availability of key resources, such as servers, whole chickens, spices, and cooking oil. Will Uniontown labor organize?
 - c. The possible distinctive competencies at Grandmother’s Chicken Restaurant include the “unique recipe,” the homey atmosphere, and friendly, prompt service.
- 10. Wild West, is recognizable as US WEST, which was bought out by Qwest in a hostile takeover in June, 2000. But many other “Baby Bells” are in a similar position.
 - a. Strategic plans include reducing overhead, reengineering operations, and investing in new technologies to meet competition. The “do-nothing” option of remaining a local monopoly telephone company is not viable because of competition from cable systems and wireless systems that are capable of business and personal communication. If the mission is too broad, Wild West should sell its financial services and commercial real-estate businesses. Those businesses do not match their distinctive competencies.
 - b. One environmental issue is whether communication, like health care, will be viewed as a “right” and therefore should be free. A significant portion of Wild West’s business is governed by regulatory agencies. Customer service in their core business is essential to maintaining a favorable regulatory environment. Other business opportunities, such as manufacturing and providing information services, are prohibited by the same court order that formed the “Baby Bells” from AT&T.
 - c. Wild West’s distinctive competency is in connecting people (or machines) for the purpose of communication. A weakness is high overhead inherited from the era of telecommunication monopoly.
- 11. Although the answers may vary depending on the “niche” elements of the business, the competitive priorities would include on-time delivery, low-cost operations, and customization. The latter competitive priority comes from the capability to assemble unique “baskets” of food items for each customer. There may be a need to coordinate a given basket between two different stores. Capabilities to develop would include information systems and Web page design, efficient scheduling of delivery trucks (which must first collect the items in the basket and then deliver them to the customer’s door), and an adequate fleet of trucks with drivers.

PROBLEMS

1. Boehring University

a. Value of output:

$$75 \frac{\text{students}}{\text{class}} \times 3 \frac{\text{credit-hours}}{\text{student}} \times \left(\frac{\$200 \text{ tuition} + \$100 \text{ state support}}{\text{credit-hours}} \right) = \$67,500/\text{class}$$

Value of input: labor + material + overhead

$$\frac{\$6500 + \left(\frac{\$25}{\text{student}} \times 75 \text{ students} \right) + \$30,000}{\text{class}} = \$38,375/\text{class}$$

Multifactor Productivity ratio:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\$67,500}{\$38,375} = 1.76$$

Compared to Solved problem 1, multifactor productivity has increased from 1.25 to 1.76.

b. Value of output is the same as in part a: \$67,500/class

Labor-hours of input:

$$20 \frac{\text{hours}}{\text{week}} \times 16 \frac{\text{weeks}}{\text{class}} = 320 \frac{\text{hours}}{\text{class}}$$

Productivity ratio:

$$\text{Labor Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\$67,500}{320 \text{ hours}} = \$210.94/\text{hour}$$

The \$192 season ticket price is not used in this calculation. It is a “red herring.”

2. Suds and Duds Laundry

a. Labor productivity

Week	Number of Workers	Input (Labor-hours)	Output (Shirts)	Output/Input Ratio
1	2	24	68	2.83 shirts/hour
2	2	46	130	2.83 shirts/hour
3	3	62	152	2.45 shirts/hour
4	3	51	125	2.45 shirts/hour
5	2	45	131	2.91 shirts/hour

b. Output per person does not vary much whether it is Sud, Dud, or Jud working. Productivity declines when all three are present. Perhaps there isn't enough work to keep three persons occupied, or perhaps there is not enough work space or equipment to accommodate three workers.

3. Compact disc players

Value of Output: \$300

Value of Input: Labor + Materials + Overhead

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\$300}{\$30 + \$70 + \$50} = 2.000$$

10% productivity improvement $\rightarrow 2.00 \times 1.10 = 2.200$

Given productivity = 2.20, and the value of output = \$300, we solve for the cost of inputs:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\$300}{\text{Input}} = 2.20$$

$$\text{Input} = \frac{\$300}{2.2} = \$136.36 \text{ or } \$136$$

The cost of inputs must decrease by $(\$150 - \$136) = \$14$.

- a. A \$14 reduction in material costs is $\$14/\$70 = 20.00\%$
 - b. A \$14 reduction in labor costs is $\$14/\$30 = 46.67\%$
 - c. A \$14 reduction in overhead is $\$14/\$50 = 28.00\%$
4. The output of a process is valued at \$100 per unit. The cost of labor is \$50 per hour including benefits. The accounting department provided the following information about the process for the past four weeks:

	Week 1	Week 2	Week 3	Week 4
Units Produced	1124	1310	1092	981
Total Value	112,400	131,000	109,200	98,100
Labor (\$)	12,735	14,842	10,603	9526
Labor (hrs)	254.7	296.8	212.1	190.5
Material (\$)	21,041	24,523	20,442	18,364
Overhead (\$)	8,992	10,480	8,736	7,848
Multifactor Productivity	2.63	2.63	2.75	2.75
Labor Productivity	4.41 units/hr	4.41units/hr	5.15 units/hr	5.15 units/hr

- a. Use the multifactor productivity ratio to see whether recent process improvements had any effect and, if so, when the effect was noticeable.

Value of output

$$1124 \text{ units} \times \$100 = \$112,400$$

Value of input: labor + material + overhead

$$\$12,735 + \$21,041 + \$8,992 = \$42,768$$

Productivity ratio:

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

$$\text{Week 1} \quad \text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\$112,400}{\$42,768} = 2.628$$

$$\text{Week 2} \quad \text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\$131,000}{\$49,845} = 2.628$$

$$\text{Week 3} \quad \text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\$109,200}{\$39,781} = 2.745$$

$$\text{Week 4} \quad \text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\$98,100}{\$35,738} = 2.745$$

$$\frac{2.745 - 2.628}{2.628} \times 100\% = 4.45\%$$

Improved 4.45% - noticeable in Week 3

- b. Has labor productivity changed? Use the labor productivity ratio to support your answer.

Labor-hours of input: Labor \$50/hour

Labor costs

$$\text{Week 1} = \$12,735 / \$50 = 254.7$$

$$\text{Week 2} = \$14,842 / \$50 = 296.84$$

$$\text{Week 3} = \$10,603 / \$50 = 212.06$$

$$\text{Week 4} = \$9,526 / \$50 = 190.52$$

Productivity ratio:

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

$$\text{Week 1} = \text{Labor Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{1124}{254.7 \text{ hours}} = 4.4130 / \text{hour}$$

$$\text{Week 2} = \text{Labor Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{1310}{296.84 \text{ hours}} = 4.413 / \text{hour}$$

$$\text{Week 3} = \text{Labor Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{1092}{212.06 \text{ hours}} = 5.1495 / \text{hour}$$

$$\text{Week 4} = \text{Labor Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{981}{190.52 \text{ hours}} = 5.1491 / \text{hour}$$

$$\frac{5.1491 - 4.4130}{4.4130} \times 100\% = 16.68\%$$

Improved 16.68%

5. Alyssa's Custom Cakes

a.

5 Birthday cakes x \$50 per cake = \$250

2 Wedding cakes x \$150 per cake = \$300

3 Specialty cakes x \$100 per cake = \$300

Total monthly revenue = \$850

Multifactor productivity ratio = output/input

$$1.25 = \$850/x$$

Solve for x = $\$850/1.25 = \$680$

Total costs = \$680

Average cost per cake = $\$680/10 = \$68/\text{cake}$

b. Labor productivity

Birthday cake = $\$50/1.5 \text{ hours} = \$33.30/\text{hour}$ Wedding Cake = $\$150/4 \text{ hours} = \$37.50/\text{hour}$ Specialty Cake = $\$100/1 \text{ hours} = \$100/\text{hour}$

c. Based on labor productivity, Alyssa should try to sell specialty cakes the most.

d. Yes, Alyssa should stop selling birthday cakes. Based on answer a, she loses $\$68 - \$50 = \$18$ every time she sells a birthday cake.

ADVANCED PROBLEMS

6. Big Black Bird Company

The Big Black Bird Company problem is based on a product made by Raven Industries. None of the numbers are representative of actual costs or volume.

a. Multifactor Productivity

Original Situation:

Value of output: $(2500 \text{ uniforms} \times \$200) = \$500,000$

Value of input: $(2500 \text{ uniforms} \times \$120) = \$300,000$

Productivity ratio:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\$500,000}{\$300,000} = 1.67$$

Overtime Situation:

Value of output: $(4000 \text{ uniforms} \times \$200) = \$800,000$

Value of input: $(4000 \text{ uniforms} \times \$144) = \$576,000$

Productivity ratio:

$$\text{Productivity} = \frac{\text{Output}}{\text{Input}} = \frac{\$800,000}{\$576,000} = 1.39$$

Productivity decreases by:

$$\frac{1.67 - 1.39}{1.67} \times 100\% = 16.77\%$$

b. Labor Productivity

Original Situation:

Value of output (from part a) is: \$500,000

Labor-hours of input: $(70 \times 40 \text{ hours}) + (30 \times 40 \text{ hours}) = 4000 \text{ hours}$

Labor productivity = $\$500,000 / 4000 \text{ hours} = \$125/\text{hour}$

Overtime Situation:

Value of output (from part a) is: \$800,000

Labor-hours of input: $(70 \times 72 \text{ hours}) + (30 \times 72 \text{ hours}) = 7200 \text{ hours}$

Labor productivity = $\$800,000 / 7200 \text{ hours} = \$111.11/\text{hours}$

Labor productivity decreases by:

$$(125/111.11) / 125 \times 100\% = 11.1\%$$

c. Gross profits

Original Situation: $\$500,000 - \$300,000 = \$200,000$

Overtime Situation: $\$800,000 - \$576,000 = \$224,000$

Weekly profits increased.

7. Mack's Guitar Company

a. Labor productivity = output/input

$$\begin{aligned} \text{Output} &= 100 \text{ guitars} \times 80\% \text{ completion rate} \times \text{price/guitar} \\ &= 80 \text{ guitars/month} \times \$250/\text{guitar} = \$20,000 \end{aligned}$$

Input

$$\begin{aligned} \text{Labor} &= 10/\text{hours per guitar} \times 100 \text{ guitars} = 1000 \text{ hours} \\ \text{Labor productivity} &= \$20,000/1000 = \$20/\text{hour} \end{aligned}$$

$$\text{Multifactor productivity ratio} = \text{output/input}$$

$$\begin{aligned} \text{Output} &= 100 \text{ guitars} \times 80\% \text{ completion rate} \times \text{price/guitar} \\ &= 80 \text{ guitars/month} \times \$250/\text{guitar} = \$20,000 \end{aligned}$$

Input

$$\begin{aligned} \text{Labor} &= \$10/\text{hour} \times 10/\text{hours per guitar} \times 100 \text{ guitars} = \$10,000 \\ \text{Material} &= \$40/\text{guitar} \times 100 \text{ guitars} = \$4,000 \\ \text{Overhead} &= \$4,000 \end{aligned}$$

$$\text{Multifactor productivity ratio} = \$20,000/\$18,000 = 1.11$$

b. Option 1. Increase sales price by 10%

$$\text{Output} = 100 \text{ guitars} \times 80\% \text{ completion rate} \times (\$250 \times 1.1) = \$22,000$$

Input

$$\begin{aligned} \text{Labor is same as in part (a)} &= \$10,000 \\ \text{Material is same as in part (a)} &= \$4,000 \\ \text{Overhead is same as in part (a)} &= \$4,000 \end{aligned}$$

$$\text{Multifactor productivity ratio} = \$22,000/\$18,000 = 1.22$$

Option 2. Improve Quality

$$\text{Output} = 100 \text{ guitars} \times 90\% \text{ completion rate} \times \$250/\text{guitar} = \$22,500$$

Input

$$\begin{aligned} \text{Labor is same as in part (a)} &= \$10,000 \\ \text{Material is same as in part (a)} &= \$4,000 \\ \text{Overhead is same as in part (a)} &= \$4,000 \end{aligned}$$

$$\text{Multifactor productivity ratio} = \$22,500/\$18,000 = 1.25$$

Option 3. Reduce costs by 10%

$$\text{Output} = \text{same as in part (a)} = \$20,000$$

Input

$$\begin{aligned} \text{Reduce costs by 10\% yields 90\% of the input costs from part (a).} \\ = \$18,000 \times 0.90 = \$16,200 \end{aligned}$$

$$\text{Multifactor productivity ratio} = \$20,000/\$16,200 = 1.23$$

Darren should choose Option 2 and improve quality because it yields the greatest improvement in multifactor productivity.

8. Productivity of Process Alpha and Process Beta

Excel used to perform all calculations

	Process		
	Alpha	Beta	
Total Value of Output	\$17,150	\$16,450	
Total Cost of Labor	\$2,600	\$3,000	
Total Cost of Materials	\$5,500	\$4,900	
Total Cost of Overhead	\$6,000	\$5,000	
Labor Productivity	\$6.596	\$5.483	unit \$/ labor \$
Multifactor Productivity	\$1.216	\$1.275	unit \$/ total \$

Process alpha has 20% $[(6.596-5.483)/5.483]$ higher labor productivity.

Process beta has 5% $[(1.275-1.216)/1.216]$ higher multifactor productivity.

While process beta generates more dollars of output per dollar invested in input, it doesn't use labor as efficiently as process alpha.

9. Morning Brew Coffee Shop

Excel used to perform all calculations

a. Current labor and multifactor productivity

Currently	Regular Coffee	Cappuccino	Vienna coffee	total
Output in dollars	\$700.00	\$300.00	\$600.00	\$1,600.00
Labor cost				\$320.00
Material cost	\$175.00	\$75.00	\$187.50	\$437.50
Equipment cost				\$125.00
Overhead cost				\$225.00
	Profit			\$492.50

Labor Productivity	5.0000
Multifactor Productivity	1.4447

After adding new product

After Adding New Product	Regular Coffee	Cappuccino	Vienna coffee	Eiskaffee	total
Output in dollars	\$700.00	\$300.00	\$600.00	\$375.00	\$1,975.00
Labor cost					\$320.00
Material cost	\$175.00	\$75.00	\$187.50	\$112.50	\$550.00
Equipment cost					\$200.00
Overhead cost					\$350.00
	Profit				\$555.00

Labor Productivity 6.1719

Multifactor Productivity 1.3908

Change in Labor Productivity 23.438%

Change in Multifactor Productivity -3.727%

- b. The units of Eiskaffee that would have to be sold to ensure that the multifactor productivity increases from its current level may be calculated as follows:

$$\frac{\text{output}}{\text{input}} = \frac{\text{Coffee sold in \$}}{\text{Labor cost} + \text{Material cost} + \text{Equipment cost} + \text{Overhead cost}} = 1.4447$$

$$\frac{350(\$2) + 100(\$3) + 150(\$4) + x(\$5)}{\$320 + (350(\$0.5) + 100(\$0.75) + 150(\$1.25) + x(\$1.5)) + 200 + 350} = 1.4447$$

$$\frac{\$1600 + \$5.0x}{\$1307.5 + \$1.5x} = 1.4447$$

$$\$1600 + \$5x = 1.4447(\$1307.5 + \$1.5x)$$

$$\$1600 + 5x = 1888.945 + 2.1670x$$

$$2.833X = 288.945$$

$$x \cong 102$$

Calculation confirmed in Excel:

After Adding New Product	Regular Coffee	Cappuccino	Vienna coffee	Eiskaffee	total
Output in dollars	\$700.00	\$300.00	\$600.00	\$510.00	\$2,110.00
Labor cost					\$320.00
Material cost	\$175.00	\$75.00	\$187.50	\$153.00	\$590.50
Equipment cost					\$200.00
Overhead cost					\$350.00
	Profit				\$649.50

Labor Productivity	6.5938
Multifactor Productivity	1.4447
Change in Labor Productivity	31.875%
Change in Multifactor Productivity	0.001%

CASE: CHAD'S CREATIVE CONCEPTS*

A. Synopsis

This case describes a small furniture manufacturing company that has gained a reputation for creative designs and quality by focusing on producing custom-designed furniture. As its reputation grew it began to sell some standard furniture pieces to retail outlets. The overall growth in sales volume and the diversification into the production of standard furniture pieces have caused a number of issues to arise concerning both the internal manufacturing operations and its relationship to the other functional areas of the company.

B. Purpose

This case is designed to be used as either a “cold-call” case for class discussion or an assigned homework reading. Major points to be brought out in the discussion include:

1. The range of decisions that are made in designing and operating processes
2. The impact that these operating decisions have on the organization as a whole, such as on marketing and finance
3. The impact that decisions made in other functional areas of the organization have on the operating function
4. The need to go beyond the “functional silo” mentality and manage in an integrative manner

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

C. Analysis

Question 1: *What types of decisions must Chad Thomas make daily for his company's operations to run effectively? Over the long run?*

The students should be able to discuss a number of short-term-oriented decisions that are facing Chad Thomas. These should include:

- a. How to set priorities and schedule different orders. Chad is receiving orders for both custom-made, low-volume furniture pieces and higher-volume, standard pieces. Sales have increased, but the amount of equipment and the production capacity of the company have not. Different orders with different manufacturing requirements are now competing for the same productive capacity.
- b. What orders to accept and how long of a lead time to plan for in promising a delivery date.
- c. What type of work policies should be maintained for his employees? Decisions such as the number and type of employees to employ, the number of hours to work per day, and the amount of overtime to allow are all work policy decisions that impact the available capacity level.
- d. The allocation of resources, equipment, labor, and money to each product line.
- e. The level of inventory to maintain at various stages of the production process for both the custom and standard furniture lines (i.e., raw material, WIP, finished goods). These decisions are linked to the longer-term, total inventory-investment decision.

Examples of longer-term decisions that face Chad Thomas include:

- a. Amount of money to tie up in the total inventory investment.
- b. The type of equipment to invest in to support efficient production. At what point should more specialized equipment be purchased to manufacture high-volume, standard furniture pieces more efficiently?
- c. What should be the overall workforce level to maintain, and what should be the proper mix of skills and capabilities?
- d. How should the facilities be laid out to accommodate the two different product lines? This gets the students into a whole range of capacity and equipment allocation decisions including size, type, and configuration.

In these decisions it is important that the students see the significance of consistency of both strategic and operating decisions across functional areas.

Question 2: *How did sales and marketing affect operations when they began to sell standard pieces to retail outlets?*

Standard furniture pieces compete on a different set of competitive priorities than custom-designed pieces. Timely delivery and low costs are much more important than product flexibility. Quality may also be defined differently. The existing facilities are set up to provide flexibility with its job-shop orientation and general-purpose equipment. By introducing a standard line that should be manufactured on a flow line with some dedicated, more specialized equipment, a conflict has developed, and scheduling problems have resulted.

Question 3: *How has the move to producing standard furniture pieces affected the financial structure of the company?*

Inventory investment and operating costs are rising because of the frequent changeovers to accommodate the two different product lines and their scheduling conflicts.

Profit margins for the standard line are smaller, which puts pressure on manufacturing to increase productivity and reduce costs. There may also be an issue concerning the assignment of overhead costs to each product line.

Finally, the potential need to rent warehouse space to store either WIP or finished-goods inventory cuts into the profit margin for the standard furniture line.

Question 4: *What might Chad Thomas have done differently to help avoid some of these problems?*

Chad needs to address issues relating to functional areas. Make sure the student is able to identify decisions that relate to more than one functional area. Examples include the following:

Operations Function

1. Monitoring capacity and utilization of facilities
2. Formulating inventory policies—dollars, items, and unit levels
3. Setting scheduling policies and priorities
4. Maintaining product line quality

Marketing and Sales

1. Accurately forecasting orders for standard pieces
2. Defining market segments and customer needs
3. Determining what delivery schedules can be promised to customers

Finance

1. Deciding level and type of investment
2. Investigating the effect of capacity investment decisions on ROI

Distribution/Logistics

1. Managing distribution and pipeline inventory
2. Comparing cost and advantages of various transportation modes
3. Meeting delivery lead times

Three possible avenues that students may focus on are: Thomas might have

- a. Established a plan for a more controlled growth. Part of this plan would be the development of the appropriate infrastructure to manage a controlled growth as to what markets to enter, what product lines to develop, and how to develop the proper manufacturing capabilities.
- b. Maintained the company focus on custom-designed furniture only. This alternative presents a whole different set of issues and decisions pertaining to future growth, but it would have avoided the issues of mixed competitive priorities and scheduling conflicts.
- c. Realized the different requirements for each product line and focused the manufacturing facilities into two separate sets of production facilities designed to cater to each product line's specific needs.

D. Recommendations

This case is not designed to be a decision-making case per se but rather a vehicle to get students thinking about the types and the integrated nature of decisions that operations managers face. The students may, indeed, have suggestions as to what should be done to help out Chad Thomas. These recommendations will more than likely follow the alternatives already discussed. As recommendations are provided by students, make sure you push them to understand the implications of their recommendations with respect to the company as a whole and the other functional areas.

E. Teaching Strategy

This case can be effectively discussed in 20 to 30 minutes by following the discussion questions provided at the end. The questions are interconnected and somewhat redundant on purpose to reinforce the interrelatedness of decisions made in various functional areas of the company. The intent is to have the students understand the range of decisions that face managers in the operating function and to realize that different types of products competing in different markets place different demands on the operating function. Therefore, productive systems will take on a variety of configurations.

Exhibit TN.1 lays out a sample table to be written on the board displaying important issues in the class discussion. Each column can be used to compare and contrast the differences in the requirements imposed by custom versus standard furniture for each area.

EXHIBIT TN.1**Board Plan**

Important Issues	Custom Furniture	Standard Furniture
Marketing		
Quality level and quality control		
Process equipment		
Process flow		
Production scheduling system		
Purchasing		
Type of inventory and inventory control system		
Type of engineering		
Type of labor and supervision needed		
Wage/reward system		
Layout		

CASE: BSB, INC.: Pizza Wars Come to Campus *

A. Synopsis

BSB, Inc. presents the situation where launching a pizza service at a food service operation on a college campus turns out to be very successful. As the manager of the food service operation is contemplating an expansion of the service, an announcement by the university that a new food court will soon be opening in the new student union causes some concern. The new food court will contain, for the first time on campus, other food service companies, including a new Pizza Hut kiosk. This causes the manager of BSB, Inc. to reevaluate the competitive environment and her own competitive priorities.

B. Purpose

BSB, Inc. provides the students an opportunity to discuss a number of strategically focused issues to include the following:

1. *Mission statements:* Mission statements describe the fundamental purpose for which the organization exists. The university decided that a focus on food service operations was not part of its primary mission, so it contracted the service out to BSB, Inc. Students should be able to describe a mission statement for BSB, Inc. This statement will help in discussing the second major focus of this case.
2. *Comparison of competitive priorities:* When the pizza service was launched a year ago, the competitive priorities were to expand the product line to offer pizza that could be delivered quickly at a reasonable price. Costs were kept low, and turnaround time was short due to the limited combination of toppings available.
With the addition of the food court and Pizza Hut on campus, competitive priorities may change. Delivery may still be a differentiating competitive priority, but product flexibility (variety) and volume flexibility (large order sizes) may become more important. BSB, Inc. may not be able to compete on low cost when compared to Pizza Hut's operations.
3. *The impact changing competitive priorities has on operating decisions:* Students need to discuss the potential impact that different competitive priorities have on process design and operating systems. If product flexibility and volume flexibility become more important, then there are implications for:
 - a. Equipment needs—conventional oven versus continuous chain drive
 - b. Capacity requirements—order size and delivery cycle
 - c. Inventory issues—inventory needed to support product flexibility
4. *Product life cycles:* Demand for pizza on campus has leveled off. Why? Has it reached its mature, steady state? What will be the impact of new competition? What can be done to reposition pizza into a growth stage? These are questions that should be asked of students to get them to think about pizza's product life cycle.

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

C. Analysis

A good analysis of the situation can be performed by going through the five questions at the end of the case. The following is what you can expect from a first-year MBA student given the case as a take-home assignment to read and to respond to the questions at the end.

Question 1: *Does BSB, Inc. enjoy any competitive advantages or distinctive competencies?*

BSB's competitive advantage is close proximity to the customers. Though 43 percent of meals are eaten off campus, 57 percent of meals are still eaten at BSB's facilities. For pizza delivery the close proximity is critical, as it allows for quicker delivery. In addition, delivery can be done at a lower cost because bikes can be used.

BSB's distinctive competencies are the location of facilities and market know-how. Being on campus, BSB can provide delivery service quicker and at a lower cost. In addition, by being on campus, BSB is closer to the customer base, which allows Kershaw, the manager, to be more knowledgeable of her customer's needs. She employs environmental scanning, such as the customer surveys, to keep abreast of her market.

Question 2: *Initially, how did Renee Kershaw choose to compete with her pizza operations? What were her competitive priorities?*

Initially, Kershaw chose to compete on delivery service and price. She used quick delivery as a key selling point. In addition, without a reasonable price, she could not compete with the off-campus pizza companies. In effect, her order qualifier was price, and her order winner was service.

Her initial competitive priorities for pizza were delivery speed and price. Her on-campus location and limited standard toppings make these priorities possible. Unfortunately, this policy limits the variety of pizzas available. The increased requests for additional topping combinations and the leveling of sales suggest this policy may be hurting BSB.

Question 3: *What impact will the new food court have on Kershaw's pizza operations? What competitive priorities might she choose to focus on now?*

The new food court introduces new competition that has the same on-campus advantage as BSB. In addition, these companies can also provide products at reasonable prices, but unlike BSB, they have brand names. Her direct competitor, Pizza Hut, can probably provide a similar price. Most likely Pizza Hut will also have limited varieties; however, BSB still maintains its delivery advantage.

The most likely new competitive priorities for BSB will be expanded product variety and longer service hours. The increased requests for alternate toppings show a customer interest in variety, and the expanded hours will enable BSB to offer service when the Pizza Hut is closed or when students are in their dorm rooms.

Question 4: *If Kershaw were to change the competitive priorities for the pizza operation, what are the gaps between the priorities and capabilities of her process? How might this impact her operating processes and capacity decisions?*

An increase in product variety will affect both service and cost. Kershaw probably cannot have as many premade pizzas ready to throw into the oven. She will also need to stock additional toppings. If she wants to maintain service, she will need to hire additional workers. She will inevitably have some trade-off between service and price if she adds product variety.

Kershaw will also need to add capacity. At present, she is near capacity with her pizza ovens. She may even have to consider a new location, as there seems to be limited space at the grill location. Clearly she will need to determine the viability of pizza service before she takes this step.

Question 5: *Can you outline a service strategy for Kershaw's operation on campus?*

If she chooses to stay in the pizza business, delivery will remain important. Food, most likely pizza, delivered from off campus, is a significant competitor. These competitive companies likely offer many pizza combinations. Therefore, BSB will need to increase variety to remain competitive. The key to this strategy is to maintain quality and to innovate on product offerings. Kershaw must use her proximity to the customer to maintain her competitive advantage in determining their pizza delivery needs.

The other strategy would be total price competition. This would require her to keep the limited menu and to push to keep costs at a bare minimum. Unfortunately this means maintaining the same basic strategy she has now. However, this strategy will most likely lead to an inevitable decline in market share. This strategy seems best if she decides to exit the market, but it gives her the opportunity to milk the market before exiting.

In reviewing the student responses the instructor should note the following:

1. On question three, the student overlooks the continued importance of convenient, quick delivery. The other food services do not provide this service.
2. Students tend to hedge on question five. They should be pressured into putting together a service strategy as opposed to describing alternative choices only.

There are a number of positions Kershaw may take. What is important, however, is to look for consistency in the strategies that students provide.

D. Teaching Strategy

This case is best assigned as a take-home assignment. Have the students focus on responding to the questions at the end of the case. Tell them to pay particular attention to the last question. The first four questions all lead up to the last one where students should describe a service strategy for pizza operations of BSB, Inc. Tell students you want them to settle on a specific strategy they can support.

In class, start with the first question and cycle through to the final question, which describes their service strategies. It is helpful to try to get two or three different strategies on the board to compare and contrast approaches. It is important that students see that there are a number of good alternative strategies and not just one best one.

A thorough discussion of this case will take 45 minutes to an hour, especially if alternative strategies are discussed.

Supplement

A Decision Making

PROBLEMS

1. Williams Products

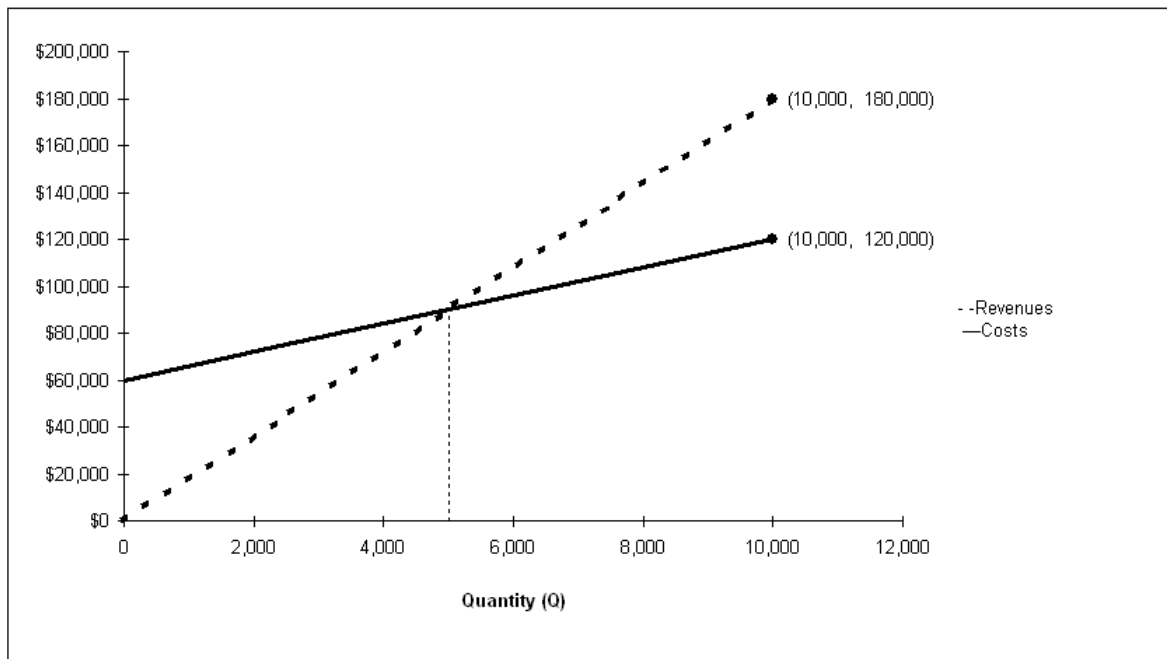
a. Break-even quantity

$$(Q) = \text{Fixed costs} / (\text{Unit price} - \text{Unit variable costs})$$

$$= \$60,000 / (\$18 - \$6)$$

$$= 5,000 \text{ units}$$

The graphic approach is shown on the following illustration, using *Break-Even Analysis Solver* of OM Explorer.



Two lines must be drawn:

$$\text{Total Revenue} = 18Q$$

$$\text{Total Cost} = 60,000 + 6Q$$

b. Profit = Total Revenue – Total Cost

$$= pQ - (F + cQ) = (\$14.00)10,000 - [\$60,000 + (\$6)10,000]$$

$$= \$140,000 - \$120,000 = \$20,000$$

c. Profit = Total Revenue – Total Cost

$$= pQ - (F + cQ) = (\$12.50)15,000 - [\$60,000 + (\$6)15,000]$$

$$= \$187,500 - \$150,000 = \$37,500$$

Therefore, the strategy of using a price of \$12.50 will result in a greater contribution to profits.

- d. Williams must also consider how this product fits within her existing product line from the perspective of required technologies and distribution channels. Other marketing, operations, and financial criteria must also be considered.

2. Jennings Company

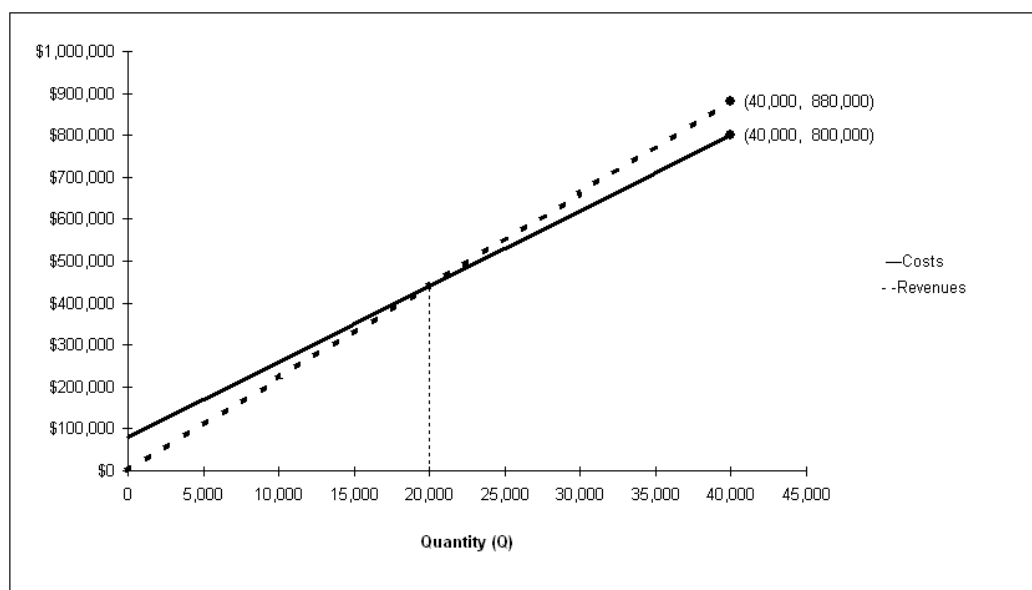
a. Break-even quantity

$$(Q) = \text{Fixed costs} / (\text{Unit price} - \text{Unit variable costs})$$

$$= \$80,000 / (\$22 - \$18)$$

$$= 20,000 \text{ units}$$

The graphic approach is shown on the following graph created by the *Break-Even Analysis Solver*.



Two lines are:

$$\text{Total Revenues:} = \$22Q$$

$$\text{Total costs:} = \$80,000 + \$18Q$$

- b. In order to calculate the new unit variable cost required to breakeven, use the breakeven equation from part a, but solve for unit variable cost (c).

$$\frac{80,000}{22 - c} = 17,500$$

$$80,000 = (22 - c)17,500$$

$$80,000 = 385,000 - 17,500c$$

$$c = 17.43$$

Thus the variable cost would have to reduce from \$18 per unit to \$17.43 per unit.

- c. With a one dollar price decrease, the breakeven quantity would be:

$$\frac{80,000}{(22-1)-18} = 26,667$$

This quantity exceeds a 50% increase in sales ($17,500 \times 1.5$) = 26,250

Thus, sales would have to increase by 52% ($26,667/17,500=1.52$) for Jennings to breakeven with a \$1 reduction in price.

- d. Alternative 1: Sales increase by 30 percent, to 22,750 units (or $17,500 \times 1.3$).

$$\begin{aligned}\text{Profit} &= pQ - (F + cQ) \\ &= (\$22)22,750 - [\$80,000 + (\$18)22,750] \\ &= \$11,000\end{aligned}$$

Alternative 2: Cost reduction to 85 percent results in \$15.30 (or $\$18 \times 0.85$) unit cost.

$$\begin{aligned}\text{Profit} &= pQ - (F + cQ) \\ &= (\$22)17,500 - [\$80,000 + (\$15.30)17,500] \\ &= \$37,250\end{aligned}$$

Therefore the cost reduction leads to much higher profits in this example.

- e. Initial unit profit is $(\$22 - \$18) = \$4.00$

Alternative 1: $(\$22 - \$18) = \$4.00$

The percentage change in profit margin is zero.

Alternative 2: $(\$22 - \$15.30) = \$6.70$

The percentage change is $[(\$6.70 - \$4)/\$4]100 = 67.5\%$ increase.

3. Interactive television service

$$\begin{aligned}F &= (p - c)Q \\ &= (\$15 - \$10)15,000 \\ &= \$75,000\end{aligned}$$

4. Brook Trout

$$\begin{aligned}Q &= F / (p - c) \\ p &= (F/Q) + c \\ &= \$10,600/800 + \$6.70 \\ &= \$19.95\end{aligned}$$

Spartan Castings

5.

a. Total cost = Fixed cost + Variable cost

$$TC = F + cQ$$

$$TC(\text{first process}) = \$350,000 + \$50Q$$

$$TC(\text{second process}) = \$150,000 + \$90Q$$

At the break-even quantity,

$$\$350,000 + \$50Q = \$150,000 + 90Q$$

$$\$200,000 = \$40Q$$

$$Q = 5000 \text{ units}$$

Beyond 5000 units the first process becomes more attractive.

b. At $Q=10,000$ units

$$TC(\text{first process}) = \$350,000 + \$50(10,000) = \$850,000$$

$$TC(\text{second process}) = \$150,000 + \$90(10,000) = \$1,050,000$$

$$\text{The difference in total cost} = \$1,050,000 - \$850,000 = \$200,000$$

6. News clipping service

$$a. \quad Q = \frac{F_m - F_a}{c_a - c_m} = \frac{\$400,000 - \$1,300,000}{\$2.25 - \$6.20} = 227,848 \text{ clippings}$$

b. Profit = Total Revenue – Total Cost

Current (manual) situation:

$$= (225,000 \times \$8.00) - [\$400,000 + (225,000 \times \$6.20)]$$

$$\text{Profit} = \$5,000$$

Modernization:

$$= (900,000 \times \$4.00) - [\$1,300,000 + (900,000 \times \$2.25)]$$

$$\text{Profit} = \$275,000$$

The clipping service should be modernized.

$$c. \quad Q = \frac{F}{p - c} = \frac{\$1,300,000}{\$4.00 - \$2.25} = 742,857 \text{ clippings}$$

7. Hahn Manufacturing

a. Total cost of buying 750 units from the supplier:

$$TC_b = (\$1,500/\text{unit})(750 \text{ units}) = \$1,125,000$$

Total cost of making 750 units in-house:

$$TC_m = (\$1,100/\text{unit} + \$300/\text{unit})(750 \text{ units}) + \$40,000 = \$1,090,000$$

Therefore Hahn should make the components in-house, saving \$35,000 per year.

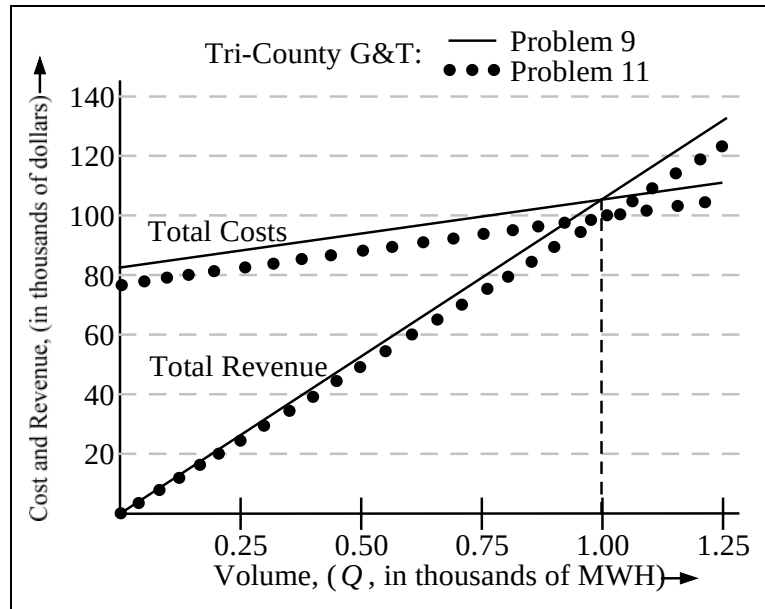
b. At the break-even quantity, the total cost of the two alternatives will be equal:

$$\$1,500Q = \$40,000 + \$1,400Q$$

$$100Q = \$40,000$$

$$Q = 400 \text{ units}$$

- c. If the decision is to “buy,” Hahn may get a quantity discount from the supplier (we would be ordering 750 per year instead of the current 150 per year). Just a \$50 per unit quantity discount would make the “buy” alternative more attractive than the “make” alternative. Because the component is a key item, Hahn should check the reliability of the supplier and of their own processes. Reliability may argue for the “make” decision.
- 8 Current Profit = (Price – Variable cost)(Annual Volume) – Annual Fixed Costs .
- $$= (\$10.00 - \$5.00)(30,000) - (\$140,000)$$
- $$= \$10,000$$
- a. Profit with new equipment = $(\$10.00 - \$6.00)(50,000) - (\$200,000) = \$0$
Because the profit decreases, Techno **should not buy** the new equipment.
- b. Profit with new equipment = $(\$11.00 - \$6.00)(45,000) - (\$200,000) = \$25,000$
Because the profit increases, Techno **should buy** the new equipment if they also raise the selling price.
9. This problem is a thinly disguised portrayal of an actual situation faced by Tri-State G&T Association, Inc. of Thornton, Colorado, and which is common to many other REA Utilities. However the costs, prices, and demands stated in the problem are fictional.
- a. $Q = \frac{F}{p - c}$
- $$p = \frac{F}{Q} + c = \frac{\$82,500,000}{1,000,000} + \$25 = \$107.5 \text{ per MWH}$$
- b. Profit (or loss) = Total Revenue – Total Cost
- $$= [(1,000,000 \times 95\%)(\$107.5)] - [\$82,500,000 + (1,000,000 \times 95\%)(\$25)]$$
- $$= \$102,125,000 - \$106,250,000$$
- $$\text{Loss} = \$4,125,000$$
- In order to break even, the price would have to be raised to $\left(\$107.5 + \frac{\$4,125,000}{950,000} = \$111.842 \right)$, assuming even more conservation would not occur at this higher price.



10. Earthquake ... Build or Buy. This problem is related to problem 9.
 Build: $F_1 + QC_1 = \$10,000,000 + (150,000\text{MWH} \times \$35) = \$15,250,000$
 Buy: $F_2 + QC_2 = \$0 + (150,000\text{MWH} \times \$75) = \$11,250,000$
 It would be less costly for Boulder to buy power from Tri-County. Note that Boulder enjoys a lower price (\$75) than Tri-County charges its own REA customers (\$107.50).
11. Tri-County G&T continued. This problem builds on problems 9 and 10 to show that Tri-County's REA customers also benefit from the bargain arrangement with Boulder.
 Contribution from sales to Boulder = $Q(p - c)$

$$= 150,000(\$75 - \$25)$$

$$= \$7,500,000$$

$$\text{Remaining fixed costs to cover} = \$82,500,000 - \$7,500,000 = \$75,000,000$$

$$Q = \frac{F}{p - c}$$

$$p = \frac{F}{Q} + c = \frac{\$75,000,000}{1,000,000} + \$25 = \$100 \text{ per MWH}$$

Note that selling power to Boulder at a reduced price also reduces the price to the REA customers. However, it may be difficult to persuade REAs that selling electricity to city slickers below "cost" also benefits rural customers.

12. Forsite Company

- a. Say that each criterion (arbitrarily) receives 20 points:

Service	Calculation	Total Score
A	$20(0.6) + 20(0.7) + 20(0.4) + 20(1.0) + 20(0.2)$	= 58
B	$20(0.8) + 20(0.3) + 20(0.7) + 20(0.4) + 20(1.0)$	= 64
C	$20(0.3) + 20(0.9) + 20(0.5) + 20(0.6) + 20(0.5)$	= 56

The best alternative is service B and the worst is service C. This relationship holds as long as any arbitrary weight is equally applied to all performance criteria.

- b. Let

x = point allocation to criteria 1, 3, 4, and 5

$2x$ = point allocation to criteria 2 (ROI)

$$x + 2x + x + x + x = 100 \text{ points}$$

$$6x = 100 \text{ points}$$

$$x = 16.7 \text{ points}$$

Product	Calculation	Total Score
A	$16.7(0.6) + 33.3(0.7) + 16.7(0.4) + 16.7(1.0) + 16.7(0.2)$	= 60.0
B	$16.7(0.8) + 33.3(0.3) + 16.7(0.7) + 16.7(0.4) + 16.7(1.0)$	= 58.4
C	$16.7(0.3) + 33.3(0.9) + 16.7(0.5) + 16.7(0.6) + 16.7(0.5)$	= 61.7

The rank order of the services has changed to C, A, B.

13. Five new suppliers

a.

Let

 x = point allocation to criteria 2 and 3 $4x$ = point allocation to criterion 1 $4x$ = point allocation to criterion 4

$$4x + x + x + 4x = 100 \text{ points}$$

$$10x = 100 \text{ points}$$

$$x = 10 \text{ points}$$

Supplier	Calculation	Total Score
A	$40(8) + 10(3) + 10(9) + 40(7)$	= 720
B	$40(7) + 10(8) + 10(5) + 40(6)$	= 650
C	$40(3) + 10(4) + 10(7) + 40(9)$	= 590
D	$40(6) + 10(7) + 10(6) + 40(2)$	= 450
E	$40(9) + 10(7) + 10(5) + 40(7)$	= 760

The threshold is $0.7[10(40 + 10 + 10 + 40)] = 700$

Because Supplier A and Supplier E score greater than 700, they should be considered.

b. If the factors are equally weighted:

Supplier	Calculation	Total Score
A	$25(8+3+9+7)$	= 675
B	$25(7+8+5+6)$	= 650
C	$25(3+4+7+9)$	= 575
D	$25(6+7+6+2)$	= 525
E	$25(9+7+5+7)$	= 700

The threshold is $0.7[10(40 + 10 + 10 + 40)] = 700$

Because no supplier's score is greater than 700, none should be considered. Stay with the current suppliers, which presumably have scores greater than 700.

14. Accel-Express Inc.

a. The weighted score for Location A:

$$(10)(8) + (10)(7) + (10)(4) + (20)(7) + (20)(4) + (30)(7) = 620$$

The weighted score for Location B:

$$(10)(5) + (10)(7) + (10)(7) + (20)(4) + (20)(8) + (30)(6) = 610$$

Location A must be chosen.

b. If equal weights are placed on the criteria, the two locations will be tied because the sum of the scores is 37 for both A and B.

15. Build-Rite Construction

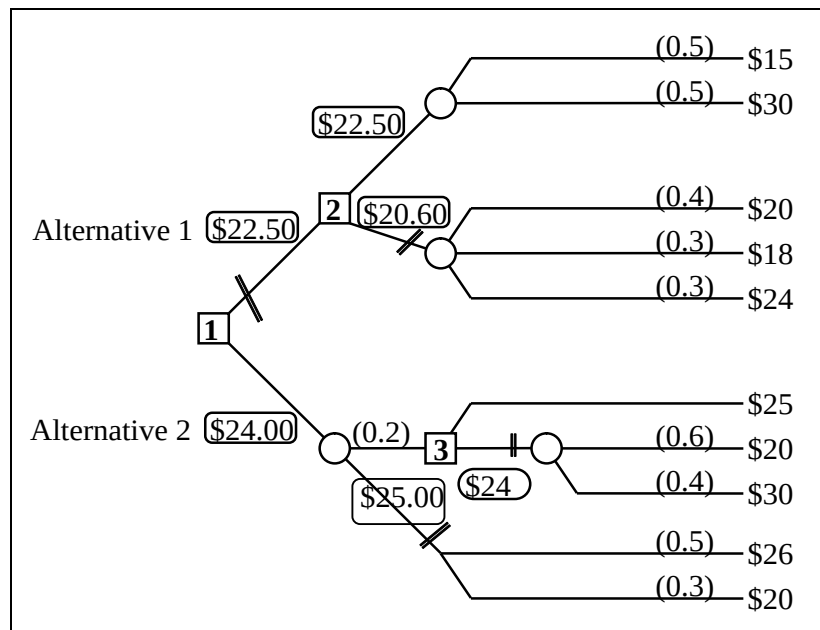
- a. Maximin Criterion—Best Decision: Subcontract ... Payoff: \$100,000
 b. Maximax Criterion—Best Decision: Hire ... Payoff: \$625,000
 c. Laplace Criterion—Best Decision: Subcontract ... Weighted Payoff: \$221,667

Alternative	Weighted Payoff
Hire	$[-\$250,000 + 100,000 + \$625,000]/3 = \$158,333$
Subcontract	$[\$100,000 + 150,000 + \$415,000]/3 = \$221,667$
Do nothing	$[\$50,000 + 80,000 + \$300,000]/3 = \$143,333$

- d. Minimax Regret Criterion—Subcontract ... Minimum Maximum Regret \$210,000

Regrets (\$000)				
Demand for Home Improvements				
Alternative	Low	Moderate	High	Maximum
Hire	$100 - (-250) = 350$	$150 - 100 = 50$	$625 - 625 = 0$	350
Subcontract	$100 - 100 = 0$	$150 - 150 = 0$	$625 - 415 = 210$	210
Hire	$100 - 50 = 50$	$150 - 80 = 70$	$625 - 300 = 325$	325

16. Decision Tree



Work from right to left. Here we begin with Decision Node 2, although Decision Node 3 would be an equally good starting point. The key concept is that we cannot begin analysis of Decision Node 1 until we know the expected payoffs for Decision Nodes 2 and 3.

Decision Node 2

1. Its first alternative (in the upper right portion of the tree) leads to an event node with an expected payoff of \$22.50 [or $0.5(15) + 0.5(30)$].
2. Its second alternative leading downward reaches an event node with an expected payoff of \$20.60 [or $0.4(20) + 0.3(18) + 0.3(24)$].
3. Thus the expected payoff for decision node 2 is **\$22.50**, because the first alternative has the better expected payoff. Prune the second alternative.

Decision Node 3

4. Its second alternative leads to an event node has an expected payoff of \$24 [or $0.6(20) + 0.4(30)$].
5. Thus the payoff for decision node 3 is **\$25**, because the first alternative (\$25) is better than the expected payoff for the second alternative (\$24). Prune the second alternative.

Decision Node 1

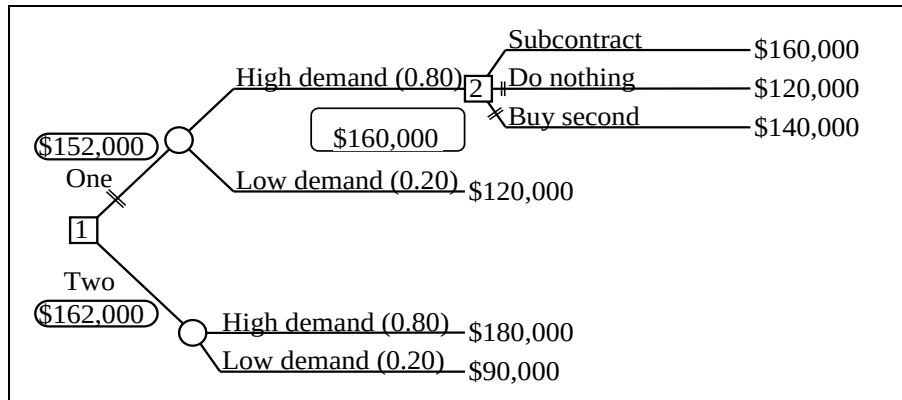
6. The second alternative leads to an event node has an expected payoff of \$24 [or $0.2(25) + 0.5(26) + 0.3(20)$].
7. Thus the expected payoff for decision node 1 is **\$24**, because the second alternative (\$24) is better than the expected payoff for the first alternative (\$22.50). Prune the first alternative.

Thus the best initial choice (Decision 1) is to select the lower branch, Alternative 2. If the top branch of the subsequent event occurs (a 20% probability), then Decision 3 must be made. Select its first alternative.

Conclusion: Select the lower branch, with an expected payoff of **\$24**.

17. One machine or two.

a. Decision Tree



b. Working from right to left:

Decision Node 2

1. The best choice is to subcontract (**\$160,000**), which becomes the expected payoff for Decision Node 2. Prune the “Do nothing” and Buy second” alternatives.

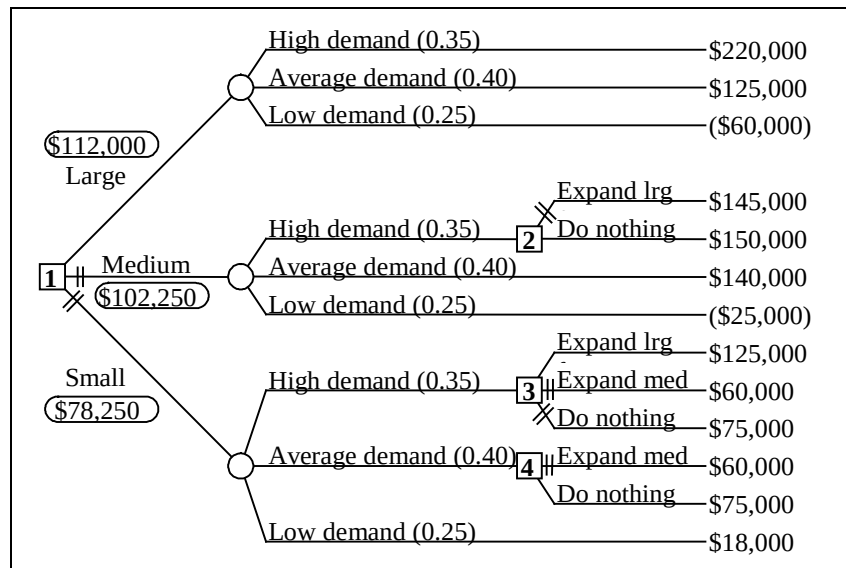
Decision Node 1

2. The alternative to buy one machine has an expected value of **\$152,000** [or $0.8(160,000) + 0.2(120,000)$].
3. The alternative to buy two machines has an expected value of **\$162,000** [or $0.8(180,000) + 0.2(90,000)$].
4. Thus the best choice is to buy two machines because it has a higher expected payoff (\$162,000 versus \$152,000). Prune the one machine alternative.

Conclusion: Buy two machines, with an expected payoff of **\$162,000**.

18. Small, medium, or large facility.

a. Decision Tree



- b. Working from right to left:

Decision Node 2

1. The best choice is to do nothing (**\$150,000**), which becomes the expected payoff for Decision Node 2. Prune the “Expand to large” alternative.

Decision Node 3

2. The best choice is the “Expand to large” alternative (**\$125,000**), which becomes the expected payoff for Decision Node 3. Prune the “Expand to medium” and “Do nothing” alternatives.

Decision Node 4

3. The best choice is to do nothing (**\$75,000**), which becomes the expected payoff for Decision Node 4. Prune the “Expand to medium” alternative.

Decision Node 1

4. The alternative to build a large facility has an expected payoff of **\$112,000** [or $0.35(220,000) + 0.40(125,000) + 0.25(-60,000)$].
5. The alternative to build a medium-sized facility has an expected payoff of **\$102,250** [or $0.35(150,000) + 0.40(140,000) + 0.25(-25,000)$].
6. The alternative to build a small facility has an expected payoff of **\$78,250** [or $0.35(125,000) + 0.40(75,000) + 0.25(18,000)$].
7. Thus the best choice is to build a large facility because it has a higher expected payoff (**\$112,000**). Prune the medium and small alternatives.

Conclusion: Build the large facility, with an expected payoff of **\$112,000**.

- c. Develop a payoff table from tree created in part a

Decision	High Demand	Average Demand	Low Demand
Small Facility	\$125,000	\$75,000	\$18,000
Medium Facility	\$150,000	\$140,000	(\$25,000)
Large Facility	\$220,000	\$125,000	(\$60,000)

Maximin Criterion—Best Decision: Small Facility

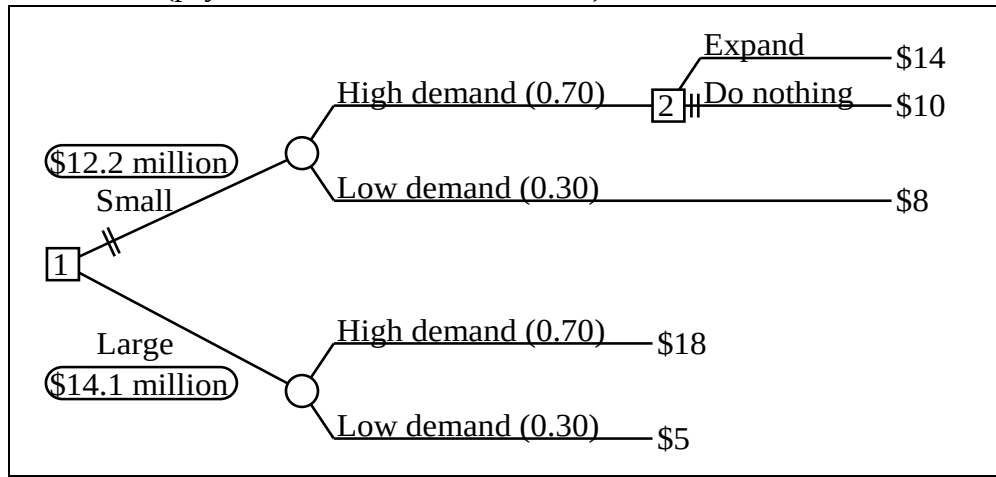
Maximax Criterion—Best Decision: Large Facility

Minimax Regret Criterion—Best Decision: Medium Facility

Regrets (\$000)				
Alternative	High	Average	Low	Maximum
Small	220-125=95	140-75=65	18-18=0	95
Medium	220-150=70	140-140=0	18-(25)=43	<u>70</u>
Large	220-220=0	140-125=15	18-(60)=78	78

19. Small or large plant.

a. Decision Tree (payoffs are in millions of dollars)



b. Working from right to left:

Decision Node 2

1. The best choice is the “Expand” alternative (\$14), which becomes the expected payoff for Decision Node 2. Prune the “Do nothing” alternative.

Decision Node 1

2. The alternative to build a small plant has an expected payoff of **\$12.2 million** [or $0.70(14) + 0.30(8)$].
3. The alternative to build a large plant has an expected payoff of **\$14.1 million** [or $0.70(18) + 0.30(5)$].
4. Thus the best choice is to build a large plant because it has a higher expected payoff (**\$14.1 million**). Prune the small plant alternative.

Conclusion: Build the large facility, with an expected payoff of **\$14.1 million**.

20. Offshore Chemicals

The decision tree would have just one decision node with two branches (“build” and “do not build”). The “build” alternative is followed by an event node: “Facility works” (0.40) and “Facility fails” (0.60).

Decision Node 1

1. The “build” alternative has an expected payoff of **\$2,000,000** [or $0.4(\$20,000,000) + 0.6(-\$10,000,000)$]
2. The “do not build” has a payoff of **\$0**.
3. Thus the best choice, based on the expected value criterion, is to build. Prune the “Do not build” alternative.

Conclusion: Build the facility, with an expected payoff of **\$2 million**. Of course, political or environmental considerations might also influence the final decision.

Chapter

2 Project Management

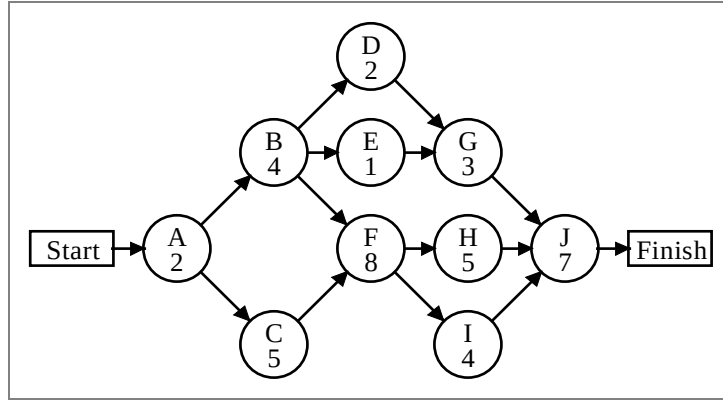
DISCUSSION QUESTIONS

1. Software is an essential element for successful management of complex projects. It can provide information on completion performance of critical activities, highlight activities that need additional resources, and suggest the project duration that will minimize costs. However, whether projects are large or small, the people who manage them or perform the activities will ultimately determine the outcome of the project. The project manager must have the ability to coalesce a diverse group of people into an effective team. The organization of the firm must also be conducive to cross-functional inputs.
2. Slack in a project is determined by calculating the early start time (ES) and the latest start time (LS) for each activity. The ES time for an activity is found by moving forward through the project network from the Start activity along the longest time path to that activity. Using the project's targeted completion date, the LS time is found by moving backward through the project network from the Finish node along the longest path to that activity. The difference $LS - ES$ determines the slack for that activity. Slack can also be calculated by taking the difference between the latest finish time (LF) and the earliest finish time (EF) for an activity. Managers need to know the slack for each activity because slack indicates how much the schedule for that activity can slip before the entire project is delayed. Activities with little or no slack need to be closely monitored. In addition, managers can move resources from activities enjoying sizeable slack to activities that have no slack or are falling behind schedule.
3. Risk is a measure of the probability and consequence of not reaching a project goal. There are four major sources of risk in a project: (1) Strategic fit, which reflects the synergy of the project to the firm's operations strategy. A lack of fit may cause myriad problems of resource allocation and managerial motivation. (2) If the project involves the introduction of a new service or product, competitor reactions, technological developments after the project has been initiated, and legal challenges brought on by unforeseen design consequences can all have a role in defining the success of the project. (3) The capability of the project team to tackle the specifications of the project play a major role in the success of the project. (4) There may be an operations risk introduced by poor information communication, poor design of the project network, or bad estimates for activity times.

PROBLEMS

1.

a. AON network diagram



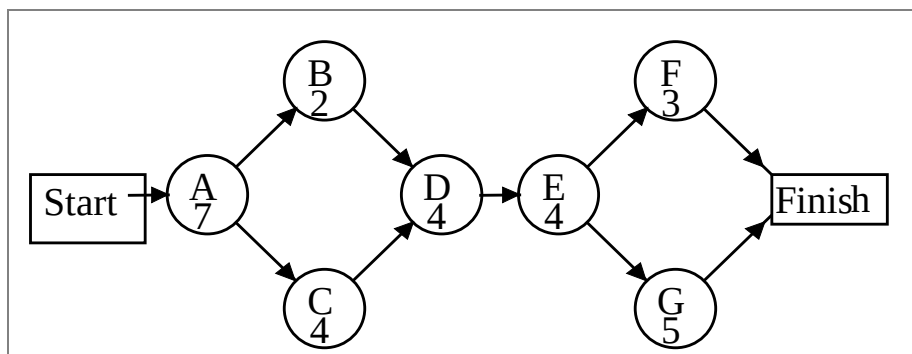
b. The critical path is A–C–F–H–J with a completion time of 27 days.

c.

Activity	Duration	Earliest Start	Latest Start	Earliest Finish	Latest Finish	Slack	On Critical Path?
A	2	0	0	2	2	0	Yes
B	4	2	3	6	7	1	No
C	5	2	2	7	7	0	Yes
D	2	6	15	8	17	9	No
E	1	6	16	7	17	10	No
F	8	7	7	15	15	0	Yes
G	3	8	17	11	20	9	No
H	5	15	15	20	20	0	Yes
I	4	15	16	19	20	1	No
J	7	20	20	27	27	0	Yes

2.

a. AON diagram



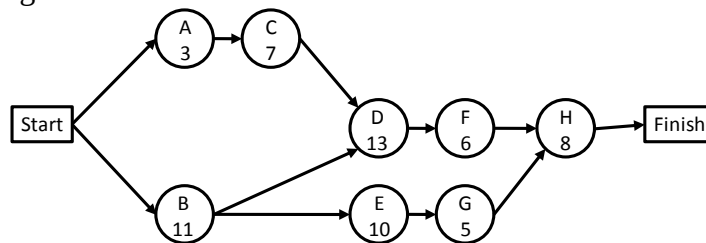
- b. The critical path is A–C–D–E–G with a completion time of 24 days.

Activity	Duration	Earliest Start	Latest Start	Earliest Finish	Latest Finish	Slack	On Critical Path?
A	7	0	0	7	7	0	Yes
B	2	7	9	9	11	2	No
C	4	7	7	11	11	0	Yes
D	4	11	11	15	15	0	Yes
E	4	15	15	19	19	0	Yes
F	3	19	21	22	24	2	No
G	5	19	19	24	24	0	Yes

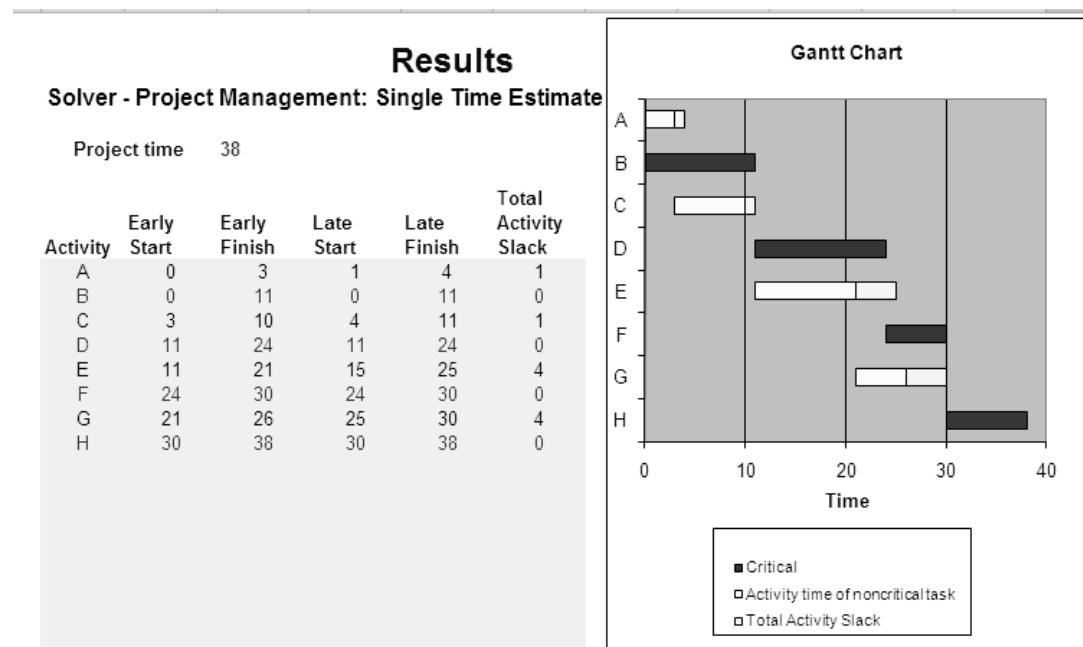
- c. Activities B and F are the only ones to have slack.

3. Billing process.

- a. AON diagram

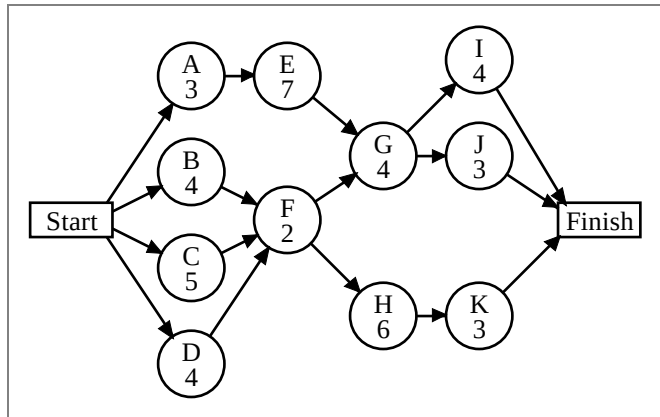


- b. The critical path is B–D–F–H with a completion time of 38 weeks. The computation of slack is provided in the following output from *Project Management Solver* of OM Explorer.



4.

a. AON diagram

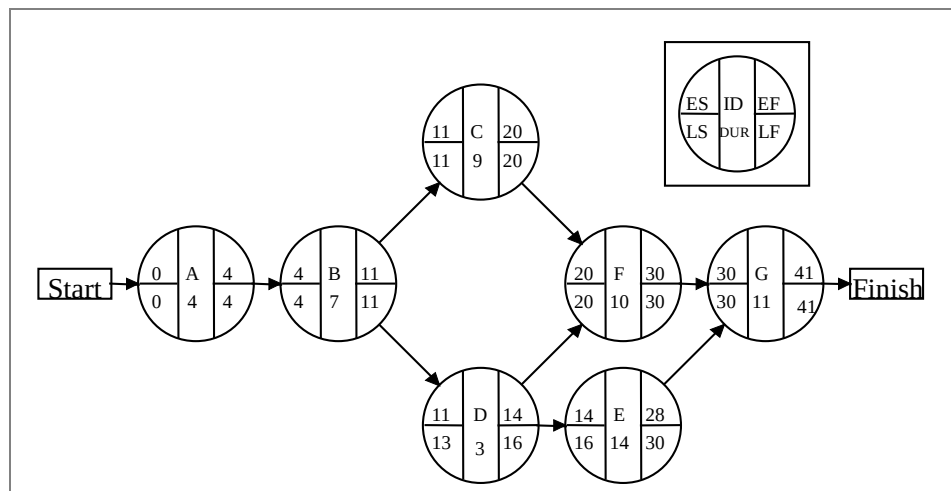


b. The critical path is A–E–G–I with a completion time of 18 days.

Activity	Duration	Earliest Start	Latest Start	Earliest Finish	Latest Finish	Slack	On Critical Path?
A	3	0	0	3	3	0	Yes
B	4	0	3	4	7	3	No
C	5	0	2	5	7	2	No
D	4	0	3	4	7	3	No
E	7	3	3	10	10	0	Yes
F	2	5	7	7	9	2	No
G	4	10	10	14	14	0	Yes
H	6	7	9	13	15	2	No
I	4	14	14	18	18	0	Yes
J	3	14	15	17	18	1	No
K	3	13	15	16	18	2	No

5.

a. The AON network is:



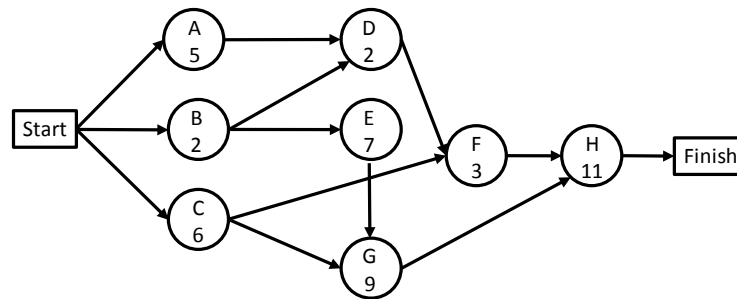
b. Activity slacks for the project:

Activity	Start		Finish		Slack	Critical Path?
	Earliest	Late	Earliest	Late		
A	0	0	4	4	0	Yes
B	4	4	11	11	0	Yes
C	11	11	20	20	0	Yes
D	11	13	14	16	2	No
E	14	16	28	30	2	No
F	20	20	30	30	0	Yes
G	30	30	41	41	0	Yes

Critical path is A–B–C–F–G, and the project completion date is week 41.

6. Crestview Bank.

a. The AON diagram is:



b. The critical path is B-E-G-H with a completion time of 29 weeks.

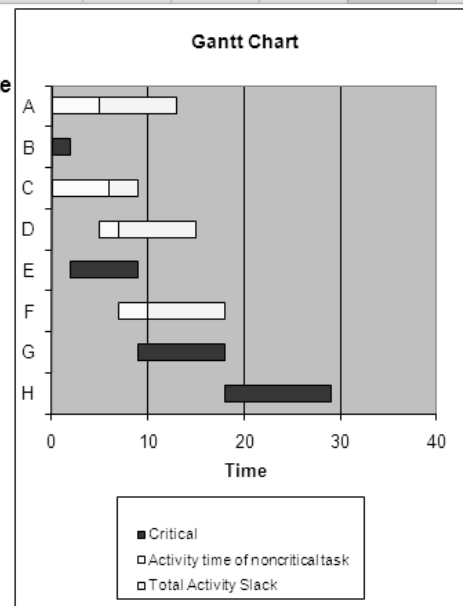
c. The computation of slack is provided in the following output from *Project Management Solver* of OM Explorer.

Results

Solver - Project Management: Single Time Estimate

Project time 29

Activity	Early Start	Early Finish	Late Start	Late Finish	Total Activity Slack
A	0	5	8	13	8
B	0	2	0	2	0
C	0	6	3	9	3
D	5	7	13	15	8
E	2	9	2	9	0
F	7	10	15	18	8
G	9	18	9	18	0
H	18	29	18	29	0



The slack for activity A = $13 - 5 = 8$ weeks.

The slack for activity D = $15 - 7 = 8$ weeks.

7. Web Ventures Inc.

Activity	Activity Statistics				
	Optimistic (a)	Most Likely (m)	Pessimistic (b)	Expected Time (t_e)	Variance (σ^2)
A	3	8	19	9	7.11
B	12	15	18	15	1.00
C	2	6	16	7	5.44
D	4	9	20	10	7.11
E	1	4	7	4	1.00

a.

$$t_e A = (3 + 4(8) + 19) / 6 = 54 / 6 = 9 \text{ days}$$

$$t_e B = (12 + 4(15) + 18) / 6 = 90 / 6 = 15 \text{ days}$$

$$t_e C = (2 + 4(6) + 16) / 6 = 42 / 6 = 7 \text{ days}$$

$$t_e D = (4 + 4(9) + 20) / 6 = 60 / 6 = 10 \text{ days}$$

$$t_e E = (1 + 4(4) + 7) / 6 = 24 / 6 = 4 \text{ days}$$

b.

$$\sigma^2 A = ((19 - 3) / 6)^2 = 7.11$$

$$\sigma^2 B = ((18 - 12) / 6)^2 = 1.00$$

$$\sigma^2 C = ((16 - 2) / 6)^2 = 5.44$$

$$\sigma^2 D = ((20 - 4) / 6)^2 = 7.11$$

$$\sigma^2 E = ((7 - 1) / 6)^2 = 1.00$$

8.

a. The expected activity times (in days) are:

Activity	Optimistic	Most Likely	Pessimistic	t_e	σ^2
A	5	8	11	8.00	1.00
B	4	8	11	7.83	1.36
C	5	6	7	6.00	0.11
D	2	4	6	4.00	0.44
E	4	7	10	7.00	1.00

Path	Total Expected Time
A-C	$8 + 6 = 14.00$
A-D-E	$8 + 4 + 7 = 19.00$
B-E	$7.83 + 7 = 14.83$

The critical path is A–D–E because it has the longest time duration. The expected completion time is 19 days.

$$b. \quad z = \frac{T - T_E}{\sigma_p}$$

Where $T = 21$ days, $T_E = 19$ days, and the sum of the variances for critical path A–D–E is $(1.00 + 0.44 + 1.00) = 2.44$.

$$z = \frac{21 - 19}{\sqrt{2.44}} = \frac{2}{1.562} = 1.28$$

Assuming the normal distribution applies (which is questionable for a sample of three activities), we use the table for the normal probability distribution. Given $z = 1.28$, the probability that the project can be completed in 21 days is 0.8997, or about 90%.

- c. Because the normal distribution is symmetrical, the probability the project can be completed in 17 days is $(1 - 0.8997) = 0.1003$, or about 10%.

9. Solved Problem 2.

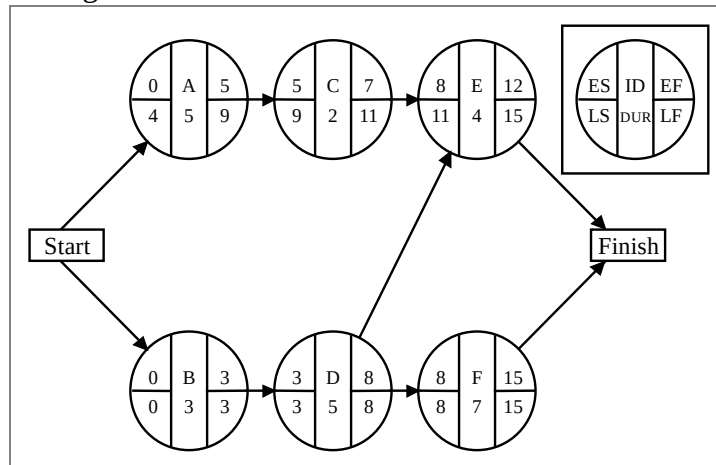
$$z = \frac{T - T_E}{\sigma_p}$$

Where $T = 20$ weeks, $T_E = (5.5 + 9.0 + 4.5) = 19$ weeks, and the sum of the variances for critical path B–F–G is $(0.69 + 2.78 + 0.69) = 4.16$.

Assuming the normal distribution applies, we use the table for the normal probability distribution. Given $z = 0.49$, the probability for activities B–F–G taking longer than 20 weeks is $(1 - 0.6879)$, or 31.21%.

10.

- a. The AON diagram is:



- b. Critical path is B–D–F. Expected duration of the project is 15 weeks.
 c. Activity slacks for the project are:

Activity	Start		Finish		Slack	Critical Path?
	Earliest	Latest	Earliest	Latest		
A	0	4	5	9	4	No
B	0	0	3	3	0	Yes
C	5	9	7	11	4	No
D	3	3	8	8	0	Yes
E	8	11	12	15	3	No
F	8	8	15	15	0	Yes

11. Bluebird University.

Calculation of activity statistics (in days):

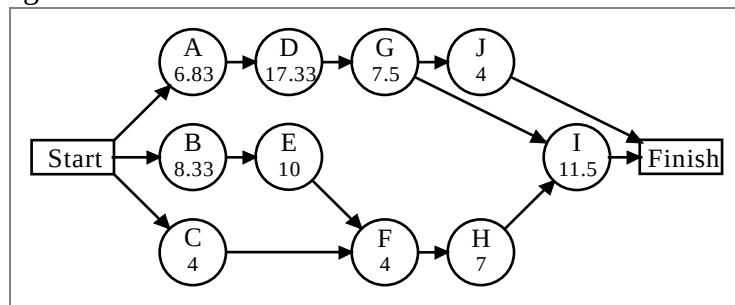
Project time 43.16667

Project standard deviation
Project variance

2.939
8.639

Activity	Expected Time	Standard deviation	Variance	Early Start	Early Finish	Late Start	Late Finish	Total Activity Slack
A	6.83	0.50	0.25	0.00	6.83	0.00	6.83	0.00
B	8.33	1.00	1.00	0.00	8.33	2.33	10.67	2.33
C	4.00	0.33	0.11	0.00	4.00	16.67	20.67	16.67
D	17.33	2.33	5.44	6.83	24.17	6.83	24.17	0.00
E	10.00	0.67	0.44	8.33	18.33	10.67	20.67	2.33
F	4.00	0.33	0.11	18.33	22.33	20.67	24.67	2.33
G	7.50	0.83	0.69	24.17	31.67	24.17	31.67	0.00
H	7.00	0.67	0.44	22.33	29.33	24.67	31.67	2.33
I	11.50	1.50	2.25	31.67	43.17	31.67	43.17	0.00
J	4.00	0.00	0.00	31.67	35.67	39.17	43.17	7.50

The AON diagram is:



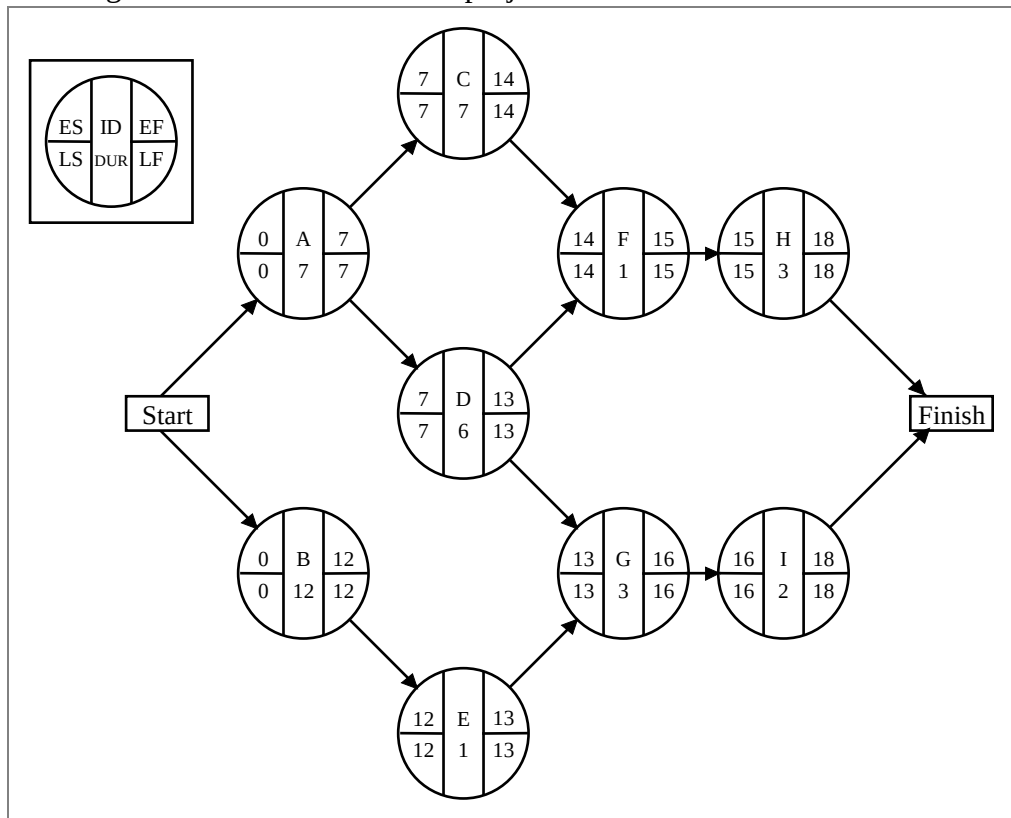
The critical path is A–D–G–I, and the expected completion time is 43.17 days.

$T = 47$ days, $T_E = 43.17$ days, and the sum of the variances for the critical activities is: $(0.25 + 5.44 + 0.69 + 2.25) = 8.63$.

$$z = \frac{T - T_E}{\sigma_p} = \frac{47 - 43.17}{\sqrt{8.63}} = \frac{3.83}{2.94} = 1.30$$

Assuming the normal distribution applies, we use the table for the normal probability distribution. Given $z = 1.30$, the probability that activities A–D–G–I can be completed in 47 days or less is 0.9032.

12. AON Diagram for the environmental project:



Trial	Crash Activity	Resulting Critical Path	Time Reduction (weeks)	Project Duration (weeks)	Crash Cost
0	—	A-C-F-H A-D-G-I B-E-G-I	—	18	0
1	A, G	A-C-F-H B-E-G-I	1	17	\$400
2	C, G	A-C-F-H A-D-F-H B-E-G-I	1	16	\$450
3	B, H	A-C-F-H A-D-F-H A-D-G-I B-E-G-I	1	15	\$600

Total crash costs = \$1450

To use OM Explorer for this problem, you need to modify the input data a little. The problem already gives the cost to crash per week for each activity. Since OM Explorer assumes it must calculate these values, multiply the number of weeks the activity can be crashed by the cost per week given in the problem

statement, e.g., for activity B, $\$250(3) = \$750$. The input sheet and the resulting crash schedule should look like the exhibits below.

Solver - Crashing

Enter data in yellow shaded areas.

Indirect cost \$ 1,600 per week
 Penalty cost \$ 1,200 per week after week 12

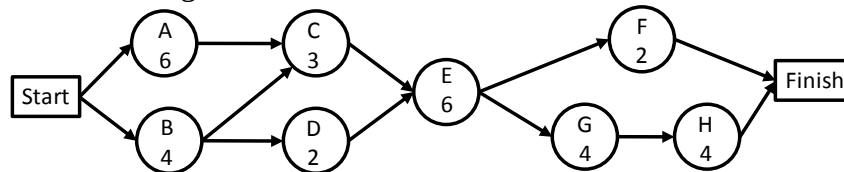
Activity	Normal Time	Normal Cost	Crash Time	Crash Cost	Precedence 1	Precedence 2	Precedence 3	Precedence 4
a	7	0	6	200				
b	12	0	9	750				
c	7	0	6	250	a			
d	6	0	5	300	a			
e	1	0	1	0	b			
f	1	0	1	0	c	d		
g	3	0	1	400	d	e		

CRASH SCHEDULE (Reduction in Time Periods)

Period	crash	Cumulative	Indirect	Direct	Penalty	Total	a	b	c	d	e	f	g	h	i
Time	cost	crash cost	costs	costs	costs	costs									
18			28,800	0	7,200	36,000									
17	400	400	27,200	0	6,000	33,600	1						1		
16	450	850	25,600	0	4,800	31,250	1		1				2		
15	600	1,450	24,000	0	3,600	29,050	1	1	1				2	1	

13. Advanced Tech

- a. The AON diagram, with all task durations at Normal Time, for the project is:



The critical path is A-C-E-G-H and the project duration is 23 days.

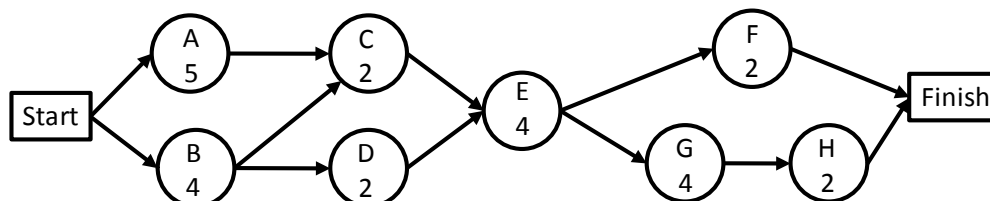
- b. The computation of minimum-cost schedule is provided in the following output from POM for Windows software.

Project time	Period crash cost	Cumulative crash cost	Original costs	Indirect costs	Penalty costs	Total project cost
23	0	0	7500	6900	1350	15750
22	150	150	7500	6600	1200	15450
21	150	300	7500	6300	1050	15150
20	200	500	7500	6000	900	14900
19	200	700	7500	5700	750	14650
18	200	900	7500	5400	600	14400
17 Minimal cost schedule	300	1200	7500	5100	450	14250

The minimum-cost schedule is found at a project duration of 17 days and total project cost of \$14,250

- c. The activities crashed to arrive at the minimum-cost schedule is provided in the following output from POM for Windows software.

Project Management (PERT/CPM) Results							
	Normal time	Crash time	Normal Cost	Crash Cost	Crash cost/pd	Crash by	Crashing cost
Project	23					17	
A	6	5	1000	1200	200	1	200
B	4	2	800	2000	600	0	0
C	3	2	600	900	300	1	300
D	2	1	1500	2000	500	0	0
E	6	4	900	1200	150	2	300
F	2	1	1300	1400	100	0	0
G	4	4	900	900	0	0	0
H	4	2	500	900	200	2	400
Direct costs			7500				7500
Indirect costs			6900				5100
Penalty costs			1350				450
Crashing costs			0				1200
Total costs			15750			Min cost	14250



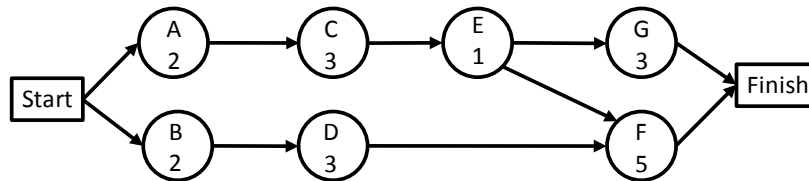
The critical path is A-C-E-G-H, and the project duration is 17 days.

14. Billing process.

- The critical path at the start is B-D-F at a duration of 18 weeks. We proceed as follows: (1) Crash Activity B to its maximum reduction because it is the cheapest activity on the critical path to crash per week and costs less than \$2,800, the sum of the indirect and penalty costs. The savings is \$3,600. The critical path is still B-D-F at a length of 16 weeks. (2) Reduce Activity D by 3 weeks for an additional savings of \$2,400. The critical path is still B-D-F at a duration of 13 weeks. No further reductions will lower total costs because the cost to crash the other activities (that is, Activity F) exceeds the potential reduction in indirect costs. Therefore, the minimum-cost schedule is 13 weeks.
- The “normal” direct cost is \$31,000, the “normal” indirect costs are \$28,800, the penalty costs are \$7,200, and the total for the normal schedule is \$67,000. The cost for the schedule in part a is \$31,000 + \$8,000 (crash costs) + \$20,800 (indirect costs) + \$1200 (penalty) = \$61,000. The total savings is \$6,000.

15. Excello Corporation..

- a. The shortest project duration time would be 7 weeks (path B-D-F), using the crash times.
- b. AON diagram with all task durations at Normal Time



The critical path is A-C-E-F with a project completion time of 11 weeks. The computation of minimum-cost schedule is provided in the following output from POM for Windows software.

Project time	Period crash cost	Cumulative crash cost	Original costs	Indirect costs	Penalty costs	Total project cost	A	B	C	D	E	F	G
11	0	0	56000	165000	18000	239000							
10	3000	3000	56000	150000	9000	218000	1						
9	5000	8000	56000	135000	0	199000	1					1	
8 Minimal cost schedule	5000	13000	56000	120000	0	189000	1					2	
7	30000	43000	56000	105000	0	204000	1		1	1		2	

Since the “normal” project time is 11 weeks, the total normal “direct” cost is \$56,000. There would also be indirect costs of \$165,000 over the 11-week period. The penalty cost would be \$18,000. The grand total is \$239,000.

Likewise, the minimum-cost schedule for completing the project in 9 weeks has a total project cost of \$199,000.

- c. The crashing required to arrive at the minimum-cost schedule is provided in the following output from POM for Windows software.

	Normal time	Crash time	Normal Cost	Crash Cost	Crash cost/wk	Crash by	Crashing cost
Project	11					8	
A	2	1	7000	10000	3000	1	3000
B	2	2	3000	3000	0	0	0
C	3	1	12000	40000	14000	0	0
D	3	2	12000	28000	16000	0	0
E	1	1	8000	8000	0	0	0
F	5	3	5000	15000	5000	2	10000
G	3	2	9000	18000	9000	0	0
Direct costs			56000				56000
Indirect costs			165000				120000
Penalty costs			18000				0
Crashing costs			0				13000
Total costs			239000			Min cost	189000

The minimum-cost schedule would take 8 weeks. This can be found in the following way: (1) the starting critical path is A-C-E-F at 11 weeks. Since Activity A is the cheapest to crash per week, crash it one week for an additional cost of \$3000. The savings is \$15,000 (indirect costs) + \$9,000 (penalty costs) - \$3,000 = \$21,000. The project duration is now 10 weeks. (2) Since Activity A cannot be crashed further, the next cheapest activity to crash that is on the critical path is Activity F. Crash F for its maximum of two weeks at an

additional cost of \$10,000. The savings would be \$30,000 (indirect costs) + \$18,000 (penalty costs) - \$10,000 = \$38,000.

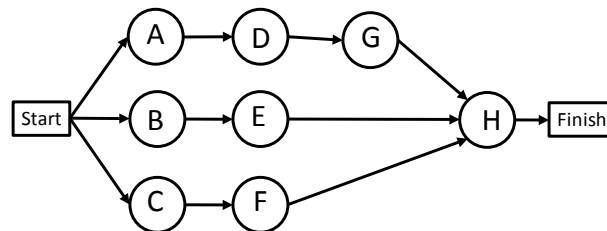
The critical path is now 8 weeks in duration. Since the penalty costs are zero for further reductions, there are no other options to reduce the project time that are less costly than the indirect costs per week. Therefore, we stop.

16. Pet Paradise

- a. Calculation of the activity statistics is provided in the following output from POM for Windows software:

	Expected Time	Early Start	Early Finish	Late Start	Late Finish	Slack	Variance
Project	17						2.78
A	3.17	0	3.17	6.83	10	6.83	.69
B	9	0	9	1	10	1	1
C	9	0	9	0	9	0	2.78
D	3	3.17	6.17	10	13	6.83	.11
E	4	9	13	10	14	1	2.78
F	5	9	14	9	14	0	0
G	1	6.17	7.17	13	14	6.83	0
H	3	14	17	14	17	0	0

The AON diagram for the hiring project is:

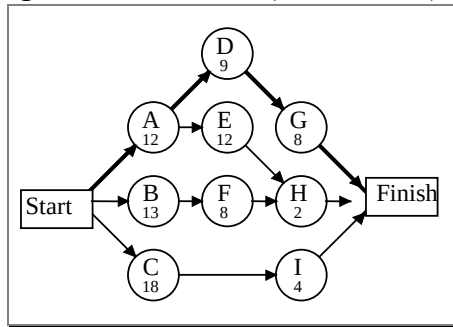


The critical path is C-F-H with an expected project completion time of 17 weeks.

$$b. \quad z = \frac{T - T_E}{\sqrt{\sigma^2}} = \frac{14 - 17}{\sqrt{2.78}} = -1.799$$

Using the normal distribution table, the probability of project completion within 14 weeks is (1-.9641=.0359) or a 3.6% chance.

17. An AON diagram using the Alternative 1 (or “normal”) times follows.



The critical path is A–D–G, and the project duration is 29 days.
Direct cost and time data:

Activity	Crash Cost/Day	Maximum Crash Time (days)
A	\$600.00	1
B	112.50	4
C	750.00	2
D	250.00	4
E	225.00	2
F	350.00	1
G	200.00	2
H	200.00	1
I	900.00	2

Cost analysis for the project:

Trial	Crash Activity	Resulting Critical Path	Time Reduction (weeks)	Project Duration (weeks)	Crash Cost
0	—	A–D–G	—	29	—
1	G	A–D–G	2	27	400
2	D	A–D–G A–E–H	1	26	250
3	D, H	A–D–G A–E–H	1	25	450

The total cost for this project is:

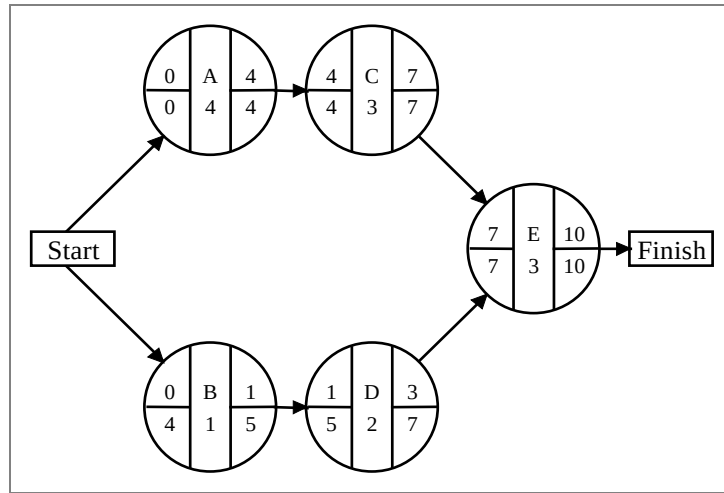
$$\$13,050 + \$400 + \$250 + \$450 = \$14,150.00$$

The activity times with crashing are:

A: 12 B: 13 C: 18 D: 7 E: 12
F: 8 G: 6 H: 1 I: 4

18. Sculptures International

a. The AON diagram for this project is:



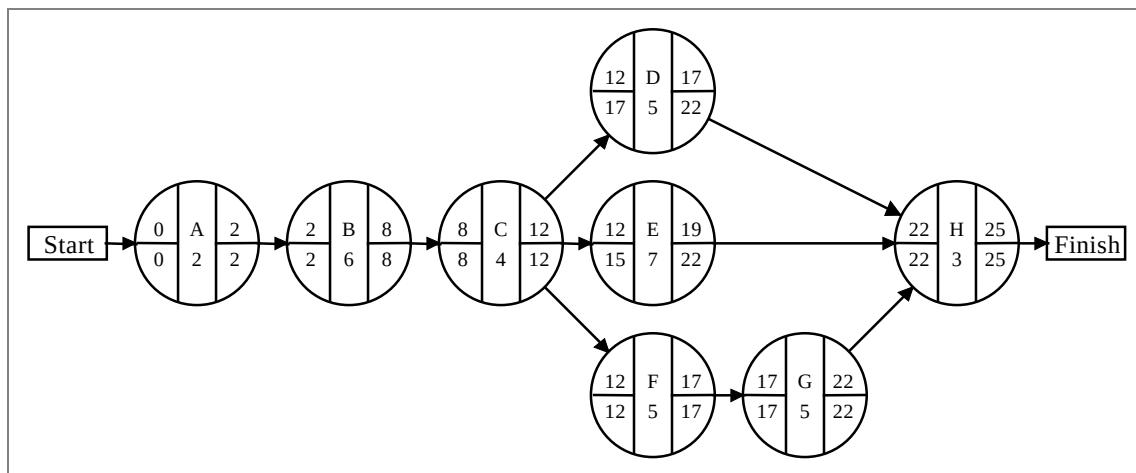
b. The critical path is A–C–E, and the project duration is 10 days.

c.

Activity	Activity Slack
A	0
B	$5 - 1 = 4$
C	0
D	$7 - 3 = 4$
E	0

19. Reliable Garage

a. The AON diagram is:



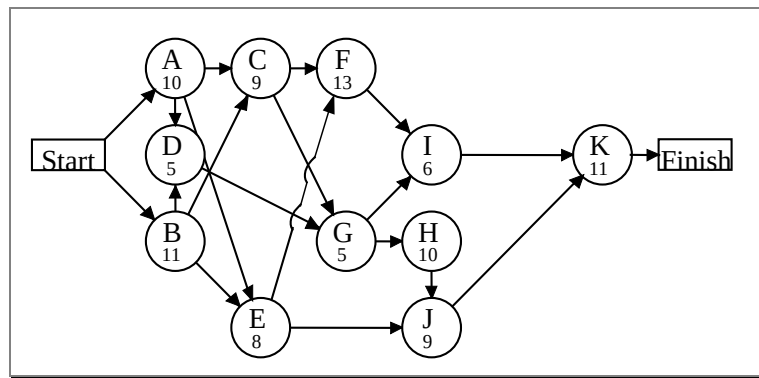
b. Critical Path is A–B–C–F–G–H, and the duration is 25 days.

c.

Activity	Activity Slack
A	0
B	0
C	0
D	$22 - 17 = 5$
E	$22 - 19 = 3$
F	0
G	0
H	0

20.

a. The AON diagram is shown below.



b. The critical path is B–C–G–H–J–K, and the expected project duration is 55 days.

21. Good Public Relations.

a. Calculation of the activity statistics:

Project time 36.333333

Project standard deviation

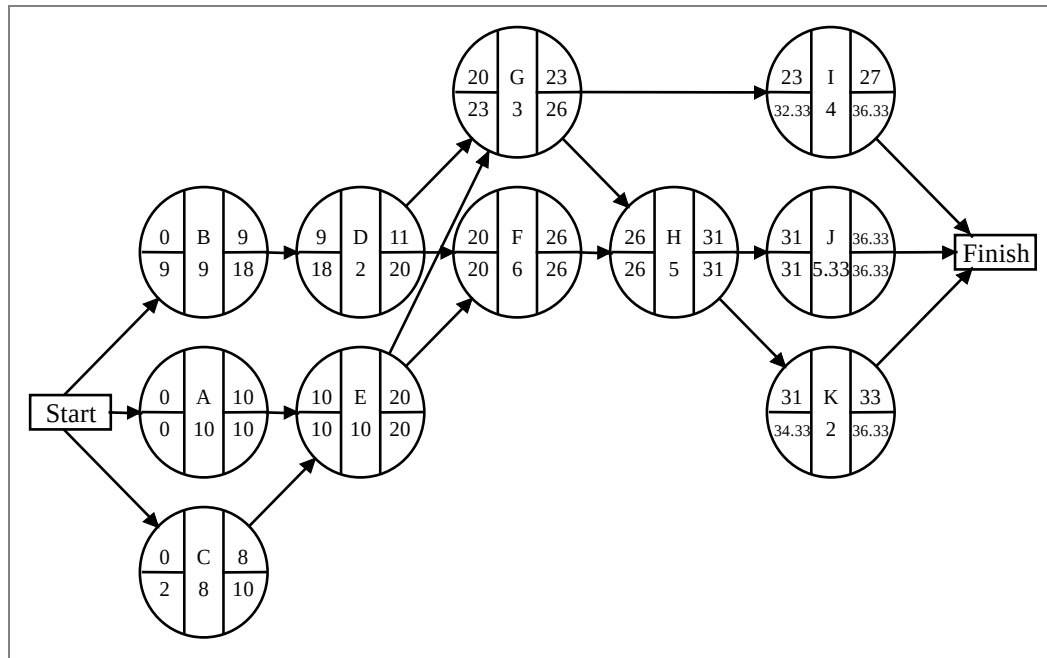
1.563

Project variance

2.444

Activity	Expected Time	Standard deviation	Variance	Early Start	Early Finish	Late Start	Late Finish	Total Activity Slack
A	10.00	0.67	0.44	0.00	10.00	0.00	10.00	0.00
B	9.00	2.00	4.00	0.00	9.00	9.00	18.00	9.00
C	8.00	0.33	0.11	0.00	8.00	2.00	10.00	2.00
D	2.00	0.33	0.11	9.00	11.00	18.00	20.00	9.00
E	10.00	0.67	0.44	10.00	20.00	10.00	20.00	0.00
F	6.00	0.33	0.11	20.00	26.00	20.00	26.00	0.00
G	3.00	0.67	0.44	20.00	23.00	23.00	26.00	3.00
H	5.00	1.00	1.00	26.00	31.00	26.00	31.00	0.00
I	4.00	0.67	0.44	23.00	27.00	32.33	36.33	9.33
J	5.33	0.67	0.44	31.00	36.33	31.00	36.33	0.00
K	2.00	0.00	0.00	31.00	33.00	34.33	36.33	3.33

The AON diagram for the advertising campaign is shown below.



The critical path is A–E–F–H–J, the expected project duration is 36.33 days, and the sum of the variances of the critical path activities is

$$(0.44 + 0.44 + 0.11 + 1.00 + 0.44) = 2.43$$

$$\text{b. } z = \frac{T - T_E}{\sigma_p} = \frac{38 - 36.33}{\sqrt{2.43}} = \frac{1.67}{1.56} = 1.07$$

The probability that the project will take more than 38 days is

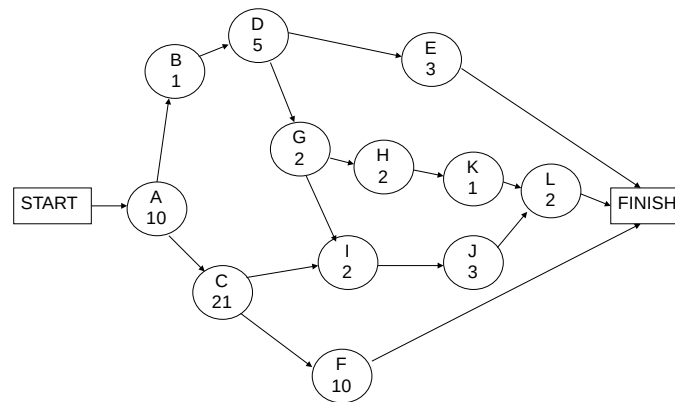
$$1 - 0.8577 \text{ or } 0.1423$$

c. The path A–E–G–H–J has a duration of 33.33 weeks with variance of 2.76.

$$\text{Therefore, } z = \frac{T - T_E}{\sigma_p} = \frac{38 - 33.33}{\sqrt{2.76}} = 2.81$$

The probability that the path A–E–G–H–J exceeds 38 weeks is $1 - 0.9975$, or 0.0025.

22. The AON diagram for the office renovation project is below.



The calculations of the time statistics are contained in the following table.

Activity	Optimistic	Most Likely	Pessimistic	Expected Time	Variance
START	0	0	0	-----	-----
A	6	10	14	10	1.78
B	0	1	2	1	0.11
C	16	20	30	21	5.44
D	3	5	7	5	0.44
E	2	3	4	3	0.11
F	7	10	13	10	1.00
G	1	2	3	2	0.11
H	0	2	4	2	0.44
I	2	2	2	2	0.00
J	2	3	4	3	0.11
K	0	1	2	1	0.11
L	1	2	3	2	0.11
FINISH	0	0	0	-----	-----

- a. The critical path is A – C - F at 41 days.

$$\text{Standard Deviation} = \text{SQRT}(1.78 + 5.44 + 1.00) = 2.867.$$

$z = (41 - 39) / 2.867 = 0.698$, which can be rounded to 0.70. From the normal tables, $P(z) = 0.758$. Therefore, $P(T < 39 \text{ days}) = 1.000 - 0.758 = 24 \text{ percent}$.

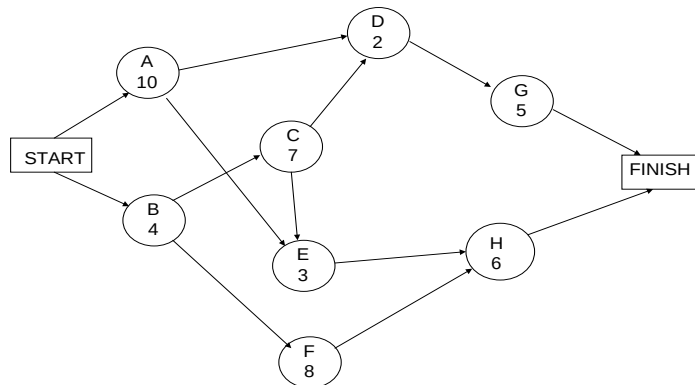
- b. We want to find the project completion time so that the probability of completion is 90 percent. The z value for 90 percent is 1.28. Consequently,

$$(T - 41) / 2.867 = 1.28$$

$$T = 1.28 (2.867) + 41$$

$$T = 44.7, \text{ or about } 45 \text{ days.}$$

23. The AON diagram for the community center project is below.



The crashing data are given in the following table.

Activity	Normal		Crash		Maximum Reduction	\$ per Day
	Time (days)	Cost (\$)	Time (days)	Cost (\$)		
START	0	0	0	0	-----	-----
A	10	50	8	150	2	50
B	4	40	2	200	2	80
C	7	70	6	160	1	90
D	2	20	1	50	1	30
E	3	30	NONE	NONE	NONE	NONE
F	8	80	5	290	3	70
G	5	50	4	180	1	130
H	6	60	3	180	3	40
FINISH	0	0	0	0	-----	-----

a. The critical path is B – C – E – H at 20 days.

b. STAGE 1

Critical path is B – C – E – H at 20 days. Crash H for 2 days. You are stopped by path B – C – D – G.

Savings: $2(50 + 40) - 2(40) = \$100$.

STAGE 2

There are two critical paths: B – C – E – H and B – C – D – G at 18 days. Crash H and D each for 1 day. Savings: $1(50 + 40) - 1(40 + 30) = \$20$.

STAGE 3

There are two critical paths: B – C – E – H and B – C – D – G at 17 days. Crash B 1 day. You are constrained by a new path, A – E – H and A – D – G. Savings: $1(50 + 40) - 1(80) = \$10$.

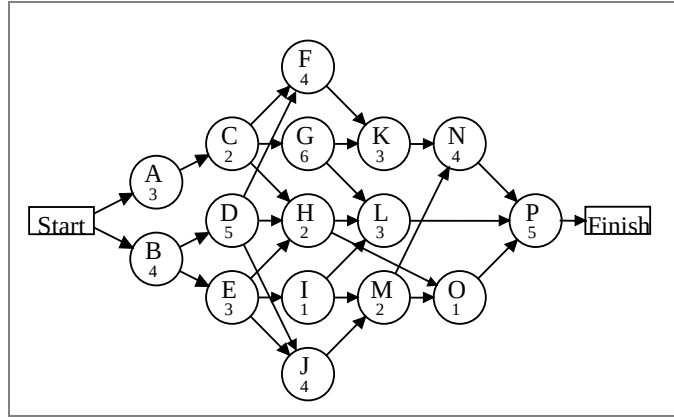
STAGE 4

There are now four critical paths: B – C – E – H, B – C – D – G, A – E – H and A – D – G each at 16 days. The only option is to crash both A and B; however the total cost of \$130 per day exceeds the potential savings. Therefore, stop.

$$\text{Total Cost} = 16(50) + 2(40) + 400 + 80 + 70 + 80 = \$1,510.$$

24.

a. AON diagram for the fund-raising project



Activity slacks for the project:

Results					
Solver - Project Budgeting					
Project time		25	Project Budget		\$2,125
Activity	Early Start	Early Finish	Late Start	Late Finish	Total Activity Slack
A	0	3	2	5	2
B	0	4	0	4	0
C	3	5	5	7	2
D	4	9	4	9	0
E	4	7	7	10	3
F	9	13	9	13	0
G	5	11	7	13	2
H	9	11	15	17	6
I	7	8	13	14	6
J	9	13	10	14	1
K	13	16	13	16	0
L	11	14	17	20	6
M	13	15	14	16	1
N	16	20	16	20	0
O	15	16	19	20	4
P	20	25	20	25	0

The critical path is B–D–F–K–N–P, and the expected completion time is 25 days.

b. Project cost with the earliest start time for each activity:

Project time 25 Project Budget \$ 2,125

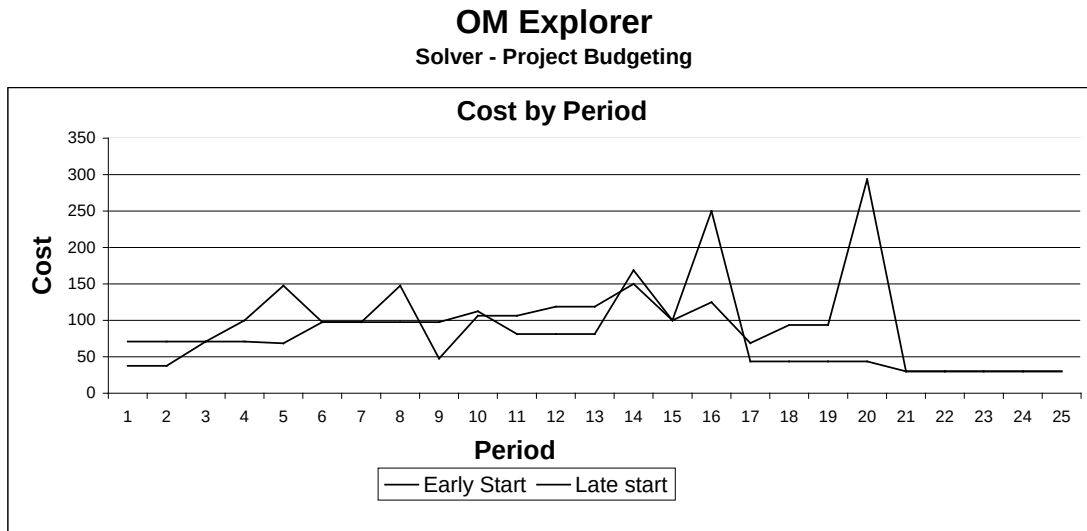
Period	Total	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	70.83	33.33	37.50														
2	70.83	33.33	37.50														
3	70.83	33.33	37.50														
4	100.00		37.50	62.50													
5	147.50			62.50	35.00	50.00											
6	97.50				35.00	50.00		12.50									
7	97.50				35.00	50.00		12.50									
8	147.50				35.00			12.50		100.00							
9	47.50				35.00			12.50									
10	106.25						50.00	12.50	25.00		18.75						
11	106.25						50.00	12.50	25.00		18.75						
12	118.75						50.00				18.75	50.00					
13	118.75						50.00				18.75	50.00					
14	150.00											50.00	50.00	50.00			
15	100.00											50.00		50.00			
16	250.00											50.00				200.00	
17	43.75														43.75		
18	43.75														43.75		
19	43.75														43.75		
20	43.75														43.75		
21	30.00																30.00
22	30.00																30.00
23	30.00																30.00
24	30.00																30.00
25	30.00																30.00

Project cost with the latest start times for each activity:

Project time 25 Project Budget \$ 2,125

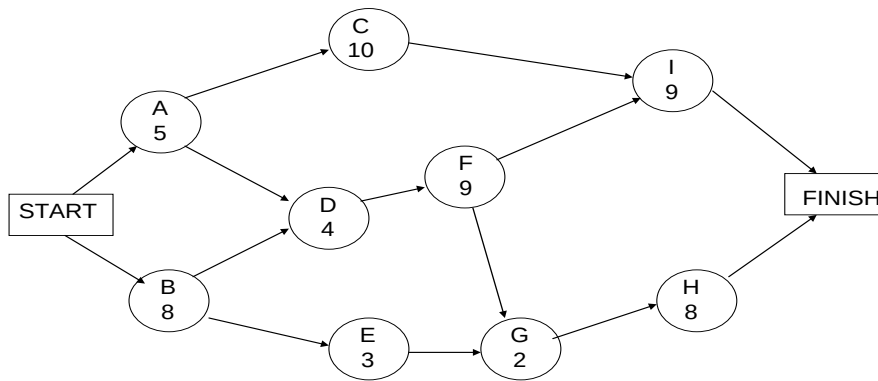
Period	Total	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	37.50		37.50														
2	37.50		37.50														
3	70.83	33.33	37.50														
4	70.83	33.33	37.50														
5	68.33	33.33			35.00												
6	97.50			62.50	35.00												
7	97.50			62.50	35.00												
8	97.50				35.00	50.00		12.50									
9	97.50				35.00	50.00		12.50									
10	112.50					50.00	50.00	12.50									
11	81.25						50.00	12.50			18.75						
12	81.25						50.00	12.50			18.75						
13	81.25						50.00	12.50			18.75						
14	168.75								100.00	18.75	50.00						
15	100.00										50.00		50.00				
16	125.00								25.00		50.00		50.00				
17	68.75								25.00						43.75		
18	93.75												50.00		43.75		
19	93.75												50.00		43.75		
20	293.75												50.00		43.75	200.00	
21	30.00																30.00
22	30.00																30.00
23	30.00																30.00
24	30.00																30.00
25	30.00																30.00

Cost by day is plotted for Early Start and Late Start Schedules.



These two plots indicate the patterns of cash flow associated with the two different project schedules. Management can select the schedule that fits better with its financial status. Notice that the latest start dates delay cash flow requirements to the later time periods of the project.

25. The AON diagram for the software installation project is below.



The crashing data are given in the following table.

Activity	Normal Time	Normal Cost	Crash Time	Crash Cost	Max reduction	\$ per Week
A	5	\$2,000	3	\$4,000	2	1,000
B	8	\$5,000	7	\$8,000	1	3,000
C	10	\$10,000	8	\$12,000	2	1,000
D	4	\$3,000	3	\$7,000	1	4,000
E	3	\$4,000	2	\$5,000	1	1,000
F	9	\$8,000	6	\$14,000	3	2,000
G	2	\$2,000	2	\$2,000	NONE	NONE
H	8	\$6,000	5	\$9,000	3	1,000
I	9	\$7,000	7	\$15,000	2	4,000

a. STAGE 1

The critical path is B – D – F – G – H at 31 weeks. Crash H by 1 week because you are constrained by path B – D – F – I. Savings: $1(3,500) - 1(1,000) = \$2,500$.

STAGE 2

There are two critical paths: B – D – F – G – H and B – D – F – I at 30 weeks. Crash F for 3 weeks. Savings: $3(3,500) - 3(2,000) = \$4,500$.

STAGE 3

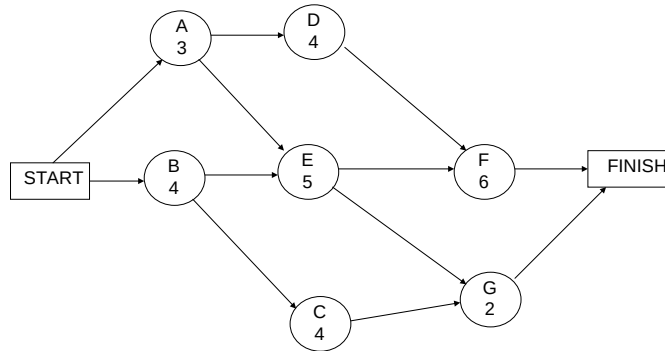
There are still two critical paths: B – D – F – G – H and B – D – F – I at 27 weeks. Crash B for 1 week. Savings: $1(3,500) - 1(3,000) = \$500$.

STAGE 4

There are still two critical paths: B – D – F – G – H and B – D – F – I at 26 weeks. All options cost more than the potential savings. Therefore, stop. Your target completion week is week 26.

b. Total Savings = $\$2,500 + \$4,500 + \$500 = \$7,500$.

26. The AON diagram for the project is below.



Additional data for the project are contained in the following table.

Activity	Time (weeks)	Early Start	Late Start	Slack
START	0	0	0	0
A	3	0	1	1
B	4	0	0	0
C	4	4	9	5
D	4	3	5	2
E	5	4	4	0
F	6	9	9	0
G	2	9	13	4
FINISH	0	15	15	0

- The critical path is B – E – F. The project will be finished in week 15.
- Activity G is on a path with 4 weeks of slack; however each week Employee A spends at Activity F, F's time goes down a week while G's goes up a week. Consequently, assigning Employee A to Activity F for 2 weeks will result in two critical paths: B – E – F at 13 weeks and B – E – G at 13 weeks. Assigning Employee A to Activity F for any more time than that will actually increase the project's time from the low of 13 weeks.

CASE: THE PERT MUSTANG *

A. Synopsis

The owner of the Roberts' Auto Sales and Service Company is interested in restoring a 1965 Shelby Mustang GT 350 for advertising a new restoration business she wants to start. The restoration project involves 22 activities and needs to be completed in 45 days so that the car can be displayed in an auto show. The owner wants an assessment of how the restoration business fits with the other businesses the company engages in, a report on the activities that need to be completed and their interrelationships, an assessment of whether the project can be completed on time, and a budget.

B. Purpose

This case provides enough data for the student to develop a PERT/CPM network for a project involving 22 activities. With this case, the class can:

- ☐ Discuss how well a new market segment can be satisfied with an existing operation.
- ☐ Gain experience in identifying the relationships between activities in a large project.
- ☐ Relate cost to the development of a project.

C. Analysis

1. The restoration business, although entailing much of the skills and resources needed for the other market segments the company serves, needs to be evaluated carefully before making a commitment. Currently, the company has three car dealerships, two auto parts stores, one body/paint shop, and one auto storage yard. These operations would be useful for the restoration business. However, the nature of the markets served by these operations is not made explicit in the case. Some questions come to mind:
 - a. Are the auto parts stores equipped to provide customers with "one-of-a-kind" parts? Restoration parts are hard to find and require access and familiarity with different information systems.
 - b. Does the body/paint shop have the ability to do custom, high-quality work, with restoration of rusty parts, or is it a high-volume operation with minimal capability to restore *any* car to its original condition?
 - c. Does the machine shop have the capability to machine one part at a time to unique specifications if the restoration part cannot be purchased from a supplier?

* This case was prepared by Dr. Sue Perrott Siferd, Arizona State University, as a basis for classroom discussion (Updated September, 2007).

- d. How useful will the salvage yard be for the restoration business? There must be a broad mix of vintage age autos in the yard in order to support the new business.

The competitive priorities for the restoration business most likely will be top quality and customization in a low-volume environment. It would seem that these competitive priorities could conflict with other market segments the company serves.

2. The project activities and the precedence relationships are given in Exhibit TN.1.
3. A PERT/CPM diagram is shown in Exhibit TN.2. The latest finish data are set for 45 days from present, which would be the day before the car must be in the show. The critical path is A–B–T–V, and the expected project duration is 41 days. The slack of each event along the critical path is 4 days, suggesting no problem in completing the project on time.
4. A project budget is shown in Exhibit TN.3. The project will meet the goal of staying below \$70,000.

A cash-flow report is shown in Exhibit TN.4. It is aggregated by weekly time periods. Activities B, C, and D are assumed to be paid when the item is received (on its early finish time). We assume that if an activity is scheduled to start during a week, the total cost is prorated for that week and following weeks. If MS Project is used for this analysis, the calendar date the students use for the start of the project may affect the weeks in which certain costs may accrue. Also, MS Project assumes a five-day workweek as a default. From Exhibit TN.4 it appears that there is a cash flow problem in week 2 because the cash required exceeds \$3,600. To resolve the problem, use the activity slack that is available and schedule one or more activities to start later than their earliest start times. For example, Activity D, receive carburetor and oil pump, has slack of 16 days (see Exhibit TN.2). Activity D could be scheduled to start in Week 3 so that it is completed in Week 4, thereby pushing the payment to Week 4. Note that Week 4 would now have \$3,550 in cash requirements, just below the constraint of \$3,600.

D. Recommendations

The owner should:

1. Carefully evaluate the potential conflicts of competitive priorities for the new restoration business.
2. Monitor the critical path of A–B–T–V, although there is slack.
3. Monitor the budget even though there should be ample room for unexpected contingencies.

E. Teaching Suggestions

This case should be an overnight assignment so that the students have the opportunity to think through the construction of the PERT/CPM diagram. This is not a difficult assignment, even though there are 22 activities. If used for discussion in class, it should be discussed after the PERT/CPM approach has been addressed in a previous class. Alternatively, the case could be used as a written assignment with no debriefing during class.

The discussion should begin with the potential conflicts with competitive priorities so that the class understands the strategic implications of the new restoration business. There is not enough information in the case to make a definitive conclusion, so the emphasis should be on the potential for conflicts and the need to do some serious exploration.

The discussion can then turn to the network diagram and the conclusions. See Exhibits TN.2 and TN.3 for suggestions.

F. Board Plan

Unique Tasks for Restoration Business	Competitive Priorities
Find parts no longer made	Top Quality
Manufacture unique parts	Customization
Low volumes	
Custom body work	
Custom paint work	
New information system	

EXHIBIT TN.1

Table of Tasks

	Task	Time	Immediate Predecessors
A	Order all needed material and parts	2 days	None
B	Receive upholstery material	30 days	A
C	Receive windshield	10 days	A
D	Receive carburetor and oil pump	7 days	A
E	Remove chrome from body	1 day	None
F	Remove body from frame	1 day	E
G	Get fenders repaired	4 days	F
H	Repair the doors, trunk, and hood	6 days	F
I	Pull engine from chassis	1 day	F
J	Remove rust from frame	3 days	I
K	Have valves reground in engine	5 days	I
L	Replace carburetor and oil pump	1 day	D, I
M	Get the chrome parts rechromed	3 days	E
N	Reinstall engine	1 day	K, L
O	Put doors, hood, and trunk back on frame	1 day	H, J
P	Get transmission rebuilt and replace brake	4 days	N, O
Q	Replace windshield	1 day	C
R	Put fenders back on	1 day	G, P
S	Get car painted	4 days	Q, R
T	Reupholster interior of car	7 days	B, S
U	Put chrome back on	1 day	M, S
V	Pull car to Studebaker show in Springfield, Missouri	2 days	T, U

EXHIBIT TN.2

PERT/CPM Network

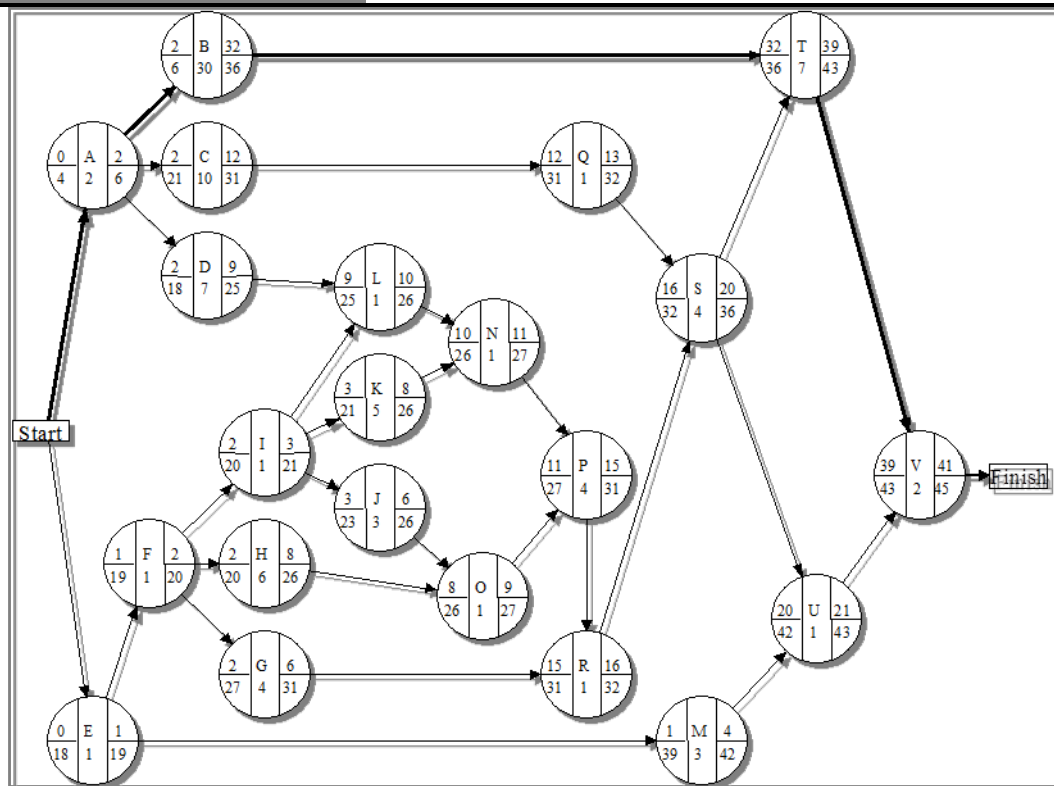


EXHIBIT TN.3

Project Budget for The PERT Mustang

Task	Estimated Cost
A	\$100
B	2,100
C	800
D	1,750
E	200
F	300
G	1,000
H	1,500
I	200
J	900
K	1,000
L	200
M	210
N	200
O	240
P	2,000
Q	100
R	100
S	1,700
T	2,400
U	100
V	<u>1,000</u>
Total Cost	\$18,100

EXHIBIT TN.4

Cash Flow Report for The Pert Mustang

Based on 5-day weeks

		1	2	3	4	5	6	7	8	9	Total
Start											
A	Order needed material and parts	\$100									\$100
B	Receive upholstery material for seat covers							\$2,100			\$2,100
C	Receive windshield			\$800							\$800
D	Receive carburetor and oil pump		\$1,750								\$1,750
E	Remove chrome from body	\$200									\$200
F	Remove body from frame	\$300									\$300
G	Fenders repaired by body shop	\$750	\$250								\$1,000
H	Repair doors, trunk, hood	\$750	\$750								\$1,500
I	Pull engine from chassis	\$200									\$200
J	Remove rust from frame	\$600	\$300								\$900
K	Regrind engine valves	\$400	\$600								\$1,000
L	Replace carburetor and oil pump		\$200								\$200
M	Rechrome the chrome parts	\$210									\$210
N	Reinstall engine			\$200							\$200
O	Put doors, hood, and trunk on frame		\$240								\$240
P	Rebuild transmission and replace brakes			\$2,000							\$2,000
Q	Replace windshield			\$100							\$100
R	Put fenders back on				\$100						\$100
S	Paint car				\$1,700						\$1,700
T	Reupholster interior							\$1,029	\$1,371		\$2,400
U	Put chrome back on					\$100					\$100
V	Pull car to Studebaker show								\$500	\$500	\$1,000
Finish											
Total		\$3,510	\$4,090	\$3,100	\$1,800	\$100	\$0	\$3,129	\$1,871	\$500	\$18,100

3 Process Strategy

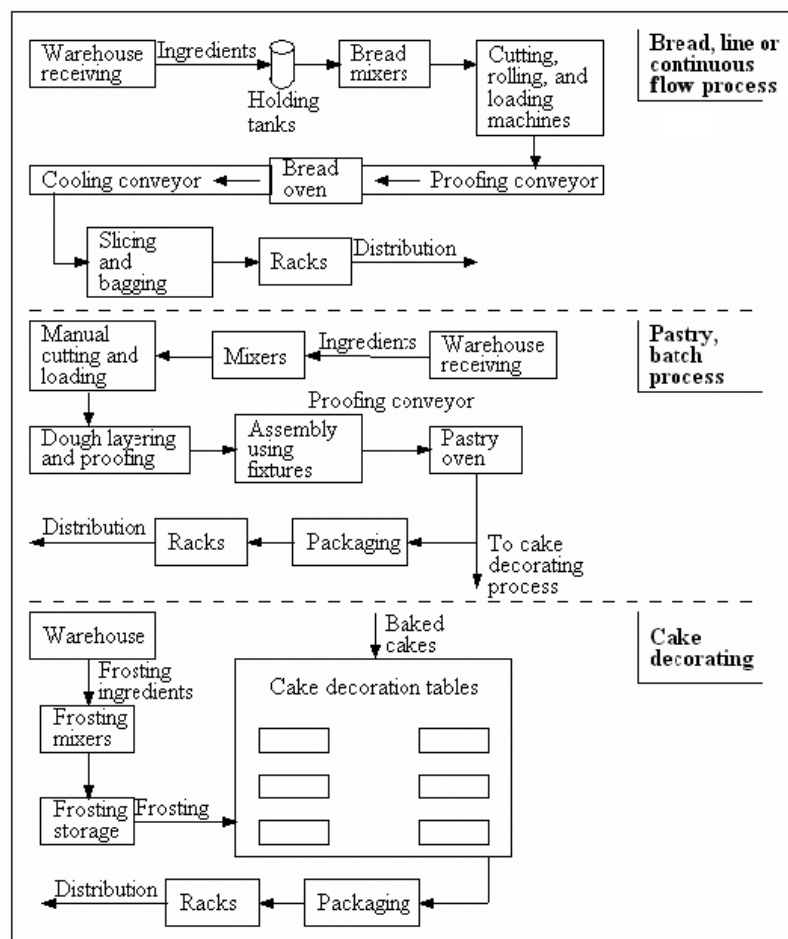
DISCUSSION QUESTIONS

1. Many processes at manufacturing facilities involve customer contact. Internal customers would include those employees whose operation(s) are subsequent. Quality Control could be considered an internal customer as could design engineering or sales. Quality Control, design engineering, marketing, sales and other organizations represent the customer at various stages of any process. Customer contact can be very high, especially between production and engineering and production and quality control.
2. Some students may see this as a difference in competitive priorities. Others may see a difference in management styles. Ritz-Carlton empowers their employees and the local restaurant does not seem to empower. Ritz-Carlton believes that by having employees treat customers and other employees with respect, customer service is enhanced. A restaurant that does not allow employees to resolve a customer issue may not see enhanced customer service. The restaurant may believe that the to-go customer will be better satisfied with fast and accurate orders. The in-store customer gets the chips and salsa to utilize the time while waiting for an order to be prepared. The to-go customer has already placed that order and it is ready when the customer arrives at the pickup window.
3. eBay has considerable arrival and request variability, because its customers do not want service at the same time or at times necessarily convenient to the company. They have request variability, seeking to buy and sell an endless number of items. Their process strategy allows significant customer involvement. Their customers perform virtually all of the selling and buying processes. McDonald's instead offers a considerable variety of foods, but from a standard menu. Staffing varies, depending on the time of day. Customization is not encouraged, and the hours during which a store is open can be controlled. Its processes have virtually no customer involvement, other than placing the order, picking up condiments or napkins, and possibly disposing of plates and containers when exiting. eBay accommodates customer-introduced variability, whereas McDonald's reduces it.
4. Student answers will vary. One idea that they may come up with is the use of electronic files. The printing industry is undergoing a shift to pdf files. Medical imaging and electronic file sharing is on the immediate horizon. The trick would be to convince physicians that want to keep their pads and pencils, that their "blackberries" are their pads and pencils.

5. Selling financial services would involve considerable customer contact, and thus be a front office. Likely activities would be to work with the customer to understand customer needs, make customized presentation to the customer, and maintain a continuing relationship with the customer to react to changing customer needs. Producing monthly client fund balance reports involves little customer contact, and thus be a back office. Likely activities would be to obtain data electronically, run the report using a standardized process, forward the hard copies and electronic files to analysts, and repeat the process monthly with little variation.
6. Layout performance measures
 - a. Airport—customer convenience, requirements for materials handling, capital investment
 - b. Bank—customer convenience, atmosphere, sales (loan applications), communication, and capital investment.
 - c. Classroom—flexibility, communication.
 - d. Product design—communication with production, work environment.
 - e. Law firm—client convenience, capital investment, communication, flexibility, atmosphere, organizational structure, and employee attitudes.
7. The process of call center services is rated in the table below. The combined score is 5.6 if each is given a weight of 0.20. Arguments could be made to give more weight to a dimension such as contact intensity, although more would need to be known about the exact process. The process's alignment on the customer-contact matrix seems to fit a front office, with more jumbled work flows and process divergence. To be properly aligned, there should be considerable resource flexibility in terms of both the employees and their equipment.

Dimension of Customer Contact		Explanation	Score
☐ Physical presence	☐	The customer is present for such steps as working to understand customer needs and answering specific questions. Other steps such as researching product information do not involve as direct contact.	1
☐ What is processed	☐	The customer is the focus of what is being processed in certain steps, such as the specific product explanation. However, researching product information lies more in the category of information-based service rather than people-processing services.	6
☐ Contact intensity	☐	The customer is actively involved and there is high service customization process	7
☐ Personal attention	☐	There is considerable personal attention and confiding in working to understand customer needs and in maintaining a continuing relationship with the customer. .	7
☐ Method of delivery	☐	Much of the delivery is through phone-to-phone contact .	7

8. King Soopers. A tour of the King Soopers bakery is provided in the video on myomlab, with the facility's layout shown below. See also The Big Picture: Process Choice at King Soopers Bakery on myomlab. The processes shown are some form of manufacturing because they are changing the material's physical properties (baking the bread), changing the material's shape (creating the pastry shapes) machining to fixed dimensions (cutting the bread), and assembling (applying the frosting to the cakes or shrink wrapping the bread). Of course, there are non-manufacturing processes going on in the office, such as planning production levels and managing the customer interface process. The process choices for bread (a line or continuous flow process), pastries (batch process), and cakes (job process) are properly aligned. For example, the bread line enjoys high volumes and low customization. Thus it is highly automated with little customer involvement and little equipment flexibility.



Some students will argue that the bread line is a continuous flow process rather than a line process. There is some merit in their position, because the bread line has rigid flows and materials move without stopping through the process. However, the process does not operate around the clock, which is one of the conditions often used for the continuous flow classification. The video also shows that the nested process for making dough is really a large batch process. Perhaps the best conclusion is that it occupies a position somewhere between a line process and continuous flow process.

PROBLEMS

1. Dr. Gulakowicz

Fixed cost, $F = \$150,000$ Revenue per patient, $p = \$3,000$ Variable cost per unit, $c = \$1000$

$$\text{Break-even volume, } Q = \frac{F}{p - c} = \frac{\$150,000}{\$3,000 - \$1000} = 75 \text{ patients}$$

2. Two manufacturing processes

$$a. \quad F_1 + c_1Q = F_2 + c_2Q$$

$$\$50,000 + \$700Q = \$400,000 + \$200Q$$

$$(\$700 - \$200)Q = (\$400,000 - \$50,000)$$

$$Q = \frac{\$350,000}{\$500} = 700 \text{ units}$$

b. Choose the second process, because 800 exceeds the break-even volume..

3. Baker Machine Company

Department Pair	Closeness Rating	Current Plan		Proposed Plan	
	w_{ij}	Distance (d_{ij})	$w_{ij}d_{ij}$	Distance (d_{ij})	$w_{ij}d_{ij}$
1-2	8	3	24	3	24
1-3	3	1	3	1	3
1-5	9	1	9	2	18
1-6	5	2	10	1	5
2-4	3	1	3	1	3
3-5	8	2	16	3	24
3-6	9	3	27	2	18
4-6	3	2	6	1	3
5-6	3	1	3	1	3
wd =			101	wd =	101

There is no change in the weighted-distance score. These layouts can be assessed using the *Layout* solver of OM Explorer, as shown following for the current plan.

Build Table		☒ Rectilinear Distances ☐ Euclidean Distances				
Department Pair	Closeness Factor	Distance	Score	3	4	2
1, 5	9	1	9	1	5	6
3, 6	9	3	27			
1, 2	8	3	24			
3, 5	8	2	16			
1, 6	5	2	10			
1, 3	3	1	3			
2, 4	3	1	3			
4, 6	3	2	6			
5, 6	3	1	3			
Total			101			

4. Baker Machine Block Plan

The following Excel spreadsheet provides the weighted-distance score for the two alternative layouts.

	Closeness Rating	Current Plan		Alternative Plan 1		Alternative Plan 2	
Department Pair	w_{ij}	Distance (d_{ij})	$w_{ij}d_{ij}$	Distance (d_{ij})	$w_{ij}d_{ij}$	Distance (d_{ij})	$w_{ij}d_{ij}$
1-2	8	3	24	1	8	2	16
1-3	3	1	3	2	6	1	3
1-5	9	1	9	1	9	2	18
1-6	5	2	10	1	5	1	5
2-4	3	1	3	1	3	1	3
3-5	8	2	16	1	8	1	8
3-6	9	3	27	1	9	2	18
4-6	3	2	6	1	3	2	6
5-6	3	1	3	2	6	1	3
		Total	101	Total	57	Total	80

While both alternative layouts are superior to the current layout, Alternative Plan 1 is the better of the two alternatives.

The *Layout Solver* of OM Explorer confirms its $w_{ij}d_{ij}$ score.

Build Table

☒ Rectilinear Distances
 ☐ Euclidean Distances

Department Pair	Closeness Factor	Distance	Score
1, 5	9	1	9
3, 6	9	1	9
1, 2	8	1	8
3, 5	8	1	8
1, 6	5	1	5
1, 3	3	2	6
2, 4	3	1	3
4, 6	3	1	3
5, 6	3	2	6
Total			57

3

6

4

5

1

2

5. Conway Consulting

The following Excel spreadsheet provides the weighted-distance score for the two alternative layouts.

	Closeness Rating	Alternative Plan 1		Alternative Plan 2		Alternative Plan 3	
Analyst Pairs	w_{ij}	Distance (d_{ij})	$w_{ij}d_{ij}$	Distance (d_{ij})	$w_{ij}d_{ij}$	Distance (d_{ij})	$w_{ij}d_{ij}$
A-C	6	2	12	1	6	1	6
B-D	12	2	24	1	12	1	12
C-D	2	1	2	2	4	2	4
C-E	7	1	7	3	21	1	7
D-F	4	1	4	2	8	2	8
		Total	49	Total	51	Total	37

Alternative Plan 3 provides the best solutions among the 3 Alternatives.

The *Layout Solver* of OM Explorer confirms its $w_{ij}d_{ij}$ score.

6	2	4
1	3	5

Rating Matrix

Dept. Name	Closeness Rating					
	1	2	3	4	5	6
1 A	---		6			
2 B		---		12		
3 C			---	2	7	
4 D				---		4
5 E					---	
6 F						---

Results**Solver - Layout**

Build Table

☒ Rectilinear Distances
 ☐ Euclidean Distances

Department Pair	Closeness Factor	Distance	Score
2, 4	12	1	12
3, 5	7	1	7
1, 3	6	1	6
4, 6	4	2	8
3, 4	2	2	4
Total			37

6	2	4
1	3	5

6. Richard Garber's designs
- Offices A and F should be located most closely, all other factors being equal.
 - The wd scores for the current plan are shown in the table following.

Department	Closeness		
	Rating (w_{ij})	Distance (d_{ij})	$w_{ij}d_{ij}$
A–F	185	1	185
C–F	125	1	125
C–E	125	2	250
B–E	105	1	105
E–F	105	1	105
A–C	90	2	180
A–B	25	3	75
D–E	25	1	25
			$wd = 1,050$

- The layout appears to be reasonably good, with most department pairs with high w_{ij} values being only one unit of distance apart. The main exceptions involve department C, because C–E and A–C are both pairings that are two units of distance apart. One possible switch is departments C and D. Department C would be closer to both A and E (but farther away from F). $WD = 985$, a 6% reduction.

Due to the large number of possible swaps, the only way to be sure which swap is best is to evaluate each one. The *Layout* module of POM for Windows can perform this analysis. The solution provided by POM for Windows follows along with the calculation of weighted-distance scores. Its explicit enumeration routine is feasible only for smaller problems ($n < 10$), because computer time increase exponentially as the number of departments increases. For larger problems, the pairwise comparisons of POM for Windows or OM Explorer are a good option.

Best Room Assignments

A	Room 1
B	Room 6
C	Room 2
D	Room 3
E	Room 5
F	Room 4

Total movement = 985

From Department	Room	To Department	Room	Distance	Closeness Factor	Weighted Distance Scores
A	Room 1	A	Room 1	0	0	0
		B	Room 6	3	25	75
		C	Room 2	1	90	90
		D	Room 3	2	0	0
		E	Room 5	2	0	0
		F	Room 4	1	185	185
B	Room 6	A	Room 1	3	0	0
		B	Room 6	0	0	0
		C	Room 2	2	0	0
		D	Room 3	1	0	0
		E	Room 5	1	105	105
		F	Room 4	2	0	0
C	Room 2	A	Room 1	1	0	0
		B	Room 6	2	0	0
		C	Room 2	0	0	0
		D	Room 3	1	0	0
		E	Room 5	1	125	125
		F	Room 4	2	125	250
D	Room 3	A	Room 1	2	0	0
		B	Room 6	1	0	0
		C	Room 2	1	0	0
		D	Room 3	0	0	0
		E	Room 5	2	25	50
		F	Room 4	3	0	0
E	Room 5	A	Room 1	2	0	0
		B	Room 6	1	0	0
		C	Room 2	1	0	0
		D	Room 3	2	0	0
		E	Room 5	0	0	0
		F	Room 4	1	105	105
F	Room 4	A	Room 1	1	0	0
		B	Room 6	2	0	0
		C	Room 2	2	0	0
		D	Room 3	3	0	0
		E	Room 5	1	0	0
		F	Room 4	0	0	0
Total						985

For additional insights, see Active Model 3.1 in MyOMLab.

7. Four departments
- a. The load-distance score is 84, as calculated in the left side of the following table.

Department Pair	Closeness Rating w_{ij}	Current Plan		Proposed Plan	
		Distance (d_{ij})	$w_{ij}d_{ij}$	Distance (d_{ij})	$w_{ij}d_{ij}$
A–B	12	1	12	1	12
A–C	10	1	10	2	20
A–D	8	2	16	1	8
B–C	20	2	40	1	20
B–D	6	1	<u>6</u>	2	<u>12</u>
			$wd = 84$		
				$wd = 72$	

- b. A better layout is one that switches departments C and D, as shown by the following block plan. The calculations on the right side of the preceding table show that its weighted-distance score drops to 72. See the *Layout* solver of OM Explorer to facilitate this analysis.

A	B
D	C

8. Department of Engineering
- a. The following heuristic process was used to construct the block plan shown following. The faculty member pairing with the highest number of contacts is B and D, which suggests B gets assigned to office 5. Putting E at office 4 responds to the frequent contacts between C and E. Member F gets assigned to office 3, the only one left.
- b. The weighted-distance score is calculated below to be 45. Only two of the least frequent contacts between C and D are not matched with the minimum distance of one unit.

Faculty Pair	Rating w_{ij}	Distance d_{ij}	$w_{ij}d_{ij}$
B–D	12	1	12
B–F	10	1	10
C–E	7	1	7
A–C	4	1	4
D–F	4	2	8
C–D	2	2	<u>4</u>
			$wd = 45$

A	C
F	E
B	D

The *Layout Solver* of OM Explorer confirms its $w_{ij}d_{ij}$ score.

Build Table				☒ Rectilinear Distances ☐ Euclidean Distances	
Department Pair	Closeness Factor	Distance	Score		
2, 4	12	1	12	1	3
2, 6	10	1	10	6	5
3, 5	7	1	7	2	4
1, 3	4	1	4		
4, 6	4	2	8		
3, 4	2	2	4		
Total			45		

CASE : CUSTOM MOLDS, INC. *

A. Synopsis

Custom Molds, Inc. is a small fabricator of custom-designed molds that are used in injection molding machines to make plastic parts. Its major customers are in the electronics industry where large volumes of plastic connectors are used. The company has recently noticed a shift in its market as the total demand for molds has declined, but the requests for molded parts have increased. In response to this shift, Custom Molds, Inc. has expanded its operations to include the manufacture of plastic parts. The case provides students with the opportunity to analyze the different processes associated with mold fabrication and parts production and to discuss the interaction between process management decisions and competitive priorities.

B. Purpose

The purpose of this case is to focus the student on issues relating to process strategy and to discuss how decisions involving process structure, customer involvement, resource flexibility, and capital intensity interact with different competitive priorities. Students need to resolve what it will take to compete effectively in each of Custom Molds' markets and how best to configure its processes. One needs to consider specific issues:

1. There are two distinctly different processes taking place in the same facility. The students should diagram each process (see flowcharts in Chapter 4) and compare/contrast the strengths and weaknesses of each.
2. The different processes serve different customer needs. Mold fabrication requires flexibility and quality where parts manufacturing competes on delivery and low cost. The margin for parts is much smaller.
3. Although the number of orders has remained relatively stable, the volume per order for **parts** has increased significantly over the last three years. This increase has caused bottlenecks in the shop and has led to late deliveries of parts.
4. The change in sales mix has created excess capacity in mold fabrication, and the owner has relegated one of the master machinists to the role of expeditor.

C. Analysis

Students should begin their analysis by examining the market trend data in the two tables in the case. These data clearly show that although the number of orders received over the three-year period for molds has remained constant, the total number of molds fabricated has shown a declining trend: 722 in 2006, 684 in 2007,

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

and 591 in 2008. With 13 master machinists employed, mold fabrication capacity can be estimated at

$$13 \text{ machinists} \times 250 \text{ days/year} \div 5 \text{ days/mold} \\ \text{or } 650 \text{ molds fabricated/year}$$

Another way to look at the excess capacity question is that each master machinist working 250 days per year, averaging five days' processing time per mold fabricated, can produce 50 molds per year. At a current demand rate of 591, only 12 master machinists are required.

As an aside, note that the regular-time capacity of 650 molds per year was actually insufficient to handle the demand in 2006 and 2007. Presumably overtime was used in these earlier years to make up the shortfall, although not stated in the case. At this point the changing sales mix not only alleviated any earlier capacity shortage, but created enough excess capacity now that Tom Miller reassigned one of the master machinists to an expediting function.

Parts manufacturing, however, shows the opposite trend. The number of orders has actually declined a bit but the total of parts processed has risen drastically over three years: 47,200 in 2006, 67,150 in 2007, and 114,850 in 2008. Although data are not provided on the processing times of individual parts, we can see that the order sizes are getting much larger. This trend has most likely caused bottlenecks at the injection molding operation, because the operations both before and after the injection machine take only one or two days to complete. Therefore, the late deliveries that customers are complaining about are probably due to molds being delayed or orders waiting for the injection machines. Delays and time pressures may also be contributing to quality problems as operators hurry to process orders.

The analysis should then determine the process flow in diagrams of each step. This will enable students to see where time and resources are being consumed. These flows can be compared to the layout block plan in Figure 3.18 to get an idea of the material flows in the plant.

In the final phase of the analysis, students should discuss the strengths and weaknesses of each process and relate these to the different competitive priorities needed to compete in each market.

Mold Fabrication	Parts Manufacturing
Job process	Line process
High customer contact	Less-skilled labor
High-skilled labor	More capital intensive
Divergent processes	Less-divergent process

The mold fabrication market requires a great deal of flexibility in order to design and custom-make molds to meet customer requirements. Quality is also very important in meeting demanding specifications. Short delivery times are less critical, as the design phase, working closely with the customer, can be lengthy. Costs are also a secondary consideration, as the cost of the mold is typically a minor component of the customer's overall cost of manufacturing.

Custom Molds, Inc. has expanded into the manufacturing of plastic parts. Parts manufacturing is a higher-volume, cost-sensitive market. Parts are needed in a timely manner to keep customer production processes running. Volume flexibility

becomes more important than product flexibility. So students should be able to see that the company has exposed itself to a different set of competitive priorities.

D. Recommendations

At this stage, early in an operations management course, specific recommendations will be difficult for students and should not be the primary focus. The instructor should look for general recommendations concerning: (1) capacity decisions and the allocation of production resources; (2) the possible orientation toward either molds fabrication or parts manufacturing; and (3) the physical separation and focusing of each distinct process. A sample student response to the discussion questions that follow will give (Exhibit TN.1) some idea of what to expect from a student in an introductory course in operations and supply chain management course.

E. Teaching Strategy

This case is designed to be used early in the course. A primary focus is to expose the students to the concept of flowcharting processes (covered more fully in Chapter 4) and using the flowcharts to analyze the strengths and weaknesses of the processes. A second focus is to show the students the impact that process choice decisions have on the ability of the company to compete on different competitive priorities.

For best results the instructor should assign this case as a homework assignment. Students should come to class prepared to share their process flow diagrams. The discussion then can pretty much follow the discussion questions at the end of the case.

First make sure the students realize the company faces capacity issues brought about by the expansion into parts manufacturing. Then move to the analysis of the flowcharts. As students begin to see the strengths and limitations of each process, you can then move on to a discussion of the interaction between market-required competitive priorities and differing process characteristics.

This case can easily take a full 50- or 75-five-minute class if students share their flowcharts and the instructor has the class as a group develop the two flowcharts on the board. This, however, is a good exercise for students to be involved in, as they learn that flowcharts for even seemingly simple processes may be more difficult to develop than they thought.

EXHIBIT TN.1

Custom Molds, Inc. Student Responses

Question 1

The Millers face a changing market environment for their two product lines—molds and plastic parts—a problem that they must address. The mold market is in the mature phase. Though the number of mold orders is constant, the average number of molds per orders is decreasing. This information may imply that customers are letting Custom Molds prototype the mold design, but they are then fabricating the molds in-house once they validate the design. The plastic parts market is in a growth phase, at least from the Millers' perspective. The plastic parts market shows a sizable increase in average order size. This market shift is

causing the Millers' problems on the shop floor as the company shifts from mold production to plastic parts production.

Question 2

The market shift from molds to plastic parts impacts Custom Molds because of the different production process required for each product. Mold production is a job process environment with only a limited number of molds manufactured per order. This process requires highly trained and skilled workers to manufacture the molds. Plastic parts production is primarily a batch process, with characteristics of a line process, which produces small runs of similar products. Unlike mold production, the skill level of the labor is not as high. However, both products are made to order, so there are similarities between the two, especially in terms of production scheduling.

Quality, product design, and flexibility are important competitive priorities for the molds. Price and delivery are competitive factors but only as order qualifiers, not order winners. For the plastic parts, delivery and price are more important; quality and flexibility become order qualifiers. The importance of maintaining the delivery schedule has caused many of the problems with Custom Molds production.

Both production processes at Custom Molds have a great deal of slack time. For example, the company schedules two to four weeks for fabrication of molds although it takes only three to five days to make the mold. For molds, these delays are not a major factor. For plastic parts, production time for 500 parts is four days' mixing, molding, trimming, inspecting, packing, and shipping. With assembly, the parts require an additional three days. Generally the company waits one week for the compounds to arrive and one week lead time before producing the molds. This provides a tight schedule for the company to meet the three-week lead time for plastic parts order promising.

Question 3

Alternatives for the Millers are as follows:

1. They can shift their focus to plastic parts production. This will require increasing the space dedicated to plastic parts production or adding additional space. This will also require a move away from the expediting mentality. The use of skilled machinists to expedite parts is a waste of resources. It is likely that the delays are due to a combination of expedited orders that slow regular orders and limited capacity. This choice will require commitment to expand resources and maintain delivery reliability. In addition, the company will need to recognize the increased importance of price competition.
2. They can move back to the focus on molds. However, this requires moving against the apparent trend in the industry. This strategy will require Custom Molds to take business away from competitors in order to grow the business. Price competition may become the primary factor in industry competition. However, it is unlikely they can profitably increase their business if they follow this strategy.

ADDITIONAL PROBLEMS AND CASES

ADDITIONAL PROBLEMS

1. CCI Electronics

This problem involves finding the best location for four departments, limiting their placement to the four locations vacated by them. The spaces vacated by D, G, K, and L are designated as 1, 2, 3, and 4, as shown in the following block plan.

1	H	B	2
F	I	J	A
C	3	E	4

The merged closeness ratings derived from Exhibit 1 are shown following for each department:

Department	A	B	C	D	E	F	G	H	I	J	K	L
A	X	...	...	...	...	...	...	...	...	90	...	80
B	—	X	...	...	...	...	30	...	50	70	...	...
C	—	—	X	...	...	120	...	...	70	...	80	60
D	—	—	—	X	120	...	...	...	...	...	...	...
E	—	—	—	—	X	...	...	...	40	...	90	...
F	—	—	—	—	—	X	120	...	...	...	...	...
G	—	—	—	—	—	—	X	40	50	...	...	...
H	—	—	—	—	—	—	—	X	80	...	...	...
I	—	—	—	—	—	—	—	—	X	...	60	...
J	—	—	—	—	—	—	—	—	—	X	...	...
K	—	—	—	—	—	—	—	—	—	—	X	...
L	—	—	—	—	—	—	—	—	—	—	—	X

Many reasonable solutions are possible using trial and error, and perhaps facilitated with the *Layout* solver of OM Explorer.

L	H	B	K
F	I	J	A
C	D	E	G

(Current Layout)

G	H	B	L
F	I	J	A
C	K	E	D

(Revised Layout)

Weighted-Distance Scores

Department Pair	Merged Closeness Rating (w_{ij})	Current Layout		Revised Layout	
		(d_{ij})	$w_{ij}d_{ij}$	(d_{ij})	$w_{ij}d_{ij}$
A-J	90	1	90	1	90
A-L	80	4	320	1	80
B-G	30	3	90	2	60
B-I	50	2	100	2	100
B-J	70	1	70	1	70
C-F	120	1	120	1	120
C-I	70	2	140	2	140
C-K	80	5	400	1	80
C-L	60	2	120	5	300
D-E	120	1	120	1	120
E-I	40	2	80	2	80
E-K	90	3	270	1	90
F-G	120	4	480	1	120
G-H	40	4	160	1	40
G-I	50	3	150	2	100
H-I	80	1	80	1	80
I-K	60	3	<u>180</u>	1	<u>60</u>
			$wd = 2,970$		$wd = 1,730$

The weighted-distance score decreased from 2,970 to 1,730, which represents a 42% reduction. The calculations for the revised layout are confirmed by the *Layout* solver, as shown following.

Build Table

☒ Rectilinear Distances
 ☐ Euclidean Distances

Department Pair	Closeness Factor	Distance	Score
3, 6	120	1	120
4, 5	120	1	120
6, 7	120	1	120
1, 10	90	1	90
5, 11	90	1	90
1, 12	80	1	80
3, 11	80	1	80
8, 9	80	1	80
2, 10	70	1	70
3, 9	70	2	140
3, 12	60	5	300
9, 11	60	1	60
2, 9	50	2	100
7, 9	50	2	100
5, 9	40	2	80
7, 8	40	1	40
2, 7	30	2	60
Total			1,730

7	8	2	12
6	9	10	1
3	11	5	4

2. Getwell Hospital

- a. The
- wd
- of the current layout (shown below) is 765.

4	6	5	7
2	8	3	1

Department Pair	Closeness Rating (w_{ij})	Distance (d_{ij})	$w_{ij}d_{ij}$
1-2	25	3	75
1-3	35	1	35
1-4	5	4	20
1-5	10	2	20
1-6	15	3	45
1-7	0	1	0
1-8	20	2	40
2-3	5	2	10
2-4	10	1	10
2-5	15	3	45
2-6	0	2	0
2-7	0	4	0
2-8	15	1	15
3-4	20	3	60
3-5	30	1	30
3-6	20	2	40
3-7	0	2	0
3-8	10	1	10
4-5	25	2	50
4-6	15	1	15
4-7	0	3	0
4-8	25	2	50
5-6	20	1	20
5-7	0	1	0
5-8	25	2	50
6-7	40	2	80
6-8	0	1	0
7-8	15	3	45
$wd =$			765

These calculations are confirmed by the *Layout Solver*, as shown following.

Build Table

☒ Rectilinear Distances
 ☐ Euclidean Distances

Department Pair	Closeness Factor	Distance	Score
6, 7	40	2	80
1, 3	35	1	35
3, 5	30	1	30
1, 2	25	3	75
4, 5	25	2	50
4, 8	25	2	50
5, 8	25	2	50
1, 8	20	2	40
3, 4	20	3	60
3, 6	20	2	40
5, 6	20	1	20
1, 6	15	3	45
2, 5	15	3	45
2, 8	15	1	15
4, 6	15	1	15
7, 8	15	3	45
1, 5	10	2	20
2, 4	10	1	10
3, 8	10	1	10
1, 4	5	4	20
2, 3	5	2	10
Total			765

4	6	5	7
2	8	3	1

- b. The following layout, and the rotations and mirror images of it, was found to have a *wd* score of only 605.

6	3	5	4
7	1	8	2

With the *Layout Solver*, as shown following, we get:

Build Table				☒ Rectilinear Distances	☐ Euclidean Distances		
Department Pair	Closeness Factor	Distance	Score				
6, 7	40	1	40	6	3	5	4
1, 3	35	1	35	7	1	8	2
3, 5	30	1	30				
1, 2	25	2	50				
4, 5	25	1	25				
4, 8	25	2	50				
5, 8	25	1	25				
1, 8	20	1	20				
3, 4	20	2	40				
3, 6	20	1	20				
5, 6	20	2	40				
1, 6	15	2	30				
2, 5	15	2	30				
2, 8	15	1	15				
4, 6	15	3	45				
7, 8	15	2	30				
1, 5	10	2	20				
2, 4	10	1	10				
3, 8	10	2	20				
1, 4	5	3	15				
2, 3	5	3	15				
Total			605				

- c. When department 1 is fixed at its current location, the best layout found is shown following. Its *wd* score increased somewhat, to 610.

7	4	8	2
6	5	3	1

With the *Layout Solver*, as shown following, we get:

Build Table				☒ Rectilinear Distances	☐ Euclidean Distances										
Department Pair	Closeness Factor	Distance	Score	<table><tr><td>7</td><td>4</td><td>8</td><td>2</td></tr><tr><td>6</td><td>5</td><td>3</td><td>1</td></tr></table>				7	4	8	2	6	5	3	1
7	4	8	2												
6	5	3	1												
6, 7	40	1	40												
1, 3	35	1	35												
3, 5	30	1	30												
1, 2	25	1	25												
4, 5	25	1	25												
4, 8	25	1	25												
5, 8	25	2	50												
1, 8	20	2	40												
3, 4	20	2	40												
3, 6	20	2	40												
5, 6	20	1	20												
1, 6	15	3	45												
2, 5	15	3	45												
2, 8	15	1	15												
4, 6	15	2	30												
7, 8	15	2	30												
1, 5	10	2	20												
2, 4	10	2	20												
3, 8	10	1	10												
1, 4	5	3	15												
2, 3	5	2	10												
Total			610												

- d. Assuming throughout the rest of the analysis that department 1 must be fixed at its current location, the 50 percent increase in the flow between the examining room and X ray (from 20 to 30) causes the *wd* score of the solution (c) to increase to 630. The best revised layout found in response to the change is shown following. Its *wd* score is slightly less, at 625.

7	4	8	2
6	3	5	1

If the flow between the examining room and X-ray is instead decreased by 50 percent (from 20 to 10), the *wd* score of the solution to (c) drops to 590. No improvements could be found over the layout in (c) to capitalize on the data change. The output on this last layout using the *Layout Solver* is shown following:

Build Table		☒ Rectilinear Distances ☐ Euclidean Distances	
Department Pair	Closeness Factor	Distance	Score
6, 7	40	1	40
1, 3	35	1	35
3, 5	30	1	30
1, 2	25	1	25
4, 5	25	1	25
4, 8	25	1	25
5, 8	25	2	50
1, 8	20	2	40
3, 6	20	2	40
5, 6	20	1	20
1, 6	15	3	45
2, 5	15	3	45
2, 8	15	1	15
4, 6	15	2	30
7, 8	15	2	30
1, 5	10	2	20
2, 4	10	2	20
3, 4	10	2	20
3, 8	10	1	10
1, 4	5	3	15
2, 3	5	2	10
Total			590

7	4	8	2
6	5	3	1

ADDITIONAL CASES

CASE: CAR LUBE OPERATIONS. *

A. Synopsis

Professor Smith, a proponent of timely preventive maintenance, cannot seem to bring himself to practice what he preaches. The distasteful chore of taking his car for an oil change takes him to two quite different providers of this service. Smith's experiences and observations at these two companies reveal some deeper underlying differences in their operations. This case contrasts two different processes for doing a car lube relative to process structure, competitive priorities, and layout.

B. Purpose

This case is designed to be used as either a “cold-call” case for class discussion or an assigned homework reading. Major points to be brought out in the discussion include:

1. Process structure
2. Competitive priorities
3. Layout
4. How these decisions fit together in creating an overall strategy

C. Analysis

1. What are the competitive priorities of Instant Lube and Tireco? How well do these priorities match their customers' needs?
 - a. The names of these two companies are disguised, but both have national brand names. It is apparent from the case that the companies provide quite different services, and serve different market segments, notwithstanding some overlap.
 - b. The first question that needs to be answered is that of “Who is the customer, and why does the customer shop at this company?”
 - For Instant Lube, the customer is someone who does not look forward to the oil change experience, and perhaps even dislikes it as much as Smith does. This customer would like to get the job done as fast as possible, at a time of his/her choosing, even if that means paying a higher price.
 - For Tireco, the typical customer is there to buy tires. Oil changes are also a part of Tireco's business, but a smaller part. A tire customer may find a low priced oil change particularly attractive. Since he/she is already there for new tires, the additional time required is minimal. Meanwhile, a customer who comes there solely for the oil change also does not seem time sensitive. Such a customer is willing to set up an appointment several days in advance. He/she does not balk or renege (see Supplement C, “Waiting Lines”) when informed that the service will take 45 minutes despite the appointment. Further, in the case of a repeat customer, he/she is willing to forgive the fact that the service went 30 minutes beyond the original 45 minute estimate. In return for such patience, the customer expects a bargain price for the service, together with the reputable brand name.
 - c. The next step is to translate the above information into competitive priorities for each company's oil change operations, in terms of cost, quality, time and flexibility.

* This case was prepared by Dr. Narendar Sumukadas, University of Hartford, as a basis for classroom discussion.

A useful analysis is to look at how each company attracts its customers, or alternatively, why its customers choose it over others.

- **Cost:** Price appears to be the primary reason that (oil change) customers patronize Tireco. Instant Lube, on the other hand, charges a higher price.
- **Quality:** Instant Lube offers customers the convenience of dropping in unscheduled, which might represent **top quality** in the customer's eyes. Instant Lube also provides a more pleasurable service interaction, as exemplified in their handling of Smith's coolant top up. Tireco perhaps offers the convenience of one-stop service. However, that convenience is of little attraction to oil change customers unless they are also seeking new tires.

Neither Instant Lube nor Tireco appears to draw its customers based solely on **consistent quality**, i.e., better conformance to specifications. However, given the two companies' brand names, the customer clearly would expect consistent quality from both.

- **Time: Delivery speed** is an important reason why the customer chooses Instant Lube, even at a higher price. Tireco, on the other hand, does not draw its oil change customers based on quick delivery. Another factor important to the customer in this case is **on-time delivery**, for which the customer is willing to pay Instant Lube a higher price. Tireco, on the other hand, was unable, by a large margin, to meet its stated delivery time. Despite Tireco's failing in that regard, it is arguable that on-time delivery should still be a competitive priority, although it is not a competitive capability.

The case does not provide much information related to **new product/service development speed**. Neither Instant Lube nor Tireco appears to draw its customers based on this priority. However, given their national brand names, customers would expect both to offer a reasonably up-to-date menu of new products/services. Further, given Instant Lube's exclusive focus on oil changes, the customer might expect a more innovative product line. Indeed, some "pure" oil change companies even tout their specialization as implying state of the art, high performance lubricants not available elsewhere.

- **Flexibility:** The customer does not expect a wide **variety** of services from Instant Lube. Tireco appears to offer somewhat more variety, in terms of one-stop shopping for oil change and tires together. However, this variety does not seem likely to be an important draw for the customer. Given that an average oil change lasts 3 months, while a tire change lasts years, it is not often that a customer's need for the two services coincides. Likewise, **customization** also does not seem to be a draw for either company. **Volume flexibility**, i.e., the ability to meet fluctuating customer demand, appears to be an important distinguishing factor between the two companies. Tireco is unable to accommodate unscheduled customer demand. Instant Lube, on the other hand, offers a drop-in service that appears to be an important factor in attracting its customers.

Exhibit TN.1 summarizes the above discussion of competitive priorities. Instant Lube attracts its customers primarily based on quick and on-time delivery, together with unscheduled drop-ins. Tireco attracts its customers based on low price (in the oil change segment), and perhaps consistent quality and on-time delivery. (Tireco's failure to achieve these priorities could mean a gap that needs to be closed with process improvements.)

Exhibit TN.1

COMPETITIVE PRIORITY	INSTANT LUBE	TIRECO
Cost	—	✓
Top quality	—	—
Consistent quality	✓	✓
Delivery speed	✓	—
On-time delivery	✓	✓
Development speed	—	—
Variety	—	—
Customization	—	—
Volume flexibility	✓	—

Exhibit TN.1 allows us to analyze the two competing oil change companies in terms of how well each operation's processes are focused on its competitive priorities.

2. What process structure has each company selected? How well does each company's process structure match its competitive priorities?

- a. **Instant Lube's process:** Instant Lube has adopted a line flow process. Such a process is well suited to producing large quantities of low variety outputs. A line flow process is also better able to offer quick delivery and on-time delivery, both of which are important to Instant Lube's customers.

On the other hand, a line flow process is not well suited to offering volume flexibility, which is also important to Instant Lube's customers. In addition, a line flow process is well suited to producing output at a low cost, which appears to be at odds with their higher price. However, low cost operations and high prices are not incompatible. Low cost operations can deliver a greater profit margin in such a situation.

Both of these apparent anomalies can be reconciled. To offer drop-in scheduling, i.e. "to jump when the customer says jump," Instant Lube needs to operate its facilities with a relatively high capacity cushion (low utilization). (see Chapter 6, "Capacity Planning"). That way, even with a line flow process, it can cater to fluctuating customer demand. As the case indicates, this capacity cushion consists of maintaining fully staffed shop bays, idle if necessary, waiting for the customer's arrival. Capacity may also be varied, and flexibly deployed, by increasing or decreasing the team size within each bay, and moving employees to bottleneck areas as needed. Such a capacity cushion, however, means that it must charge a higher price than would be expected for a line flow process for a service without the competitive priority of delivery speed.

- b. **Tireco's process:** Tireco has adopted a flexible flow process of sorts, in that some cars are moved from one bay to another, such as those requiring wheel alignment. Also, while most cars are assigned a single workstation, and are serviced at that same workstation, the key difference relative to Instant Lube is that the workstation is flexible and can perform a variety of services. The workforce also has multiple skills. Such a process is well suited to producing multiple outputs in small quantities.

Accordingly, the process would be able to perform different tire related jobs as well as oil changes.

A flexible flow process is not well suited to producing output at a low cost. Tireco's process, therefore, appears to be mismatched with its low price offering. However, Tireco's process is not really a flexible flow process in the traditional sense. It can be capable of low cost operations because it involves simple tasks. Further, in the case of a combo tire and oil change, economies of scale and scope become possible (see economies of scale, Chapter 6, "Capacity Planning").

Tireco does have a dilemma of how to effectively handle the oil-change-only customers. These customers typically want fast service, and just mixing them in with the tire customers causes processing problems because of uncertainties that often crop up when tires are replaced (shock absorbers need replacing, a wheel alignment is needed, leaks are discovered). One approach is to devote a bay to do just oil changes. In other words, Tireco could redesign their processes to allow for some "focus."

Another approach is to develop a complementary stream of business that can be scheduled for non-peak hours (see Chapter 14, "Operations Planning and Scheduling"). Further, to the extent that this secondary demand is less time sensitive, it can be "wait-listed" if necessary to give priority to the primary demand. An analogous arrangement may be found in the airline industry, where less time sensitive passengers are sometimes offered lower fares to fly standby. Tireco's oil change customers, looking for a good deal on price, represent such a complementary business that can be scheduled for the non-peak hours, and afforded lower priority. Tireco need only charge these customers a little more than is enough to cover its variable costs. This is the approach that Tireco is attempting to implement with the use of an appointment system. However, the execution of that process is lacking, and the customers suffer.

D. Teaching Strategy

1. The case is short enough that it may be handed out for a quick read in class. Yet, it is also general enough to be assigned for a take home written case analysis, adopting a big picture perspective. Students may be asked to "throw the textbook" at the case, and explain how they would expect the two companies in the case to differ with regard to every textbook concept. The assignment questions could then be more general and open ended: How do the operations of Instant Lube and Tireco differ? What is each of the companies attempting to achieve? How well is its delivery system designed to fulfill that purpose?
2. As an in-class handout, the case is particularly suited for use in conjunction with the topics of operations strategy and process management. It is useful if the students have been exposed to the customer-contact matrix, the product-process matrix, and the major process flow strategies, namely line flow, flexible flow, and hybrid. Students should also be able to discuss the compatibility of the different flow strategies with the nine possible competitive priorities.
3. The instructor can begin the class discussion with an analysis of the competitive priorities for the two companies' oil change operations. If students are yet to fully comprehend the competitive priorities, it is sometimes useful to work through each of the nine competitive priorities. A good method is to discuss whether each priority is the reason that the customer chooses Instant Lube versus Tireco. Once the class develops a list of the important competitive priorities for each company (see Exhibit TN.1), the discussion can turn to the customer-contact matrix.

4. Students can be asked to position each company's process along the diagonal of the customer-contact matrix. To simplify the discussion (for a class session relatively early in the course), the instructor can limit the matrix to just the two ends of the diagonal, labeled as line flow and flexible flow. Such a simplification serves to highlight the contrast between the two companies.
5. The class discussion can then turn to how well each company's process is suited for focusing on that company's competitive priorities. This part of the discussion will reveal how a line flow process is consistent with Instant Lube's focus on quick and on-time delivery, but inconsistent with its higher pricing. The discussion will also reveal how Tireco's flexible flow process is inconsistent with its focus on low price, as far as the oil change business is concerned.
6. As the discussion progresses further and the above anomalies are examined, students will develop a good understanding of the linkages between the customer-contact matrix and competitive priorities. Students can also be prompted to better appreciate the linkages between different topics in the course. For example, Instant Lube's higher price may have to do with a higher capacity cushion to provide higher volume flexibility, whereas simply looking at a line flow process would suggest otherwise. Likewise, Tireco's low price may not be consistent with its flexible flow process, but it may make sense in the larger context, for a complementary business.

CASE: HIGHTEC, INC. *

A. Synopsis

This case describes the problems that the owner of a small but rapidly expanding company faces. The space restrictions of the current layout are too tight, and expansion is necessary. There are three options, although the first one, renting portable units, has been discarded. The second option is to build a new facility, and the third option is to continue to rent the current facility plus additional space in a nearby facility. Glenn Moore must first design the layout for each option and then judge whether the layout for the second option is sufficiently better than that of the third option to justify the higher expansion costs. Both qualitative and quantitative factors must be considered.

B. Purpose

The purpose of this case is to allow the student to get involved in developing an effective block plan and to understand the various factors that must be considered in evaluating it. The case shows how space allocations can complicate the analysis, particularly if each department must be kept together and not be split up. This case shows one way that layout problems differ from location problems. The case also demonstrates the close connection between layout, capacity, and location decisions, and how investment requirements mandate a close relationship between operations and finance.

C. Analysis

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

Glenn Moore identified three alternatives, but has already eliminated the first one, use of temporary structures, as undesirable. We are left with the second and third alternatives, Option 2 and Option 3, from which to choose. Several good block plans can be developed. Exhibit TN.1 shows one possible block plan for each option. Remember that neither are department 8 (Machine Shop) and department 10 (Cleaning) to be next to each other.

Total scores for these layouts are computed in Exhibit TN.2, using a scoring method whereby those department pairs that are contiguous in one of the two layouts are listed in the table. “Contiguous” means that they share a common border and are not just touching at a corner. A total score is then found by adding the individual closeness ratings for the contiguous department pairs. The higher the score, the better the layout. Another form of analysis would be to compute the *wd* scores. For example, the *Layout* solver of OM Explorer could be used. A block plan with three rows and six columns would fit within the size limitations of the solver. One block of space would be given to each of 12 departments, and Departments 8 and 9 given three blocks of space each. Using the *wd* score approach would take into account how close two departments are to each other, not just whether they are contiguous.

Exhibit TN.2 shows that the total contiguous approach score for Option 2 (111) is higher than the score for Option 3 (92), and therefore, it is a more effective layout. If we make our decision strictly on the basis of layout effectiveness, Option 2 seems better. It also seems to be a better way for handling future expansion, beyond the fifth year, if growth continues as expected. There is one big disadvantage of Option 2, however; it requires a major investment in a new facility. The initial investment cost is \$100,000 for land, \$760,000 for construction (19,000 sq ft × \$40/sq ft), and \$20,000 for relocation costs. The total initial cost for Option 3 is only \$15,000 for the corridor. However, the rental payments are \$33,600 per year (or \$2,800/mo. × 12 mo/yr). As a start, we could ask whether the increase in one-time investment dollars of \$865,000 (or \$880,000 – \$15,000) outweighs the present value of the rental payments for five years. Even when we ignore the time value of money, the rental payments are only \$168,000. Of course, we must also consider the residual value of the building at the end of five years.

Although the purpose of this case is not to get into the financial analysis too much, Exhibits TN.3 and TN.4 show some detailed calculations using MACRS and straight-line depreciation (see Supplement F, “Financial Analysis” on myomlab). They make the following assumptions, which must be specified for a complete analysis:

1. Depreciation: Because this project is only for 5 years, students might want to depreciate the project over the five-year life span. However, to be correct for income-tax purposes, the MACRS 31.5-year depreciation schedule should be used (see Exhibit TN.3 here and Supplement F, “Financial Analysis”). For simplicity and planning purposes, Exhibit TN.4 uses 10-year straight-line depreciation.
2. The second assumption deals with the salvage value of the building in Option 2. Because this is a five-year project, we assume that the building and land will be disposed of after five years. Will Hightec dispose of it at

book value, or will it realize a profit (or a loss) at the end of five years? This assumption can be the determining factor in selecting the better option.

3. The treatment of the monthly rent in Option 3 requires assumptions, too. For this solution, we assume the rent is payable at the beginning of each month; thus, we have calculated a beginning-of-year present value of \$31,400 for the entire year's rent. Because this amount is the present value of each year's rent payments measured at the beginning of the year, we show it accordingly. The rent is not shown at the end of year 5 (beginning of year 6), as year 6 is outside the scope of this project.
4. For the Option 3 financial analysis, the connecting corridor between the two buildings would be abandoned at the end of the five years. Although its value has been depreciated (see assumption 2), abandonment will produce a loss (book value depreciation salvage value) that can be deducted from taxable income.

Based on the financial analysis, the decision should be to use Option 3, renting the two buildings and building a corridor between them. (Again, the disposal value of the new building and land that the student assumes in Option 2 could lead to acceptance of Option 2.)

D. Recommendations

Here is a case where both qualitative and quantitative factors must be carefully considered. Not all of the considerations can be captured by a single financial figure of merit, such as net present value. Option 2 is the more effective layout and should translate into lower operating costs and higher sales over the planning horizons. Much depends on whether Moore prefers an expansionist or wait-and-see strategy to capacity expansion. On the other hand, the financial analysis of investment requirements seems to favor Option 3, renting the two buildings and building a corridor between them. (Of course, the cost savings and new revenues that will be possible with a more favorable layout have not been considered in Exhibits TN.3 and TN.4, and much also depends on the assumed disposal value of the new building and land in Option 2.) The students might want to indicate what additional information (if any) they would like to collect to be more comfortable with their final recommendation.

E. Teaching Strategy

This case can be used as a “cold-call” case, concentrating mainly on the development of a good block plan by inspection. After the students have read the case, develop a plan with them for one of the two options. Make an enlarged transparency of each option shown in Exhibit 2. Then go from one student to another, allowing each to add a new department to the “blank sheet” and explain his or her logic. To keep things tractable, do not allow much backtracking, so that each addition to the layout builds on the decision made by the earlier students. Once a layout is developed, circle on the Closeness Matrix (Exhibit 1) the scores that are for contiguous departments (touching each other) and have a student add them up. Alternatively, allow teams to develop solutions on transparencies provided by the instructor. Students could then share their results with the rest of the class. The

instructor may or may not have time to develop a layout for both options. The instructor might then share the solutions in Exhibit TN.1, which are then evaluated in Exhibit TN.2.

Ask the class to identify and discuss the different factors to consider in reaching a decision and whether the scores in Exhibit TN.2 are sufficient. Other factors can be uncertainties in future demand growth, the best capacity expansion strategy for such a small business, dealing with the differences in investment requirements, dependencies between operations and finance perspectives, and flexibility beyond the five-year horizon. Exhibits TN.3 and TN.4 can be shown to understand the financial aspects of the case better.

This case can also be prepared by students or groups of students prior to class. They could use the *Layout* solver to identify effective block plans. As a homework assignment, students would know only the *wd* approach for making making comparisons. Departmental space allocation would have to be trimmed back somewhat, to fit within the upper limit of 25 grid squares. However, the basic relationships could be analyzed with a simpler block plan, and then extended later to the full dimensions. To create a department with two grid squares, represent it with two subdepartments and assign half of each of the department's flows to each subdepartment.

EXHIBIT TN.1

Possible Block Plans

A. Option 2: Construct new building

2	1	1	1	13	13	5	5
3	3	7	6	10	12	11	15
8	8	7	4	9	9	9	9
8	8	8	8	9	9	9	14

B. Option 3: Rent additional space

13	1	1				12	3	3	15
13	6	1				8	4	10	9
2	7	7		8	8	8	9	9	9
5	5	14		8	8	11	9	9	9

EXHIBIT TN.2

Total Contiguous Approach Scores for Two Layouts

From	To	Score		From	To	Score	
		Option 2	Option 3			Option 2	Option 3
1	2	1		4	10		6
1	3	6		6	7	6	6
1	6	6	6	6	13		4
1	7	5	5	7	8	6	
1	13	5	5	8	9	6	6
3	4		4	8	11		4
3	7	3		8	12		3
3	8	6		9	10	6	6
3	10		5	9	11	6	6
3	12		5	9	12	4	
3	15		3	9	14	4	
4	6	6		9	15	6	6
4	7	6		10	12	3	
4	8	6	6	11	12	3	
4	9	6	6	12	13	5	
Totals						111	92

EXHIBIT TN.3

Financial Analysis with MACRS Depreciation Schedule

A. Option 2: Construct new building

	Current	End of Year 1	End of Year 2	End of Year 3	End of Year 4	End of Year 5
Investment costs:						
Construction costs	(\$760,000)					
Land	(\$100,000)					
Relocation costs	(\$20,000)					
Operating costs:						
Less: Depreciation		(\$12,063)	(\$24,127)	(\$24,127)	(\$24,127)	(\$24,127)
Taxes (35%)		\$651,429	\$8,444	\$8,444	\$8,444	\$8,444
Plus: Depreciation		\$100,000	\$24,127	\$24,127	\$24,127	\$24,127
Salvage						
Construction costs	\$651,429					\$651,429
Land	\$100,000					\$100,000
TOTAL CASH FLOW	(\$880,000)	\$4,222	\$8,444	\$8,444	\$8,444	\$759,873
NPV of option 2 cash flows at 15%		(\$418,933)				

B. Option 3: Rent additional space

	Current	End of Year 1	End of Year 2	End of Year 3	End of Year 4	End of Year 5
Investment costs:						
Construction costs	(\$15,000)					
Relocation costs	\$0					
Operating costs:						
Rent	(\$31,410)	(\$31,410)	(\$31,410)	(\$31,410)	(\$31,410)	\$0
Less: Depreciation		(\$238)	(\$476)	(\$476)	(\$476)	(\$476)
Taxes (35%)		\$11,077	\$11,160	\$11,160	\$11,160	\$167
Plus: Depreciation		\$238	\$476	\$476	\$476	\$476
Salvage						
Tax benefit of salvage loss						
(\$12,858)						\$4,500
TOTAL CASH FLOW	(\$46,410)	(\$20,333)	(\$20,250)	(\$20,250)	(\$20,250)	\$4,667
NPV of option 3 cash flows at 15%		(\$88,674)				

Note: NPV of rent at 15% per year; rent paid at the beginning of the month.

At an interest of 15% for 12 months, interest = 1.25% per month.

The PV for a year's rent payments = \$31,410.

EXHIBIT TN.4

Financial Analysis with 10-Year Depreciation Schedule

A. Option 2: Construct new building

	Current	End of Year 1	End of Year 2	End of Year 3	End of Year 4	End of Year 5
Investment costs:						
Construction costs	(\$760,000)					
Land	(\$100,000)					
Relocation costs	(\$20,000)					
Operating costs:						
Less: Depreciation		(\$76,000)	(\$76,000)	(\$76,000)	(\$76,000)	(\$76,000)
Taxes (35%)		\$26,600	\$26,600	\$26,600	\$26,600	\$26,600
Plus: Depreciation		\$76,000	\$76,000	\$76,000	\$76,000	\$76,000
Salvage						
Construction costs						\$380,000
Land						\$100,000
TOTAL CASH FLOW	(\$880,000)	\$26,600	\$26,600	\$26,600	\$26,600	\$506,600
NPV of option 2 cash flows at 15%		(\$480,163)				

B. Option 3: Rent additional space

	Current	End of Year 1	End of Year 2	End of Year 3	End of Year 4	End of Year 5
Investment costs:						
Construction costs	(\$15,000)					
Relocation costs	\$0					
Operating costs:						
Rent	(\$31,410)	(\$31,410)	(\$31,410)	(\$31,410)	(\$31,410)	\$0
Less: Depreciation		(\$1,500)	(\$1,500)	(\$1,500)	(\$1,500)	(\$1,500)
Taxes (35%)		\$11,519	\$11,519	\$11,519	\$11,519	\$525
Plus: Depreciation		\$1,500	\$1,500	\$1,500	\$1,500	\$1,500
Salvage						
Tax benefit of salvage loss						\$4,500
(\$12,858)						
TOTAL CASH FLOW	(\$46,410)	(\$19,892)	(\$19,892)	(\$19,892)	(\$19,892)	\$5,025
NPV of option 3 cash flows at 15%		(\$87,566)				

Note: NPV of rent at 15% per year; rent paid at the beginning of the month.

At an interest of 15% for 12 months, interest = 1.25% per month.

The PV for a year's rent payments = \$31,410.

CASE: THE PIZZA CONNECTION. *

A. Synopsis

This case presents the situation in which a restaurant, the Pizza Connection, has been successful at providing a consumer benefit package that meets customer expectations. However, competition from other restaurant alternatives has increased while at the same time the expectations of the pizza customer have been changing. In response to these changing market conditions the owner/operator, Mike Trautman, is looking to reconfigure the layout of his facility. Students are provided with the layout of the existing facility along with a description of the changing characteristics of the customer requirements.

B. Purpose

This case is positioned to provide students the opportunity to address issues of configuring and laying out facilities in a service industry environment. Students are challenged to reconfigure a pizza restaurant to respond to changing consumer expectations. Issues of space and capacity allocation, configuration of work centers, the relative location of work centers, and customer flow patterns must be addressed. After the facility is reconfigured, the issue of how to measure the effectiveness of the new layout should be addressed.

C. Analysis

The analysis in this case focuses on redesigning the layout of the restaurant to meet changing customer requirements better. Key factors to consider in the reconfiguration include the following:

1. Customers are looking for convenience and speed in being processed through the service delivery flow.
 - ❑ There is a problem at the cash register during peak hours when dine-in customers are waiting for tables and trying to pay their bill, while carryout customers are waiting to pick up their pizzas. Customers want to get in, be serviced, and get out.
2. Customers want alternative dining experiences.
 - ❑ These alternative dining experiences include home delivery, pickup/carryout, a quiet dining experience, and family dining with areas and activities for the kids.
3. Customers are looking for a place to cater parties and outings.
 - ❑ Events such as these usually entail large groups of people who want to celebrate and have a good time. It is a good idea to separate these activities from other customers to minimize any disruption that might occur.
4. In reconfiguring the facilities, some areas or facilities must remain stationary.
 - ❑ In the case of the restaurant, the restrooms should remain where they are due to the complicated nature of replumbing the facility to change their location. Likewise, it could be argued that the ovens and preparation area in the

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

kitchen should not be moved because of gas lines to the oven and the location of the sink and plumbing in the preparation area. Of course, if the changes to be made are drastic enough to require that these facilities be moved, it is entirely possible; however, the costs will be much higher, so the potential return must be greater.

5. Trautman is finding it hard to maintain his waitstaff.

- ❑ This is a typical problem in restaurants such as this and other fast-food establishments. The waitstaff is typically young and less reliable. Turnover is usually high. Can the facilities be designed to relieve some of this turnover pressure?

These factors led to the conclusion that customer flows need to be changed. If possible, pickup/carryout customers should be separated from the dine-in customers, and a party area should be established, preferably away from the regular dine-in customers. The layout should be convenient and responsive to customer needs.

Exhibit TN.1 provides the new layout as the owner reconfigured it. Significant changes include:

- ❑ The pizza production area was reconfigured to accommodate a drive-up window for pickup customers and a self-service line for dine-in customers. The oven and preparation areas were left in place. The parking lot was also reconfigured.
- ❑ The wall along the cut and box area was removed, and a self-service line was established for dine-in customers.
- ❑ A cash register was placed at the beginning of the self-service line. Here dine-in customers would place their orders and pay. Then they would proceed to get their own drinks, plates, silverware, and so on and be seated to await their order number to be called. They would proceed to the service counter to pick up their order. This strategy reduces the need for waitstaff personnel.
- ❑ A separate carryout lobby with its own entrance was enclosed to provide an area for customers to wait, pick up, and pay for carryout orders.
- ❑ A separate game room/party room was walled off to accommodate private parties and family dining activities for kids.

Students should notice that the size of the facility was unchanged. The issue was what type of service areas were required for the new layout and what would be their relative location and size. The new service areas included a party room and carryout lobby. This required taking space from the pizza preparation area and the main dining area. The beverage area was eliminated by providing the self-service line. The main dining area lost space for the party room; this cost the area three tables.

Different students will generate a multitude of layout configurations. Make sure they are able to explain the rationale and the trade-offs that were made in developing their layout. Finally, ask students to explain how they would measure the effectiveness of the new layout. Typical measurement areas might include:

- ❑ Looking for a consistent, efficient flow of materials, people, and communication in the service delivery
- ❑ Measuring the utilization of labor and equipment for each service task or area
- ❑ Measuring the amount of queue time for customers as they wait for different parts of the service
- ❑ Measuring the total flow time, throughput time, for customers

D. Teaching Suggestions: As an Experiential Exercise

This case works extremely well as an experiential exercise that connects with several topics in Parts 1 and 2, including competitive priorities, process management, quality, and capacity. Perhaps this exercise, and the layout section in Chapter 3, are the only thing that you do with Layout. Begin the exercise by pointing out that a layout brings together in a tangible form the various choices that have been made on processes.

Give each team a transparency, a transparency marker, and the task of preparing a layout that they think would be effective. It should take about 45 minutes, with 15–20 minutes for them to present their solutions. They really get into the task. When each team presents its recommendations, we discover some basic similarities and yet some multiple and creative ways to design layouts that help gain a competitive advantage.

E. Teaching Suggestions: Out-of-Class Exercise

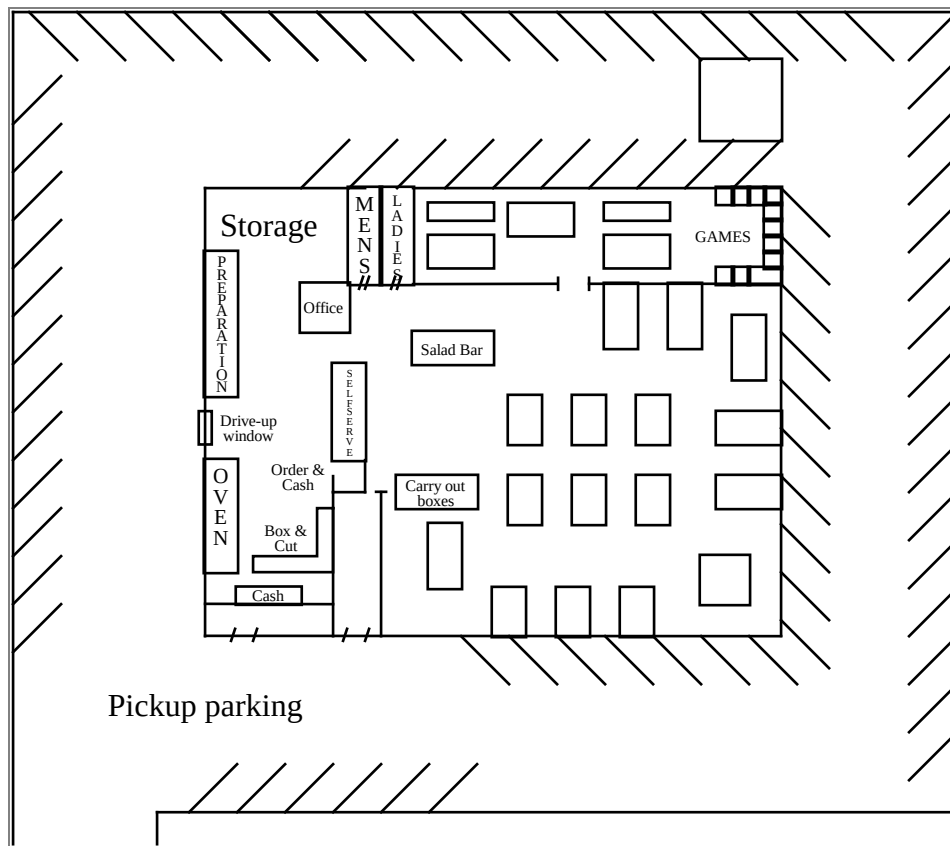
This case can also be used as an assigned take-home case to be prepared prior to class discussion. The students' primary assignment is to consider the changing market requirements and to develop a new layout to meet these needs. In class, it is best to begin by having the students identify the key factors that need to be addressed by the new layout. As the list is being developed, make sure to have the students discuss how each factor may alternatively be addressed. Try to have them see that, in many cases, these factors are interdependent due to space and relative location constraints.

After a full list of key factors is on the board, ask to see some alternative layout designs. Have the students explain their rationale and how their designs address the key factors identified on the board. Wrap up the discussion by showing the layout in Exhibit TN.1 This is the layout the owner actually implemented. Close the case discussion by asking students how they would measure the effectiveness of the new layout. Remind them that it is difficult to come up with that one best layout and that the decision is usually one of compromise, especially when redesigning an existing facility.

If the students are prepared with their new layout, the discussion should take approximately 30 to 45 minutes.

EXHIBIT TN.1

The Layout The Owner Actually Implemented



CASE: BILL'S HARDWARE. *

1. POS systems record sales on a real-time basis. By accurately tracking sales, Bill Murton and other members of the cooperative will also have the capacity to identify inventory levels that are becoming dangerously low. POS systems are also helpful in automating the process of altering prices. Thus, changes such as discounts, markdowns and promotions are much easier to execute as well as track both at Bill's store as well as across the stores in the cooperative. Finally, employees can be more profitably occupied helping customers instead of counting and reconciling inventory levels.
2. POS systems that are connected across the cooperative can ensure that prices remain stable among member locations. Further, the cooperative can balance inventory levels by enabling stores experiencing stock outs to find necessary inventory or negotiate offloading excess inventory to cooperative members in need.

* This case was prepared by Dr. Larry Meile, Boston College, as a basis for classroom discussion.

3. The benefits of POS technology should be assessed from both the customer's perspective as well as store operations. A POS system should speed checkout times as well as enhance the ability for employees to answer customer questions regarding pricing, inventory level and location. Further, the system should free employee time to help serve customers better. From a store operations perspective, a POS system should improve inventory turns as well as inventory availability. The essence of a POS system is to allow stores to have the right inventory at the right place at the right time.

POS system costs that must be considered include (1) software costs, including required software upgrades (2) hardware purchase and maintenance costs (3) employee and management training costs (4) system start-up costs to install the hardware and configure data (5) ongoing costs to maintain correct inventory and pricing information.

Chapter

4 Process Analysis

DISCUSSION QUESTIONS

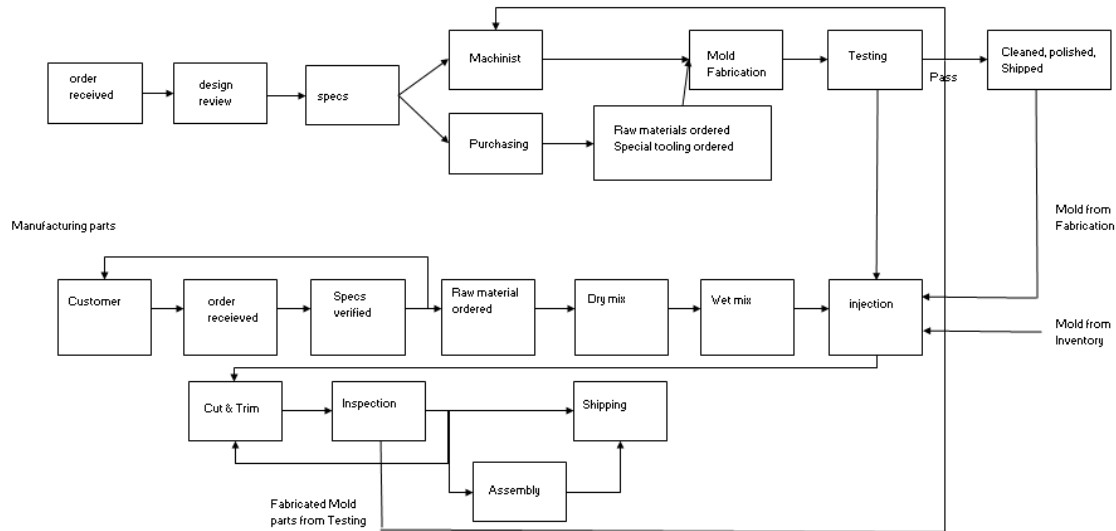
1. The answer can be debated. On one hand, relentless pressure to improve can create considerable benefits over time, and could well put a company at the top of the industry. On the other hand, small improvements do not lead to break-through solutions that might be what is needed to remain competitive, particularly in an industry marked by rapid change. However, radical change and process reengineering is strong medicine and not always needed or successful.
2. This question was inspired by a similar situation faced by Ontario Hydro-Electric. Today electricity is a commodity that competes on the basis of low-cost operations and reliability. If the environmental protection equipment is installed, HEC must either absorb the costs as a loss (immediate bankruptcy) or attempt to pass on the costs to customers and see further erosion of their market (eventual bankruptcy). HEC would probably decide to delay investment in environmental protection equipment for as long as possible. Some discussion may focus on the issue of whether customers, as users of both electricity and the environment, are better served by competition (lower cost of electricity) or by regulated monopolies (better environment).
3. For background reading, see: Paul O'Neill, "Why the U.S. Healthcare System Is So Sick and What O.R. Can Do To Cure It." *OR/MS Today* (December, 2007).
 - a. Although many ideas are possible, a typical response is some kind of computer order-entry system. Although we asked for blue sky ideas, these systems do cost a medium-sized hospital about \$10 million. They also solve only half of the problems, but the remaining half can become complicated and less tractable than the ones you started with.
 - b. Same set of ideas possible here as well.
 - c. Fill carts on a daily basis, more computerized information system, and so forth.
 - d. Ideas could include more nurses, or one of several ways to remind nurses when a drug is to be administered.
 - e. Many ideas are possible, ranging from mattresses on the floor to more nurse check-ins during the night.
 - f. Better sterilization procedures, better training on patient care, research on the causes of the infections, and more thorough house cleaning are just a few ideas. Students will come up with more.

PROBLEMS

1. Custom Molds

Custom Molds, Inc.

Mold fabrication

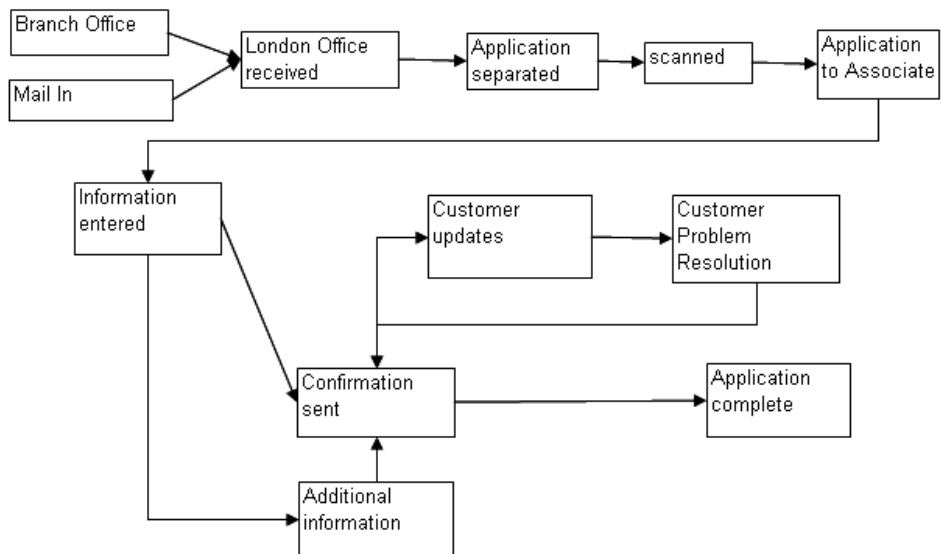


2. Process chart for Custom Molds with metrics

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Process Chart for Custom Molds													
2														
3	Step	Cost (\$)	Time (min)	Time Delay (min)	Distance Moved (feet)	Scrap (%)	Rework (%)	Environmental waste (lbs)	Energy required (\$)	External customer contact (1-7)	Demand rate (units)	Process divergence (1-7)	Inventory (units)	Customer complaints (%)
4	Mold fabrication													
5	1. Order received													
6	2. Design review													
7	3. Specs													
8	4. Machinist													
9	5. Purchasing													
10	6. Order materials and tooling													
11	7. Mold Fabrication													
12	8. Mold Testing													
13	9. Go to Step 10 or 17 as needed													
14	10. Clean, polish and ship													
15														
16	Manufacturing parts													
17	11. Customer order received													
18	12. Specs verified with customer													
19	13. Order materials													
20	14. Dry mix													
21	15. Wet mix													
22	16. Get mold from fabrication or inventory													
23	17. Injection													
24	18. Cut and trim													
25	19. Inspection													
26	20. Back to steps 4, 18, 21, or 22 as needed													
27	21. Assembly													
28	22. Shipping													
29	TOTALS													

3. ABC Insurance Company

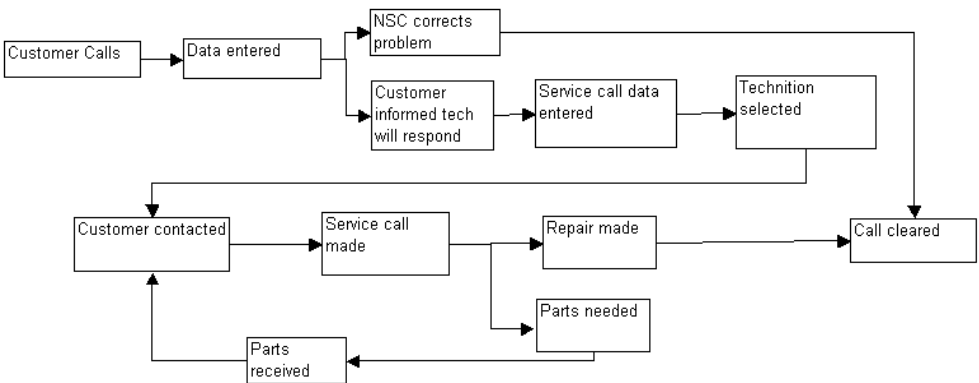
ABC



4. ABC Process Chart

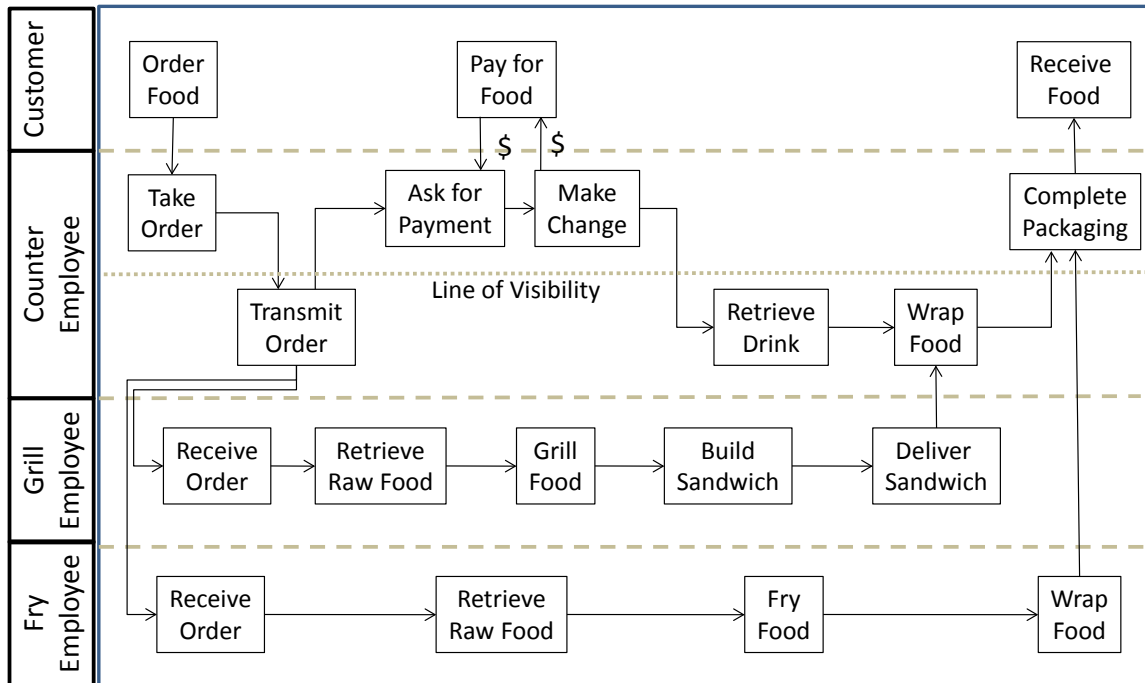
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	Process Chart for ABC															
2																
3	Step	Cost (\$)	Process Time (min)	Time Delay (min)	Cumulative Elapsed Time min	Customer Error (%)	Associate Error (%)	Rework (%)	Environmental waste (lbs)	Energy required (\$)	External Customer Contact (1-7)	Applications per Week	Process Divergence (1-7)	Customer Satisfaction (1-7)	Number of applications in queue	Customer complaints (%)
4	1. Branch office															
5	2. Mail in															
6	3. London office receives from Steps 1 or 2															
7	4. Application separated															
8	5. Scanned															
9	6. Application to associate															
10	7. Information entered															
11	8. Go to Steps 9 or 10 as needed															
12	9. Additional information															
13	10. Confirmation sent															
14	11. Go to Step 12 or 15 as needed															
15	12. Customer updates															
16	13. Customer problem resolution															
17	14. Go to Step 10															
18	15. Application complete															
19	TOTALS															

5. DEF Flowchart

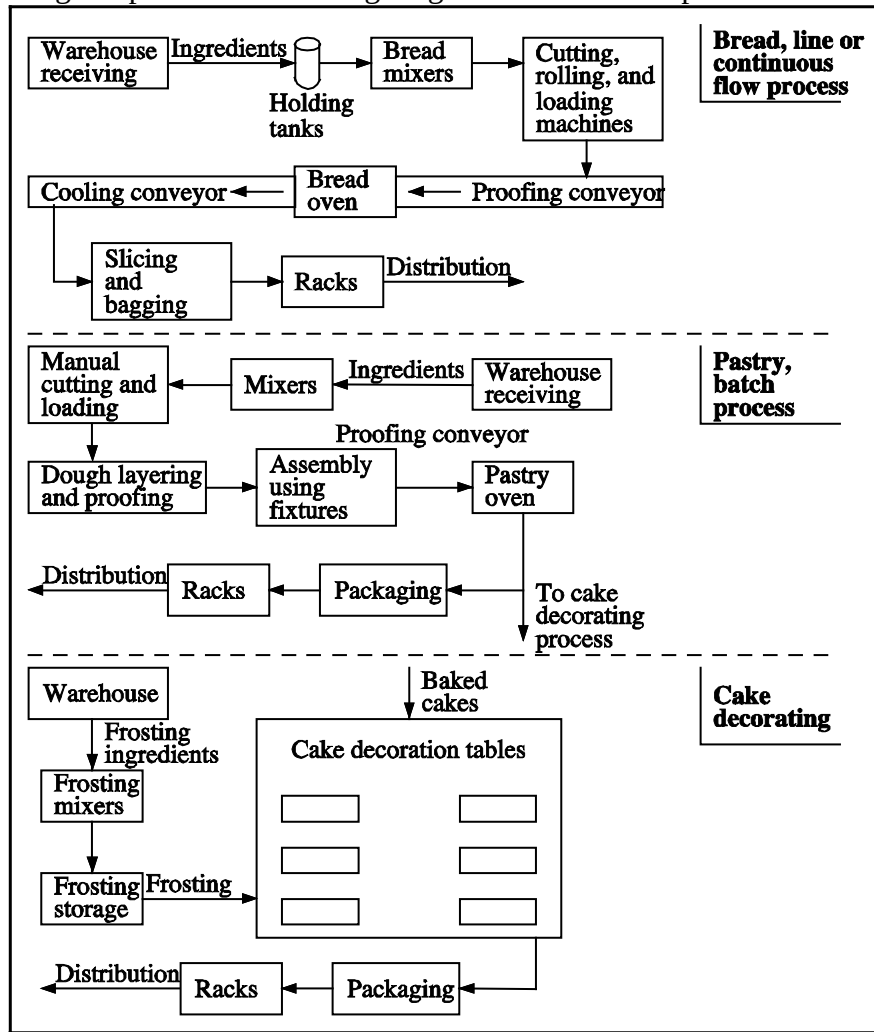


6. Big Bob's Service Blueprint

Service Blueprint for Big Bob's Burger Barn

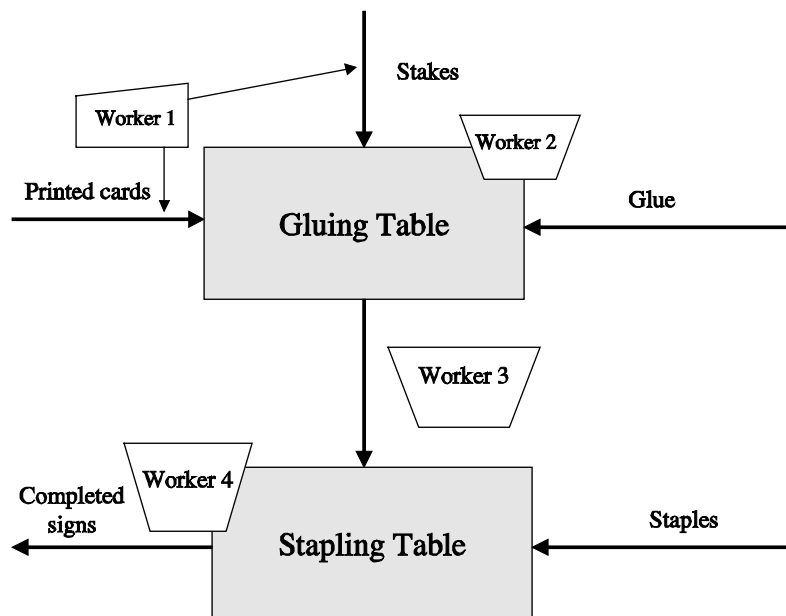


7. King Soopers. The following diagram illustrates the processes in the bakery.



8. Referendum 13

Flowchart for yard sign assembly:



Human resource requirements:

One of many possible arrangements is to create several cells with four workers in each cell.

Worker 1 is a materials handler, bringing printed cards and stakes (say in stacks or bundles of 25) to the gluing table and taking completed signs (again in bundles of 25) to the shipping area.

Worker 2 glues printed cards to the stakes. Worker 2 is also responsible for keeping the area supplied with glue, staples, pizza, and soft drinks.

Worker 3 is also a materials handler, transferring glued signs in small quantities (a transfer batch) to the stapling table.

While worker 3 holds the material in place, Worker 4 staples the card to the stake to hold it while the glue dries. Worker 4 also inspects the staples, drives loose ones home with a hammer, and stacks completed signs in bundles of 25 for Worker 1 to take away.

Accounting for interruptions, material shortages, and chaos, each cell will complete about eight signs per minute, or about two signs per worker-minute. 10,000 signs would require about 5,000 worker-minutes, or 83.33 worker-hours. In order to accomplish this work within three hours (maximum attention span of college students) $83.33/3 = 27.78$ or about 28 student volunteers are required to staff 7 cells.

Material requirements (for 7 cells of 4 workers each):

10,000	printed cards
10,000	stakes
32,000	staples (16 boxes of 2,000 each)
28	12-ounce bottles of wood glue
4	cases
10	pizzas

Equipment requirements:

14	tables
7	staple guns
7	hammers (to set staples)

Process chart (using *Process Chart Solver of OM Explorer*):

Process:	Yard sign assembly (25)	Summary			
Subject:	Volunteer				
Beginning:	Material to table	Activity	Number of Steps	Time (min)	Distance (ft)
Ending:	Completed signs removed	Operation ●	2	6.2	
		Transport ➡	4	4.0	155
		Inspect ■	1	1.0	
		Delay ◐	1	1.0	
		Store ▼	2	1.5	
	Insert Step				
	Append Step				
	Remove Step				

Step No.	Time (min)	Distance (ft)	●	➡	■	◐	▼	Step Description
1	0.5	50		X				25 printed cards to gluing table
2	0.5	50		X				25 stakes to gluing table
3	3.2		X					Glue 25 cards to 25 stakes
4	2.5	5		X				Transfer individually to stapling
5	1.0					X		Hold in position for stapling
6	3.0		X					Insert three staples per sign
7	1.0				X			Inspect staples
8	1.0						X	Stack signs into bundles of 25
9	0.5	50		X				Carry signs to shipping area
10	0.5						X	Store signs until distributed

9. Mailing to the alumni of your college
 a. A sample process chart for 2000 letters follows.

Process:	Alumni Mailing	Summary			
Subject:	Letters and envelopes				
Beginning:	Process letter	Activity	Number of Steps	Time (min)	Distance (ft)
Ending:	Place stamp on envelope	Operation ●	5	0.57	
	Insert Step	Transport ➡			
	Append Step	Inspect ■			
	Remove Step	Delay ◐			
		Store ▼			

Step No.	Time (min)	Distance (ft)	●	➡	■	◐	▼	Step Description
1	0.20		X					Process letter
2	0.12		X					Fold letter
3	0.10		X					Stuff into correct envelope
4	0.05		X					Seal envelope
5	0.10		X					Place stamp on envelope

- b. Total time for 2000 letters = $[(0.57 \text{ min}) / 60 \text{ min per hour}] \times 2000 \text{ letters} = 19 \text{ hours}$. The cost to process 2000 letters = $(\$8/\text{hr})(19 \text{ hr}) = \$152$.
- c. Changes that would reduce the time and cost of the process:
- A letterhead with “Dear Alumnus” will make step 1 (process letter) not necessary, saving 400 minutes and \$53.33 $[\$8(400/60)]$.
 - With mailing labels, step 1 involves matching the letters with labels rather than with addressed envelopes, but now we must stick the label to the envelope. We do everything we did before plus the extra step. The time would increase by 200 minutes and cost \$26.66 $[\$8(200/60)]$ more.
 - Prestamped envelopes will eliminate step 5 and save 200 minutes and \$26.67 $[\$8(200/60)]$.
 - If envelopes are to be stamped by a postage meter, it will take, 10 minutes $[2000/200]$. This results in a savings of 190 minutes and \$25.33 $[\$8(190/60)]$.
 - Window envelopes eliminate the need to match envelopes to letters, resulting in a savings of \$53.33.
- d. Using the letter with “Dear Alumnus” may reduce the effectiveness of the project because it would be less personal. This concern goes also for the use of mailing labels.

- e. Although including a preaddressed envelope will increase time and cost of the process, alumni may be more likely to contribute if they have an envelope available to them.

10. Gasoline Stations

- a. The gas station in part (b) has a more efficient flow from the perspective of the customer because traffic moves in only one direction through the system.
- b. The gas station in part (a) creates the possibility for a random direction of flow, thereby causing occasional conflicts at the gas pumps.
- c. At the gas station in part (b) a customer could pay from the car. However, this practice could be a source of congestion at peak periods.

11. Just Like Home Restaurant

- a. The summary of the process chart should appear as follows:

Activity		Number of Steps	Time (min)	Distance (ft)
Operation	●	6	1.70	
Transport	➡	6	0.80	31
Inspect	■	1	0.25	
Delay	◐	1	0.50	
Store	▼	--	--	

- b. Each cycle of making a single-scoop ice cream cone takes $1.70 + 0.80 + 0.25 + 0.50 = 3.25$ minutes. The total labor cost is $(\$10/\text{hr})[(3.25 \text{ min/cone})/60 \text{ min}](10 \text{ cones/hr})(10 \text{ hr/day})(363 \text{ day/yr}) = \$19,662.50$.
- c. To make this operation more efficient, we can eliminate delay and reduce traveling by having precleaned scoops available. The improved process chart follows.

13. DMV

The process chart is as follows.

Process:	Automobile license	Summary			
Subject:	Customer				
Beginning:	Customer arrives	Activity	Number of Steps	Time (min)	Distance (ft)
Ending:	Customer leaves	Operation ●	5	9	
	Insert Step	Transport ➡	6	0	265
	Append Step	Inspect ■	1	0	
	Remove Step	Delay ◐	4	351	
		Store ▼	1	0	

Step No.	Time (min)	Distance (ft)	●	➡	■	◐	▼	Step Description
1			X					Take a number
2		50		X				Walk to waiting area
3	240					X		Wait for service
4					X			Number is called and checked
5		60		X				Walk to clerk
6	4		X					Calculate/pay city sales taxes
7		80		X				Walk to property tax area
8			X					Take a number
9	100					X		Wait for service
10		25		X				Walk to clerk
11	2		X					Calculate/pay property taxes
12		50		X				Walk to license area
13	10					X		Wait for service
14	3		X					Calculate/pay license fee
15	1					X		Abuse license clerk
16				X				Walk to car in parking lot
17							X	Crash with bus, return to step 1

The tax assessment clerks' time is being wasted by an inefficient waiting line process. Whenever the customer arrival rate approaches the service rate, a waiting line will form. While the clerk is waiting for phantom customers, service rate declines, and waiting lines become even longer. More disgusted customers leave the waiting area (renege).

This process can be improved by arranging the waiting area to work like the "batter's circle and batter's box" in baseball. Customers who have reneged would be replaced before the clerks' time is wasted. Service rates would increase and waiting lines would decrease.

Typical of many service situations, the customer's anger is misguided. It is directed at the last person in the process (the license clerk), who has done nothing wrong. The customer pays for this misguided anger. While taking the one minute to abuse the license clerk, a bus approaches. Blinded by rage, the taxpayer drives his new car into the path of the oncoming bus, and the car is totaled. Now the customer will have to start the process again!

Epilogue.

It is almost sad how little exaggeration was used in creating this problem. When this location of the DMV closed, the local news announcer referred to it as “the city’s most popular place to wait in line.” This DMV process has since been replaced by an automated one-stop, one-transaction process. Just today I visited the new DMV and completed the entire process in five minutes.

14. Oil Change

- a. Each oil changing cycle takes $16.5 + 5.5 + 5.0 + 0.7 + 0.3 = 28$ minutes. The total labor cost is
 $(\$40/\text{hr})[(28 \text{ min/service})/(60 \text{ min/hr})](2 \text{ services/hr} \times 10 \text{ hrs/day} \times 300 \text{ days/yr})$
 $= \$112,000$
- b. $(\$40/\text{hr}) \times (2.7 \text{ minutes saved per service}/60 \text{ min/hr}) (2 \text{ services/hr} \times 10 \text{ hrs/day} \times 300 \text{ days/yr}) = \$10,800$ saved per year

15. Time Study of Assembling Peanut Valves

Average Time = $[14(15)+12(20)+15(25)] / (14+12+15) = 20.12$ seconds

Normal Time = $20.12 \times 0.95 = 19.11$ seconds

Standard Time = $19.11 \times 1.20 = 22.93$ seconds

16. Time Study of Process

Element	Performance Rating	Obs 1	Obs 2	Obs 3	Obs 4	Obs 5	Average Time	Normal Time
Element 1	70	4	3	5	4	3	3.8	2.66
Element 2	110	8	10	9	11	10	9.6	10.56
Element 3	90	6	8	7	7	6	6.8	<u>6.12</u>

Total = 19.34

Standard Time = $19.34 \times 1.20 = \mathbf{23.21 \text{ minutes}}$

17. Work Sampling on Idle Time

a. Idle Time = $(17+18+14+16) / (44+56+48+60) \times 100 = 31.25$ percent.

Working Time = $100 - 31.25 = 68.75$ percent.

- b. Different root causes can be explored in an expanded work sampling study, with new categories replacing idle, such as: waiting for materials, waiting for instructions, equipment failures, breaks, or conversations with co-workers.

18. Bid on Swimming Pools

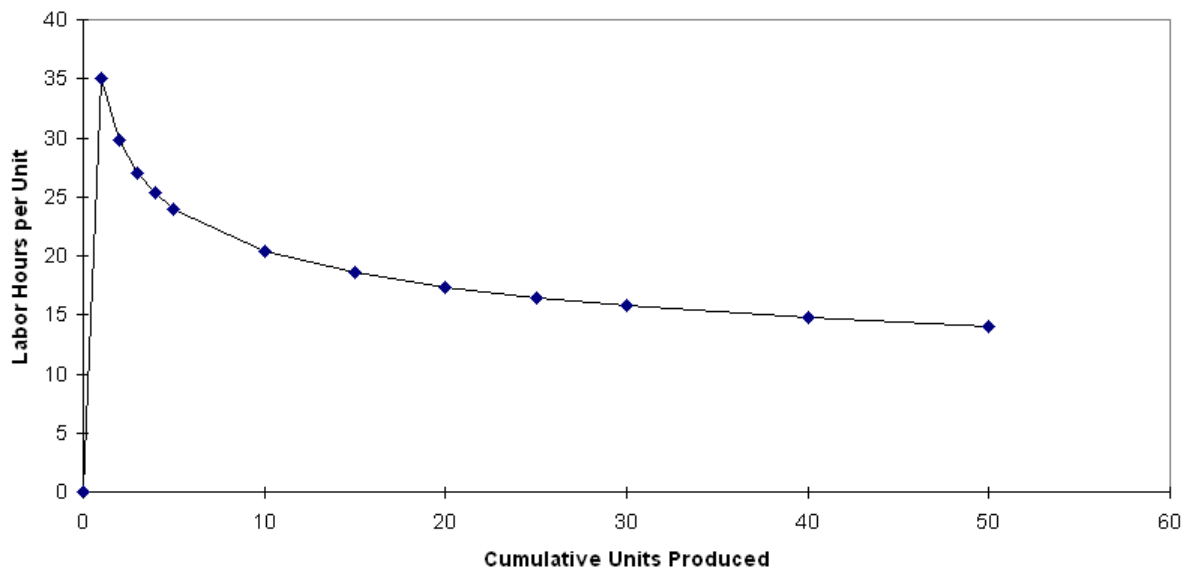
a. 2nd Pool Time = $35 \times 0.85 = 29.75$ hours

b. 4th Pool Time = $29.75 \times 0.85 = 25.29$ hours

19. Bid Using *OM Explorer*

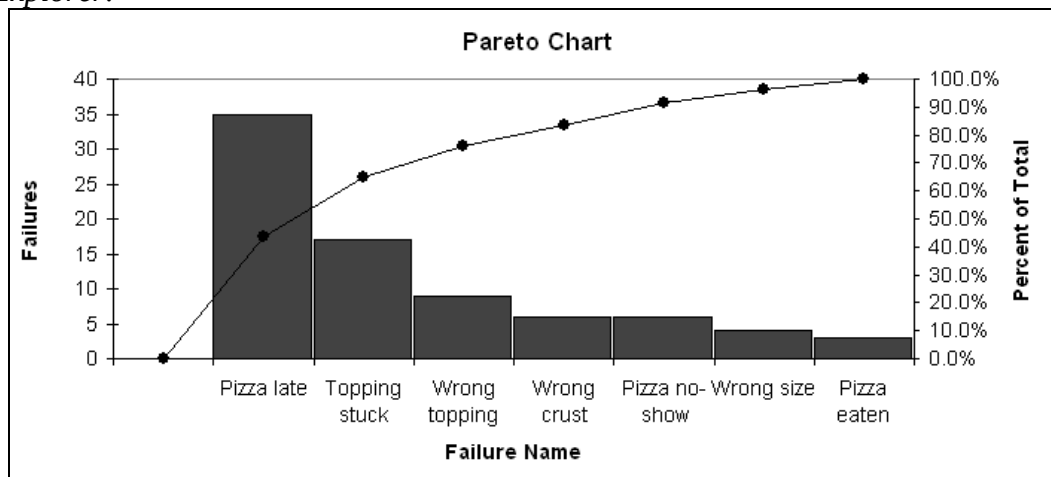
Time for first unit	35
Unit number	5
Time for unit 5	24.02
Cumulative average time per unit	28.22

The 5th pool should take just over 24 hours, with the cumulative average time for all five pools being 28.2 hours. Total Time = $(28.2)(5) = 141$ hours. The learning curve follows.

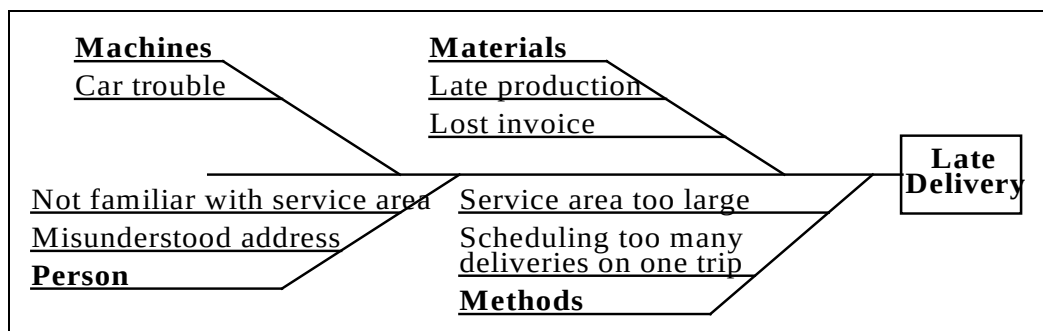


20. Perrotti's Pizza Pareto chart

- a. Although the frequency of partly eaten pizza is low, it is a serious quality problem because it is deliberate rather than accidental. It is likely to cause extreme loss of goodwill. A common root cause of many of these problems could be miscommunication between the customer and the order taker, between the order taker and production and between production and distribution. This chart was created using *the Bar, Pareto, and Line Charts Solver of OM Explorer*.

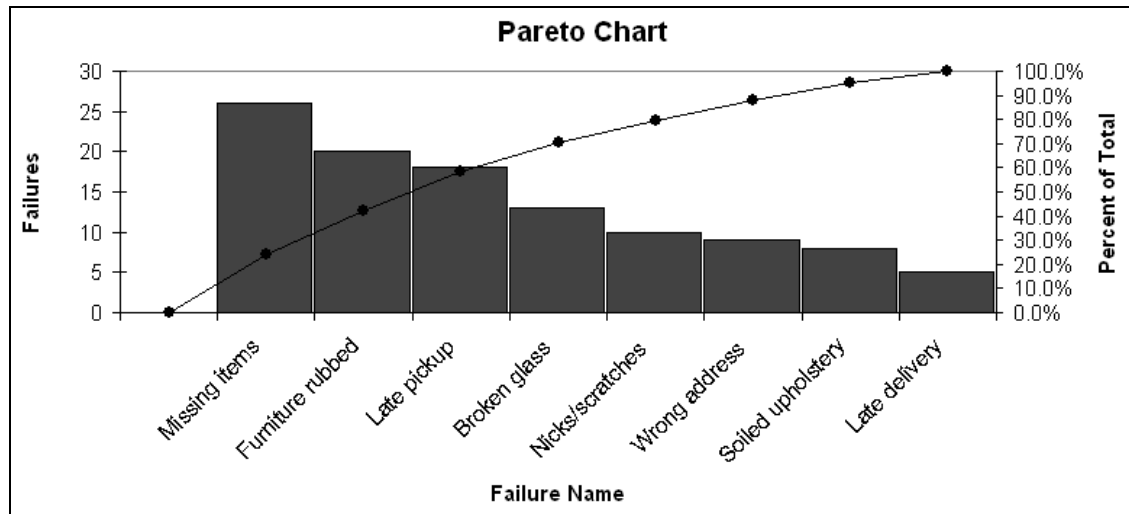


- b. Cause-and-effect diagram

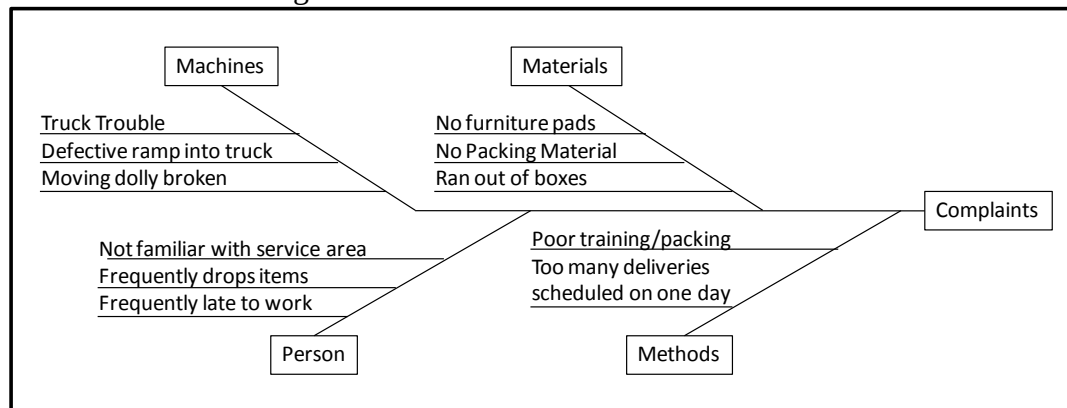


21. Smith, Schroeder, and Torn (short moves)

- a. The tally sheet given in the problem is essentially a horizontal bar chart. To create a Pareto diagram, the categories are arranged in order of decreasing frequency. This diagram was created using *the Bar, Pareto, and Line Charts Solver of OM Explorer*.



b. Cause-and-effect diagram

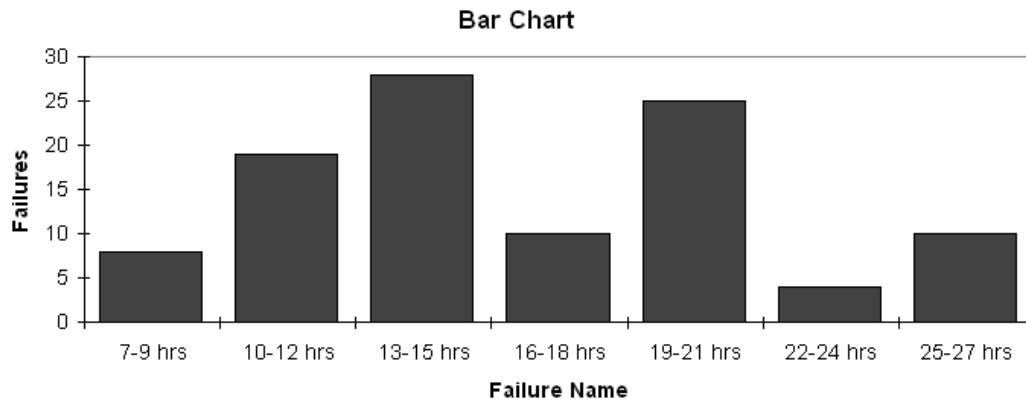


22. Golden Valley Bank

- a. Bar chart, from *the Bar, Pareto, and Line Charts Solver of OM Explorer*.

$$\text{average} = \frac{(8 \times 8) + (19 \times 11) + (28 \times 14) + (10 \times 17) + (25 \times 20) + (4 \times 23) + (10 \times 26)}{104}$$

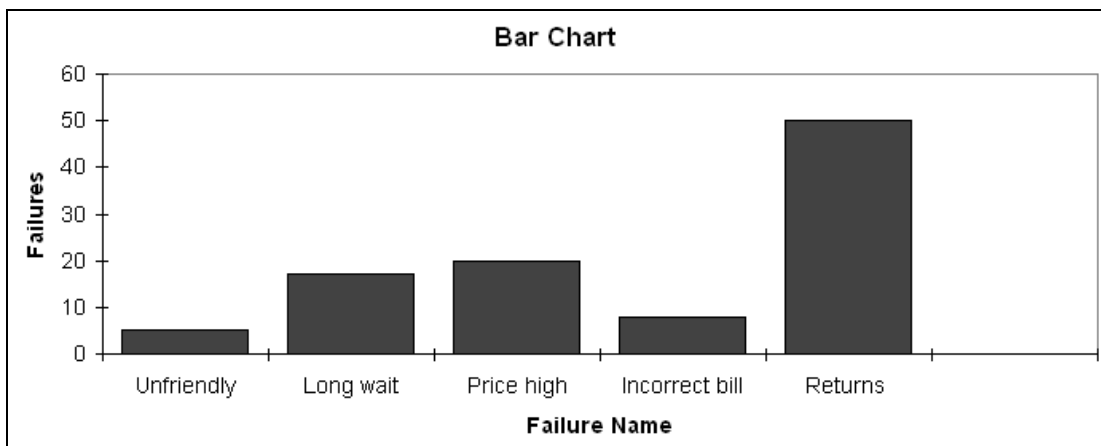
$$= 16.2 \text{ hours}$$



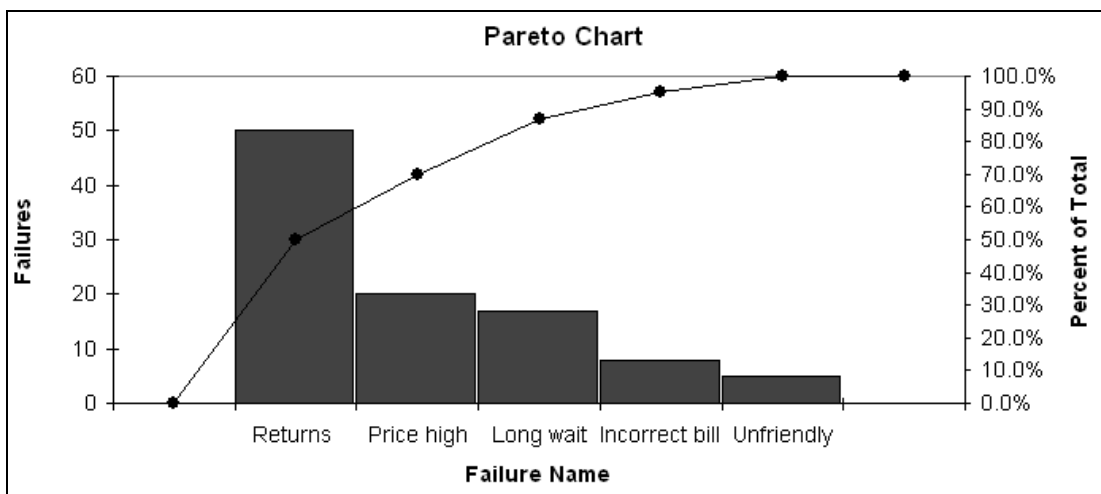
- b. Golden Valley's average time is 16.2 hours or about two business days. However, 39 of 104 customers waited longer than 18 "business hours." DeNeeffe should first investigate the 14 applications that required more than 22 hours to find causes of long delays.

23. East Woods Ford

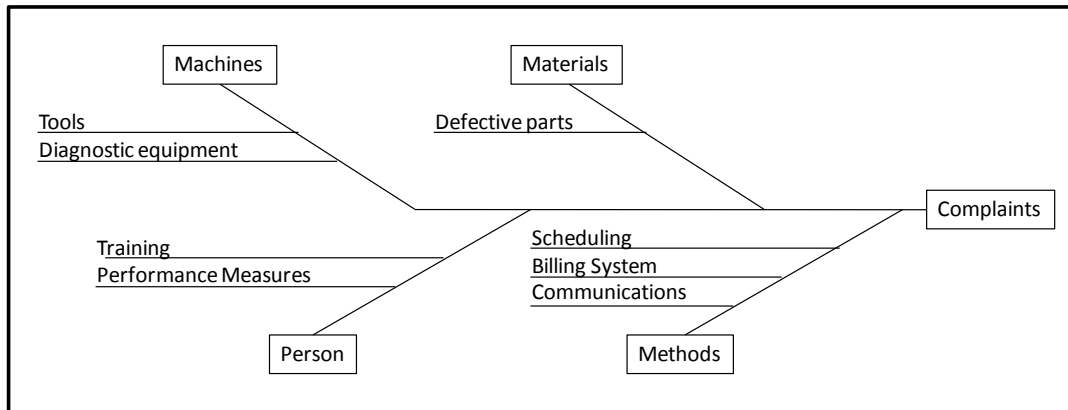
- a. Bar chart, from *the Bar, Pareto, and Line Charts Solver of OM Explorer*.



Pareto chart, from *the Bar, Pareto, and Line Charts Solver of OM Explorer*..

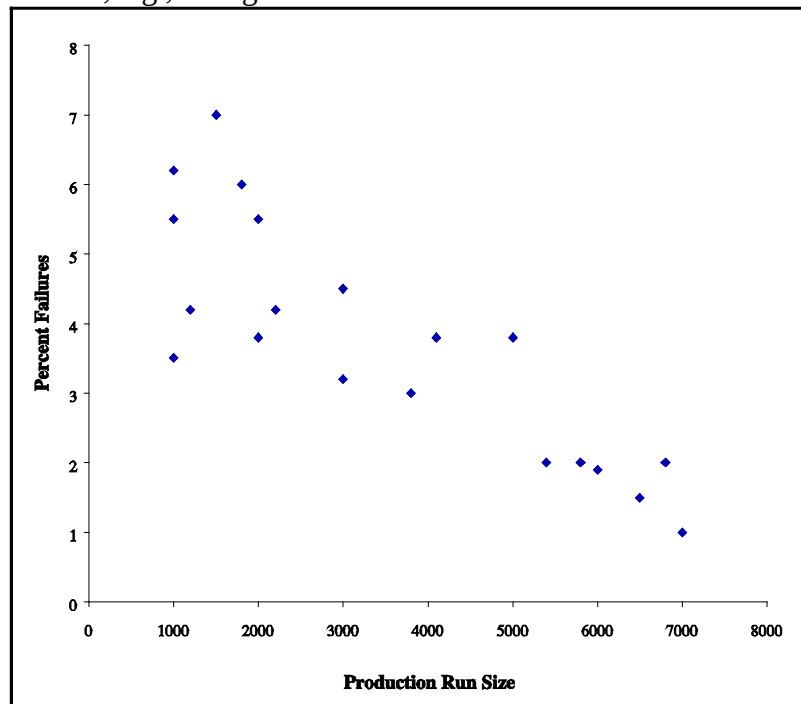


b. Cause-and-effect diagram drawn using PowerPoint.



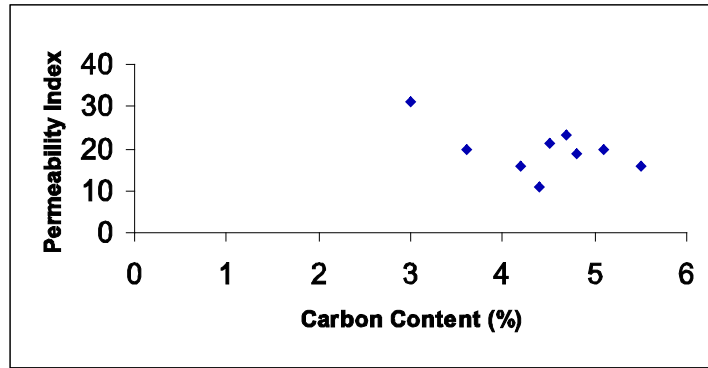
24. Oregon Fiber Board

- Scatter diagram (see following)
- As the production run size increases, the percent of failures decreases. Should schedule large runs when possible and determine what causes smaller runs to be problematic, e.g., changeover issues.



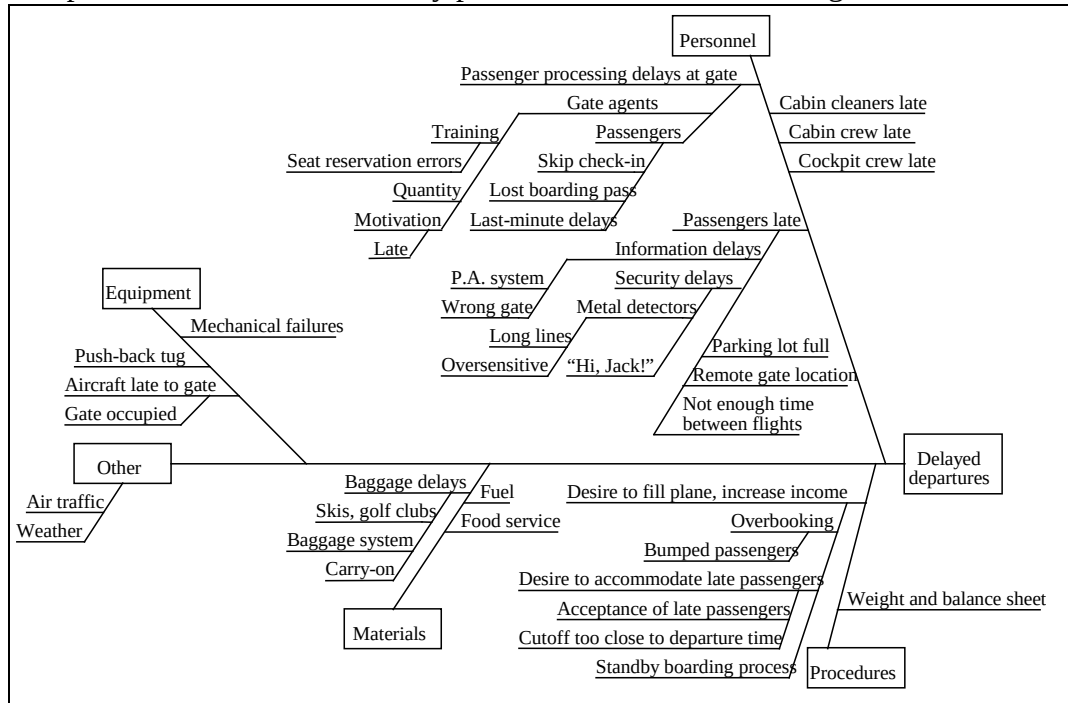
25. Grindwell, Inc.

- Scatter diagram



- b. Correlation coefficient $\rho = -0.547$. There is a negative relationship between permeability and carbon content, although it is not too strong.
- c. Carbon content must be increased to reduce permeability index.

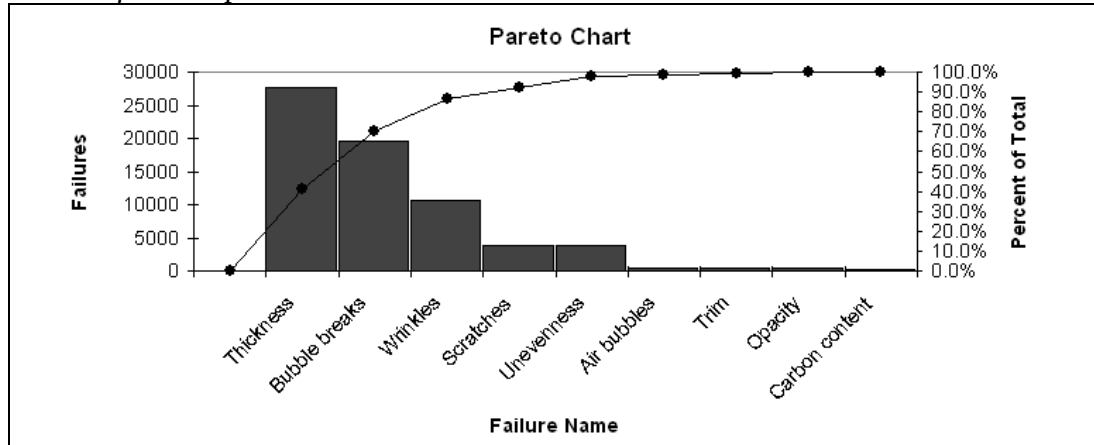
26. Superfast Airlines. One of many possible cause-and-effect diagrams follows.



27. Plastomer, Inc.

Type of Failure	Amount of Scrap (lb)	Percent of Total Amount
1. Air bubbles	500	0.7%
2. Bubble breaks	19,650	29.3%
3. Carbon content	150	0.2%
4. Unevenness	3,810	5.7%
5. Gauge/Thickness	27,600	41.1%
6. Opacity	450	0.7%
7. Scratches	3,840	5.7%
8. Trim	500	0.7%
9 Wrinkles	<u>10,650</u>	<u>15.9%</u>
Totals	67,150	100.0%

The following Pareto chart was created using the *Bar, Pareto, and Line Charts Solver of OM Explorer*.



Management should attempt to improve the “thickness/gauge” problem first.

28. Shampoo bottling company

a. The tally of data into cells will be as follows.

Cell Number	Cell Boundaries	Tally	Frequency
1	12.65 up to 12.85		4
2	12.85 up to 13.05		8
3	13.05 up to 13.25		9
4	13.25 up to 13.45		9
5	13.45 up to 13.65		11
6	13.65 up to 13.85		12
7	13.85 up to 14.05		16
8	14.05 up to 14.25		11
9	14.25 up to 14.45		10
10	14.45 up to 14.65		8
11	14.65 up to 14.85		2

b. 4% of the bottles filled by the machine will be out of specification; 4% are below the lower limit, and none are above the upper limit. NOTE: If you turn the table 90 degrees counterclockwise, the tallies create a histogram.

ADVANCED PROBLEMS

29. Team exercise on shaving

a. One possible solution would look like this:

Process:	Shaving	Summary			
Subject:	Man				
Beginning:	Remove tools	Activity	Number of Steps	Time (min)	Distance (ft)
Ending:	Clear area	Operation ●	4	6.20	
		Transport ➡	4	0.50	20
		Inspect ■	1	0.50	
		Delay ◐	9	9.00	
		Store ▼	--	0.00	

Insert Step

Append Step

Remove Step

Step No.	Time (min)	Distance (ft)	●	➡	■	◐	▼	Step Description
1	0.10	5		X				Remove shaving bowl and soap from cabinet
2	0.10	5		X				Remove brush from cabinet
3	0.10					X		Turn warm water faucet on
4	3.00					X		Hold hand under faucet until water is warm
5	1.00					X		Create shaving lather with brush & warm water
6	1.00		X					Apply shaving lather to face
7	0.10					X		Plug sink
8	3.00					X		Turn faucet off when sink is half full
9	0.10	5		X				Remove razor from cabinet
10	0.50					X		Insert new razor blade
11	0.10		X					Draw blade across face
12	0.10					X		Rinse blade in sink
13	5.00		X					Repeat steps 11-12 until face clear of stubble
14	0.50				X			Inspect face
15	0.20					X		Thoroughly rinse razor
16	0.10		X					Dry face with towel
17	0.20	5		X				Return tools to cabinet
18	1.00					X		Unplug sink, drain completely, and clear area

Additional comments (students may have slightly different observations): After Step 2, he “walks back to sink”; Steps 3-4 and 7 & 8 are operations; The Delay step between 7 & 8 is “Wait for sink to half fill”; Between Steps 8 & 9 he “walks over to cabinet” to remove the razor (unless he gets it at Step 1 or 2) and he needs to “walk back to sink” to unplug and clean.

b. Some ideas generated from brainstorming the process:

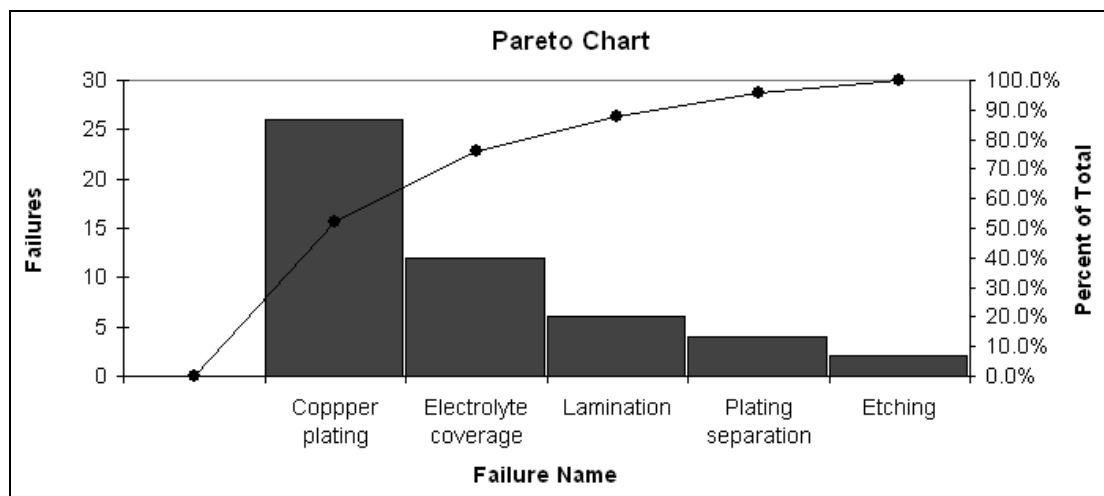
1. Leave bowl, soap, razor, and brush on the counter.
2. Turn water on first.
3. Buy new water heater so water warms faster.
4. Use shaving cream or gel.
5. Shave in the shower.
6. Plug sink before turning water on.
7. Run water while shaving instead of plugging and filling sink.
8. Fill sink one-fourth full instead of half full.
9. Use disposable razor or electric razor.
10. Replace razor every other day.
11. Grow a mustache, beard, or goatee to reduce shaving time.
12. Go to a barber.
13. Let face air dry.
14. Use cold water.
15. Do not inspect the face but shave accurately the first time.
16. Shave every other day.
17. Don't rinse blade each time.

30. Conner Company

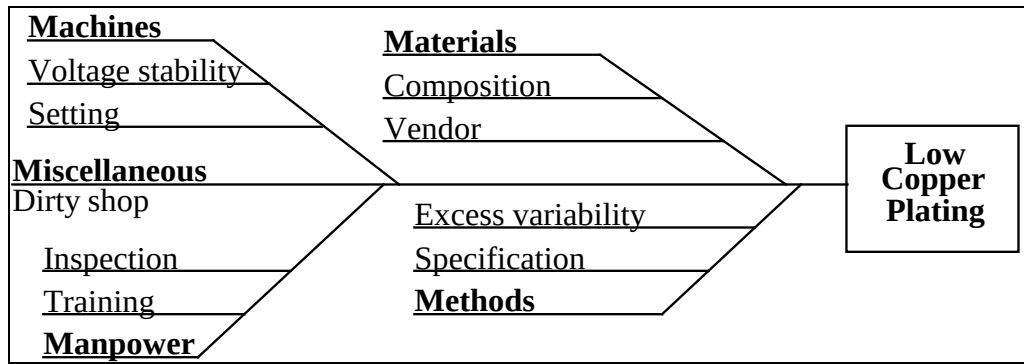
a. Tally sheet

Type of Failure	Tally	Number of Rejected Boards
A. Poor electrolyte coverage		12
B. Lamination problems		6
C. Low copper plating		26
D. Plating separation		4
E. Etching problems		2
Total	50	50

b. Pareto chart, from OM Explorer.



- c. Cause-and-effect diagram (Note: several alternative ideas are possible here.)



CASE: JOSE'S AUTHENTIC MEXICAN RESTAURANT *

A. Synopsis

Jose's Authentic Mexican Restaurant is a small, independently owned local restaurant. Ivan, the waiter, has noticed a significant reduction in the size of tips, leading him to concerns about the quality of the food and service. The characteristics of the restaurant and the process that takes place in the restaurant are described following. Students are asked to think of the characteristics of this environment that define quality to the various players, identify the implied costs of quality, and apply some of the analysis tools provided in the text.

B. Purpose

This case provides a scenario to which students can relate. Nearly every student has eaten at a small ethnic restaurant, and you can count on their collective experience to flesh out the unspoken issues presented in the case. There is sufficient description of the process to spark considerable discussion as to how the nature of the process (and the internal customer chain) interacts with the external customer's perception of quality. The students need to develop definitions and measures of quality from several perspectives and then think of how to integrate these different views. A discussion of the restaurant's management has been purposefully excluded from this case so that the students can freely devise the interventions that should be taken to improve quality at Jose's.

C. Discussion

1. The first question, asking how quality is defined, is designed to get students to think of defining quality from the perspective of the various players. At a minimum, the students should be able to describe the external customers as the patrons (diners) and the internal customer chain as the cook and wait staff. Other expansions may be offered as well (hostess, management, busboys, other kitchen staff, suppliers, community, etc.). A partial list of factors is presented below. No doubt, your students will come up with many more characteristics that can be used to define quality.

A. To the external customers (the diners), quality is defined by their expectations. The case does not explicitly describe all of the following but much may be inferred by the students based on their experiences with restaurants. The customers can expect any or all of the following:

1. Location and access (to be in a reasonably safe, aesthetically acceptable location, to be within walking distance, have adequate parking, be served by public or other transportation).
2. Ambiance. The appearance of the facility should fit its place and purpose.
3. Appropriate recognition on arrival (greeted by the hostess, apprised of any wait, seated in an acceptable location).

* This case was prepared by Dr. Larry Meile, Boston College, as a basis for classroom discussion.

4. Pleasant and attentive interaction with the wait staff (a greeting shortly after being seated, orders taken when *they* are ready, well-paced delivery of food items, periodic checks for additional needs, the bill presented when *they* are ready). Of course, determining the specific desires of each party is a particular challenge that must be met by the waiter. Do they want to speedily complete the meal and be on their way? Or, do they prefer a leisurely paced repast? Is the party in the mood for some light banter from the waiter or do they prefer to be left alone? This may be the quality characteristic over which Ivan has the most control.
 5. Good-tasting food served in an appealing fashion (taste, temperature, portion, presentation). This characteristic, if held constant, is probably most important for first-time patrons. Repeat patrons already know what they are in for.
 6. Conformance to regulatory agency guidelines. If the restaurant is open, it is assumed that it has been inspected and passed by the appropriate regulatory agencies.
 7. Value. The combination of all the preceding when price is factored in.
- B. To the cook, an internal customer, quality is largely related to the work environment.
1. The raw materials are available when needed, are fresh and tasty, have good appearance, are easy to prepare (perhaps even have some of the nasty tasks already completed—like prepeeled potatoes), and are consistent from purchase to purchase.
 2. The equipment is properly suited for the task, performs reliably (e.g., the oven is always at 350° when the dial is set to 350), is easy to use, and is laid out effectively.
 3. The environment is satisfactory; it is well lit and temperature controlled, coworkers and management offer respect, work load is reasonably level (ideally there is no mealtime rush to contend with), working hours are acceptable, wages and benefits are competitive, salary is paid on time.
- C. To Ivan (also an internal customer), quality also relates to the workplace environment.
1. The quality of the finished goods (the meals). The meal is the one described in the menu, it is of adequate portion, it is produced in a timely fashion, it tastes good, and it has a pleasant appearance.
 2. The serving equipment is appropriate, functional, and clean. The dishes, cups, glasses, tableware are clean and appropriate for the purpose. The tablecloth and seating area are clean and orderly. The waitstation has the appropriate equipment (coffeemaker, ice and water dispenser, etc.)
 3. The environment provides a place in which it is pleasant to work (many of the same issues as the cook, listed earlier).
- D. To the restaurant's management, quality is primarily related to the firm's image (in addition to the personal working environment issues faced by all employees).
1. The restaurant's reputation in the community: viewed as an asset to the community, a community supporter, a source of gainful employment, a nonpolluter, a good neighbor.

2. The restaurant's image in the eye of the consumer (diner): all of the customer's quality issues mentioned previously are met.
3. The restaurant's image with governmental agencies: the health department finds little fault with its operation, fire codes are met, appropriate security measures have been taken, taxes are paid in full and on time.

Quality definitions can also be discussed by category:

- ☐ Customer-driven definitions of quality
 - ☐ Conformance to specifications—food (weight, appearance, congruent with menu description), preparation time, meeting health regulations.
 - ☐ Value—customers feel that the food, service, and ambiance are worth the price.
 - ☐ Fitness for use—customers leave feeling well fed. Dietary concerns are met (low fat, low sodium, etc. where appropriate)
 - ☐ Support (recovery from failure)—if something is not satisfactory, how is it rectified (issue recognized, apology offered, items quickly replaced, substitutes offered, bill adjusted, etc.)?
 - ☐ Psychological impressions—the feeling the diner gets based on the atmosphere of the restaurant, the interactions with the staff, and the characteristics of the food.
2. Question two asks the students to list some of the costs of poor quality. Although specific values cannot be placed on them, conceptual sources of costs can be identified. Note that these can be viewed from the restaurant's perspective and from Ivan's perspective, and by shifting the view, the interventions (and costs) change. A short list of possible actions and costs is provided following:

A. Prevention:

Restaurant: Purchase better food stock (dollars). Reject and reorder subpar supplies (time)
 Set (and meet) food preparation standards (time)
 Ivan: Cull out poorly prepared meals; ask for replacements (time)

B. Appraisal:

Restaurant: Inspect incoming food stock (time)
 Survey
 Ivan: Inspect meals prepared by the cook (time)

C. Internal failure:

Restaurant: Replace (or rework) rejected meals (time, dollars)
 Ivan: Help the cook get an order out faster (time)

D. External failure:

Restaurant: Unsatisfactory customer experience (dollars)
 Ivan: Poor-quality meal to be served to customer (dollars)

3. Four of the quality tools are appropriate for Question Three. Checklists are already done. Results of the customer satisfaction survey are shown in the case. From this list a histogram or bar chart of the customer complaints can be made (see Exhibit TN.1) and a Pareto chart ranking them in importance can be constructed (see Exhibit TN.2).

It may be useful to ask the students if the survey results include all Jose's customers. The concept of nonresponse bias can be brought forth. Maybe long-time satisfied customers figure if nothing is wrong, no reply is needed. Maybe disgusted customers are so put out that they don't even want to take the time to help rectify the situation. They will simply vote with their feet and not return. Also note that the data collected clusters the results from both first-time and returning customers. Point out to the students that a great deal of information may be lost by not reporting these results separately.

Also ask the students about what information was *not* captured when a negative response was given to any of the customer survey questions. If they were not seated promptly, how long did they wait? If the waiter was not satisfactory, what was lacking? If the food was not enjoyable, what was the problem? Finally, if the dining experience was not worth the cost, what needs to be changed?

A cause-and-effect (fishbone) diagram (see Exhibit TN.3) can be constructed from the results of the survey, the information given in the text of the case, and some assumptions about the behavior of the restaurant (as suggested by the students from their dining experiences).

D. Recommendations

Although no specific recommendations are called for, the students should be pressed to think of what Ivan can do to improve his situation. The concept of employee involvement (one of the elements of the TQM Wheel) can be discussed here. This case provides a reverse view of the material discussed in the chapter. The chapter talks of management's challenge in establishing appropriate cultural change (including awareness of the voice of the customer, advocating the concept of an internal customer chain, and quality at the source), promoting individual development, and creating effective awards and incentives. All of these issues can be viewed from Ivan's perspective and point out the frustrations experienced by employees if good quality management is not practiced.

E. Teaching Suggestions

It is effective to ask the students to read this case before the discussion of the material in the chapter. The case then can act as a common situation that can be used when lecturing on the various quality topics. As the topics addressed by the questions at the end of the case are covered by lecture, the students can be asked to respond to them as part of the classroom discussion.

If the case is used after the chapter material has been covered, it can be used as a cold-call case or it can be assigned for preparation before discussion in class. If prior preparation is done, it may be effective to have the students answer the questions by themselves and then meet as small groups to consolidate their ideas.

When discussing the costs of poor quality, it may be useful to provide a table for the students on the board or on an overhead transparency listing the four costs and providing two columns, one for the restaurant and one for Ivan as follows:

	Restaurant	Ivan
Prevention		
Appraisal		
Internal failure		
External failure		

Possible points for discussion (those points in italics are covered in the preceding discussion):

Customer-driven definitions of quality

Conformance to specifications

Value

Fitness for use

Support (recovery from failure)

Psychological Impressions

Quality as a competitive weapon

Employee involvement

Customer definition

External

Internal

Continuous improvement

Plan-do-act-check cycle

Costs of poor quality

Prevention

Appraisal

Internal failure

External failure

Improvement through TQM

Benchmarking (Not done within the case but the concept could be discussed.)

Product/service design

Reliability

Tools for improving quality

Checklists (customer satisfaction survey)

Histograms/bar charts

Pareto charts

Cause-and-effect (fishbone) diagram

EXHIBIT TN.1

A Bar Chart of the Customer Complaints from the Customer Satisfaction Survey Shown in the Case

Were you seated promptly?	Yes	70		No	13
Was your waiter satisfactory?	Yes	73		No	10
Were you served in a reasonable time?	Yes	58		No	25
Was your food enjoyable?	Yes	72		No	11
Was your dining experience worth the cost?	Yes	67		No	16

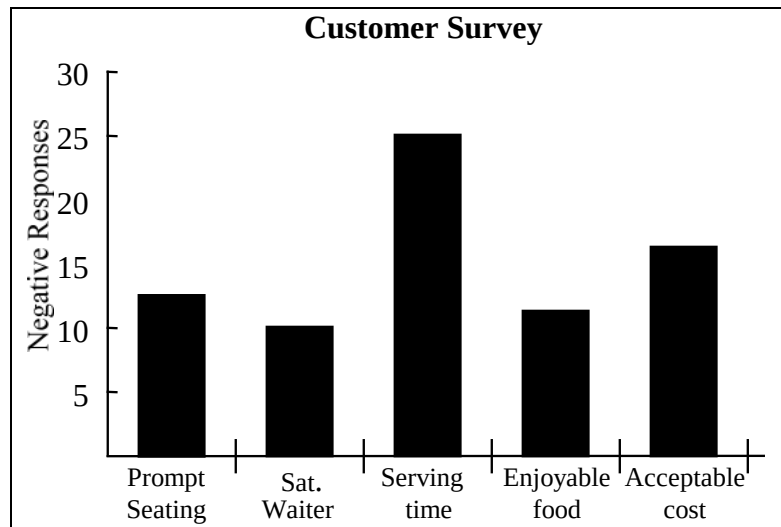


EXHIBIT TN.2

A Pareto Chart Ranking Customer Complaints

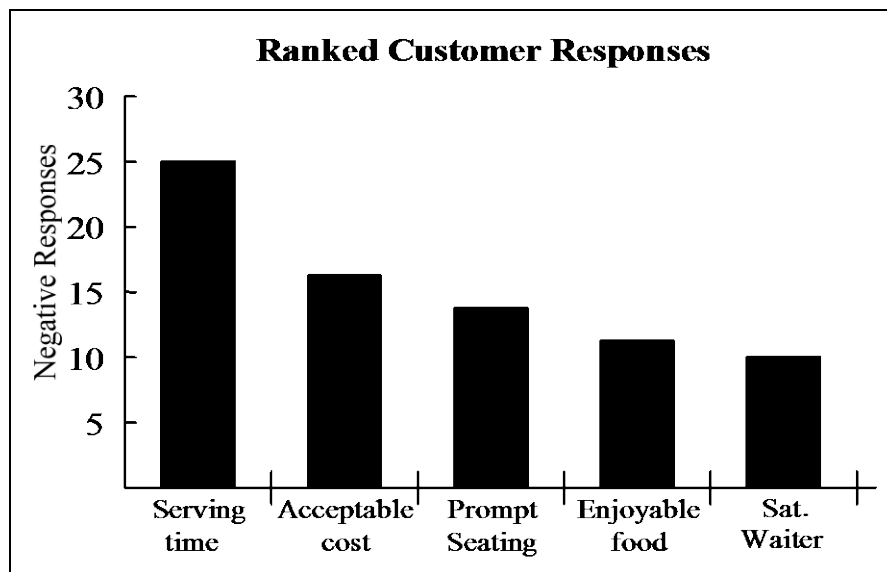
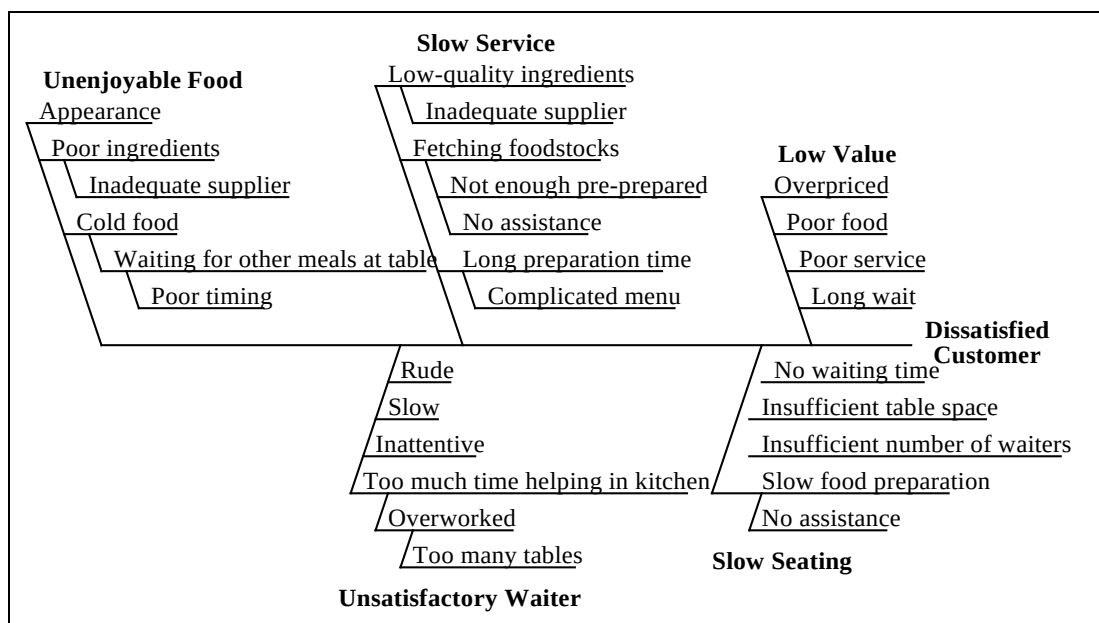


EXHIBIT TN.3

A Possible Cause-and-Effect (Fishbone) Diagram

**Alternate survey:**

1 = Completely Satisfied; 5 = Extremely Dissatisfied

How satisfied were you with	Customer survey results (Number of replies to each response option)				
	1	2	3	4	5
Promptness of seating	129	63	19	14	9
Service of your waiter	134	56	31	0	14
Speed of service	110	45	40	9	31
Enjoyability of food	122	52	31	16	14
Price of dinner	129	71	19	2	14

ADDITIONAL CASE IN myomlab

CASE: THE FACILITIES MAINTENANCE PROBLEM AT MIDWEST UNIVERSITY *

A. Synopsis

This case describes the problems facing a medium-sized university, Midwest University, as it tries to maintain 60 buildings on campus. The specific problem is slow response time in completing work-order requests. The facilities maintenance area is organized, structured, and scheduled around skilled craft areas. The issue facing Sean Allen, manager of the facilities area, is how to organize and manage his personnel to reduce this poor response time.

B. Purpose

The focus of this case is to highlight the importance that job design plays in the delivery of a quality service package. As it now stands, the facilities maintenance area at Midwest University is organized around craft functions, in much the same way most traditional organizations are organized around finance, marketing, and operations. The problem is that the processes necessary to provide a quality service require coordination and integration across the skilled crafts. This leads to the necessity of redesigning the way work is to be completed. The issues of job design brought out in the case include:

1. Movement from a vertical organizational structure to a multicraft team-oriented, horizontal organization
2. Use of enlargement, rotation, and enrichment as jobs are redesigned
3. Training requirements necessary to support the new job designs
4. Measuring the performance of the new organizational structure and providing appropriate recognition

C. Analysis

The analysis and class discussion should begin by focusing on the issue of why facilities maintenance is providing such poor response times to work-order requests. Students who have ever lived on campus will readily identify with this problem. Five- to ten-day lead times for work requests that, for the most part, take less than one hour do seem a little absurd. The analysis of the problem should focus on the key factors that contribute to this poor performance. Students should quickly be able to identify the following three factors:

1. The difficulty in prioritizing work-order requests across both crafts and buildings for scheduling purposes

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

2. The frequent need to involve more than one craft in order to complete the work-order request
3. The geographical dispersion of 60 different buildings that need to be maintained
 As the problem-identification discussion continues, students may add other factors to these three. The instructor's job here is to bring the students to the realization that the top-down scheduling of work-order requests across crafts and 60 different buildings is a very complex and integrative process. Students should begin to realize that poor lead-time performance is actually a symptom of a much larger problem, that is, the conflicts that are present by having a "functional silo" orientation to job design when the performance of the job to meet customer requirements calls for a multidisciplinary team approach. The rest of the analysis should focus on the seven key elements of job design for horizontal organizations:
 1. *Organize around processes:* Ask students to identify the core processes that are critical to the success of the facilities maintenance area. Key processes identified should include:
 - ☐ Order receipt and processing
 - ☐ Work scheduling and dispatching
 - ☐ Physical maintenance and repair
 2. *Flatten the organizational hierarchy:* Supervision can be reduced by breaking down the "functional craft silos" and the inherent managerial redundancy created by each craft managing itself.
 3. *Teams manage the organization:* Teams can be organized around the core processes identified in point #1. Another factor to consider is the geographical dispersion of the buildings on campus. Teams could be organized not only as multicraft maintenance and repair groups but also around specific geographical areas of the campus. Teams could then receive, schedule, and repair their own work requests over a designated number of buildings. This would push responsibility through the teams and help alleviate the problem of travel across campus.
 4. *Customers drive performance:* By having teams assigned to specific buildings, relationships that would enhance the teams' knowledge of customer requirements could be developed. Specific measures of customer satisfaction would need to be developed.
 5. *Management rewards team per performance:* This structure naturally leads to cross-training opportunities for which team members could be rewarded. Other measures, such as number of work requests completed per time period, average time to complete a work request, and customer satisfaction index ranking, need to be established to evaluate the performance of the team as a whole.
 6. *Supplies and customer contact:* Geographical assignments will help foster customer contact. This decentralization may, however, remove the teams from maintenance and repair suppliers.

7. *Training programs for all employees:* Training should not only include the opportunity for cross-craft skill training but should also look at communication, team building, process improvement, problem solving, and administrative skills.

D. Recommendations

The instructor should focus the students on looking at the “big picture” in making recommendations with respect to job design. Students should address the issue of moving toward a horizontal organization and away from the traditional, vertically oriented craft silos. Their recommendations should encompass each of the seven key factors of job design.

As a side note, the manager of facilities maintenance actually created cross-functional craft teams and assigned these teams to specific areas of the campus. Individual teams were responsible for scheduling and completing work within their own assigned geographical area. The custodial staff was also integrated into the team, which helped in planning and completing routine maintenance. The teams were able to become familiar with both their “customers” and the individual needs of the buildings in their area. Response times have been drastically reduced, with 50% of the requests getting same-day service and 80% of the work-order requests getting next-day service. Large requests that exceed the resources of an individual team are still coordinated by the main office.

E. Teaching Strategy

This is a short cold-call case that is positioned to get students thinking about the impact job design has on an organization’s ability to satisfy customer needs. Students should draw not only from the material on teams in Chapter 5, “Quality and Performance”, but also from the concepts in Chapter 3, “Process Strategy”.

If you like using groups, this case can be effectively discussed by breaking the class into groups and giving them 15 to 20 minutes to brainstorm alternative approaches to reducing the response time to work-order requests. Then get them back together and go around to each group for a report on what they brainstormed, putting each group’s responses on the board. Compare and contrast the similarities and differences in each group’s approach.

The instructor should take the last 10 to 15 minutes to categorize the group’s responses on the board with respect to the major concepts of the chapter. Indicate which alternatives focus on each of the seven key factors of job design; which responses deal with enlargement, rotation, or enrichment; which focus on the development of standards, training needs, or incentive plans. By doing this summary, the instructor has the opportunity to tie the concepts of job design together into an integrated whole. You can conclude by describing briefly what actually happened as presented in the recommendation section.

Chapter

5 Quality and Performance

DISCUSSION QUESTIONS

1. The use of automation in a highly craft-oriented process is certainly something to ponder over. Steinway grand pianos are objects of beauty, each with its own personality because the fine woods for the exterior finishes and the sound board all have their own natural differences, thereby requiring craftsmen to bring it all together to achieve the high quality of appearance and sound. The use of automation here is not to reduce the cost of manufacturing because the profit margins are large. However, the “action” mechanisms are standard in their design and can be produced in larger quantities. These mechanisms must be produced to fine specifications so that the craftsmen involved with the “voicing process” and “tone regulation” can have a firm basis from which to do their work. In essence, Steinway has reduced the inherent variability of their manufacturing process by adhering to strict conformance to specifications in the action mechanisms.
2. It is important for the new corporation to have a high-quality product right at the start because it has no market presence in the automobile market. Making sure that the process is capable is very important for a secure start and long-term presence. Many companies have failed miserably when introducing a new product because the production system was not capable of producing a product without defects. The automobile industry is very demanding from a quality perspective. Quality can be considered an “order qualifier” in many instances. This puts pressure on any new venture, but especially on a new company trying to compete against Japanese, American, and German companies who have been in the market a long time. However, delaying a market entry has important marketing implications. Competitors have more time to combat the entry and secure their own market shares.
3. Unethical business practices degrade the quality of a service or product because quality, from a consumer’s perspective, is often defined by the experience involved with the consumption of the service or product. This experience involves the interactions with the business or organization providing the service or product. If the consumer feels exploited, thinks the provider has lied about something, or thinks that the provider is trying to garner more than a fair compensation for the service or product the quality of the experience deteriorates. The International Organization for Standardization (IOS) has developed ISO 26000:2010, which is a set of guidelines on social responsibility for organizations to follow. It is generally accepted that ethical behavior is the best avenue for the long-term growth of organizations.

PROBLEMS

1. Quickie Car Wash

$$\bar{x} = 390 \text{ sec}, n = 9, \bar{R} = 10 \text{ sec}$$

From Table 5.1,

$$A_2 = 0.337, D_3 = 0.184, D_4 = 1.816$$

$$UCL_{\bar{R}} = D_4 \bar{R} = 1.816(10 \text{ sec}) = 18.16 \text{ sec}$$

$$LCL_{\bar{R}} = D_3 \bar{R} = 0.184(10 \text{ sec}) = 1.84 \text{ sec}$$

$$UCL_{\bar{x}} = \bar{x} + A_2 \bar{R} = 390 \text{ sec} + 0.337(10 \text{ sec}) = 393.37 \text{ sec}$$

$$LCL_{\bar{x}} = \bar{x} - A_2 \bar{R} = 390 \text{ sec} - 0.337(10 \text{ sec}) = 386.63 \text{ sec}$$

2. Isogen Pharmaceuticals

$$\bar{x} = 150 \text{ milliliters}, n = 4, \bar{R} = 3 \text{ ml}$$

From Table 5.1,

$$A_2 = 0.729, D_3 = 0.0, D_4 = 2.282$$

$$UCL_{\bar{R}} = D_4 \bar{R} = 2.282(3 \text{ ml}) = 6.846 \text{ ml}$$

$$LCL_{\bar{R}} = D_3 \bar{R} = 0.0(3 \text{ ml}) = 0.0 \text{ ml}$$

$$UCL_{\bar{x}} = \bar{x} + A_2 \bar{R} = 150 \text{ ml} + 0.729(3 \text{ ml}) = 152.187 \text{ milliliters}$$

$$LCL_{\bar{x}} = \bar{x} - A_2 \bar{R} = 150 \text{ ml} - 0.729(3 \text{ ml}) = 147.813 \text{ milliliters}$$

3. Garcia's Garage

$$\bar{p} = 0.10, n = 100, z = 2$$

$$\sigma_p = \sqrt{\bar{p}(1-\bar{p})/n} = \sqrt{0.10(0.90)/100} = 0.03$$

$$UCL_p = \bar{p} + z\sigma_p = 0.10 + 2(0.03) = 0.16$$

$$LCL_p = \bar{p} - z\sigma_p = 0.10 - 2(0.03) = 0.04$$

At 8 of 100, the number of returns for service is below average, but this observation is within the control limits. The repair process is still in control.

4. Canine Gourmet Company

$$\bar{x} = 45 \text{ grams}, n = 10, \bar{R} = 6 \text{ grams}$$

a. From Table 5.1,

$$A_2 = 0.308, D_3 = 0.223, D_4 = 1.777$$

$$UCL_{\bar{R}} = D_4 \bar{R} = 1.777(6 \text{ grams}) = 10.662 \text{ grams}$$

$$LCL_{\bar{R}} = D_3 \bar{R} = 0.223(6 \text{ grams}) = 1.338 \text{ grams}$$

$$UCL_{\bar{x}} = \bar{x} + A_2 \bar{R} = 45 \text{ grams} + 0.308(6 \text{ grams}) = 46.848 \text{ grams}$$

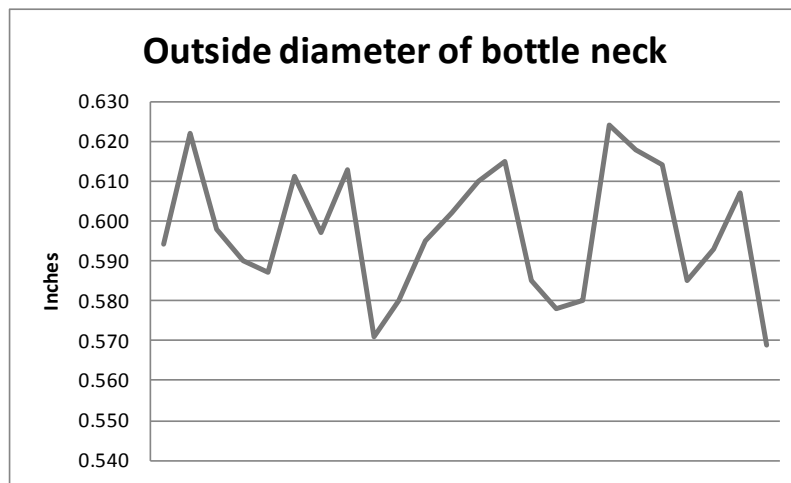
$$LCL_{\bar{x}} = \bar{x} - A_2 \bar{R} = 45 \text{ grams} - 0.308(6 \text{ grams}) = 43.152 \text{ grams}$$

- b. The range is in statistical control; however, the averages of samples 2, 4, and 5 are out of statistical control, therefore, the process is out of control.

5. Aspen Plastics

For a quick overview of the data, we can use an Excel Spreadsheet which shows among other things that $\bar{\bar{x}} = 0.597''$ and $\bar{R} = 0.035$. The graph tracks the outside diameters over the 6 samples, with four in each sample.

Sample	Bottle				$\bar{\bar{x}}$	R
	1	2	3	4		
1	0.594	0.622	0.598	0.590	0.601	0.032
2	0.587	0.611	0.597	0.613	0.602	0.026
3	0.571	0.580	0.595	0.602	0.587	0.031
4	0.610	0.615	0.585	0.578	0.597	0.037
5	0.580	0.624	0.618	0.614	0.609	0.044
6	0.585	0.593	0.607	0.569	0.589	0.038
Average					0.597	0.035



- a. $\bar{\bar{x}} = 0.597''$, $n = 4$, $\bar{R} = 0.035''$

From Table 5.1

$$A_2 = 0.729, D_3 = 0.0, D_4 = 2.282$$

$$UCL_R = D_4 \bar{R} = 2.282(0.035'') = 0.080''$$

$$LCL_R = D_3 \bar{R} - 0.0(0.035'') = 0.0''$$

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2 \bar{R} = 0.597'' + 0.729(0.035'') = 0.623''$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2 \bar{R} = 0.597'' - 0.729(0.035'') = 0.571''$$

b. Process capability index:

$$C_{pk} = \text{Minimum of} \left[\frac{\bar{\bar{x}} - \text{Lower specification}}{3\sigma}, \frac{\text{Upper specification} - \bar{\bar{x}}}{3\sigma} \right]$$

$$\frac{0.597 - 0.550}{3(0.013)} = 1.21 \quad \frac{0.650 - 0.597}{3(0.013)} = 1.36$$

$$C_{pk} = 1.21$$

The process capability ratio:

$$C_p = \frac{\text{Upper specification} - \text{Lower specification}}{6\sigma}$$

$$C_p = \frac{0.650 - 0.550}{6(0.013)} = 1.28$$

- c. The process variability is below four-sigma quality, which has a target process capability index of 1.33. Management and employees should look for ways to reduce the variability in the process and then recheck the process capability index.

6. Mega-Byte Academy

We initially assume the historical grand average is adequate for the central line of the chart:

Year	Student										Average
	1	2	3	4	5	6	7	8	9	10	
1	63	57	92	87	70	61	75	58	63	71	69.7
2	90	77	59	88	48	83	63	94	72	70	74.4
3	67	81	93	55	71	71	86	98	60	90	77.2
4	62	67	78	61	89	93	71	59	93	84	75.7
5	85	88	77	69	58	90	97	72	64	60	76.0
6	60	57	79	83	64	94	86	64	92	74	75.3
7	94	85	56	77	89	72	71	61	92	97	79.4
8	97	86	83	88	65	87	76	84	81	71	81.8
9	94	90	76	88	65	93	86	87	94	63	83.6
10	88	91	71	89	97	79	93	87	69	85	84.9
											$\bar{\bar{x}} = 77.8$

The average for the process, $\bar{\bar{x}} = 77.8$, and the standard deviation of the 100 historical data points in Table 5.2 is 13.

$$\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}} = \frac{13}{\sqrt{10}} = 4.1$$

$$UCL_{\bar{x}} = \bar{\bar{x}} + z\sigma_{\bar{x}} = 77.8 + (2 \times 4.1) = 86.0$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - z\sigma_{\bar{x}} = 77.8 - (2 \times 4.1) = 69.6$$

Although the process is in control, the last four observations are all above the average and exhibit an ever-increasing trend. Mega-Byte should explore for causes of corruption, such as instructor or performance measures, which give incentives for improved test scores. It is

possible that students are getting brighter or are becoming more highly motivated. Perhaps admissions standards have been raised. It is possible that teaching methods have improved. The point shown here is: the process must be stable while data are collected for setting control limits.

7. Hospital administrator

a. $\bar{p} = \text{Total absent/Total observations}$

$$= 49/15(64) = 0.051$$

$$\sigma_p = \sqrt{\bar{p}(1-\bar{p})/n} = \sqrt{0.051(1-0.051)/64} = 0.0275$$

$$UCL_p = \bar{p} + z\sigma_p = 0.051 + 2.58(0.0275) = 0.1219$$

$$LCL_p = \bar{p} - z\sigma_p = 0.051 - 2.58(0.0275) = -0.01995, \text{ adjusted to zero.}$$

- b. The data from the last three weeks fall within the control limits. Therefore we accept the estimate of 5.1% absenteeism. You must now assess whether this amount of absenteeism is typical for nurse's aides.

8. Textile manufacturer

a. $\bar{c} = 10.25$

$$UCL_c = \bar{c} + 3\sqrt{\bar{c}} = 10.25 + 3\sqrt{10.25} = 19.85$$

$$LCL_c = \bar{c} - 3\sqrt{\bar{c}} = 10.25 - 3\sqrt{10.25} = 0.65$$

- b. Because the last two samples with 22 and 21 irregularities plot outside the upper control limit, we conclude that the process is out of control.

9. IRS

The following table provides the POM for Windows output for this problem. Note that the “number of defects” column corresponds to (25 – the number of correctly answered questions).

Sample	Number of Defects	Fraction Defective		3 sigma (99.73%)
Sample 1	7	.28	Total Defects	125
Sample 2	9	.36	Total units sampled	500
Sample 3	6	.24	Defect rate (pbar)	.25
Sample 4	4	.16	Std dev of proportions	.0866
Sample 5	5	.2		
Sample 6	9	.36	UCL (Upper control limit)	.5098
Sample 7	4	.16	CL (Center line)	.25
Sample 8	9	.36	LCL (Lower Control Limit)	0
Sample 9	8	.32		
Sample 10	15	.6		
Sample 11	0	0		
Sample 12	7	.28		
Sample 13	0	0		
Sample 14	9	.36		
Sample 15	5	.2		
Sample 16	10	.4		
Sample 17	2	.08		
Sample 18	6	.24		
Sample 19	4	.16		
Sample 20	6	.24		

$$n = 25, \bar{p} = .25$$

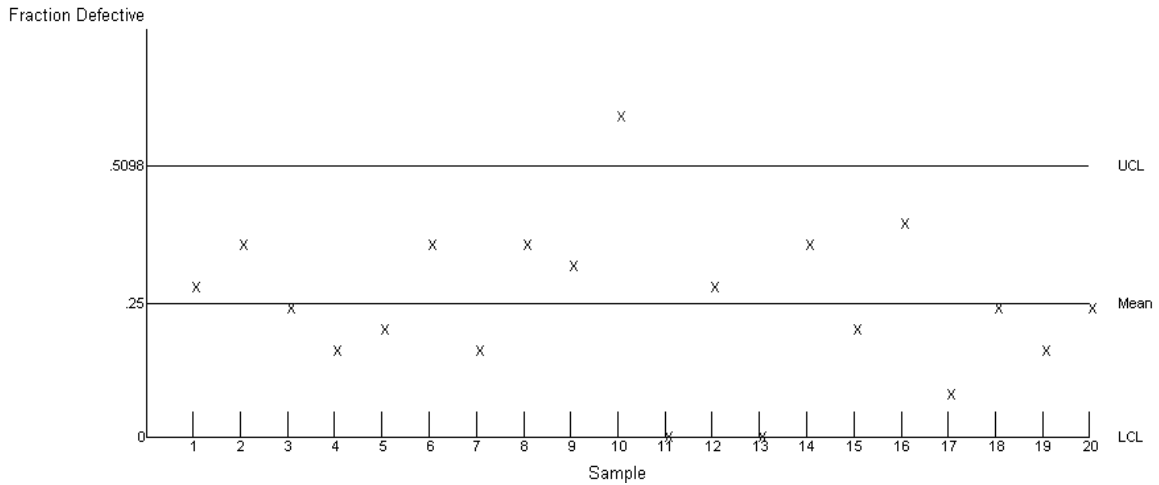
a. $\sigma_p = \sqrt{\bar{p}(1-\bar{p})/n} = \sqrt{.25(.75)/25} = .08660$

$$UCL_p = \bar{p} + z\sigma_p = .25 + 3(.08660) = 0.5098$$

$$LCL_p = \bar{p} - z\sigma_p = .25 - 3(.08660) = 0.0$$

The average proportion of incorrect responses for the sample of 20 observations is 0.25.

- b. The following Control Charts was developed using POM for Windows.



One observation falls outside of the control limits. Sample 10 with 60% incorrect answers should alert the IRS to look into the background and training of this individual to learn what went wrong. Perhaps this individual needs more training.

10. Travel agency

Because we cannot estimate how many errors were *not* made, we use a c -chart.

a. $\bar{c} = 3$

$$\sigma_c = \sqrt{\bar{c}} = \sqrt{3} = 1.732$$

$$UCL_c = \bar{c} + z\sigma_c = 3 + 2(1.732) = 6.464$$

$$LCL_c = \bar{c} - z\sigma_c = 3 - 2(1.732) = -0.464, \text{ adjusted to zero.}$$

- b. The number of defects, 6, is within the upper control limit. Consequently, nothing has changed. However, 6 defects in an itinerary will not be acceptable to customers. The average of 3 needs to be reduced.

11. Jim's Outfitters Inc.

a. $\bar{c} = \frac{(8+0+7+12+5+10+2+4+6+6)}{10} = 6$

$$\sigma_c = \sqrt{\bar{c}} = \sqrt{6} = 2.45$$

$$UCL_c = \bar{c} + z\sigma_c = 6 + (3 \times 2.45) = 13.35$$

$$LCL_c = \bar{c} - z\sigma_c = 6 - (3 \times 2.45) = -1.35 \quad (\text{adjusted to zero}).$$

- b. The number of defectives is close to, but does not exceed, the upper control limit. Therefore, the process is assumed to be in control.

12. Big Black Bird

$$a. \quad \bar{c} = \frac{(7+9+14+11+3+12+8+4+7+6)}{10} = 8.1$$

$$\sigma_c = \sqrt{\bar{c}} = \sqrt{8.1} = 2.846$$

$$UCL_c = \bar{c} + z\sigma_c = 8.1 + (3 \times 2.846) = 16.64$$

$$LCL_c = \bar{c} - z\sigma_c = 8.1 - (3 \times 2.846) = -0.438 \quad (\text{adjusted to zero}).$$

- b. The lower control limit is adjusted to zero because the number of dimples cannot be negative. In this observation, the 15 defectives are above average, but below the upper control limit. On the basis of this one observation, we cannot say that this process is out of control.

13. Sunny Soda, Inc.

Sample	Observation				$\bar{x}$	R
	1	2	3	4		
1	12.00	11.97	12.10	12.08	12.0375	0.13
2	11.91	11.94	12.10	11.96	11.9775	0.19
3	11.89	12.02	11.97	11.99	11.9675	0.13
4	12.10	12.09	12.05	11.95	12.0475	0.15
5	12.08	11.92	12.12	12.05	12.0425	0.20
6	11.94	11.98	12.06	12.08	12.015	0.14
7	12.09	12.00	12.00	12.03	12.03	0.09
8	12.01	12.04	11.99	11.95	11.9975	0.09
9	12.00	11.96	11.97	12.03	11.99	0.07
10	11.92	11.94	12.09	12.00	11.9875	0.17
11	11.91	11.99	12.05	12.10	12.0125	0.19
12	12.01	12.00	12.06	11.97	12.01	0.09
13	11.98	11.99	12.06	12.03	12.015	0.08
14	12.02	12.00	12.05	11.95	12.005	0.10
15	12.00	12.05	12.01	11.97	12.0075	0.08
AVERAGE					12.0095	0.12666

$$\bar{\bar{x}} = 12.0095 \text{ ounces, } n = 4, \bar{R} = 0.12666 \text{ ounces}$$

From Table 5.1,

$$A_2 = 0.729, D_3 = 0.0, D_4 = 2.282$$

$$UCL_R = D_4 \bar{R} = 2.282(0.12666) = 0.28904 \text{ ounces}$$

$$LCL_R = D_3 \bar{R} = 0.0(0.12666) = 0.0 \text{ ounces}$$

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2 \bar{R} = 12.0095 + 0.729(0.12666) = 12.1018 \text{ ounces}$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2 \bar{R} = 12.0095 - 0.729(0.12666) = 11.9171 \text{ ounces}$$

- a. The range and the process average for each sample are within statistical control.
 b. The standard deviation of the data is 0.05667.

$$C_{pk} = \text{minimum of } \left[\frac{\bar{\bar{x}} - \text{Lower specification}}{3\sigma}, \frac{\text{Upper specification} - \bar{\bar{x}}}{3\sigma} \right]$$

$$C_{pk} = \text{minimum of } \left[\frac{12.0095 - 11.9000}{3(0.05667)}; \frac{12.1000 - 12.0095}{3(0.05667)} \right] = [0.644, 0.532]$$

$$= 0.532, \text{ which is far below the target of } 1.33.$$

This process is **not** capable. It will produce too many bottles outside of the allowable tolerances. To show that process variability is the culprit, compute the process capability ratio:

$$C_p = \frac{\text{Upper specification} - \text{Lower specification}}{6\sigma}$$

$$= \frac{12.1 - 11.9}{6(0.05667)} = \frac{0.200}{0.34002} = 0.5882$$

The value of 0.5882 is also below the target value of 1.33.

14. The Money Pit

- a. The control chart values based on the initial 15 observations are:

$$R\text{-Chart: } \bar{R} = (6 + 11 + \dots + 13)/15 = 9.933 \text{ days}$$

$$\text{Central line} = \bar{R} = 9.933$$

$$D_3\bar{R} = LCL_R = 0$$

$$D_4\bar{R} = UCL_R = (2.115)(9.933) = 21.0 \text{ days}$$

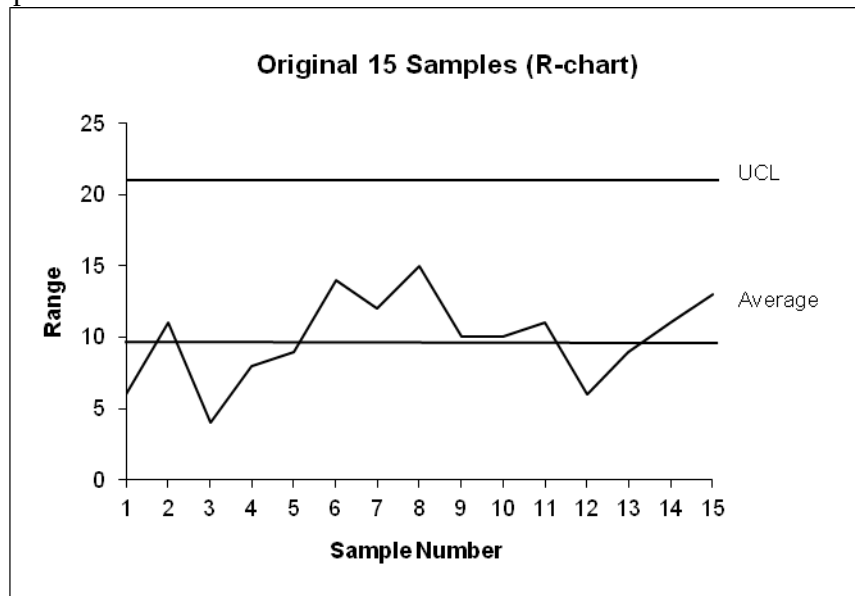
$$\bar{X}\text{-Chart:}$$

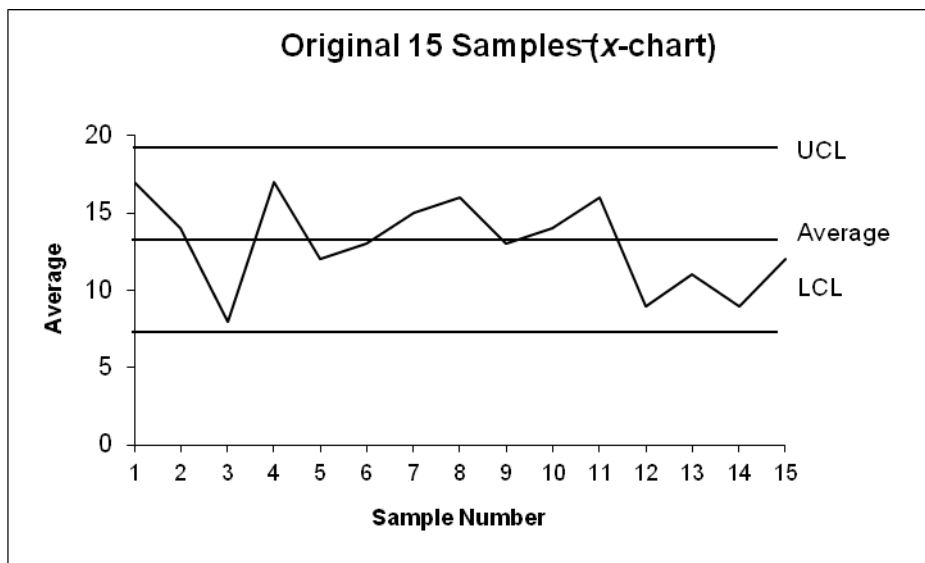
$$\text{Central line } \bar{\bar{X}} = (17 + 14 + \dots + 12)/15 = 13.066 \text{ days}$$

$$LCL_{\bar{X}} = \bar{\bar{X}} - A_2(\bar{R}) = 13.066 - 0.577(9.933) = 7.33 \text{ days}$$

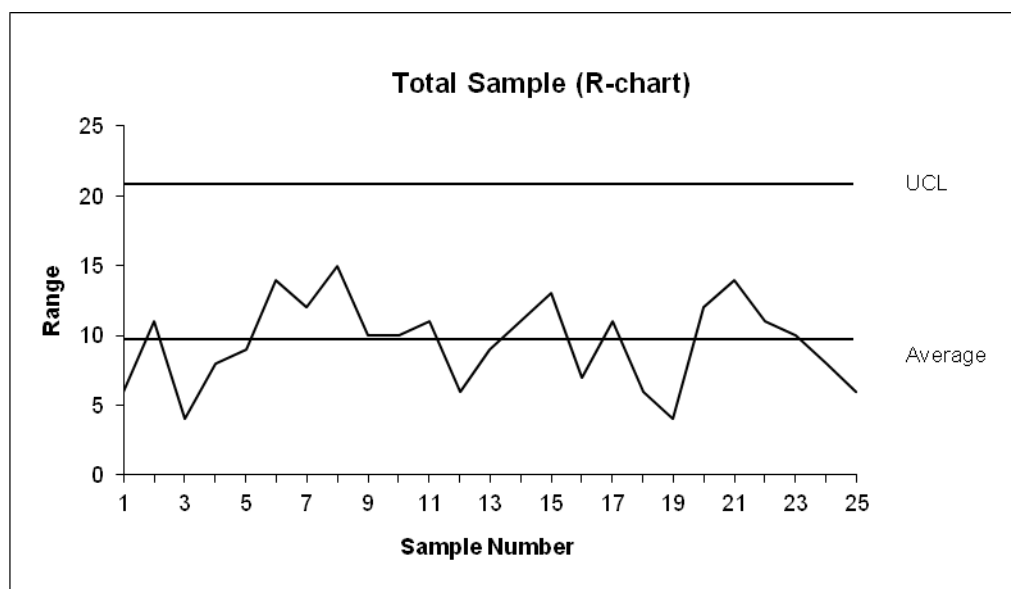
$$UCL_{\bar{X}} = \bar{\bar{X}} + A_2(\bar{R}) = 13.066 + 0.577(9.933) = 18.8 \text{ days}$$

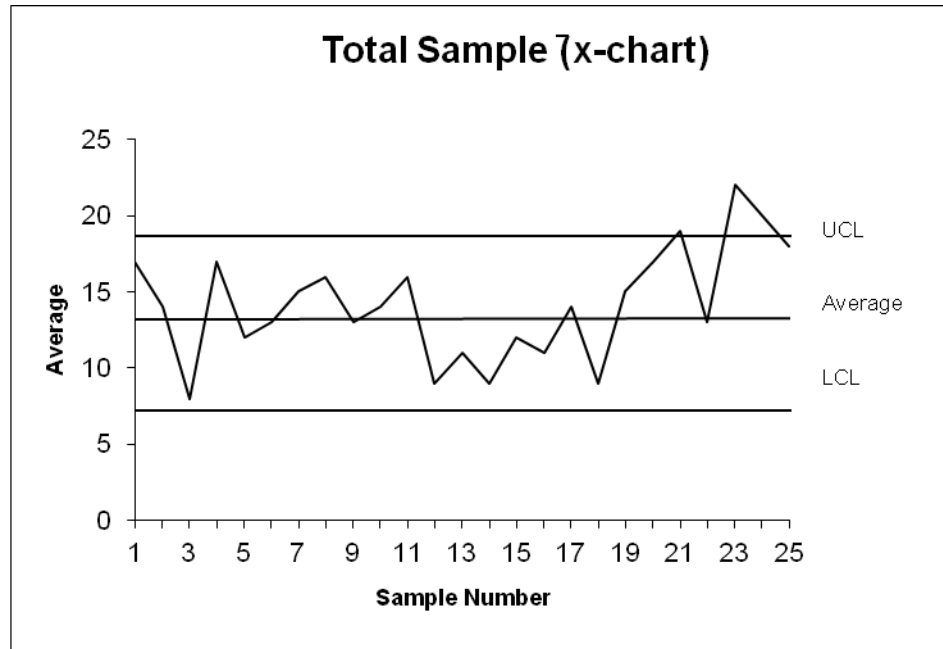
The value of D_3 , D_4 , and A_2 are obtained from Table 5.1 for $n = 5$. The resulting control charts are shown with the initial 15 points. From the control charts, it is evident that the process is in control.





- b. Plot of the 25 samples including the 10 additional samples, starting at sample 16. The process is still in control





Although the process variability is still in control, the mean is drifting upward and has surpassed the upper control limit on days 21 and 23.

- c. The process average is out of control. The drift in the mean must be corrected.

15. The Money Pit

a. Lower Specification Calculation $\frac{13.066 - 5.00}{(3)(4.21)} = 0.64$

Upper Specification Calculation $\frac{25.00 - 13.066}{(3)(4.21)} = 0.94$

$$C_{pk} = \min(0.64, 0.94) = 0.64$$

$$C_p = \frac{25 - 5}{6(4.21)} = 0.79$$

- b. Because C_p and C_{pk} have values less than 1, the process is not capable of meeting specifications. Yes, valid because the process is under statistical control, as can be shown by plotting the last 15 observations on control charts. Ask students to demonstrate that the process is in statistical control.
- c. The variability of the process must be greatly reduced. Also, the process should be better centered between the specification limits.

16. Webster Chemical Company

Sample	Tube Number								Avg.	Range
	1	2	3	4	5	6	7	8		
1	7.98	8.34	8.02	7.94	8.44	7.68	7.81	8.11	8.040	0.76
2	8.33	8.22	8.08	8.51	8.41	8.28	8.09	8.16	8.260	0.43
3	7.89	7.77	7.91	8.04	8.00	7.89	7.93	8.09	7.940	0.32
4	8.24	8.18	7.83	8.05	7.90	8.16	7.97	8.07	8.050	0.41
5	7.87	8.13	7.92	7.99	8.10	7.81	8.14	7.88	7.980	0.33
6	8.13	8.14	8.11	8.13	8.14	8.12	8.13	8.14	8.130	0.03
									8.067	0.38

- a. $\bar{\bar{x}} = 8.067$ (process should be centered on 8.000), $\bar{R} = 0.38$, $n = 8$

From Table 5.1,

$$A_2 = 0.373, D_3 = 0.136, D_4 = 1.864$$

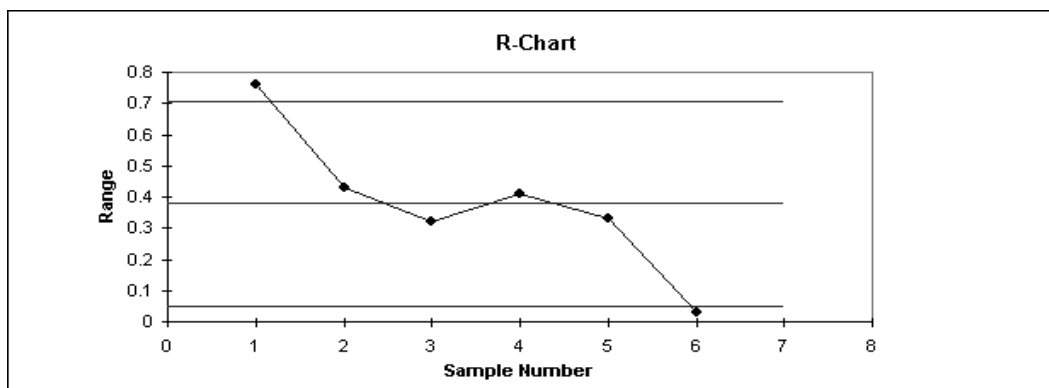
$$UCL_R = D_4 \bar{R} = 1.864(0.38) = 0.708$$

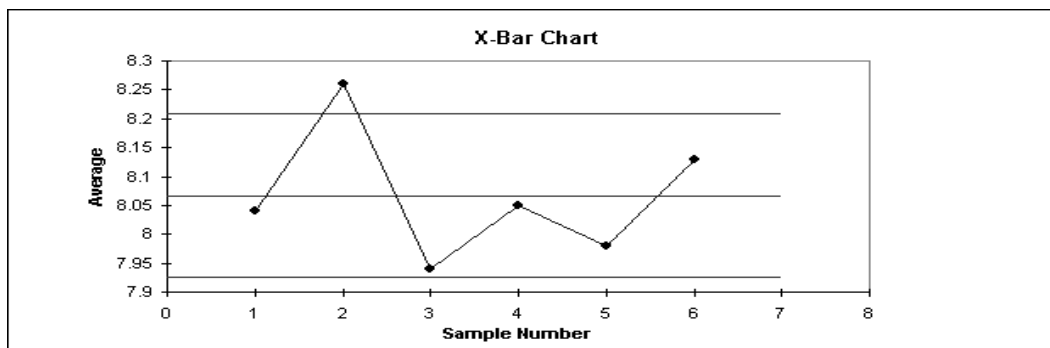
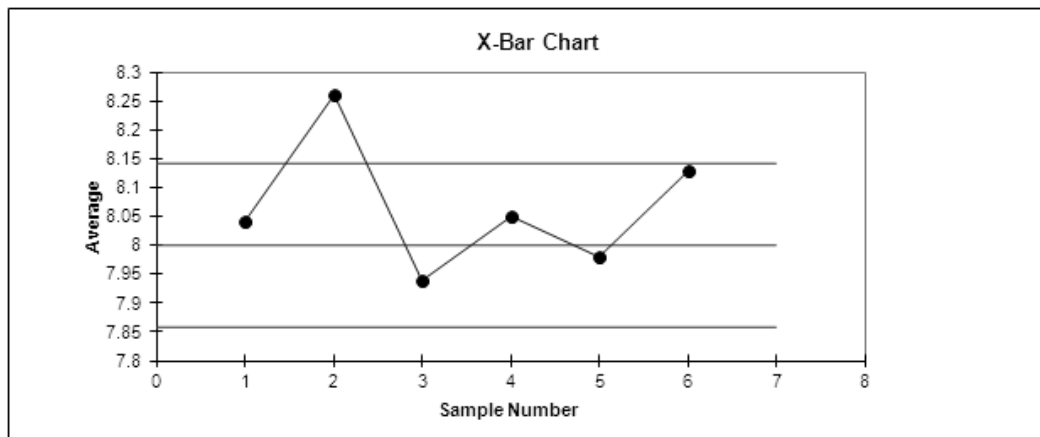
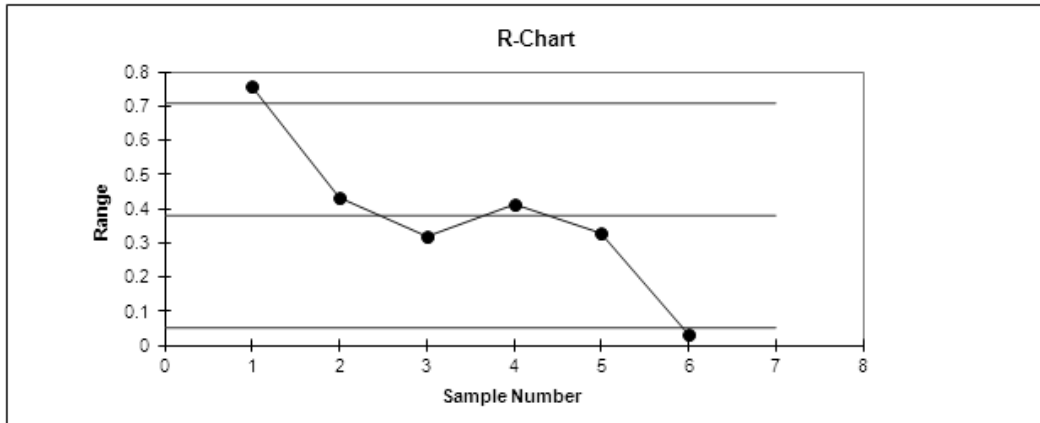
$$LCL_R = D_3 \bar{R} = 0.136(0.38) = 0.052$$

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2 \bar{R} = 8.000 + 0.373(0.38) = 8.142$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2 \bar{R} = 8.000 - 0.373(0.38) = 7.858$$

- b. The range went out of control on the first sample. However, it has steadily gone down since then. Something good has taken place and should be exploited. Checking the process average is moot since the estimate of the range is not in control. We should look for assignable causes for the performance in the variability of the process and, in this case, exploit them. Then the charts should be redone. These charts were created from OM Explorer.





17. Webster, p -chart

$$n = 144, \bar{p} = \frac{72}{20(144)} = 0.025$$

$$\sigma_p = \sqrt{\bar{p}(1-\bar{p})/n} = \sqrt{0.025(0.975)/144} = 0.013$$

$$UCL_p = \bar{p} + z\sigma_p = 0.025 + 3(0.013) = 0.064$$

$$LCL_p = \bar{p} - z\sigma_p = 0.025 - 3(0.013) = -0.014, \text{ adjusted to zero}$$

The highest proportion of defectives occurs in sample #10, but is still within the control limits. $p = 9/144 = 0.0625$. The process is in control.

18. Webster, c -chart

$$\bar{c} = \frac{(6+5+0+4+6+4+1+6+5+0+9+2)}{12} = 4$$

$$\sigma_c = \sqrt{\bar{c}} = \sqrt{4} = 2$$

$$UCL_c = \bar{c} + z\sigma_c = 4 + (2 \times 2) = 8$$

$$LCL_c = \bar{c} - z\sigma_c = 4 - (2 \times 2) = 0$$

The 11th tube has too many lumps (9), so the process should be checked. If there is an assignable cause for the 11th tube, it should be corrected before recalculating the control limits of the chart.

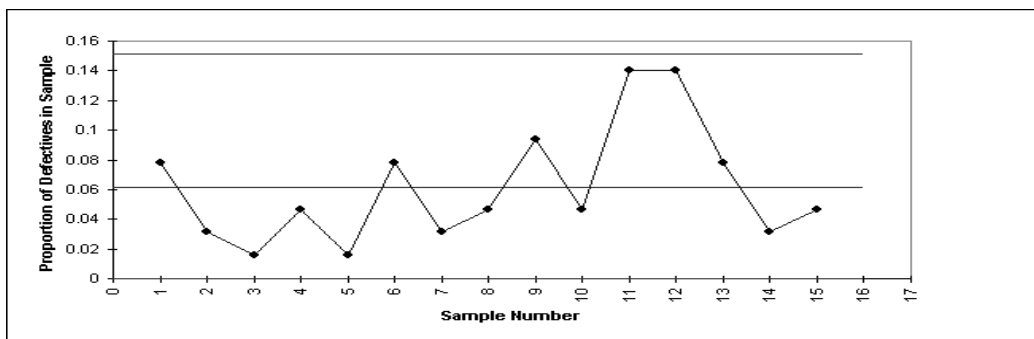
19. Pine Crest Medical Clinic

$$\text{a. } \bar{p} = \frac{59}{15(64)} = 0.0615 \quad \sigma_p = \sqrt{\frac{0.0615(0.9385)}{64}} = 0.0300$$

$$UCL_p = 0.0615 + 3(0.0300) = 0.1515$$

$$LCL_p = 0.0615 - 3(0.0300) = -0.0285, \text{ which is translated to be "zero" for the control chart.}$$

b. The control chart from the OM Explorer Solver for p -charts is shown below.



Since none of the proportions fall outside of the control limits, we can conclude that the process is in statistical control regarding patient wait times. The question for management, however, is whether six percent of the patients waiting more than 30 minutes is acceptable. The analysis with the control chart merely allows us to be confident in the estimate of six percent.

20. Patriot Insurance

Using POM for Windows we get the following p-chart results

Sample	Number of Defects	Fraction Defective		3 sigma (99.73%)
Sample 1	20	.1	Total Defects	617
Sample 2	18	.09	Total units sampled	6000
Sample 3	29	.145	Defect rate (pbar)	.1028
Sample 4	12	.06	Std dev of proportions	.0215
Sample 5	14	.07		
Sample 6	11	.055	UCL (Upper control limit)	.1673
Sample 7	30	.15	CL (Center line)	.1028
Sample 8	25	.125	LCL (Lower Control Limit)	.0384
Sample 9	27	.135		
Sample 10	16	.08		
Sample 11	25	.125		
Sample 12	18	.09		
Sample 13	25	.125		
Sample 14	16	.08		
Sample 15	20	.1		
Sample 16	15	.075		
Sample 17	40	.2		
Sample 18	35	.175		
Sample 19	21	.105		
Sample 20	24	.12		
Sample 21	9	.045		
Sample 22	20	.1		
Sample 23	17	.085		
Sample 24	28	.14		
Sample 25	10	.05		
Sample 26	17	.085		
Sample 27	22	.11		
Sample 28	14	.07		
Sample 29	19	.095		
Sample 30	20	.1		

- a. From the Table above we get the following statistics:

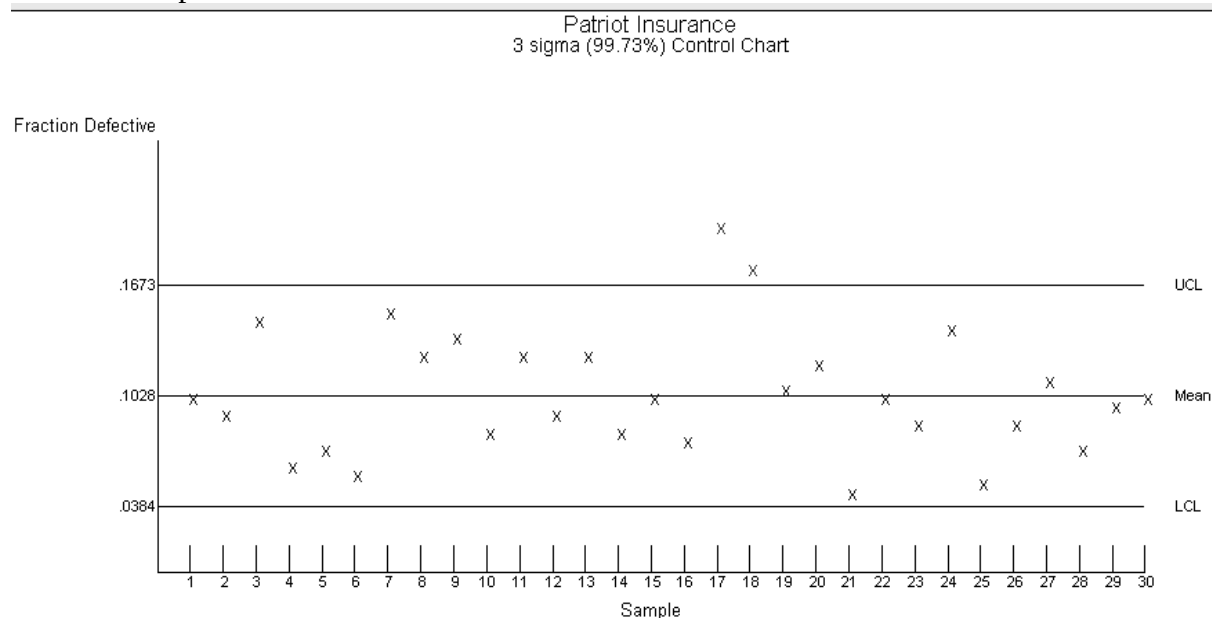
$$\bar{p} = 0.1028$$

$$\sigma = 0.0215$$

For three-sigma control limits, we have:

Upper Control Limit	0.1673
Lower Control Limit	0.0384

- b. The POM for Windows graph below shows that observations 17 and 18 are out of control. Management should look for assignable causes during the time-frame those samples were taken.



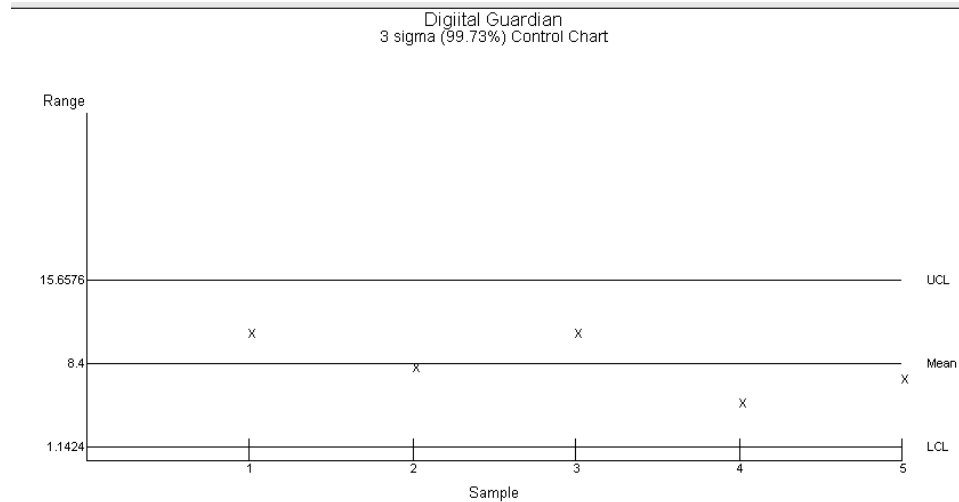
21. Digital Guardian Company

Using POM for Windows we get the following mean and range chart results

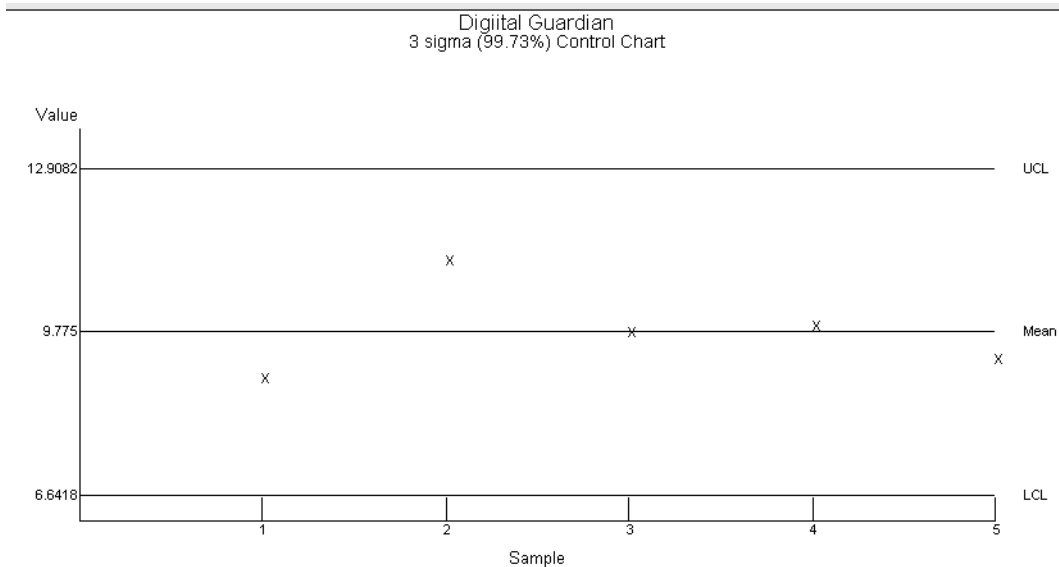
Sample	Mean	Range	3 sigma (99.73%)	X-bar Chart	Range Chart
Sample 1	8.875	11	UCL (Upper control limit)	12.9082	15.6576
Sample 2	11.125	8	CL (Center line)	9.775	8.4
Sample 3	9.75	11	LCL (Lower Control Limit)	6.6418	1.1424
Sample 4	9.875	5			
Sample 5	9.25	7			
Averages	9.775	8.4			

- The process average is $(8.875 + 11.125 + \dots + 9.25)/5 = 9.775$
- The average range is $(11 + 8 + \dots + 7)/5 = 8.4$
- The control charts for the range and the average are shown below.

The range chart as provided by POM for Windows



The mean chart as provided by POM for Windows



While the charts show that the process has not generated output that breaks past the control limits, and the number of samples is limited, the variability has a downward trend. That is actually good news and management should look into what might be the cause of this good fortune.

22. Farley Manufacturing

Sample	Observation (millimeters)							
	1	2	3	4	5	6	7	8
1	9.100	8.900	8.800	9.200	8.100	6.900	9.300	9.100
2	7.600	8.000	9.000	10.100	7.900	9.000	8.000	8.800
3	8.200	9.100	8.200	8.700	9.000	7.000	8.800	10.800
4	8.200	8.300	7.900	7.500	8.900	7.800	10.100	7.700
5	10.000	8.100	8.900	9.000	9.300	9.000	8.700	10.000

Since we are to assume that the process is in statistical control, we can get the mean and standard deviation for the data in the table:

Process mean: 8.675 mm

Standard deviation: 0.851 mm

The critical value for the analysis is 1.0 for three-sigma quality. Using the OM Explorer Solver for Process Capability, we get the following results:

Lower Spec Calculation 1.44

Upper Spec Calculation 0.91

Process Capability Index 0.91 **Index is below critical value.**

Since the Capability Index fails the test, we know the process is not capable at the three-sigma level. However, we do not know if it is a problem with variability or process centering. The results for the Capability Ratio are:

Process Capability Ratio 1.18 **Ratio meets or exceeds critical value.**

Since the Capability Ratio passes the test, but the capability index does not, we can conclude that there is a process centering problem.

23. Call Center Process capability

- a. To show that the process is in statistical control, we must show that both the range and the average are in control. From Table 5.1 we have:

$$A_2 = 1.023, \quad n = 3, \quad D_3 = 0, \quad D_4 = 2.575$$

The sample averages and ranges are:

Sample	$\bar{x}$	R
1	498	6
2	508	8
3	501	8
4	497	11
$\bar{\bar{x}}$	501	$\bar{R} = 8.25$

$$UCL_R = D_4(\bar{R}) = 2.575(8.25 \text{ sec}) = 21.24 \text{ sec}$$

$$LCL_R = D_3(\bar{R}) = 0(8.25 \text{ sec}) = 0 \text{ sec}$$

All ranges fall within the control limits; therefore, we can say the variability is in statistical control.

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2(\bar{R}) = 501 \text{ sec} + 1.023(8.25 \text{ sec}) = 509.44 \text{ sec}$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2(\bar{R}) = 501 \text{ sec} - 1.023(8.25 \text{ sec}) = 492.56 \text{ sec}$$

All averages fall within the control limits; therefore, we can say the process average is in statistical control.

- b. The standard deviation of the process output has been given as $\sigma = 5.77$ sec. We can calculate the capability index and capability ratio as follows:

$$\begin{aligned} C_{pk} &= \min \left[\frac{\bar{x} - \text{Lower specification}}{3\sigma}, \frac{\text{Upper specification} - \bar{x}}{3\sigma} \right] \\ &= \min \left[\frac{501 - 482}{3(5.77)}, \frac{518 - 501}{3(5.77)} \right] \\ &= \min [1.097, 0.982] = 0.982 \end{aligned}$$

$$\begin{aligned} C_p &= \frac{\text{Upper specification} - \text{Lower specification}}{6\sigma} \\ &= \frac{518 - 482}{6(5.77)} = \frac{36}{34.62} = 1.039 \end{aligned}$$

We conclude that the process is not capable because C_{pk} is less than 1.0. Since the process variability is good enough for three-sigma quality, the process distribution is centered too close to the upper specification of the product. Perhaps more capacity is needed.

24. Automatic lathe

- a. Control, limits for $\bar{X}$ - chart

$$UCL_{\bar{X}} = 8.50 + 0.577(0.31) = 8.6789$$

$$LCL_{\bar{X}} = 8.50 - 0.577(0.31) = 8.3211$$

Control limits for R -chart

$$UCL_R = D_4 \bar{R} = (2.115)(0.31) = 0.6556$$

$$LCL_R = D_3 \bar{R} = 0$$

- b. $\sigma = 0.13$

$$C_{pk} = \min \left\{ \frac{8.75 - 8.5}{(3)(0.13)}, \frac{8.5 - 8.25}{(3)(0.13)} \right\} = \{0.64, 0.64\} = 0.64$$

The process is not capable of meeting specifications at the four-sigma level of quality.

- c. Percent nonconforming = $P(X \leq 8.25) + P(X \geq 8.75)$

$$\begin{aligned} Z_{LSL} &= \frac{8.25 - 8.50}{0.13} = -1.92 \\ &= P(Z \leq -1.92) + P(Z \geq 1.92) \\ &= 0.0274 + 0.0274 \\ &= 0.0548 \\ &\text{or } 5.48\% \end{aligned}$$

ADVANCED PROBLEMS

25. Canine Gourmet

The standard deviation of the packet population is 1.01 grams. The packaging process is essentially a sampling process from that population, with a sample size of 8. The standard deviation of the box population is:

$$\sigma^2 = \sum_1^8 (1.01)^2$$

$$\sigma = (1.01)\sqrt{8} = 2.857$$

To test for capability, we first compute the process capability index,

$$n_{pk} = \text{minimum of } \left[\frac{8(43)-336}{3(2.857)}; \frac{360-8(43)}{3(2.857)} \right]$$

$$= \text{minimum of } [0.933; 1.867]$$

$$= 0.933, \text{ lower than the target of } 1.33.$$

To make sure that process variability is not causing this problem, we use the process capability ratio:

$$C_p = \frac{360 - 336}{6(2.857)} = 1.40$$

The variability is fine. The packet-filling process needs to be centered on the target of 43.5 grams.

26. Precision Machining Company (measurements in thousandths of inches)

a. With $n = 4$, $\bar{R} = 2.0$, $\bar{\bar{x}} = 15$ the parameters of the $\bar{x}$ -chart are:

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2 \bar{R} = 15 + 0.729(2) = 16.46$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2 \bar{R} = 15 - 0.729(2) = 13.54$$

Sample	Minutes	$\bar{x}$
1	1–4	15.75
2	9–12	15.00
3	17–20	13.75
4	25–28	14.75
5	33–36	15.50
6	41–44	16.25
7	49–52	14.75
8	57–60	16.00
9	65–68	14.00
10	73–76	16.75*

*Out-of-control points are observed in the 10th sample. The process would be stopped at the 76th minute.

- b. With $n = 8$, $\bar{R} = 2.0$, $\bar{\bar{x}} = 15$ the parameters of the $\bar{x}$ -chart are:

$$UCL_{\bar{x}} = \bar{\bar{x}} + A_2 \bar{R} = 15 + 0.373(2) = 15.746, \text{ or } 15.75$$

$$LCL_{\bar{x}} = \bar{\bar{x}} - A_2 \bar{R} = 15 - 0.373(2) = 14.254, \text{ or } 14.25$$

Sample	Minutes	$\bar{x}$
1	1–8	15.625
2	13–20	14.875
3	25–32	15.375
4	37–44	16.250*

*Out of control.

- We would stop the process at the end of minute 44.
- Taking larger samples on a frequent sampling interval will catch process average shifts more quickly than taking smaller samples.

27. Precision Machining, continued

- a. From Problem 26a, $UCL_{\bar{x}} = 16.46$ and $LCL_{\bar{x}} = 13.54$.

Sample	Minutes	$\bar{x}$
1	1–4	15.75
2	13–16	16.00
3	25–28	14.75
4	37–40	16.25
5	49–52	14.75
6	61–64	16.50*

*Out of control.

We would stop the process at the end of minute 64.

- b. From Problem 26b, $UCL_{\bar{x}} = 15.75$ and $LCL_{\bar{x}} = 14.25$

Sample	Minutes	$\bar{x}$
1	1–8	15.625
2	17–24	14.75
3	33–40	15.875*

*Out of control.

We would stop the process at the end of minute 40.

- Larger sample sizes resulted in faster detection of changes in the process average; however, the cost of inspection may be greater than for taking smaller sample sizes. The real trade-off is the cost of inspection versus the cost of not detecting the shift in the process average.

28. Data Tech Credit Card Service Company

Using POM for Windows we get the following p-chart results

Sample	Number of Defects	Fraction Defective		3 sigma (99.73%)
Sample 1	3	.012	Total Defects	195
Sample 2	8	.032	Total units sampled	7500
Sample 3	5	.02	Defect rate (pbar)	.026
Sample 4	11	.044	Std dev of proportions	.0101
Sample 5	7	.028		
Sample 6	1	.004	UCL (Upper control limit)	.0562
Sample 7	12	.048	CL (Center line)	.026
Sample 8	9	.036	LCL (Lower Control Limit)	0
Sample 9	0	0		
Sample 10	8	.032		
Sample 11	3	.012		
Sample 12	5	.02		
Sample 13	7	.028		
Sample 14	9	.036		
Sample 15	11	.044		
Sample 16	3	.012		
Sample 17	2	.008		
Sample 18	9	.036		
Sample 19	13	.052		
Sample 20	4	.016		
Sample 21	12	.048		
Sample 22	10	.04		
Sample 23	6	.024		
Sample 24	2	.008		
Sample 25	1	.004		
Sample 26	7	.028		
Sample 27	10	.04		
Sample 28	5	.02		
Sample 29	8	.032		
Sample 30	4	.016		

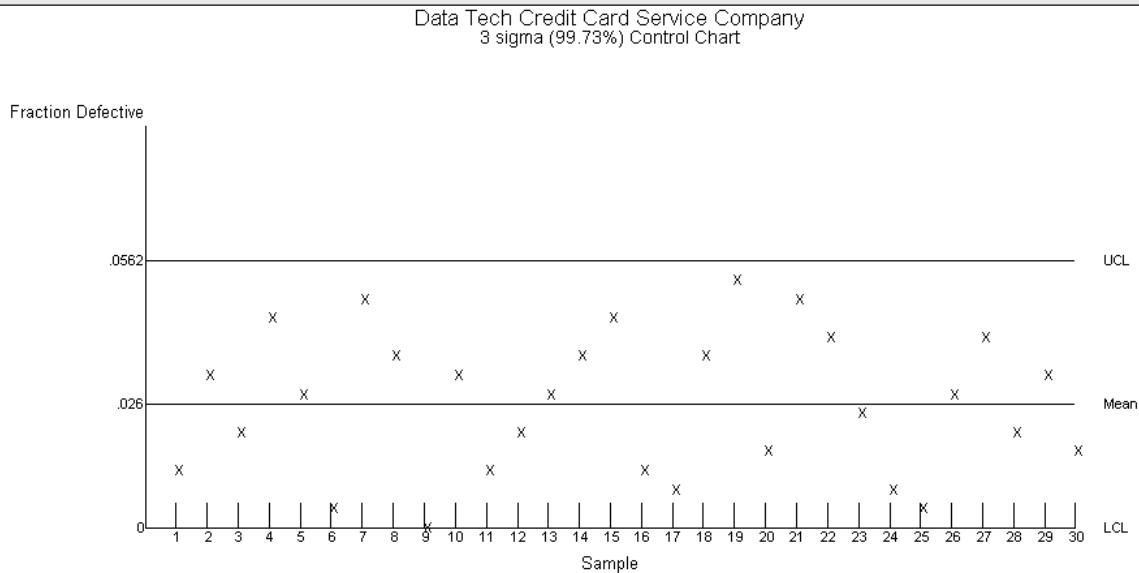
From data in Table 5.5, assuming 3-sigma control limits

$$\bar{p} = \frac{195}{30(250)} = 0.026, \sigma_p = \sqrt{\frac{0.026(0.974)}{250}} = 0.01006$$

a. $UCL_p = \bar{p} + 3\sigma_p = 0.026 + 3(0.01006) = 0.0562$

$LCL_p = \bar{p} - 3\sigma_p = 0.026 - 3(0.01006) = 0.0$

- c. The POM for Windows graph below shows that all samples fall within the control limits, but samples 11, 12, 13, 14, and 15 have an upward run and samples 21, 22, 23, 24, and 25 have a downward run. Because runs of 5 or more usually indicate nonrandom behavior, we should investigate. We would like to avoid whatever was done when samples 11–15 were taken and to repeat what was done during samples 21–25.



29. Red Baron Airlines

- a. Management has set a high standard of 98 percent on-time performance, so the target value for the chart's central line is:

$$\bar{p} = 1.0 - 0.98 = 0.02$$

$$UCL_p = \bar{p} + 3\sigma_p = 0.02 + 3\sqrt{\frac{0.02(0.98)}{300}} = 0.044$$

$$LCL_p = \bar{p} - 3\sigma_p = 0.02 - 3\sqrt{\frac{0.02(0.98)}{300}} = -0.004$$

(adjusted to zero)

Sample	Proportion Defective	Sample	Proportion Defective
1	0.010	16	0.017
2	0.027	17	0.013
3	0.017	18	0.030
4	0.037	19	0.043
5	0.023	20	0.013
6	0.007	21	0.040
7	0.040	22	0.033
8	0.030	23	0.020
9	0.003	24	0.007
10	0.027	25	0.003
11	0.010	26	0.027
12	0.017	27	0.013
13	0.023	28	0.017
14	0.030	29	0.027
15	0.040	30	0.007

The data indicate that all samples were within the control limits. Management should determine what occurred during samples 11–15 (an upward run) and samples 21–25 (a downward run) to determine the cause of the nonrandom behavior.

30. Beaver Brothers

a. Sample means and ranges

Sample #	R	X-bar
1	7.4	163.5
2	9.1	161.3
3	4.1	164.4
4	7.4	164.0
5	9.2	161.8
6	1.2	163.9
7	7.2	161.2
8	7.3	161.5
9	7.4	162.0
10	7.4	160.5
11	6.8	161.4
12	6.1	161.9
13	6.4	161.3
14	6.1	162.2
15	6.8	162.5
16	6.1	162.3
17	7.2	162.8
18	9.8	161.1
19	5.8	162.5
20	6.1	163.0
21	5.2	163.1
22	10.9	164.2
23	10.8	164.4
24	0.5	165.7
25	2.5	165.0

$$\bar{R} = 164.8/25 = 6.6 \text{ (Center line for } R\text{-chart)}$$

$$UCL_R = 2.115\bar{R} = 2.115(6.6) = 14.0$$

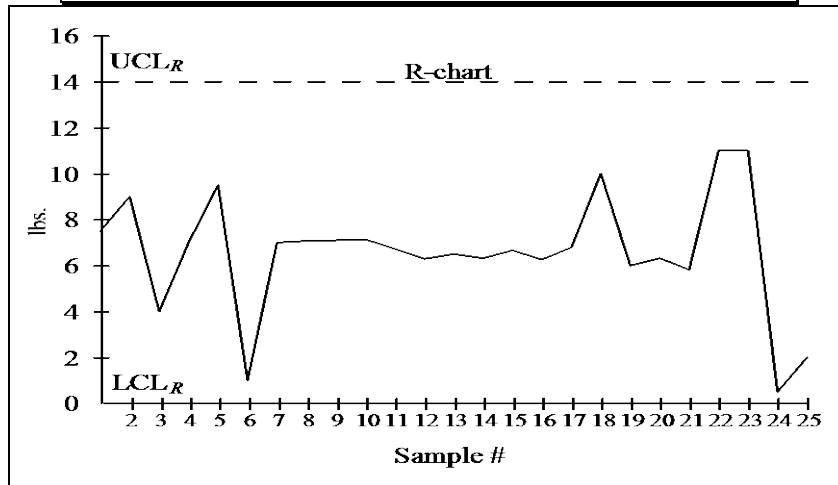
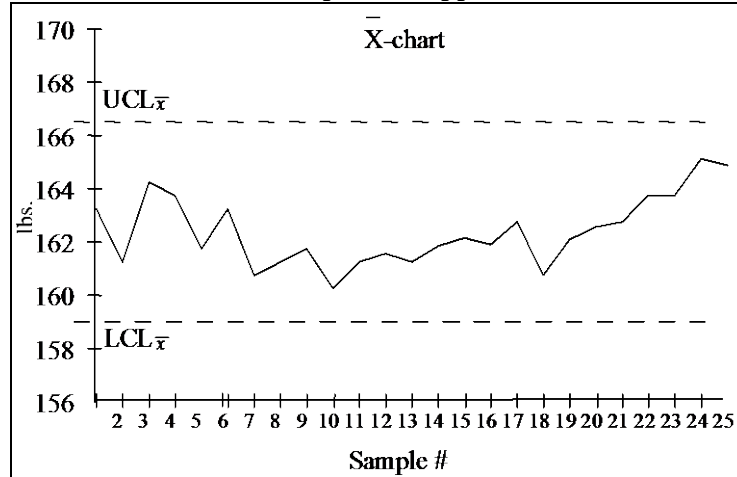
$$LCL_R = 0$$

$$\bar{X} = 4067.5/25 = 162.7 \text{ (Center line for } \bar{X}\text{-bar chart)}$$

$$UCL_{\bar{X}} = 162.7 + 0.577(6.6) = 166.5$$

$$LCL_{\bar{X}} = 162.7 - 0.577(6.6) = 158.9$$

Based on the R - and $\bar{X}$ -bar chart, the process appears to be in statistical control.



$$b. \quad C_{pk} = \min \left\{ \frac{170 - 162.7}{(3)(2.83)}, \frac{162.7 - 162}{(3)(2.83)} \right\} = \{0.860, 0.0824\} = 0.0824$$

$$C_p = \frac{USL - LSL}{(6)(\sigma)} = \frac{170 - 162}{(6)(\sigma)} = \frac{8}{(6)(2.83)} = \frac{8}{17} = 0.47$$

Note: The standard deviation was calculated from the sample data in Table 5.7. The process is not capable.

$$\text{c. } C_{pk} = \min \left\{ \frac{170-163}{(3)(1)}, \frac{163-162}{(3)(1)} \right\} = 0.33$$

$$C_p = \frac{170-162}{(6)(1)} = \frac{8}{6} = 1.33$$

The process is still not centered well. The variance is good enough for four-sigma quality.

- d. If the process is centered at 166 grams,

$$C_{pk} = \min \left\{ \frac{170-166}{(3)(1)}, \frac{166-162}{(3)(1)} \right\} = 1.33$$

The process would be capable at the level of four-sigma if centered at 166 grams.

EXPERIENTIAL LEARNING: STATISTICAL PROCESS CONTROL WITH A COIN CATAPULT *

A. Overview/Purpose

This exercise gives the students some hands-on experience in creating and using SPC charts. Students will operate a process, collect data, develop a process control chart, and then use the chart to monitor the process and detect any change that may occur. Maximum efficiency is obtained by conducting this exercise after the students have read the chapter material but before classroom lecture/discussion has taken place. Their experiences in the exercise help give a context to the topics as they are covered in class.

B. Preparation Time Required

Instructor: Once the materials have been assembled, it should take about a half hour to read these notes and experiment with the catapult yourself. Because the materials are reusable, subsequent setup time should be negligible. Reproducible worksheets are included in this teaching note (Exhibits TN.1 and TN.2). Each student should receive a copy of each Exhibit prior to beginning the experiment.

Students: The students should read through the exercise instructions as they complete each step.

C. Class Time Required

This exercise has been run three ways. If a 90-minute class period is available, the students can complete both Exercise A (SPC for variables) and Exercise B (SPC for attributes). The combined exercise can be completed in about a half hour with the remaining time for debriefing and discussion. If time is more constrained, the teams can be divided into two groups, one doing Exercise A and the other Exercise B. When the students have completed the experiments, each group shares its results. This approach takes from 40 to 50 minutes. This exercise has also been given as a homework assignment. If assigned this way, some time should still be devoted to discussion so that the students can share their experiences and cement their understanding of the results.

D. Conducting the Exercise

Divide the class into teams. The tasks are defined in the students' instructions. Briefly review the sequence of steps they will follow. Demonstrate how to catapult a coin. This exercise needs a large, solid, flat surface; a student's armchair will not do. Many have chosen to work on the floor. (You may want to suggest that they dress appropriately if this is a possibility.) Remind them about where the A_2 and D_3 and D_4 values can be found in the book (or, alternatively, project a table of values using an overhead projector). Then turn them loose. The activity for each exercise will be completed in about 15 minutes.

Although separate tasks are assigned to each team member, the development of the charts (Steps 2 and 3 in Exercise A, Step 2 in Exercise B) is best done by all team members

* This case was prepared by Dr. Larry Meile, Boston College, as a basis for classroom discussion.

together. Also note that the size of the team is somewhat flexible. If you are going to have each team do both Exercise A and B, it may be best to form three-person teams so that the team size will be reasonable for each.

E. Debriefing/Discussion

Questions are interspersed throughout the instructions that direct the discussion. Ask the students what they discovered. One topic will be the cause of variation in the process (assignable cause), especially for catapulting the coins into the cup. Some students will come up with methods for releasing the catapult (other than with their finger) that will greatly reduce process variability. Take advantage of this to bring into the discussion the concept of robust process design. Ask them how many samples need to be taken to detect a change (if a change is present). This will lead into an analysis of the data patterns that reveal a change in the process, even if a point is not outside one of the control limits.

Bring up the topic of monitoring the process **as it occurs**, rather than after the fact. Point out how control would be lost if the data were collected throughout the day and analyzed only at the end.

You may want to discuss the concept of sampling the output. This exercise is somewhat artificial because units of output were not produced, from which a random sample was drawn.

In Exercise B, you may find a wide range of abilities exhibited when students try to flip the coin into a cup. Some students will be able to land the coin in the cup so consistently that no errors show up in the 10-trial samples. Others will struggle to get it in even half the time. Use this variation to drive a discussion of when it is appropriate to use SPC and what the percent of defects has on the chart's control limits. This also leads well into a discussion of sample size. In Exercise B, for example, the sample size may have to be increased to find, on the average, at least two defects per sample.

Another concept to explore with this experiment is a confidence interval and the effect of altering the number of standard deviations used to establish the UCL and LCL.

Many other topics can arise from these exercises as well. The more times you run this exercise in class, the more topics you will find to explore. This exercise can also be easily extended to show the use of the standard deviation method for determining control limits for variable sampling.

EXHIBIT TN.1

Coin Catapult Worksheet

EXERCISE A

Data Table

Sample Number	1	2	3	4	5	Sample Mean $\bar{x}$	Sample Range R
1							
2							
3							
4							

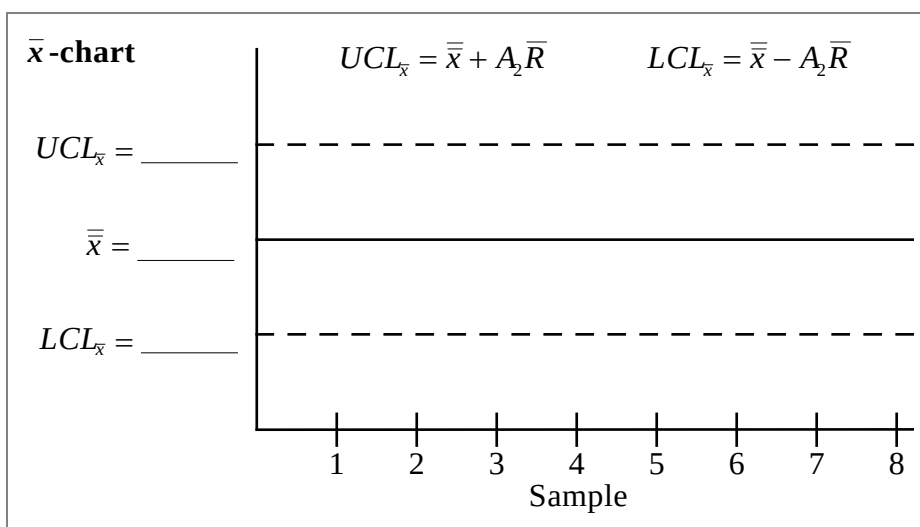
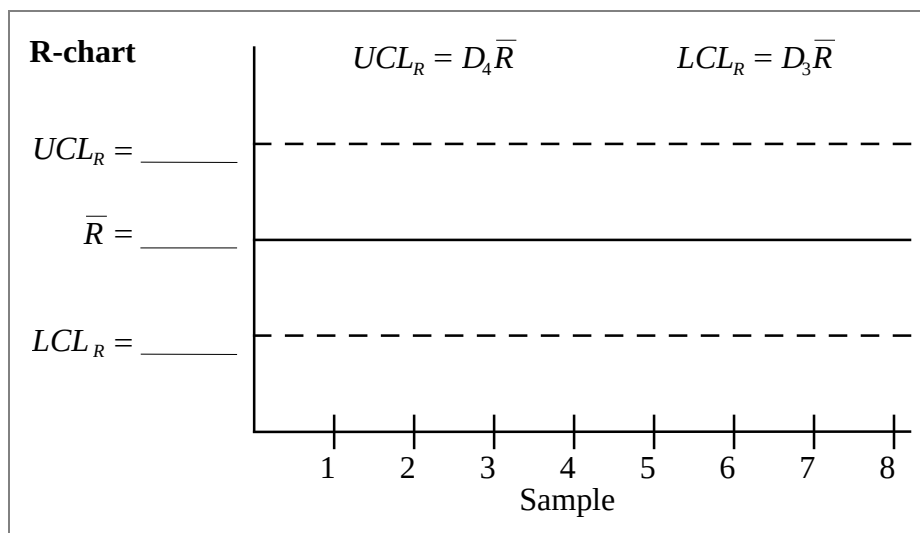
 $\bar{\bar{x}} = \underline{\hspace{2cm}} \quad \bar{\bar{R}} = \underline{\hspace{2cm}}$


EXHIBIT TN.1 (Cont.)

Coin Catapult Worksheet

Data Table (for additional observations)

Sample Number	Observation					Sample Mean $\bar{X}$	Sample Range R
	1	2	3	4	5		
5							
6							
7							
8							

EXHIBIT TN.2

Exercise B

Data Table

Sample Number	Observation										Misses	p
	1	2	3	4	5	6	7	8	9	10		
1												
2												
3												
4												

$$p = \frac{\text{misses}}{n}$$

First, calculate the average fraction defective, $\bar{p}$.

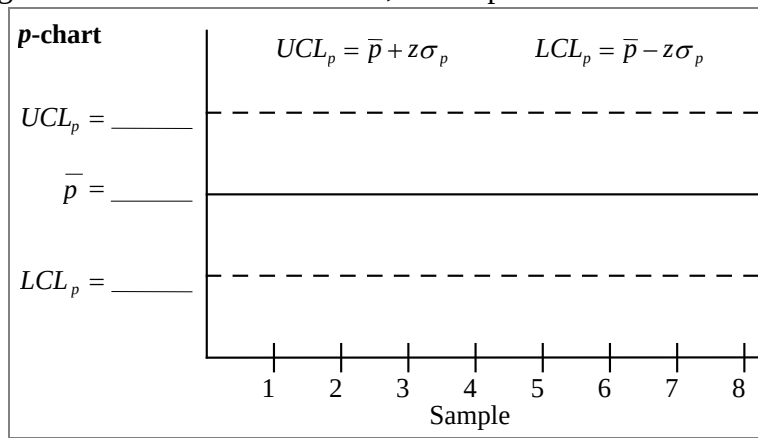
$$\bar{p} = \frac{\text{total defects}}{\text{total observations}} \quad \bar{p} = \underline{\hspace{2cm}}$$

Next, calculate the standard deviation of the distribution of $\bar{p}$. Remember that n represents the sample size (in this case 10), not the number of samples or the total number of observations.

$$\sigma_p = \sqrt{\frac{\bar{p}(1-\bar{p})}{n}} \quad \sigma_p = \underline{\hspace{2cm}}$$

Now determine the confidence level for the UCL and LCL. This is the number of standard deviations required for a two-tailed confidence interval. Frequently a 3-sigma value is used to obtain a 99% confidence interval, although other intervals can be used as well. For this example use 3 sigmas ($z = 3$).

Finally, using the values determined above, develop the UCL and LCL.



Chapter

6 Capacity Planning

DISCUSSION QUESTIONS

1. The primary economies of scale concern spreading the instructor's salary over a larger class and filling classrooms to capacity (and then some). Diseconomies occur when additional help is required to review homework, administer tests, and coordinate schedules of students and assistants. Growth eventually requires larger classrooms or lecture halls. If we view the product as learning, there is a possibility that diminishing returns on the amount of learning occur as class size increases. Symptoms of diseconomies of scale setting in are decreased job satisfaction for instructors and unmotivated, dissatisfied students. If close customer contact is needed for this kind of service process, diseconomies of scale tend to set in earlier.
2. When demand for the drink is large enough, there are several ways that economies of scale would benefit the boy. First, he can save on raw material costs. For example, one 32-ounce box of lemonade mix costs less than four 8-ounce boxes. Also, he could get a price break by buying ice in bulk. Second, the cost of larger iceboxes can be spread over more units (sales), keeping the cost per sale low. Diseconomies of scale can set in if business expands to the point that the boy cannot run the lemonade stand efficiently.

PROBLEMS

1. Dahlia Medical Center
Labor room capacity = $30 \text{ rooms} \times 3 \text{ days} \times 24 \text{ hours/day} = 2160 \text{ hours}$
Labor room utilization = $(60 \text{ babies} \times 24 \text{ hours/baby}) / (2160 \text{ hours}) = 66.67\%$
Combination labor-delivery room capacity = $15 \text{ rooms} \times 3 \text{ days} \times 24 \text{ hours/day} = 1080 \text{ hours}$
Combination labor-delivery room utilization $(45 \text{ babies} \times 24 \text{ hours/baby}) / (1080 \text{ hours}) = 100.00\%$
Delivery room capacity = $3 \text{ rooms} \times 3 \text{ days} \times 24 \text{ hours/day} = 216 \text{ hours}$
Delivery room utilization = $(60 \text{ babies} \times 1 \text{ hour/baby}) / (216 \text{ hours}) = 27.78\%$
The combination labor-delivery rooms have the highest utilization.

NOTE: The 1st printing of the book made mention of a complicated delivery room. This feature was unnecessarily confusing and was removed. The only change in the solution is that the labor room utilization is now 66.67% rather than 71.11%.

2. Capacity requirements in five years

This year's capacity requirement, allowing instead for just a 5-percent capacity cushion, is 52.63 (or $50 / [1.0 - 0.05]$) customers per day. Essentially you should divide by the desired utilization rate. Five years from now, if demand is only 75 percent of the current level, the customer requirement will be 39.47 (or 52.63×0.75) customers per day.

3. Airline company

This year's capacity requirement, allowing for a 25-percent capacity cushion, is 93.3 (or $70 / [1.0 - 0.25]$) customers per day. Three years from now, if demand increases by 20 percent, the customer requirement will be about 112 (or 93.3×1.2) customers per day for this flight segment.

4. Macon Controls

- a. The total machine hour requirements for all three demand forecasts are provided in the following Excel spreadsheet:

Capacity Information for Macon Controls		Capacity Calculations					
Control Unit		Pessimistic		Expected		Optimistic	
		Process Time (Dp)	Setup Time (D/Q)s	Process Time (Dp)	Setup Time (D/Q)s	Process Time (Dp)	Setup Time (D/Q)s
A		750.0	250.0	900.0	300.0	1,250.0	416.7
B		2,000.0	562.5	2,600.0	731.3	3,400.0	956.3
C		850.0	1,161.7	1,250.0	1,708.3	2,000.0	2,733.3
Demand		5,574.2		7,489.6		10,756.3	

The number of hours (N) provided per machine is:

$$N = (2 \text{ shifts/day} \times 8 \text{ hours/shift} \times 5 \text{ days/week} \times 52 \text{ weeks/year})(1.0 - 0.2) \\ = 3,328 \text{ hours/machine}$$

The capacity requirements for three forecasts are:

Pessimistic: $M = 5,574.2/3328 = 1.67$ or 2 machines

Expected: $M = 7,489.6/3328 = 2.25$ or 3 machines

Optimistic: $M = 10,756.3/3328 = 3.23$ or 4 machines

- b. The total machine hour requirements given that lot sizes are doubled are provided in the following Excel spreadsheet:

Capacity Information for Macon Controls	Capacity Calculations					
Control Unit	Pessimistic		Expected		Optimistic	
	Process Time (Dp)	Setup Time (D/Q)s	Process Time (Dp)	Setup Time (D/Q)s	Process Time (Dp)	Setup Time (D/Q)s
A	750.0	125.0	900.0	150.0	1,250.0	208.3
B	2,000.0	281.3	2,600.0	365.6	3,400.0	478.1
C	850.0	580.8	1,250.0	854.2	2,000.0	1,366.7
	Demand	4,587.1	Demand	6,119.8	Demand	8,703.1

The capacity requirements for three forecasts are now:

Pessimistic: $M = 4,587.1/3328 = 1.38$ or 2 machines

Expected: $M = 6,119.8/3328 = 1.84$ or 2 machines

Optimistic: $M = 8,703.1/3328 = 2.62$ or 3 machines

- c. The total machine hour requirements for all three demand forecasts given a 20% setup time reduction follows:

Capacity Information for Macon Controls	Capacity Calculations					
Control Unit	Pessimistic		Expected		Optimistic	
	Process Time (Dp)	Setup Time (D/Q)s	Process Time (Dp)	Setup Time (D/Q)s	Process Time (Dp)	Setup Time (D/Q)s
A	750.0	200.0	900.0	240.0	1,250.0	333.3
B	2,000.0	450.0	2,600.0	585.0	3,400.0	765.0
C	850.0	929.3	1,250.0	1,366.7	2,000.0	2,186.7
	Demand	5,179.3	Demand	6,941.7	Demand	9,935.0

The capacity requirements for three forecasts are now:

Pessimistic: $M = 5,179.3/3328 = 1.56$ or 2 machines

Expected: $M = 6,941.7/3328 = 2.09$ or 3 machines

Optimistic: $M = 9,935.0/3328 = 2.99$ or 3 machines

The plant has adequate capacity (3 machines) to meet all demand without increasing lot sizes

5. Up, Up and Away

The number of hours provided per machine is:

$$N = [2 \text{ shifts/day} \times 8 \text{ hours/shift} \times 200 \text{ days/year}] = 3,200. H = (3,200)(1 - 0.25) \\ = 2,400 \text{ hours/machine}$$

Summing up the machine hour requirements for two products, we get:

$$M = [30,000(0.30) + (30,000/20)(3)] + [12,000(1.0) + (12,000/70)(4)] \\ = 26,186 \text{ hours}$$

The capacity requirement is:

$$M = R/H = 26,186/2,400 = 10.91 \text{ or } 11 \text{ machines}$$

This analysis can also be done with the *Capacity Requirements Solver* of OM Explorer:

Components	Processing (hr/unit)	Setup (hr/lot)	Lot Size (units/lot)	Demand Forecast
A	0.30	3.0	20	30,000
B	1.00	4.0	70	12,000
Productive hours from one capacity unit for a year				
	2,400			
Hours Required				
		Process	Setup	
A		9,000	4,500.0	
B		12,000	685.7	
		21,000	5,185.7	
Total hours required			26,185.7	
Total capacity requirements (M)				10.91
Rounded				11

The capacity gap is $(11 - 4.0) = 7$ machines. Seven more machines must be purchased if short-term options are not allowed.

6. Tuff-Rider

The number of hours (H) provided per workstation is

$$N = [8 \text{ hours/day} \times 5 \text{ days/week} \times 50 \text{ weeks/year}] = 2,000. H = (2,000)(1.0 - 0.15) \\ = 1,700 \text{ hours}$$

Summing up the machine hour requirements for both bikes:

$$M = [5,000(0.25) + (5,000/100)(2.0)] + [10,000(0.5) + (10,000/100)(3.0)] \\ = 6,650 \text{ hours}$$

The capacity requirement is:

$$M = R/H = 6,650/1,700 = 3.92 \text{ or } 4 \text{ workstations}$$

Tuff-Rider will require 4 workstations.

7. The French Prints of Arabelle

The solution is based on the assumption that sales vary in direct proportion to floor area.

- a. The last column in the table shows quarterly before-tax cash flows. The first year's \$16,000 loss is followed by a \$1,000 loss in the second year.

Year	Quarter	Sales (\$ per sf)	30% of Sales × 1000 sf	Incremental Quarterly Rent	Incremental Salaries	Incremental Revenue Minus Costs
1	1	\$ 90.00	\$27,000	\$27,500	\$12,000	(\$12,500)
	2	\$ 60.00	\$18,000	\$27,500	\$ 8,000	(\$17,500)
	3	\$110.00	\$33,000	\$27,500	\$12,000	(\$6,500)
	4	\$240.00	\$72,000	\$27,500	\$24,000	\$20,500
2	1	\$ 99.00	\$29,700	\$27,500	\$12,000	(\$9,800)
	2	\$ 66.00	\$19,800	\$27,500	\$ 8,000	(\$15,700)
	3	\$121.00	\$36,300	\$27,500	\$12,000	(\$3,200)
	4	\$264.00	\$79,200	\$27,500	\$24,000	\$27,700

- b. The third year looks better. However, the \$15,500 gain just about covers the first year's loss. Considering the time value of money would further discourage this expansion.

Year	Quarter	Sales (\$ per sf)	30% of Sales × 1000 sf	Incremental Quarterly Rent	Incremental Salaries	Incremental Revenue Minus Costs
3	1	\$108.90	\$32,670	\$27,500	\$12,000	(\$6,830)
	2	\$ 72.60	\$21,780	\$27,500	\$ 8,000	(\$13,720)
	3	\$133.10	\$39,930	\$27,500	\$12,000	\$430
	4	\$290.40	\$87,120	\$27,500	\$24,000	\$35,620

8. Astro World

- a. The table shows incremental before-tax cash flows

Year	Projected Attendance	Incremental Attendance (with expansion)	Admis- sion Price	Incremental Revenue (with expansion)	Investment and Operating Costs	Cash Flow
0					\$800,000	(\$800,000)
1	30,000	9,000	\$30	\$270,000	\$100,000	\$170,000
2	34,000	10,200	\$30	\$306,000	\$100,000	\$206,000
3	36,250	10,875	\$35	\$380,625	\$100,000	\$280,625
4	38,500	11,550	\$35	\$404,250	\$100,000	\$304,250
5	41,000	12,300	\$35	\$430,500	\$100,000	\$330,500

- b. Payback occurs during the 4th year. At the end of 3 years, all but \$143,375 of the initial investment has been recovered. $\$143,375 / \$304,250 = 0.47$. Payback occurs at about 3.47 years.

9. Kim Epon

Capacity of washing and drying station = $(30 \text{ cars/hour}) \times (12 \text{ hours/day}) = 360 \text{ cars/day}$

Capacity of manual interior cleaning station = 200 cars/day

Incremental revenues (Friday, Saturday, and Sunday) from increasing capacity of interior cleaning station to 300 cars will be:

$$4 [(280 - 200) + (300 - 200) + (250 - 200)] = 4(230) = \$920/\text{week}$$

$$\text{Payback period} = \$50,000 / (\$920/\text{week} \times 52 \text{ weeks}) = 1.05 \text{ years}$$

Yes, Kim should install additional equipment.

10. Roche Brothers

a. Expand to 700,000 capacity now.

Year	Customers	Incremental Customers	2% of Sales	Incremental Revenue	Incremental Costs & Rent	Incremental Cash Flow
0					\$200,000	(\$200,000)
1	560,000	60,000	\$1.00	\$60,000	\$120,000	(\$60,000)
2	600,000	100,000	\$1.06	\$106,000	\$120,000	(\$14,000)
3	685,000	185,000	\$1.12	\$207,200	\$120,000	\$87,200
4	700,000	200,000	\$1.20	\$240,000	\$120,000	\$120,000
5	715,000*	200,000	\$1.28	\$256,000	\$120,000	\$136,000

* For year 5 the potential demand exceeds the 700,000-customer capacity, and so the incremental customers gained remains at 200,000.

b. Expand to 700,000 capacity, end of year 2.

Year	Customers	Incremental Customers	2% of Sales	Incremental Revenue	Incremental Costs & Rent	Incremental Cash Flow
0						
1	560,000	0	\$1.00	\$0		
2	600,000	0	\$1.06	\$0	\$240,000	(\$240,000)
3	685,000	185,000	\$1.12	\$207,200	\$144,000	\$63,200
4	700,000	200,000	\$1.20	\$240,000	\$144,000	\$96,000
5	715,000*	200,000	\$1.28	\$256,000	\$144,000	\$112,000

* For year 5 the potential demand exceeds the 700,000-customer capacity, and so the incremental customers gained remains at 200,000.

11. MKM International

a. Machine 1 option:

Year	Projected Cost	Savings with New Machine 1	Cash Flow
0			(\$500,000)
1	1,000,000	150,000	150,000
2	1,350,000	202,500	202,500
3	1,400,000	210,000	210,000
4	1,450,000	217,500	217,500
5	2,550,000	382,500	382,500

$$\begin{aligned}
 \text{NPV} &= -500,000 + [(150,000/1.12)] + [202,500/1.12^2] + [210,000/1.12^3] + \\
 &\quad [217,500/1.12^4] + [382,500/1.12^5] \\
 &= -500,000 + 133,929 + 161,432 + 149,474 + 138,225 + 217,041 \\
 &= -500,000 + 800,101 \\
 &= \$300,101
 \end{aligned}$$

Machine 2 option:

Year	Projected Cost	Savings with New Machine 2	Cash Flow
0			(\$900,000)
1	1,000,000	250,000	250,000
2	1,350,000	337,500	337,500
3	1,400,000	350,000	350,000
4	1,450,000	362,500	362,500
5	2,550,000	637,500	637,500

$$\begin{aligned}
 \text{NPV} &= -900,000 + [(250,000/1.12)] + [337,500/1.12^2] + [350,000/1.12^3] + \\
 &\quad [362,500/1.12^4] + [637,500/1.12^5] \\
 &= -900,000 + 223,214 + 269,053 + 249,123 + 230,375 + 361,735 \\
 &= -900,000 + 1,333,500 \\
 &= \$433,500
 \end{aligned}$$

MKM International should choose Machine 2 because it yields a higher NPV over these 5 years.

b. Machine 1 option:

$$\begin{aligned}
 \text{NPV} &= -500,000 + [(150,000/1.08)] + [202,500/1.08^2] + [210,000/1.08^3] + \\
 &\quad [217,500/1.08^4] + [382,500/1.08^5] \\
 &= -500,000 + 138,889 + 173,611 + 166,705 + 159,869 + 260,323 \\
 &= -500,000 + 899,397 \\
 &= \$399,397
 \end{aligned}$$

Machine 2 option:

$$\begin{aligned}
 \text{NPV} &= -900,000 + [(250,000/1.08)] + [337,500/1.08^2] + [350,000/1.08^3] + \\
 &\quad [362,500/1.08^4] + [637,500/1.08^5] \\
 &= -900,000 + 231,481 + 289,352 + 277,841 + 266,448 + 433,872 \\
 &= -900,000 + 1,498,994 \\
 &= \$598,994
 \end{aligned}$$

With a discount rate of 8%, Machine 2 still yields the higher NPV of cash flows over these 5 years.

12. Dawson Electronics

a. **Water Saver 1000**

$$\begin{aligned}
 \text{With Capacity Expansion, EV} &= \\
 &= (.25 \times 1000 + .5 \times 2000 + .25 \times 3000)1000 = \$2,000,000
 \end{aligned}$$

$$\begin{aligned}
 \text{Without Capacity Expansion, EV} &= \\
 &= (.25 \times 700 + .5 \times 1000 + .25 \times 2000)1000 = \$1,175,000
 \end{aligned}$$

Greener Grass 5000

$$\begin{aligned}
 \text{With Capacity Expansion, EV} &= \\
 &= (.25 \times 2500 + .5 \times 3000 + .25 \times 5000)1000 = \$3,375,000
 \end{aligned}$$

$$\begin{aligned}
 \text{Without Capacity Expansion, EV} &= \\
 &= (.25 \times 1000 + .5 \times 2000 + .25 \times 3000)1000 = \$2,000,000
 \end{aligned}$$

b. Since the expected value (EV) for the Greener Grass 5000 of \$3,375,000 is higher than the EV for the Water Saver 1000 (\$2,000,000), Denise should buy additional machines and choose to produce the Greener Grass 5000.

13. Knott's Industries

- a. The number of hours provided per machine is:

$$N = [250 \text{ days/year} \times 8 \text{ hours/day} \times 60 \text{ min/hour}] = 120,000.$$

$$H = 120,000 \times (1 - 0.2) = 96,000 \text{ minutes/year/machine}$$

Summing up the machine hour requirements for two products, we get:

$$R = [20,000 (7) + (20,000/50) (30)] + [10,000 (20) + (10,000/30) (45)] \\ = 367,000 \text{ minutes}$$

$$M = R/H = 367,000/96,000 = 3.822 \text{ machines or 4 machines}$$

Since Knott's already has 4 machines currently, there is sufficient capacity available to meet next year's demand.

- b. The number of hours provided per machine is:

$$N = [250 \text{ days/year} \times 8 \text{ hours/day} \times 60 \text{ min/hour}] = 120,000.$$

$$H = 120,000 \times (1 - 0.2) = 96,000 \text{ minutes/year/machine}$$

Summing up the machine hour requirements for the two products, we get:

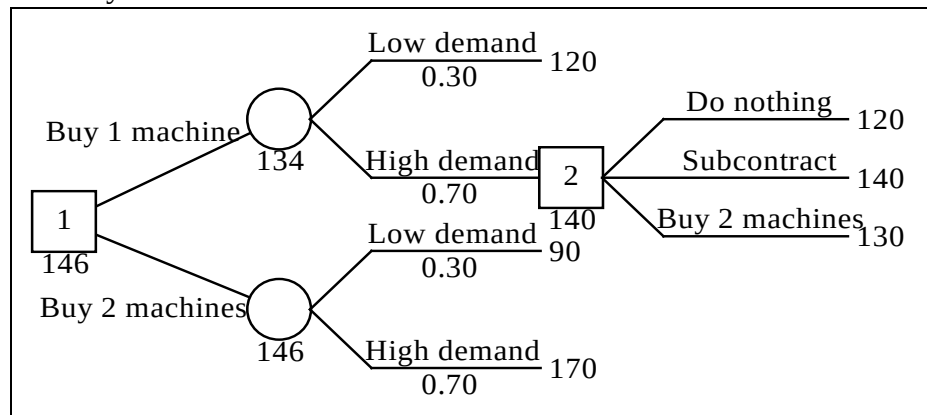
$$R = [20,000 (7) + (20,000/50) (30)] + [20,000 (20) + (20,000/30) (30)] \\ = 572,000 \text{ minutes}$$

$$M = R/H = 572,000/96,000 = 5.96 \text{ machines or 6 machines}$$

Even if the set-up time is reduced to 30 minutes for the super premium swing sets, there is not enough capacity to produce 20,000 units of each type of swing set since Knott's has only 4 machines while 6 machines are required.

14. Purchasing one or two machines

- a. Note: Payoffs are in \$000s.



- b. Best decision is to buy 2 machines. Expected payoff is \$146,000.

15. River City

a. **Alternative 1 (A1)**

There must be an 80 million-gallon expansion now, which has a cash outflow of \$50 million. There are no other cash flows over the horizon.

Alternative 2 (A2)

There must be a 40 million-gallon expansion now (160–120) and another 40 million-gallon expansion (200–160) at the end of 10 years. These expansions require a \$30 million cash outflow at the end of years 0 and 10.

Alternative 3 (A3)

There must be a 20 million-gallon expansion at the end of years 0, 5, 10, 15. Each expansion is accompanied by an \$18 million cash outflow.

- b. We will use the present value factors in Supplement F, “Financial Analysis” in MyOMLab to find the present value of cash flows for each alternative.

Present Values (millions of dollars)		
	$r = 12\%$	$r = 16\%$
A1	\$50	\$50
A2	$\$30(1 + 0.3220) = \$39.660$	$\$30(1 + 0.2267) = \$36.801$
A3	$\$18(1 + 0.5674 + 0.3220 + 0.1827) = \$37.298$	$\$18(1 + 0.4761 + 0.2267 + 0.1079) = \$32.593$

At both extremes of the hurdle rate, Alternative 3 is the best.

- c. The expansion probably requires a special bond issue, and it is probably safer to go with an alternative that requires less of an outlay now (such as Alternative 2 or 3).

16. Mars Incorporated

- a. The Excel spreadsheets below compute the cash flow and NPV for:

Alternative 1 assuming small increases in the cost of electrical power.

Year	Demand in devices	Cash Inflow (outflow)	Cumulative Cash Inflow (outflow)	NPV at 10%
0		-\$250,000.00	-\$250,000.00	-\$250,000.00
1	1,000.00	\$425,000.00	\$175,000.00	\$386,363.64
2	5,000.00	\$2,125,000.00	\$2,300,000.00	\$1,756,198.35
3	1,000.00	\$425,000.00	\$2,725,000.00	\$319,308.79
4	15,000.00	\$6,375,000.00	\$9,100,000.00	\$4,354,210.78
5	18,000.00	\$7,650,000.00	\$16,750,000.00	\$4,750,048.12
				\$11,316,129.67

Alternative 2 assuming small increases in the cost of electrical power.

Year	Demand in devices	Cash Inflow (outflow)	Cumulative Cash Inflow (outflow)	NPV at 10%
0		\$0.00	\$0.00	\$0.00
1	1,000.00	\$200,000.00	\$200,000.00	\$181,818.18
2	5,000.00	\$1,000,000.00	\$1,200,000.00	\$826,446.28
3	1,000.00	\$200,000.00	\$1,400,000.00	\$150,262.96
4	15,000.00	\$3,000,000.00	\$4,400,000.00	\$2,049,040.37
5	18,000.00	\$3,600,000.00	\$8,000,000.00	\$2,235,316.76
				\$5,442,884.55

Alternative 1 maximizes the NPV under these conditions

- b. The Excel spreadsheets below compute the cash flow and NPV for:

Alternative 1 assuming large increases in the cost of electrical power.

Year	Demand in devices	Cash Inflow (outflow)	Cumulative Cash Inflow (outflow)	NPV at 10%
0		-\$250,000.00	-\$250,000.00	-\$250,000.00
1	1,000.00	\$425,000.00	\$175,000.00	\$386,363.64
2	8,000.00	\$3,400,000.00	\$3,575,000.00	\$2,809,917.36
3	15,000.00	\$6,375,000.00	\$9,950,000.00	\$4,789,631.86
4	20,000.00	\$8,500,000.00	\$18,450,000.00	\$5,805,614.37
5	30,000.00	\$12,750,000.00	\$31,200,000.00	\$7,916,746.87
				\$21,458,274.09

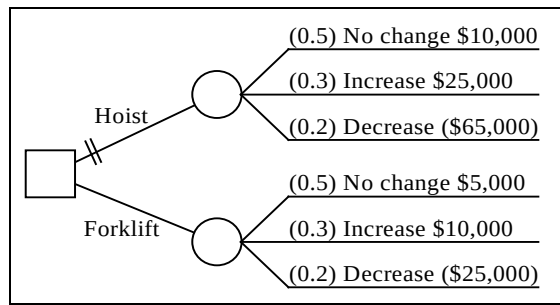
Alternative 2 assuming large increases in the cost of electrical power.

Year	Demand in devices	Cash Inflow (outflow)	Cumulative Cash Inflow (outflow)	NPV at 10%
0		\$0.00	\$0.00	\$0.00
1	1,000.00	\$200,000.00	\$200,000.00	\$181,818.18
2	8,000.00	\$1,600,000.00	\$1,800,000.00	\$1,322,314.05
3	15,000.00	\$3,000,000.00	\$4,800,000.00	\$2,253,944.40
4	20,000.00	\$4,000,000.00	\$8,800,000.00	\$2,732,053.82
5	30,000.00	\$6,000,000.00	\$14,800,000.00	\$3,725,527.94
				\$10,215,658.39

Alternative 1 maximizes the NPV under these conditions

17. Acme Steel Fabricators

a. Decision tree



Expected Value of Hoist = $[(0.5 \times \$10,000) + (0.3 \times \$25,000) - (0.2 \times \$65,000)] = -\$500$

Expected Value of Forklift = $[(0.5 \times \$5,000) + (0.3 \times \$10,000) - (0.2 \times \$25,000)] = \$500$

b. Purchase Forklift

18. Macon Controls part 2

The Excel spreadsheet below calculates the total capacity required to meet “pessimistic” demand.

Control Unit	Total Production Assuming Pessimistic Demand			Capacity Required	
	2 Machines			2 machines	
				Process Time (Dp)	Setup Time (D/Q)s
A	15,000			750.0	250.0
B	10,000			2000.0	562.5
C	17,000			850.0	1161.7
Demand					5574.2

Two machines can meet all demand at pessimistic levels of 42,000 (15,000+10,000+17,000) control units.

Next, assuming an “expected” demand level, calculate the demand that can be satisfied.

Control Unit	Total Production Assuming Expected Demand			Capacity Required			
	2 Machines	3 Machines		2 Machines		3 Machines	
				Process Time (Dp)	Setup Time (D/Q)s	Process Time (Dp)	Setup Time (D/Q)s
A	18,000	18,000		900.0	300.0	900.0	300.0
B	9,750	13,000		1950.0	548.4	2600.0	731.3
C	25,000	25,000		1250.0	1708.3	1250.0	1708.3
Demand				6656.8		7489.6	

Two machines can produce up to 52,750 units (18,000+9,750+25,000) and three machines can meet all demand (56,000 units) under “expected” conditions.

Assuming “optimistic” demand, calculate the demand that can be satisfied.

Control Unit	Total Production Assuming Optimistic Demand			Capacity Required					
	2 Machines	3 Machines	4 Machines	2 Machines		3 Machines		4 Machines	
				Process Time (Dp)	Setup Time (D/Q)s	Process Time (Dp)	Setup Time (D/Q)s	Process Time (Dp)	Setup Time (D/Q)s
A	25,000	25,000	25,000	1250.0	416.7	1250.0	416.7	1250.0	416.7
B	1,000	14,000	17,000	200.0	56.3	2800.0	787.5	3400.0	956.3
C	40,000	40,000	40,000	2000.0	2733.3	2000.0	2733.3	2000.0	2733.3
Demand				6656.3		9987.5		10756.3	

Two machines can produce up to 66,000 units (25,000+1,000+40,000), three machines can produce up to 79,000 units (25,000+14,000+40,000), and four machines can meet all demand (82,000 units) under “optimistic” conditions.

Using these production results, the Excel spreadsheet below provides the payoffs of a decision to purchase 2, 3 or 4 machines under the three demand states of nature. The calculation of each payoff proceeds as follows:

Payoff=Expected Revenue – Cost.

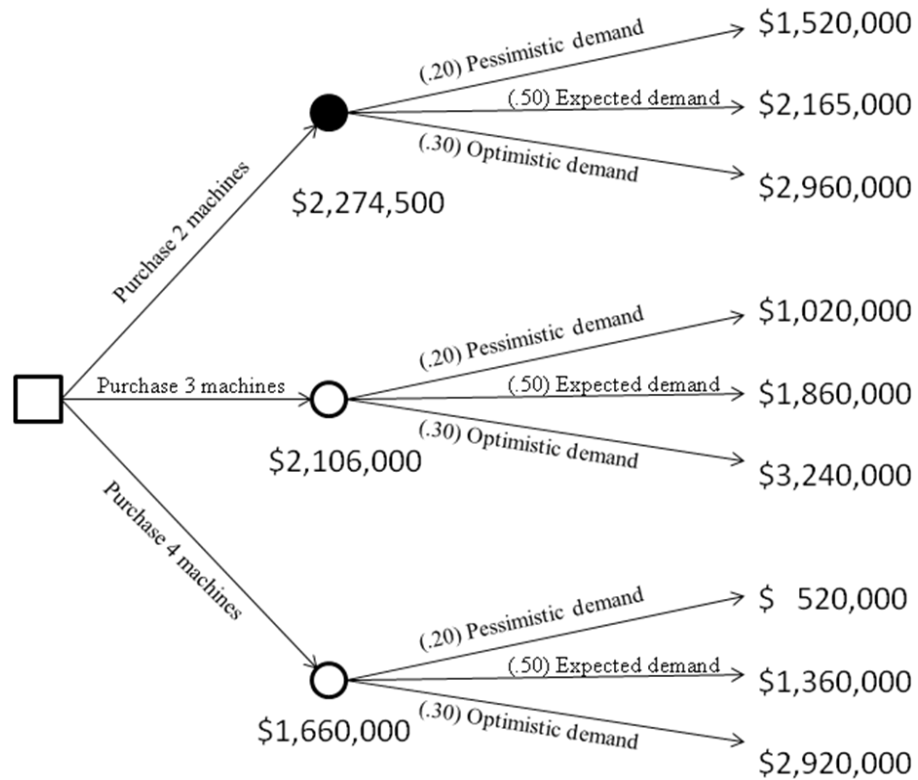
Expected Revenue = Total Production*Price. (each control unit’s price is \$110)

Cost = Machine cost + Total variable cost. (each machine costs \$500,000 and variable cost is \$50 per unit)

	Payoff		
	Pessimistic	Expected	Optimistic
Purchase 2	\$1,520,000	\$2,165,000	\$2,960,000
Purchase 3	\$1,020,000	\$1,860,000	\$3,240,000
Purchase 4	\$520,000	\$1,360,000	\$2,920,000

For example, the payoff for purchasing 2 machines under Expected demand conditions equals: $52,750 \times \$110 - [(2 \times \$500,000) + (52,750 \times \$50)] = \$2,165,000$

a. The decision tree



b. Using an Expected Value approach, the best decision is to purchase 2 machines with an expected payoff of \$2,274,500.

19. Gas n' Go

a.

Year	New Customers	Sales Per Customer	Profit Margin	Profit	Costs	Cash Flow
0					\$380,000	(\$380,000)
1	40,000	\$5.00	20%	\$40,000	\$0	\$40,000
2	40,000	\$6.50	25%	\$65,000	\$0	\$65,000
3	40,000	\$8.00	30%	\$96,000	\$0	\$96,000
4	40,000	\$10.00	35%	\$140,000	\$0	\$160,000
5	40,000	\$11.00	40%	\$176,000	\$0	\$176,000

$$\begin{aligned}
 \text{NPV} &= -380,000 + [(40,000/1.08)] + [65,000/1.08^2] + [96,000/1.08^3] + \\
 &\quad [140,000/1.08^4] + [176,000/1.08^5] \\
 &= -380,000 + 37,037.04 + 55,727.02 + 76,207.9 + 102,904.18 + 119,782.64 \\
 &= -380,000 + 391,658.78 \\
 &= \$11,658.78
 \end{aligned}$$

b. During the first four years, incremental cash flows are only \$ 271,876.14 (37,037.04+55,727.02+76,207.9+102,904.18). Additional cash flows of \$108,123.86 require additional 0.903 (108,123.86/119,782.64) years of operation. Thus the payback occurs at about 4.903 years. Since the payback

period is longer than 4 years, it does not meet Darren's threshold. Consequently, the project should not be undertaken.

20. Mackelprang Inc.

- a. *Indian river*: $\$4\text{M} \times .3 + \$2.5\text{M} \times .4 + \$1\text{M} \times .3 = \$2.5\text{M}$

Expected Payoff = 2.5-2.6 or -\$100,000

The Cactus: $\$2\text{M} \times .2 + \$1.5\text{M} \times .5 + \$1\text{M} \times .3 = \$1.45\text{M}$

Expected Payoff = 1.45-1.25 or \$200,000

Wildwood: $\$2\text{M} \times .3 + \$4\text{M} \times .5 + \$1\text{M} \times .2 = \$2.8\text{M}$

Expected Payoff = 2.8-2.5 or \$300,000

Mackelprang Inc. should build the Wildwood and Cactus golf courses for

- b. a combined payoff of \$500,000.

21. Grandmother's Chicken

Alternative 1: Expand both kitchen and dining area now to 130,000 capacity, cost \$336,000.

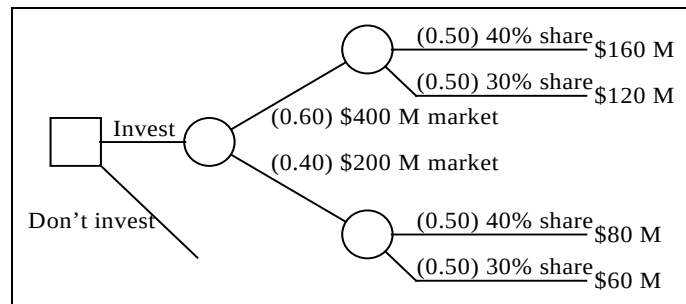
Year	Projected Demand (meals/year)	Projected Capacity (meals/year)	Calculation of Incremental Cash Flow Compared to Base Case 80,000 meals/year	Cash Inflow (outflow)
0	80,000	130,000		(336,000)
1	90,000	130,000	80,000 meals (\$2.20 – \$2.00) = 90,000 – 80,000 = 10,000 meals (\$2.20/meal) =	\$16,000 <u>+\$22,000</u> \$38,000
2	100,000	130,000	80,000 meals (\$2.20 – \$2.00) = 100,000 – 80,000 = 20,000 meals (\$2.20/meal) =	\$16,000 <u>+\$44,000</u> \$60,000
3	110,000	130,000	80,000 meals (\$2.20 – \$2.00) = 110,000 – 80,000 = 30,000 meals (\$2.20/meal) =	\$16,000 <u>+\$66,000</u> \$82,000
4	120,000	130,000	80,000 meals (\$2.20 – \$2.00) = 120,000 – 80,000 = 40,000 meals (\$2.20/meal) =	\$16,000 <u>+\$88,000</u> \$104,000
5	130,000	130,000	80,000 meals (\$2.20 – \$2.00) = 130,000 – 80,000 = 50,000 meals (\$2.20/meal) =	\$16,000 <u>+\$110,000</u> \$126,000

Alternative 2: Expand only kitchen now to 105,000 capacity, cost \$220,000. At end of Year 3, expand kitchen and dining to 130,000 capacity, cost \$224,000.

Year	Projected Demand (meals/year)	Projected Capacity (meals/year)	Calculation of Incremental Cash Flow Compared to Base Case 80,000 meals/year	Cash Inflow (outflow)
0	80,000	105,000	Investment	(220,000)
1	90,000	105,000	80,000 meals (\$2.20 – \$2.00) = 90,000 – 80,000 = 10,000 meals (\$2.20/meal) =	\$16,000 <u>+\$22,000</u>
2	100,000	105,000	80,000 meals (\$2.20 – \$2.00) = 100,000 – 80,000 = 20,000 meals (\$2.20/meal) =	\$16,000 <u>+\$44,000</u>
3	110,000	105,000	80,000 meals (\$2.20 – \$2.00) = 105,000 – 80,000 = 25,000 meals (\$2.20/meal) = Investment =	\$16,000 <u>+\$55,000</u> <u>(\$204,000)</u>
4	120,000	130,000	80,000 meals (\$2.20 – \$2.00) = 120,000 – 80,000 = 40,000 meals (\$2.20/meal) =	\$16,000 <u>+\$88,000</u>
5	130,000	130,000	80,000 meals (\$2.20 – \$2.00) = 130,000 – 80,000 = 50,000 meals (\$2.20/meal) =	\$16,000 <u>+\$110,000</u> \$126,000

Comparing just the sum of the cash flows for Alt. 1, \$74,000 and Alt 2, – \$25,000 to the old technology flows, the old technology turns out to be best, introduced with a one-stage expansion. To complete the analysis, discounted after-tax cash flows should be calculated recognizing the time value of money. Old Tech PRE NPV flows calculations in 1,000's were: Y0 – \$200, Y1 \$20, Y2 \$40, Y3 \$60, Y4 \$80, Y5 \$100 = +\$100

22. Dintell Corporation. Assuming a five-year life.
Decision tree:



Expected Sales = $\{(0.6)[(0.5)(\$160 \text{ M}) + (0.5)(\$120 \text{ M})]\} + \{(0.4)[(0.5)(\$80 \text{ M}) + (0.5)(\$60 \text{ M})]\} = \$112,000,000$ per year

Gross Profit = Sales – COGS = $\$112,000,000 - (70\% \times \$112,000,000) = \$33,600,000$

Initial information						
Initial investment	\$50,000,000					
Tax rate	0.40					
Discount rate	0.12					
MACRS depreciation	0.2000	0.3200	0.1920	0.1152	0.1142	0.0576
Present value factor	0.8929	0.7972	0.7118	0.6355	0.5674	0.5066
	Year					
	1	2	3	4	5	6
Expected sales	\$112,000,000	\$112,000,000	\$112,000,000	\$112,000,000	\$112,000,000	\$0
Expenses: COGS = 70%	\$78,400,000	\$78,400,000	\$78,400,000	\$78,400,000	\$78,400,000	\$0
Depreciation shelter	<u>\$10,000,000</u>	<u>\$16,000,000</u>	<u>\$9,600,000</u>	<u>\$5,760,000</u>	<u>\$5,710,000</u>	<u>\$2,880,000</u>
Pretax income	\$23,600,000	\$17,600,000	\$24,000,000	\$27,840,000	\$27,890,000	<u>(\$2,880,000)</u>
Taxes	<u>\$9,440,000</u>	<u>\$7,040,000</u>	<u>\$9,600,000</u>	<u>\$11,136,000</u>	<u>\$11,156,000</u>	<u>(\$1,152,000)</u>
Net operating income	\$14,160,000	\$10,560,000	\$14,400,000	\$16,704,000	\$16,734,000	<u>(\$1,728,000)</u>
Add back depreciation	\$10,000,000	\$16,000,000	\$9,600,000	\$5,760,000	\$5,710,000	\$2,880,000
Total cash flow	\$24,160,000	\$26,560,000	\$24,000,000	\$22,464,000	\$22,444,000	\$1,152,000
Net present value	\$21,571,429	\$21,173,469	\$17,082,726	\$14,276,278	\$12,735,328	\$583,639
Sum of NPV	\$37,422,869					

a. Dintell should make the investment. The NPV is positive. Even in the worst case, as shown below (Sales = \$60 M), the NPV remains positive.

Initial information						
Initial investment	\$50,000,000					
Tax rate	0.40					
Discount rate	0.12					
MACRS depreciation	0.2000	0.3200	0.1920	0.1152	0.1142	0.0576
Present value factor	0.8929	0.7972	0.7118	0.6355	0.5674	0.5066
	Year					
	1	2	3	4	5	6
Expected sales	\$60,000,000	\$60,000,000	\$60,000,000	\$60,000,000	\$60,000,000	\$0
Expenses: COGS = 70%	\$42,000,000	\$42,000,000	\$42,000,000	\$42,000,000	\$42,000,000	\$0
Expenses: investment						
Depreciation shelter	<u>\$10,000,000</u>	<u>\$16,000,000</u>	<u>\$9,600,000</u>	<u>\$5,760,000</u>	<u>\$5,710,000</u>	<u>\$2,880,000</u>
Pretax income	\$8,000,000	\$2,000,000	\$8,400,000	\$12,240,000	\$12,290,000	<u>(\$2,880,000)</u>
Taxes	<u>\$3,200,000</u>	<u>\$800,000</u>	<u>\$3,360,000</u>	<u>\$4,896,000</u>	<u>\$4,916,000</u>	<u>\$1,152,000</u>
Net operating income	\$4,800,000	\$1,200,000	\$5,040,000	\$7,344,000	\$7,374,000	<u>(\$1,728,000)</u>
Add back depreciation	\$10,000,000	\$16,000,000	\$9,600,000	\$5,760,000	\$5,710,000	\$2,880,000
Total cash flow	\$14,800,000	\$17,200,000	\$14,640,000	\$13,104,000	\$13,084,000	\$1,152,000
Net present value	\$13,214,286	\$13,711,735	\$10,420,463	\$8,327,829	\$7,424,213	\$583,639
Sum of NPV	\$3,682,164					

b. The decision remains the same. Greater expected payoffs favor making the investment.

- c. A decrease in the discount rate will have no effect on the decision. The following spreadsheet shows that even at a discount rate = 12% + 15% = 27%, the NPV remains positive.

Initial information						
Initial investment	\$50,000,000					
Tax rate	0.40					
Discount rate	0.27					
MACRS depreciation	0.2000	0.3200	0.1920	0.1152	0.1142	0.0576
Present value factor	0.7874	0.6200	0.4882	0.3844	0.3027	0.2383
		Year				
	1	2	3	4	5	6
Expected sales	\$112,000,000	\$112,000,000	\$112,000,000	\$112,000,000	\$112,000,000	\$0
Expenses: COGS = 70%	\$78,400,000	\$78,400,000	\$78,400,000	\$78,400,000	\$78,400,000	\$0
Depreciation shelter	<u>\$10,000,000</u>	<u>16,000,000</u>	<u>\$9,600,000</u>	<u>\$5,760,000</u>	<u>\$5,710,000</u>	<u>\$2,880,000</u>
Pretax income	\$23,600,000	\$17,600,000	\$24,000,000	\$27,840,000	\$27,890,000	(\$2,880,000)
Taxes	<u>\$9,440,000</u>	<u>\$7,040,000</u>	<u>\$9,600,000</u>	<u>\$11,136,000</u>	<u>\$11,156,000</u>	<u>(\$1,152,000)</u>
Net operating income	\$14,160,000	\$10,560,000	\$14,400,000	\$16,704,000	\$16,734,000	(\$1,728,000)
Add back depreciation	\$10,000,000	\$16,000,000	\$9,600,000	\$5,760,000	\$5,710,000	\$2,880,000
Total cash flow	\$24,160,000	\$26,560,000	\$24,000,000	\$22,464,000	\$22,444,000	\$1,152,000
Net present value	\$19,023,622	\$16,467,233	\$11,716,559	\$8,635,196	\$6,793,313	\$274,556
Sum of NPV	\$12,910,479					

- d. If we consider an additional investment of \$10,000,000 in the third year, depreciation would greatly complicate the calculations, but would not change the answer. Perhaps the easiest approach would be to generate another section of the spreadsheet showing just the effect on total cash flow of depreciating \$10,000,000 over the remaining three years of life. Then use that information to adjust the total cash flow. The NPV will remain positive.

Initial investment	\$50,000,000					
Third year investment			\$10,000,000			
Tax rate	0.40					
Discount rate	0.12					
MACRS depreciation			0.3333	0.4445	0.1481	0.0741
Present value factor	0.8929	0.7972	0.7118	0.6355	0.5674	0.5066
		Year				
	1	2	3	4	5	6
Depreciation shelter			<u>\$3,333,000</u>	<u>\$4,445,000</u>	<u>\$1,481,000</u>	<u>\$741,000</u>
Pretax income (loss)			(\$3,333,000)	(\$4,445,000)	(\$1,481,000)	(\$741,000)
Taxes			<u>\$1,333,200</u>	<u>(\$1,778,000)</u>	<u>(\$592,400)</u>	<u>(\$296,400)</u>
Net operating income			(\$1,999,800)	(\$2,667,000)	(\$888,600)	(\$444,600)
Add back depreciation			\$3,333,000	\$4,445,000	\$1,481,000	\$741,000
Adjustment to cash flow			(\$8,666,800)	\$1,778,000	\$592,400	\$296,400
Previous cash flow	\$24,160,000	\$26,560,000	\$24,000,000	\$22,464,000	\$22,444,000	\$1,152,000
Total cash flow	\$24,160,000	\$26,560,000	\$15,333,200	\$24,242,000	\$23,036,400	\$1,448,400
Net present value	\$21,571,429	\$21,173,469	\$10,913,869	\$15,406,229	\$13,071,472	\$733,805
Sum of NPV	\$22,870,273					

CASE: FITNESS PLUS (PART A) *

A. Synopsis

Fitness Plus is a full-service health, fitness, and sports club located in a growing market. The increase in demand on its facilities brought on by a sizable growth in membership over the past few years has led to membership's complaints of overcrowding of club facilities and the unavailability of equipment. As with most service organizations, Fitness Plus experiences large shifts in demand both during the week and within each particular day. The owners are wondering what the existing capacity of the club is and whether it is time to think about a capacity expansion move.

B. Purpose

The case presents the students with a set of capacity planning issues within the context of a service organization. Data in the case provide the opportunity to address the following issues:

1. How should capacity of the facility be measured? Is there an overall measure of facility capacity, or is it more appropriate to look at the individual areas (work centers) and measure their capacity? The different areas may require different types of capacity measurement. The cardiovascular room can accommodate only 29 people and is more like a job shop where the Nautilus area is similar to an assembly line where people flow through the equipment.
2. There is the issue of calculating capacity levels and distinguishing between utilization of capacity at peak versus average demand levels. Toward this end, students should address the issue of how large a capacity cushion is desired in this service setting.
3. A major decision facing the students after the measurement issues have been addressed is the capacity expansion issue. There is information that requires the students to focus not only on the timing and sizing issue but also on the location issue.
4. Finally, the students must address the competitive priorities issue as they decide on a capacity expansion strategy. This is a long-term decision, and new competition has entered the market. Does Fitness Plus compete by having a full-service line of equipment, providing flexibility and quality; or is convenience and location a major competitive factor? Also, what part does cost/price play in attracting and retaining members?

C. Analysis

Students should begin by analyzing the capacity of the facility; however, the analysis is not as straightforward as it first may seem. There is an issue of how

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

capacity should be measured. Students should quickly recognize that an overall measure of capacity for the facility isn't much help in determining if Fitness Plus is capacity constrained. If the service delivery process for each member were homogeneous, such as a cafeteria or airline flight, then an overall measure of capacity, such as the number of members serviced over a given period of time, would be an appropriate measure of capacity. However, the service delivery process at Fitness Plus is a menu-driven process where each member chooses from a range of services the club provides. Therefore, capacity must be measured for each service item provided. In some areas of the club, such as aerobics, this may be an "output measure" of capacity, such as the number of members per hour that can do aerobics. In other areas, such as the Nautilus equipment, the measure may be an "input measure," the number of machines available.

A second set of complicating issues deals with the impact that management policies and assumptions have on capacity measures. In their analysis the students need to determine how many members can be serviced in each area of the club. The number served per hour in the cardiovascular area, for example, will depend on whether management chooses to limit the time on each machine during peak hours of demand. Many health clubs limit the use to 30 minutes per member during periods of heavy load. This would, in effect, double the output measure of capacity per hour, but it would not affect the input measure of total machine hours available.

An assumption that could be made is that each member takes one minute for each piece of Nautilus equipment used. If management arranges the equipment in a sequential flow so that members begin at the first station and continue through the equipment in a set sequence, then the capacity can be measured by cycle times and throughput per hour in a manner much like measuring the capacity of an assembly line.

With these issues in mind, the students can develop capacity estimates similar to the following:

1. Aerobics
 - ❑ Assumption: Aerobics classes begin on the hour and last for 50 minutes.
 - ❑ Capacity: 1 class per hour for 35 members
2. Cardiovascular
 - ❑ Assumption: During peak demand times, each piece of equipment is limited to 30 minutes per member.
 - ❑ Capacity: With 29 pieces of C-V equipment, 58 members per hour peak capacity
3. Nautilus
 - ❑ Assumptions: Each member takes 1 minute to complete each exercise. The machines are set up so members flow through in a sequential manner.
 - ❑ Capacity: Maximum capacity at a steady state; cycle time 1 minute. 60 members per hour

Over the three-hour peak demand period, the Nautilus area may only process 156 members because it will take 24 minutes for the first member to complete the entire 24-machine cycle.

These three areas of the club are the major areas of concern due to customer complaints, and they are where students should concentrate their analysis. The tennis and racquetball areas can service the following number of members per hour:

Tennis:	12 members/hour for singles
	24 members/hour for doubles
Racquetball:	16 members/hour for singles
	32 members/hour for doubles

There were no details given in the case to determine the capacity of the free-weight area. So, if we aggregate the individual capacities into an overall measure, the club can accommodate a peak capacity of 181 to 209 members per hour, excluding the free-weight area—far more than the peak demand of 80 per hour. Of course, what is important is not the aggregate demand level, but rather the demand mix and how this mix matches the individual area capacities.

The next step in the analysis is to focus the students on estimating the demands that are placed on the club facilities. Because this is a service being provided, the focus should be on looking at the club's ability to satisfy peak demand. Students should quickly derive the following estimates of peak demand:

Arrival rate at peak	= 80 members/hour
Aerobics @ 30%	= 24 members/hour
Cardiovascular @ 40%	= 32 members/hour
Nautilus @ 25%	= 20 members/hour
Racquetball @ 15%	= 12 members/hour
Tennis @ 10%	= 8 members/hour
Free-Weights @ 20%	= 16 members/hour

These potential demand rates during the peak times indicate a number of things. First, when compared to the area capacities calculated earlier, there seems to be plenty of excess capacity in all areas of the club. Second, it is obvious that members use more than one area of the club during their visits, as the total potential demand across all areas of the club adds to 112-person hours, impossible with only 80 members arriving per hour.

At this time, the instructor needs to direct the students' attention and discussion toward the issue of determining the size of capacity cushion that Fitness Plus should target to maintain acceptable service levels for its members. One reason complaints may be occurring, even though the comparison of demands and capacities looks fine, is that a member may enter the club, warm up in the cardiovascular room for a few minutes, then go through a Nautilus workout before doing more cardiovascular training or an aerobics workout. In effect, we made the inherent assumption in the earlier analysis that members use only one area of the club during their visit and that they work out for only 1 hour. These are simplifying assumptions that ease the burden of analysis. However, assumptions such as these and the use of averages in measuring demands and capacities can lead to an underestimation of the capacity actually required to meet demands at some established service level.

Once the discussion of "capacity cushions" has taken place, the final issue of capacity expansion needs to be addressed. The fact is, members are complaining, and expected service levels are not being met. The analysis should focus on both short-term and long-term solution alternatives and looking at the pros/cons of each.

Exhibit TN.1 gives an example of how to present this analysis. Be sure to tie the alternatives into other operating decisions and discuss how each may impact different competitive priorities, such as convenience and location, full-service range of activities with quality facilities, availability of services in a timely manner, or low costs/price.

D. Recommendations

When this decision case is used as an outside assignment, the instructor should be prepared to respond to three types of recommendations:

1. *No action needed:* Students who compare the demand rates at peak times with the designed capacity may conclude that there is plenty of excess capacity. These students will not seriously consider the need for a capacity cushion, or conclude that it is already large enough.
2. *Expand the existing facility:* The use of short-term measures and the limited expansions of the existing facility are enough to create a reasonable capacity cushion. Some students may recommend adjusting the capacity space allocations among competing areas of the club. This is a short-term, middle-of-the-road type of recommendation.
3. *Expand to a new location:* This is a more long-term strategic decision that should focus on competitive priorities. Students recommending this course of action are looking to expand into new markets and meet competition head on.

E. Teaching Suggestions

This case is best used as an in-class discussion case to present the issues surrounding capacity management decisions in service organizations. If a more in-depth discussion is desired, the case can be assigned overnight. However, the data are not present in the case to allow a thorough analysis of the capacity expansion issue. Students will find it difficult to address the “capacity cushion” issues. However, if the case is used in class to introduce capacity concepts, then the discussion can be quite good.

The class discussion should begin with determining how capacity in a service organization should or can be measured. Make sure students understand the importance of peak-load planning. The second stage of the discussion should flow to the determination of demands on the service system. Once the variability in demand across time and service areas is established and it looks as though capacity is sufficient, the concept of “capacity cushions” should be introduced. Finally, get the students to address the various capacity alternatives, both short and long term. Here you can reintroduce the concept of competitive priorities and discuss how different capacity strategies support different competitive strategies.

To fully discuss each of these four areas—capacity measurements, demand measurements, capacity cushions, and capacity expansion alternatives—will take a good 45 minutes, especially when the students begin to argue about different managerial assumptions and policies that affect capacity.

F. Board Plan

Capacity Measures	Demand Measures	Expansion	Alternatives
		Short	Long
		+ -	+ -

G. A Note on Waiting Lines

Some students may try to apply waiting line models. Waiting line theory does not apply very well to the *Fitness Plus (A)* case, because of inappropriate assumptions and missing information. The aerobics class is a good example of inappropriate assumptions. Most likely an aerobics class is prescheduled, and everybody arrives at the start of the class. There is no variability on the processing rate. The time it takes for one customer is the same that it takes to handle 35 customers simultaneously, assuming a one hour class.

On the other hand, we might apply at least approximately waiting line analysis to an operation such as the 29 pieces of cardiovascular equipment. We must make some Herculean assumptions to proceed. However, let's assume that all 29 machines are available (no maintenance downtime), and that 32 customers will spend their time at this operation for about 20 minutes per machine and work out on between 2 and 3 machines (say 2.5 machines on the average) during their visit. Thus the service rate might be 3 customers per hour (20 minutes per machine). As for the arrival rate, we could assume that a customer "enters" the system an average of 2.5 times during an hour. If we assume 32 customers arrive to the whole operation per hour, this pace gets translated into an arrival rate of 80 customers per hour (32×2.5), taking into account repeat visits.

Shown below is some output from OM Explorer's *Waiting Lines* Solver that approximates this set of assumptions. Here the capacity cushion is less than 10 percent and ON EACH MACHINE the customer waits an average of 8.6 minutes to get a machine (0.1428×60).

A second way to analyze the situation is to look at some of the more popular cardiovascular machines (the real bottlenecks) and apply the single channel approach used in the *Queuing at 1st Bank Villa Italia* bank video. It is still an approximation, but should give some insight. However, customers surely will "balk" and "renege" as shown in the video. They will move from one place to another, depending on the lines. To capture more realism such as that, you can turn to simulation (such as with the SimQuick package).

Of course, there is also a fourth method—actually observing the operation in peak periods to see how the customers behave, how long the lines are, and so forth. Interviewing customers who have complaints (the Six Sigma way) would also give insights.

Inputs

Solver - Waiting Lines

Enter data in yellow shaded areas.

☐ Single-server model ☒ Multiple-server model ☐ Finite-source model	
Servers	29
Arrival Rate (λ)	80
Service Rate (μ)	3
Probability of zero customers in the system (P_0) 0.0000	
Probability of at most ▼ 4 customers in the system (P_n)	0.0000
Average utilization of the server (ρ)	0.9195
Average number of customers in the system (L)	38.0942
Average number of customers in line (L_q)	11.4276
Average waiting/service time in the system (W)	0.4762
Average waiting time in line (W_q)	0.1428

EXHIBIT TN.1

Capacity Expansion Alternatives

A. Short-term alternatives

1. *Use of differential pricing*: base on either time of the day or area of the club to be used.
2. *Time limits during peak hours*: increase the use of time restrictions being placed on or adjusted for equipment that is heavily in demand.
3. *Market alternative training*: market the use of free-weights as an alternative to Nautilus equipment to add variety to the workout; or perhaps joining an aerobics class as an alternative to using the cardiovascular equipment.
4. *Reallocation of existing space*: use one of the racquetball courts as a warm-up area by putting in some cardiovascular equipment and limiting the time to a 10-minute warm-up.

B. Long-term alternatives

1. *Expand existing facility*: this would entail both adding on to the facility where possible and redesigning the existing space to accommodate high-demand services.

+		-	
☐ Help balance demand and service area usage		☐ May be temporary solution to long-term problem of growth	
☐ Less costly		☐ Disruption to members during renovation	
☐ Can be done more quickly than a new facility		☐ Does not expand geographical influence and tap new downtown market	

2. *Open a new facility downtown:* this is a more aggressive long-term move to expand the market area.

+		-	
☐ Is a strategic answer to a long-term issue	☐ May not help overcrowding at original facility		
☐ Open new markets when competition is increasing at original facility	☐ More costly; take longer to bring new capacity on line		
	☐ Takes longer to bring capacity on line		

CASE: FITNESS PLUS (PART B) *

A. Synopsis

This sequel of Fitness Plus (A) opens up even more options for dealing with capacity issues that are developing at the Greensboro Industrial Park. The economic growth in the downtown area gives Fitness Plus several new options as they look to expand. It can restructure the existing layout, expand at the current facility, or add a new downtown location. If it locates downtown, it can have a one- or two-stage expansion plan.

B. Purpose

Taken together with Fitness Plus (A), this case lends itself to group projects, including written report and class presentation. It also can be used on a “cold-call” basis, if the focus is how the students would proceed in doing the analysis, rather than actually doing it. It draws from several concepts in the chapter, such as capacity strategy, decision trees, utilization measures, and cushions. It provides a nice transition to Chapter 11, “Location”, which comes next. It is more complex than meets the eye, in terms of capital budgeting analysis and decision trees. Both qualitative and quantitative analyses are important. The case can be team taught with a Finance professor to bring home the cross-functional connections.

C. Analysis

Students should analyze the projected revenue and cost streams for the different options, taking into account the time value of money and the different demand scenarios. This analysis can be done with decision trees, with financial analysis used to determine the present value of different combinations of demand forecasts and expansion options. The OM Explorer Software offers a spreadsheet approach to facilitate the financial analysis. Sensitivity analysis is also desirable.

D. Recommendations

A decision tree for the expansion decision is given in Exhibit TN.1, and the associated NPV, IRR, and payback periods are provided in Exhibit TN.2. Exhibits TN.3 through TN.8 give the detailed financial analysis for each branch in the decision tree. These exhibits are from a student analysis and are generally well

* This case was prepared with important inputs from Maureen Campanella of *Be Fit*.

done. The decision on used versus new equipment is not shown on the decision tree, based on the argument that used equipment should be ruled out because it might undermine quality as a competitive priority. Fitness Plus must maintain a professional appearance, particularly at its downtown facility. The quality of services offered requires new equipment that has the latest product technologies. If used equipment is not disqualified, it would look more attractive based on the financial analysis. The overall downtown market should be closely reviewed. It may not be economically feasible to proceed with the new club based on future competition and trends that may influence the necessity of expanding into the downtown market. For instance, the recent growth in exclusively outdoor activities, such as cross-country running, Rollerblading and biking, will impact the growth in future memberships. Other types of equipment and activities should be examined and new programs introduced as a way to capture this diverging market. Finally, the effect of the expansion into the downtown area could act to erode the number of members who currently use the suburban location.

One reasonable, albeit conservative, solution is to expand to the downtown by starting out with a small facility until forecasted demand is more certain. This recommendation is supported by the decision tree analysis. It also makes sense because a drop in the predicted customer membership can dramatically influence NPV, payback, and IRR calculations. Exhibit TN.7 shows how an adjustment down in membership numbers, such as 25 percent, can significantly affect the outcome. A large facility would yield a \$72,000 NPV, but a 25 percent drop in memberships shows NPV at a negative \$26,000.

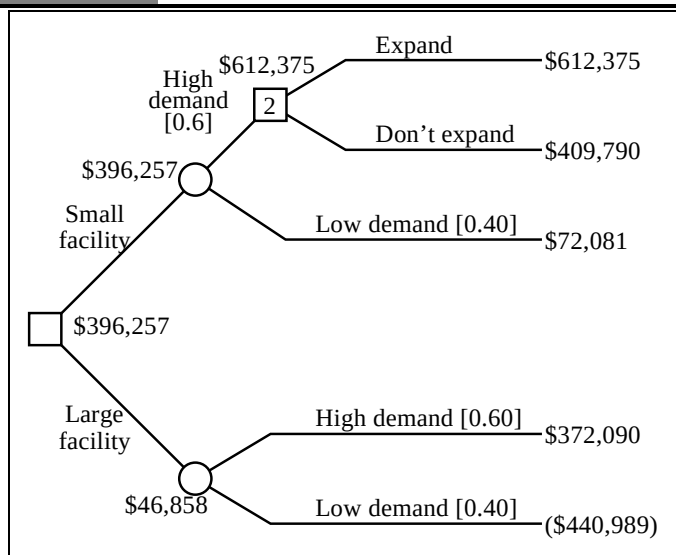
In addition to the quantitative analysis, other factors need to be considered. Comparisons of these numbers alone will not necessarily determine the best alternative, and these other factors have to be weighed.

This solution must be coordinated with what is planned for the existing facility, as discussed for the Fitness Plus (A) case. It may be possible to realign the capacity to better serve the aerobics, cardiovascular and Nautilus areas. If this is not possible due to the expansion in the downtown locations, several less-costly solutions are possible, such as:

- ❑ Redesign the floor plan to give less room to some of the areas that are operating well within the range of the desired capacity cushion. Economies of scale in purchasing new equipment for downtown location. Get some more cardiovascular equipment for the industrial park location.
- ❑ Promote time limits on the most popular cardiovascular equipment.
- ❑ Cross-train members in other fitness areas.
- ❑ Give price breaks if people only work out during nonpeak hours.
- ❑ Encourage “lunch-time” workouts for people within the industrial park.
- ❑ Work on the positioning of the club. With increased competition in the area, there appears to be a marketable niche for a “family club.”

E. Teaching Suggestions

Address the issues in Fitness Plus (A) first, and then move into Fitness Plus (B). Develop a decision tree on the board with class inputs, and then ask for the NPV results for the different branches. For at least one of them, investigate the spreadsheets that were developed. Finally, bring in the insights from sensitivity analysis and the fit with the firm's overall strategy.

EXHIBIT TN.1**Decision Tree****EXHIBIT TN.2****Small Facility/High Demand/Expand**

		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	
Revenue		\$347,280	\$449,344	\$583,408	\$717,472	\$851,536	\$985,600	\$985,600	\$985,600		
Expenses fixed		\$ 64,000	\$124,000	\$124,000	\$124,000	\$124,000	\$124,000	\$124,000	\$124,000		
Expenses variable			\$167,400	\$267,200	\$267,200	\$267,200	\$267,200	\$267,200	\$267,200		
Depreciation (7 yr MACRS)		\$ 24,896	\$ 64,437	\$ 67,781	\$ 48,406	\$ 34,586	\$ 29,163	\$ 29,163	\$ 21,357	\$ 6,779	\$326,568
Pretax income		\$ 90,984	\$ 93,507	\$124,427	\$277,866	\$425,750	\$565,237	\$565,237	\$573,043	\$(6,779)	
Taxes (40%)		\$ 36,393	\$ 37,403	\$ 49,771	\$111,147	\$170,300	\$226,095	\$226,095	\$229,217	\$(2,712)	
Net operating Income		\$ 54,590	\$ 56,104	\$ 74,656	\$166,720	\$255,450	\$339,142	\$339,142	\$343,826	\$(4,068)	
Total cash flow		\$ 79,487	\$120,541	\$142,437	\$215,125	\$290,036	\$368,305	\$368,305	\$365,183	\$2,712	
Annual demand		300	440	580	720	860	1000	1000	1000		
Investment	\$174,222		\$152,346								\$326,568
Interest (disc.) Rate	15%	0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269	0.2843	
NPV		\$ 69,121	\$ 91,141	\$ 93,652	\$123,009	\$144,206	\$159,218	\$138,446	\$119,378	\$771	\$612,375,271
	30%	0.7692	0.5917	0.4520	0.3501	0.2693	0.2072	0.1594	0.1226	0.0943	
	36%	0.7353	0.5407	0.3975	0.2923	0.2149	0.1580	0.1162	0.0854	0.0628	
	30%	\$ 61,141	\$ 71,324	\$ 64,382	\$ 75,315	\$ 78,107	\$ 76,313	\$ 58,708	\$ 44,771	\$ 256	\$356,095
	36%	\$ 58,446	\$ 65,177	\$ 56,619	\$ 62,881	\$ 62,329	\$ 58,192	\$ 42,797	\$ 31,187	\$ 170	\$172,435
IRR	> 36%										
Payback		\$200,028	\$126,540	\$0.34							
			2.34 years								

EXHIBIT TN.3		Small Facility/High Demand/Don't Expand								
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9
Revenue		\$347,280	\$449,344	\$490,800	\$478,800	\$478,800	\$478,800	\$478,800		
Expenses fixed		\$ 64,000	\$ 64,000	\$ 64,000	\$ 64,000	\$ 64,000	\$ 64,000	\$ 64,000		
Expenses variable		\$167,400	\$167,400	\$167,400	\$167,400	\$167,400	\$167,400	\$167,400		
Depreciation (7 yr MACRS)		\$ 24,896	\$ 42,667	\$ 30,471	\$ 21,760	\$ 15,558	\$ 15,558	\$ 15,558	\$ 7,753	\$174,222
Pretax income		\$ 90,984	\$175,277	\$228,929	\$225,640	\$231,842	\$231,842	\$231,842	\$(7,753)	
Taxes (40%)		\$ 36,393	\$ 70,111	\$ 91,571	\$ 90,256	\$ 92,737	\$ 92,737	\$ 92,737	\$(3,101)	
Net operating Income		\$ 54,590	\$105,166	\$137,357	\$135,384	\$139,105	\$139,105	\$139,105	\$(4,652)	
Total cash flow		\$ 79,487	\$147,833	\$167,829	\$157,144	\$154,663	\$154,663	\$154,663	\$ 3,101	
Annual demand		300	400	500	500	500	500	500	500	
Investment	\$174,222									\$174,220
Interest (disc.) rate 15%		0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269	
NPV		\$ 69,121	\$111,777	\$110,347	\$ 89,855	\$ 76,899	\$ 66,861	\$ 58,138	\$ 1,014	\$409,790
	36%	0.7353	0.5407	0.3975	0.2923	0.2149	0.1580	0.1162	0.0854	
	36%	\$ 58,446	\$ 79,933	\$ 66,712	\$ 45,933	\$ 33,237	\$ 24,437	\$ 17,972	\$ 265	\$152,714
IRR	> 36%									
Payback		\$ 79,487	\$ 94,735	\$ 0.61						
			1.61 years							

EXHIBIT TN.4		Small Facility/Low Demand							
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8
Revenue (A)		\$173,640	\$224,672	\$291,704	\$358,736	\$425,768	\$492,800	\$420,000	
Expenses fixed (B)		\$ 64,000	\$ 64,000	\$ 64,000	\$ 64,000	\$ 64,000	\$ 64,000	\$ 64,000	
Expenses variable (C)		\$167,400	\$167,400	\$167,400	\$167,400	\$167,400	\$167,400	\$167,400	
Depreciation (7 yr MACRS) (D)		\$ 24,896	\$ 42,667	\$ 30,471	\$ 21,760	\$ 15,558	\$ 15,558	\$ 15,558	\$ 7,753
Pretax income (E)	(A-B-C-D)	\$ (82,656)	\$(49,395)	\$ 29,833	\$105,576	\$178,810	\$245,842	\$173,042	\$(7,753)
Taxes (40%) (F)	(E x 40%)	\$ (33,063)	\$(19,758)	\$ 11,933	\$ 42,230	\$ 71,524	\$ 98,337	\$ 69,217	\$(3,101)
Net operating Income (G)	(E-F)	\$ (49,594)	\$(29,637)	\$ 17,900	\$ 63,345	\$107,286	\$147,505	\$103,825	\$(4,652)
Total cash flow (H)	(D+G)	\$ (24,697)	\$ 13,030	\$ 48,371	\$ 85,106	\$122,844	\$163,063	\$119,383	\$ 3,101
Annual demand		150	220	290	360	430	500	500	500
Investment (I)	\$174,222								\$174,222
Interest (disc.) rate (J) 15%		0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269
NPV (K)		\$ (21,477)	\$ 9,852	\$ 31,804	\$ 48,663	\$ 61,078	\$ 70,492	\$ 44,876	\$ 1,014
	22%	0.8197	0.6719	0.5507	0.4514	0.3700	0.3033	0.2486	0.2038
		\$ (20,245)	\$ 8,755	\$ 26,638	\$ 38,417	\$ 45,452	\$ 49,457	\$ 29,679	\$632
IRR (L)	> 22%								
Payback (M)		\$121,809.22	\$52,412.78	\$0.32					
			4.32 years						

(A) (150 Members × 12 months × \$70 monthly fee) + (150 members × \$200 membership fee) + Juice bar sales (1150 members × 12 months × 70) × (14%)

(B) \$8/sq foot × 8,000 sq. feet

(C) Salaries & wages of \$120,000 + insurance & liability of \$25,000 + maintenance of \$2,400 + electricity of \$20,000

(D) Investment of \$174,222 × 1st year's depreciation percentage of 14.29%

(I) New equipment \$160,000 + carpet \$14,222 (\$1.77 per sq. foot × 8,000 sq. feet)

(J) Expected ROI & present value table amounts

(K) (J) × (H)

(L) Used 22% because it was the closest % on the table that brings the investment near its IRR

(M) Using Row H (-24,697+13,030+48,371+85,106 = 121,809.22, or 4 years) + the investment of 174,222/121,809.22 .32

(N) Sum of row (K) less the initial investment.

EXHIBIT TN.5		Large Facility/High Demand								
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	
Revenue		\$347,280	\$449,344	\$583,408	\$717,472	\$851,536	\$985,600	\$985,600		
Expenses fixed		\$124,000	\$124,000	\$124,000	\$124,000	\$124,000	\$124,000	\$124,000		
Expenses variable		\$267,200	\$267,200	\$267,200	\$267,200	\$267,200	\$267,200	\$267,200		
Depreciation (7 yr MACRS)		\$ 46,672	\$ 79,987	\$ 57,124	\$ 40,793	\$ 29,166	\$ 29,166	\$ 29,166	\$ 14,534	\$326,609
Pretax income		\$(90,592)	\$(21,843)	\$135,084	\$285,479	\$431,170	\$565,234	\$565,234	\$(14,534)	
Taxes (40%)		\$(36,237)	\$ (8,737)	\$ 54,034	\$114,191	\$172,468	\$226,094	\$226,094	\$ (5,814)	
Net operating Income		\$(54,355)	\$(13,106)	\$ 81,050	\$171,287	\$258,702	\$339,140	\$339,140	\$ (8,720)	
Total cash flow		\$ (7,683)	\$ 66,881	\$138,174	\$212,081	\$287,868	\$368,306	\$368,306	\$ 5,814	
Annual demand Investment	\$326,609	300	440	580	720	860	1000	1000		\$326,609
Interest (disc.) rate 15%		0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269	
NPV		\$ (6,681)	\$ 50,569	\$ 90,850	\$121,268	\$143,128	\$159,219	\$138,446	\$1,900	\$372,090
	32%	0.7576	0.5739	0.4348	0.3294	0.2495	0.189	0.1432	0.1085	
	36%	0.7353	0.5407	0.3975	0.2923	0.2149	0.158	0.1162	0.0854	
	32%	\$ (5,821)	\$ 38,383	\$ 60,078	\$ 69,859	\$ 71,823	\$ 69,610	\$ 52,721	\$ 631	\$ 30,696
	36%	\$ (5,649)	\$ 36,163	\$ 54,924	\$ 61,991	\$ 61,863	\$ 58,192	\$ 42,797	\$ 496	\$(15,831)
IRR	35%									
		\$ 59,198	\$267,411	\$ 0.73						
Payback		2.73 years								

EXHIBIT TN.6		Large Facility/Low Demand								
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	
Revenue		\$173,640	\$224,672	\$291,704	\$358,736	\$425,768	\$492,800	\$420,000		
Expenses fixed		\$124,000	\$124,000	\$124,000	\$124,000	\$124,000	\$124,000	\$124,000		
Expenses variable		\$267,200	\$267,200	\$267,200	\$267,200	\$267,200	\$267,200	\$267,200		
Depreciation (7 yr MACRS)		\$ 46,672	\$ 79,987	\$ 57,124	\$ 40,793	\$ 29,166	\$ 29,166	\$ 29,166	\$ 14,534	\$ 326,609
Pretax income		\$(264,232)	\$(246,515)	\$(156,620)	\$(73,527)	\$ 5,402	\$ 72,434	\$(366)	\$(14,534)	
Taxes (40%)		\$(105,693)	\$ (98,606)	\$ (62,648)	\$(29,303)	\$ 2,161	\$ 28,974	\$(146)	\$(5,814)	
Net operating Income		\$(158,539)	\$(147,909)	\$ (93,972)	\$(43,954)	\$ 3,241	\$ 43,460	\$(220)	\$(8,720)	
Total cash flow		\$(111,867)	\$ (67,922)	\$ (36,848)	\$(3,161)	\$ 32,407	\$ 72,626	\$ 28,946	\$ 5,814	
Annual demand Investment	\$326,609	300	440	580	720	860	1000	1000		\$ 326,609
Interest (disc.) rate 15%		0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269	
NPV		\$ (97,280)	\$ (51,356)	\$ (24,228)	\$(1,807)	\$ 16,113	\$ 31,396	\$ 10,881	\$ 1,900	\$ (440,989)
	6%	0.9434	0.8900	0.8396	0.7921	0.7473	0.7050	0.6651	0.6274	
	1%	0.9901	0.9803	0.9706	0.9610	0.9515	0.9420	0.9327	0.9235	
	6%	\$(105,535)	\$ (60,451)	\$(30,938)	\$(2,504)	\$ 24,218	\$ 51,202	\$ 19,252	\$ 3,647	\$(427,717)
	1%	\$(110,760)	\$ (66,584)	\$(35,765)	\$(3,038)	\$ 30,836	\$ 68,414	\$ 26,998	\$ 5,369	\$(411,138)
IRR	< 0%									
		\$ (80,004)	\$ 406,613	\$5.60						
Payback		> 8 years								

EXHIBIT TN.7		Large Facility/25% Demand Decrease								
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	
Revenue		\$260,460	\$337,008	\$ 437,556	\$538,104	\$638,652	\$739,200	\$739,200		
Expenses fixed		\$124,000	\$124,000	\$124,000	\$124,000	\$124,000	\$124,000			
Expenses variable		\$267,200	\$267,200	\$ 267,200	\$267,200	\$267,200	\$267,200	\$267,200		
Depreciation (7 yr MACRS)		\$ 46,672	\$ 79,987	\$ 57,124	\$ 40,793	\$ 29,166	\$ 29,166	\$ 29,166	\$ 14,534	\$ 326,609
Pretax income		\$(177,412)	\$(134,179)	\$(10,768)	\$106,111	\$218,286	\$318,834	\$318,834	\$(14,534)	
Taxes (40%)		\$ (70,965)	\$ (53,671)	\$(4,307)	\$ 42,444	\$ 87,314	\$127,534	\$127,534	\$ (5,814)	
Net operating Income		\$(106,447)	\$(80,507)	\$(6,461)	\$ 63,666	\$130,971	\$191,300	\$191,300	\$(8,720)	
Total cash flow		\$ (59,775)	\$(521)	\$50,663	\$104,460	\$160,138	\$220,466	\$220,466	\$ 5,814	
Annual demand		225	330	435	540	645	750	750	750	
Investment	\$326,609									\$ 326,609
Interest (disc.) rate	15%	0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269	
NPV		\$ (51,980)	\$(394)	\$ 33,311	\$ 59,730	\$ 79,620	\$ 95,308	\$ 82,873	\$ 1,900	\$ (28,240)
	14%	0.8772	0.7695	0.675	0.5921	0.5194	0.4556	0.3996	0.3506	
	12%	0.8929	0.7972	0.7118	0.6355	0.5674	0.5066	0.4523	0.4039	
	14%	\$ (52,435)	\$(401)	\$ 34,198	\$ 61,851	\$ 83,176	\$100,445	\$ 88,098	\$ 2,038	\$ (9,639)
	12%	\$ (53,373)	\$(415)	\$ 36,062	\$ 66,384	\$ 90,862	\$111,688	\$ 99,717	\$ 2,348	\$ 26,665
IRR	13%									
Payback		\$254,965	\$ 71,644	\$ 0.32						
		5.32 years								

Fitness Plus is thoroughly investigating the option of opening a new facility downtown. Doing so would be an aggressive capacity expansion strategy, opening up new markets when competition is increasing at the original facility. This strategy would enable Fitness Plus to expand its market area, but may not help the overcrowding at the current facility. There are several uncertainties as to future costs, customer demands, and strategies of competitors. It also will take some time to bring the new capacity on line. However, the resurgence in activity downtown makes this option worth more careful analysis.

Fitness Plus can lease a facility at \$8 per square feet at a new downtown location. It would be very accessible to the new offices and businesses that are moving back into downtown. The lot is sufficiently large to handle a full-service club comparable in size with the original facility, with ample room for parking. It would probably take about one year before financing could be arranged, the workforce hired and trained, and the facility open to customers.

The new facility would have 8,000 square feet, without further expansion. Either new or used Nautilus and cardiovascular equipment can be purchased for the new facility. Buying the full complement (53 machines) of equipment currently at the original facility would be \$160,000 new, and only \$80,000 used. However, there is a concern that a brand new facility furnished with used equipment would not project a good image, and that membership might be adversely affected. The initial investment in carpeting (and rubber matting just for the weight lifting area) would cost a total of \$16 per square yard for the whole facility. Annual costs would include \$120,000 for salaries and wages, \$25,000 for insurance and liability, \$2,400 for maintenance, and \$20,000 for electricity.

The facility should attract customers from a 6-mile radius. Membership fees would be \$70 per month, with an additional \$200 initiation fee in the first year. A juice bar and tanning beds can be added to bring in additional revenues. The juice bar can generate an added 14% of sales, and tanning beds can add another 1% of sales. A tanning bed costs around \$5000 with a payback of just one year.

Demand for the new facility can be low or high. If low, there would be 150 members in the first year of operation, and grow until reaching a 500-member plateau in the 6th year. This level is the largest the leased facility can currently handle. If demand for the new facility is high, the membership would be 300 in the first year and could increase to 1000 in the 6th year (assuming sufficient capacity). If demand turns out to be this high, Fitness Plus has the option of having the leased facility expanded to 14,000 square feet. This expansion would accommodate a 1000-person membership. If expansion occurs before the facility is opened, the lease cost will increase only to \$9 per square foot. If expansion occurs after the facility is opened, the leasing cost would jump to \$10 per square foot once the expansion is finished. Although the facility would not close down during this later expansion (which would affect revenues), construction costs would be disproportionately higher and thus the \$10 leasing rate thereafter.

A larger facility also means that annual costs would increase to \$4200 for maintenance, \$195,000 for salaries and wages, \$30,000 for insurance and liability, and \$38,000 for electricity. There would also be the added investment of \$10,500 in carpeting. The investment in equipment would also have to be increased from 53 to 100 machines to handle the larger demand.

Management believes that the high-demand scenario is 60 percent likely, with the small demand estimates only 40 percent likely. It should be clear the end of the first year of operation whether the high- or low-demand scenario is correct. Of course, if demand is high, the best decision might not be to expand but instead forego any increase in market share in the downtown area.

The MACRS accelerated depreciation schedules would be used when estimating after-tax cash flows for any new capital investments in the facility and equipment. The income-tax rate, including relevant federal, state, and local taxes, would be 40 percent. This rate is based on the average income-tax rate experienced by Fitness Plus over the past several years. Management is not sure what discount rate should be used, but generally expects a return on investment of at least 15 percent.

Supplement

B Waiting Lines

PROBLEMS

1. Solomon, Smith and Samson

- a. Single-server model, average utilization rate.

$$\rho = \frac{\lambda}{\mu} = \frac{8}{10} = 0.8 \text{ or } 80\% \text{ utilization}$$

- b. The probability of four or fewer documents in the system is 0.6723 as shown following. Therefore, the probability of more than four documents in the system is $1 - 0.6723 = 0.3277$.

$$P_n = (1 - \rho)(\rho)^n$$

$$P_4 = (1 - 0.8)(0.8)^4 = 0.0819$$

$$P_3 = (1 - 0.8)(0.8)^3 = 0.1024$$

$$P_2 = (1 - 0.8)(0.8)^2 = 0.1280$$

$$P_1 = (1 - 0.8)(0.8)^1 = 0.1600$$

$$P_0 = (1 - 0.8)(0.8)^0 = \underline{\underline{0.2000}} \\ = 0.6723$$

- c. The average number of pages of documents waiting to be typed,

$$L_q = \rho L = \left(\frac{\lambda}{\mu}\right)\left(\frac{\lambda}{\mu - \lambda}\right) = \left(\frac{8}{10}\right)\left(\frac{8}{10 - 8}\right) = 3.2 \text{ pages}$$

2. Benny's Arcade

Because there are only six machines, we must use the finite source model.

Solver - Waiting Lines

Enter data in yellow shaded areas.

☒ Single-server model
 ☐ Multiple-server model
 ☐ Finite-source model

Customers 6
 Arrival Rate (λ) 0.02
 Service Rate (μ) 0.0667

Probability of zero customers in the system (P_0) 0.0719
 Probability of at most 4 customers in the system (P_n) #N/A
 Average utilization of the server (ρ) 0.9281
 Average number of customers in the system (L) 2.9048
 Average number of customers in line (L_q) 1.9766
 Average waiting/service time in the system (W) 46.9227
 Average waiting time in line (W_q) 31.9302

- a. Jimmy's utilization is 0.9281
 - b. Average number of machines out of service: $L = 2.9048$
 - c. Average time a machine is out of service: $W = 46.9227$ hours
3. Moore, Akin, and Payne (dental clinic). Multiple-server model. This problem is solved with the help of the Waiting Line Analysis module in POM for Windows
- a. Operating characteristics when 3 chairs are staffed

Parameter	Value
Arrival rate(λ)	5
Service rate(μ)	2
Number of servers	3
Result	Value
Average server utilization	.83
Average number in the line(L_q)	3.51
Average number in the system(L)	6.01
Average time in the line(W_q)	.7
--- Minutes	42.13
--- Seconds	2528.09
Average time in the system(W)	1.2
--- Minutes	72.13
--- Seconds	4328.09

Operating characteristics when 4 chairs are staffed

Parameter	Value

Arrival rate(λ)	5
Service rate(μ)	2
Number of servers	4
Result	Value

Average server utilization	.63
Average number in the line(L_q)	.53
Average number in the system(L)	3.03
Average time in the line(W_q)	.11
--- Minutes	6.4
--- Seconds	383.83
Average time in the system(W)	.61
--- Minutes	36.4
--- Seconds	2183.83

Operating characteristics when 5 chairs are staffed

Parameter	Value

Arrival rate(λ)	5
Service rate(μ)	2
Number of servers	5
Result	Value

Average server utilization	.5
Average number in the line(L_q)	.13
Average number in the system(L)	2.63
Average time in the line(W_q)	.03
--- Minutes	1.56
--- Seconds	93.87
Average time in the system(W)	.53
--- Minutes	31.56
--- Seconds	1893.87

When 3 dentists are on staff, average waiting time in line is 42.13 minutes.
Adding a 4th dentist reduces average waiting time to 6.4 minutes.

- b. The changes in operating characteristics when 3 or 4 dentists are on staff are summarized in the table below:

	3 dentists	4 dentists	% change
Average utilization	.83	.63	-24%
Average number of customers in line	3.51	.53	-85%
Average number of customers in the system	6.01	3.03	-50%

- c. The changes in operating characteristics when 3 or 5 dentists are on staff are summarized in the table below:

	3 dentists	5 dentists	% change
Average utilization	.83	.50	-40%
Average number of customers in line	3.51	.13	-96%
Average number of customers in the system	6.01	2.63	-56%

4. Fantastic Styling Salon. This problem is solved with the help of the Waiting Line Analysis module in POM for Windows

- a. Operating characteristics with 3 stylists and one line

Parameter	Value

Arrival rate(λ)	9
Service rate(μ)	4
Number of servers	3
Result	Value

Average server utilization	.75
Average number in the line(L_q)	1.7
Average number in the system(L)	3.95
Average time in the line(W_q)	.19
--- Minutes	11.36
--- Seconds	681.31
Average time in the system(W)	.44
--- Minutes	26.36
--- Seconds	1581.31

Average waiting time is 11.36 minutes

- b. Operating characteristics with 3 stylists and individual lines. The following results are the characteristics of one of the three waiting lines. The arrival rate for each stylist is 1/3 the rate of the salon.

Parameter	Value

Arrival rate(λ)	3
Service rate(μ)	4
Number of servers	1
Result	Value

Average server utilization	.75
Average number in the line(L_q)	2.25
Average number in the system(L)	3
Average time in the line(W_q)	.75
--- Minutes	45
--- Seconds	2700
Average time in the system(W)	1
--- Minutes	60
--- Seconds	3600

Average waiting time increases to 45.00 minutes. This phenomenon is often called a loss of pooling synergy.

c. Operating characteristics with 2 stylists and one line.

Parameter	Value

Arrival rate(λ)	6
Service rate(μ)	4
Number of servers	2
Result	Value

Average server utilization	.75
Average number in the line(L_q)	1.93
Average number in the system(L)	3.43
Average time in the line(W_q)	.32
--- Minutes	19.29
--- Seconds	1157.14
Average time in the system(W)	.57
--- Minutes	34.29
--- Seconds	2057.14

Average waiting time is 19.29 minutes (note the longer waiting time compared to part a. even though utilization is unchanged)

d. Operating characteristics with 2 stylists and one line:

Characteristics of Perez's line:

Parameter	Value

Arrival rate(λ)	3.6
Service rate(μ)	4
Number of servers	1
Result	Value

Average server utilization	.9
Average number in the line(L_q)	8.1
Average number in the system(L)	9
Average time in the line(W_q)	2.25
--- Minutes	135
--- Seconds	8100
Average time in the system(W)	2.5
--- Minutes	150
--- Seconds	9000

Characteristics of Sloan's line:

Parameter	Value
Arrival rate(λ)	2.4
Service rate(μ)	4
Number of servers	1

Result	Value
Average server utilization	.6
Average number in the line(L_q)	.9
Average number in the system(L)	1.5
Average time in the line(W_q)	.38
--- Minutes	22.5
--- Seconds	1350
Average time in the system(W)	.63
--- Minutes	37.5
--- Seconds	2250

Average waiting time is 135.00 minutes for Perez and 22.50 minutes for Sloan.
 Overall average waiting time is $(135.00 \times 0.6) + (22.50 \times 0.4) = 90$ minutes

5. Local Bank

Multiple server model: $s = 3$, $\lambda = 50$ customers/ hour., $\mu = 60/3$ min. per customer
 = 20 customers/hour.

Solver - Waiting Lines

Enter data in yellow shaded areas.

☒ Single-server model

☒ Multiple-server model

☐ Finite-source model

Servers 3
 Arrival Rate (λ) 50
 Service Rate (μ) 20

Probability of zero customers in the system (P_0)	0.0449
Probability of at least ▼ 1 customers in the system (P_n)	0.9551
Average utilization of the server (ρ)	0.8333
Average number of customers in the system (L)	6.0112
Average number of customers in line (L_q)	3.5112
Average waiting/service time in the system (W)	0.1202
Average waiting time in line (W_q)	0.0702

- a. Average utilization: $\rho = 0.8333$
- b. Probability of no customers in the bank: $P_0 = 0.0449$
- c. Average number of customers waiting in line: $L_q = 3.5112$
- d. Average waiting time in line: $W_q = 0.0702$ hour, or 4.212 minutes
- e. Average number of customers in the bank: $L = 6.0112$ or 6 customers

6. Pasquist Water Company

- a. Behavior of waiting trucks
 - 1. Will not balk
 - 2. Will wait until served
 - 3. Will arrive according to a Poisson process
- b. What is the probability that exactly 10 trucks will arrive between 1:00 p.m. and 2:00 p.m. next Tuesday?

$$P_{10} = \frac{[14(1)]^{10}}{10!} e^{-14(1)} = .06628 \quad \text{or} \quad 6.628\%$$

How likely is it that once a truck is in position at the wellhead, the filling time will be less than 15 minutes?

$$P(t \leq T) = 1 - e^{-4(0.25)} = 1 - .36788 = 0.63212 \quad \text{or} \quad 63.212\%$$

- c. Suppose that PWC has only four wellhead pumps.
One waiting line feeding all four stations.

Model selected: M/M/4 Servers: 4 λ : 14 μ : 4

System utilization: 88%

Probability that the system is empty: .01 or 1%

Average number in queue: 5.17

Average number in system: 8.67

Average time in queue: .37 hr

Average time in system: .62 hr

One waiting line feeding two wellhead pumps and a second waiting line feeding two other wellhead pumps. Assume that drivers cannot see each line and must choose randomly between them. Further, assume that once a choice is made, the driver cannot back out of the line.

Model selected: 2(M/M/2) Servers: 2 λ : 7 μ : 4

System utilization: 88%

Probability that the system is empty: $.07 \times .07 = .0049$ or 0.5%

Average number in queue: $5.72 \times 2 = 11.44$

Average number in system: $7.47 \times 2 = 14.94$

Average time in queue: 0.82 hr

Average time in system: 1.07 hrs.

7. Precision Machine Shop. Single-server model.

With the junior attendant, the average number of idle machinists, L

$$L = \frac{\lambda}{\mu - \lambda} = \frac{8}{10 - 8} = 4$$

Average hourly idle machinist cost = $\$20(L) = \$20(4) = \$80$

With the senior attendant, average number of idle machinists, L

$$L = \frac{\lambda}{\mu - \lambda} = \frac{8}{16 - 8} = 1$$

Average hourly cost of idle machinists drops to $\$20(L) = \$20(1) = \$20$

Adding the attendant pay gives a total cost of \$85 per hour (\$80 + \$5) for the junior attendant and \$32 per hour (\$20 + \$12) for the senior attendant. The best choice is the senior attendant.

8. Hasty Burgers. Single-server model, $\lambda = 20$

- a. Find μ resulting in $L = 4$.

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

$$4 = \frac{20}{\mu - 20}$$

$$4\mu - 80 = 20$$

$$4\mu = 100$$

$$\mu = 25$$

The required service rate is 25 customers per hour.

- b. Find the probability that *more than* four customers are in the system. This is one minus the probability of four or fewer customers in the system.

First we calculate average utilization of the drive-in window.

$$\rho = \frac{\lambda}{\mu} = \frac{20}{25} = 0.8$$

The probability that more than four customers are in line and being served is:

$$P = 1 - (P_0 + P_1 + P_2 + P_3 + P_4)$$

where

$$P_n = (1 - \rho)(\rho)^n$$

$$P = 1 - \left\{ [(1 - \rho)(\rho)^0] + [(1 - \rho)(\rho)^1] + [(1 - \rho)(\rho)^2] + [(1 - \rho)(\rho)^3] + [(1 - \rho)(\rho)^4] \right\}$$

$$P = 1 - \left\{ (1 - \rho)[(\rho)^0 + (\rho)^1 + (\rho)^2 + (\rho)^3 + (\rho)^4] \right\}$$

when $\rho = 0.8$

$$P = 1 - \left\{ (0.2)[1 + 0.8 + 0.64 + 0.512 + 0.4096] \right\}$$

$$P = 0.3277$$

Consequently, there is about a 33 percent chance of more than four customers in the system.

- c. Find the average time in line.

$$W_q = \rho W = \rho \left(\frac{1}{\mu - \lambda} \right)$$

$$= 0.8 \left(\frac{1}{25 - 20} \right)$$

$$W_q = 0.16 \text{ hours or 9.6 minutes}$$

Ten minutes borders on being unbearable, particularly in the atmosphere of exhaust fumes. Keep in mind that this is an **average**, and some people must wait longer.

9. Banco Mexicali. Little's Law.

$$\lambda = 20 \text{ customers/hour}$$

$$L = 4 \text{ customers}$$

$$L = \lambda W, \text{ or } W = L/\lambda$$

$$W = (4 \text{ customers})/(20 \text{ customers/hour}) = 0.20 \text{ hour, or 12 minutes.}$$

10. Paula Caplin. Little's Law.

a. $\lambda = 120 \text{ jobs/day}$

$$W = 4 \text{ days}$$

$$\text{Current work-in-process: } L = \lambda W = (120 \text{ jobs/day})(4 \text{ days}) = 480 \text{ jobs.}$$

- b. L must be reduced to 240 jobs. Therefore, either the average number of repairs, λ , or the time in the system, W , must be cut in half (or some combination). Paula has little or no control over the number of repairs, but has several options for reducing the time in the system. First, she can identify the bottleneck in the total repair process and apply the theory of constraints to utilize the bottleneck to its maximum performance. Second, she can do a process analysis and improve the work methods at the bottleneck as well as all other processes feeding the bottleneck to improve overall throughput in the repair process. Finally, if all else fails, she can add capacity until the goal has been met.

ADVANCED PROBLEMS

- 11 Failsafe Textiles. Multiple-server model. This problem is solved with the help of the Waiting Line Analysis module in POM for Windows.

In this analysis we determine the expected total labor and machine failure costs for the existing complement of three employees and then compare it to larger maintenance complements until costs begin to rise.

Three maintenance people:

Parameter	Value	
Arrival rate(λ)	.33	
Service rate(μ)	.13	
Number of servers	3	
Result		Value
Average server utilization		.89
Average number in the line(L_q)		6.31
Average number in the system(L)		8.97
Average time in the line(W_q)		18.95
--- Minutes		1137.07
--- Seconds		68224.34
Average time in the system(W)		26.95
--- Minutes		1617.07
--- Seconds		97024.34

The total expected hourly costs for the crew size of three employees is:

Labor:	3 (\$80 per hour)	\$ 240.00
Machine downtime:	8.97 (\$100 per hour)	<u>897.00</u>
	TOTAL	\$1137.00

Four maintenance people:

Parameter	Value	
Arrival rate(λ)	.33	
Service rate(μ)	.13	
Number of servers	4	
Result		Value
Average server utilization		.67
Average number in the line(L_q)		.75
Average number in the system(L)		3.42
Average time in the line(W_q)		2.26
--- Minutes		135.61
--- Seconds		8136.52
Average time in the system(W)		10.26
--- Minutes		615.61
--- Seconds		36936.52

The total expected hourly costs for the crew size of four employees is:

Labor:	4 (\$80 per hour)	\$ 320.00
Machine downtime:	3.42 (\$100 per hour)	<u>342.00</u>
TOTAL		\$ 662.00

Five maintenance people:

Parameter	Value

Arrival rate(λ)	.33
Service rate(μ)	.13
Number of servers	5
Result	Value

Average server utilization	.53
Average number in the line(L_q)	.18
Average number in the system(L)	2.85
Average time in the line(W_q)	.55
--- Minutes	33.1
--- Seconds	1986.21
Average time in the system(W)	8.55
--- Minutes	513.1
--- Seconds	30786.21

The total expected hourly costs for the crew size of five employees is:

Labor:	5 (\$80 per hour)	\$ 400.00
Machine downtime:	2.85 (\$100 per hour)	<u>285.00</u>
TOTAL		\$ 685.00

This total is higher than that for employing four maintenance people. Therefore, the manager should add only one more maintenance person.

12. Benton University

Finite Source Model: $\lambda = 0.40$ copy machines/day, $\mu = 2.5$ machines/day

Solver - Waiting Lines

Enter data in yellow shaded areas.

☒ Single-server model

☐ Multiple-server model

☐ Finite-source model

Customers 5
Arrival Rate (λ) 0.4
Service Rate (μ) 2.5

Probability of zero customers in the system (P_0)	0.3775
Probability of at least ▼ 1 customers in the system (P_n)	#N/A
Average utilization of the server (ρ)	0.6225
Average number of customers in the system (L)	1.1094
Average number of customers in line (L_q)	0.4869
Average waiting/service time in the system (W)	0.7129
Average waiting time in line (W_q)	0.3129

- Utilization of the maintenance person: $\rho = 0.6225$
- Copy machines in repair system: $L = 1.094$
- Time spent in repair system: $W = 0.7129$ day, or 5.70 hours assuming an 8-hour day.

13. Quarry

- Current System: Single-server model

$\lambda = 9/\text{hour}$; $\mu = 10/\text{hour}$

Average time in the system $W = \frac{1}{\mu - \lambda} = \frac{1}{10 - 9} = 1$ hour or 60 minutes

- First Alternative:** Improved single-server model

$\lambda = 6/\text{hour}$; $\mu = 15/\text{hour}$

Average time in the system $W = \frac{1}{\mu - \lambda} = \frac{1}{15 - 6} = 0.1111$ hour or 6.67 minutes

- Second Alternative:** Two-server model, $s = 2$, $\lambda = 9$ trucks/hour, $\mu = 10$ trucks/hour.

Solver - Waiting Lines

Enter data in yellow shaded areas.

☒ Single-server model☐ Multiple-server model☐ Finite-source model

Servers 2
 Arrival Rate (λ) 9
 Service Rate (μ) 10

Probability of zero customers in the system (P_0)	0.3793
Probability of at least 1 customers in the system (P_n)	0.6207
Average utilization of the server (ρ)	0.4500
Average number of customers in the system (L)	1.1285
Average number of customers in line (L_q)	0.2285
Average waiting/service time in the system (W)	0.1254
Average waiting time in line (W_q)	0.0254

Average time in the system: $W = 0.1254$ hour, or 7.52 minutes.

The second alternative results in an 87 percent reduction in waiting time relative to the current system, however, the first alternative dominates the second alternative in time and cost. Nonetheless, to make a final determination between the current system and the first alternative, the cost of the waiting time of the trucks must be considered.

Chapter

7

Constraint Management

DISCUSSION QUESTIONS

1. Examples of everyday bottlenecks include traffic lights, drive-thru windows at the bank or fast food restaurants. On the highway merging lanes and speed zones. Efficiency can be improved by maintaining constant speeds, setting traffic lights to coordinate traffic patterns and only allowing highway construction after rush hour. Fast food restaurants have two windows, pull over spots and new cash card options to reduce time at the window.
2. A change in demand can easily shift bottlenecks. For instance, fast food restaurants can provide promotional pricing on certain types of sandwiches or fries, which would make their workstations take longer than normal and become capacity constrained. Banks can provide incentives for new accounts to be opened, causing bottlenecks at teller windows where none existed before.
3. There are many ways that process efficiency may be improved further. In the case of our banking example, a manager might: (1) reduce processing time by providing forms to be filled out by the customer before the customer reaches the teller window, (2) reduce processing variability by restricting each customer to three transactions, (3) reduce the arrival variability of customers by requiring that customers make an appointment to see a teller, (4) add resource capacity by increasing the number of tellers during busy periods, (5) improve resource flexibility by ensuring that all tellers are cross trained and will help co-workers with complex transactions, (6) improve resource availability by restricting lunch and break time for tellers, (7) coordinate the movement of customers by making sure that all teller windows are available to all arriving customers, (8) outsource non-value-adding activities such as rework by rerouting difficult customers to branch management, and (9) create standardized work procedures for routine, non-complex processes.

PROBLEMS

1. Bill's Barbershop
 - a. $10 + 8 + (15+10)/2 + 9 = 39.5$ minutes
 - b. Step B1 is the bottleneck, it can only handle 6 customers per hour while the rest of the steps can handle 7.5, 10 ($60/10 + 60/15$), and 6.67 customers per hour.
 - c. This process is limited by step B1, therefore the entire process can only serve 6 customers per hour.

2. Barbara's Boutique

- 3 [the bottleneck is step T4 at 18 minutes – 3.33 customers per hour or 3]
- Step T6 at 22 minutes limits Type B to $60/22 = 2.73$ customers/hr.
- $3.33(.3) + 2.73(.7) = 2.91$ customers on average

With an arrival rate greater than 5 customers per hour into the process, then type A customers may wait at step T1, T2 and T4. Waiting occurs at these steps because the arrival rate of customers into their step is greater than that step's processing rate.

Also assuming that the arrival rate is greater than 5 customers per hour, type B customers may wait steps T1, T5, and T6 because these steps' processing times are slower than the processing time of their immediate preceding steps.

3. CKC

Station X is the bottleneck – 2600 minutes

Work Station	Product A	Product B	Total Load
W	$10 \times 90 = 900$	$14 \times 85 = 1190$	2090
X	$10 \times 90 = 900$	$20 \times 85 = 1700$	2600
Y	$15 \times 90 = 1350$	$11 \times 85 = 935$	2285

4. CKC

- Traditional Method: Product B has the higher contribution margin/unit

	Product A	Product B
Price	55.00	65.00
Raw and Purchased Parts	5.00	10.00
Contribution Margin	50.00	55.00

Work Station	Minutes at Start	Mins. Left after Making 85 Bs	Mins. Left after Making 90 As	Can Only Make 70 As
W	2400	1210	310	
X	2400	700		$700/10 = 70$
Y	2400	1465	115	

85 units of B and 70 units of A (Product B will use 1700 minutes at station X leaving 700 for Product A).

Product	Overhead	Raw Mat'l	Labor	Purchase Parts	Total Costs	Revenues
A		$70 \times 2 = 140$		$70 \times 3 = 210$		$70 \times \$55 = 3850$
B		$85 \times 5 = 425$		$85 \times 5 = 425$		$85 \times \$65 = 5525$
Totals	3500	565	$3 \times \$6 \times 40 \text{ hrs} = 720$	635	5420	9375

Revenue – costs = profit
 $\$9,375 - \$5,420 = \$3,955$

- b. Bottleneck-based approach: Product A has the higher contribution margin/unit at the bottleneck

	Product A	Product B
Margin	50.00	55.00
Time at bottleneck	10 min	20 min
Contribution margin per minute	5.00	2.75

Work Station	Minutes at Start	Mins. Left after Making 90 As	Mins. Left after Making 85 Bs	Can Only Make 75 Bs
W	2400	1500	310	
X	2400	1500		1500/20 = 75
Y	2400	1050	115	

Make 90 units of A (900 minutes used – leaves 1500 minutes) can make 75 units of B

Product	Overhead	Raw Mat'l	Labor	Purchase Parts	Total Costs	Revenues
A		90 x 2 = 180		90 x 3 = 270		90 x \$55 = 4950
B		75 x 5 = 375		75 x 5 = 375		75 x \$65 = 4875
Totals	3500	555	3 x \$6 x 40 hrs = 720	640	5415	9825

$$\text{Profit} = \text{Revenue} - \text{costs}$$

$$\$9,825 - \$5,415 = \$4,410$$

- c. \$4,410 - \$3,955 = \$455 increase using TOC, which is a 12% increase

5. Assembly-line balancing with longest work element rule to produce 40 units per hour.

$$a. \quad c = \frac{1}{r} = \frac{1 \text{ hour}}{40 \text{ units}} = \frac{3600 \text{ sec}}{40 \text{ units}} = 90 \frac{\text{sec}}{\text{unit}}$$

$$b. \quad TM = \frac{\sum t}{c} = \frac{415}{90} = 4.611 \text{ or } 5$$

- c. S1 = {A, C, E}, S2 = {B}, S3 = {G, D}, S4 = {H, F, I}, S5 = {J, K}

Station	Candidate(s)	Choice	Work Element Time (sec)	Cumulative Time (sec)	Idle Time (c = 90 sec)
S1	A	A	40	40	50
	C	C	30	70	20
	E	E	20	90	0
S2	B	B	80	80	10
S3	D, F, G	G	60	60	30
	D, F, I	D	25	85	5
S4	F, H, I	H	45	45	45
	F, I	F	15	60	30
	I	I	10	70	20
S5	J	J	75	75	15
	K	K	15	90	0

$$d. \text{ Efficiency (\%)} = \frac{(\sum t)}{nc}(100\%) = \frac{415}{5(90)} = 92.2\%$$

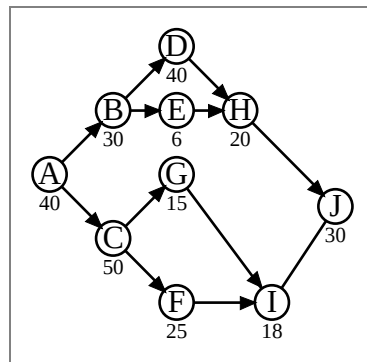
$$\begin{aligned} \text{Balance delay (\%)} &= 100\% - \text{Efficiency} \\ &= 100\% - 92.2\% \\ &= 7.8\% \end{aligned}$$

$$e. S1 = \{A, C, E\}, S2 = \{B\}, S3 = \{F, D, H\}, S4 = \{G, I\}, S5 = \{J, K\}$$

Station	Candidate(s)	Choice	Work Element Time (sec)	Cumulative Time (sec)	Idle Time (c = 90 sec)
S1	A	A	40	40	50
	C	C	30	70	20
	E	E	20	90	0
S2	B	B	80	80	10
S3	D, F, G	F	15	15	75
	D, G, J	D	25	40	50
	H	H	45	85	5
S4	G, J	G	60	60	30
	I	I	10	70	20
S5	J	J	75	75	15
	K	K	15	90	0

Stations 3 and 4 have been reconfigured with different tasks, but have the same idle time.

6. Johnson Cogs



- a. Before calculating the theoretical minimum number of stations, we find the cycle time as: $c = \frac{3600 \text{ sec/hr}}{60 \text{ units/hr}} = 60 \text{ sec/unit}.$

$$\text{Then we find } TM = \frac{\sum t}{c} = \frac{274}{60} = 4.556 \text{ or } 5$$

- b. Task assignments using longest work-element time rule:

Station	Candidates	Assignment	Cumulative Time	Idle Time (c = 60)
S1	A	A	40	20
S2	B, C	C	50	10
S3	B, F, G	B	30	30
	E, F, G	F	55	5
S4	D, E, G	D	40	20
	E, G	G	55	5
S5	E, I	I	18	42
	E	E	24	36
	H	H	44	16
S6	J	J	30	30

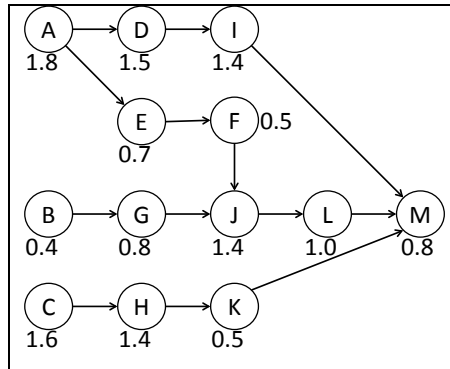
Six workstations are required.

- c. Efficiency with 5 workstations:

$$\text{Efficiency} = \frac{\sum t}{c} (100\%) = \frac{274}{5(60)} (100\%) = 91.33\%$$

7. Trim line at PW

- a. Precedence diagram for PW.



- b. The trim line must handle 20 cars per hour. This translates into 3 minutes per car. Thus, the cycle time is 3 minutes.
- c. The total work content is 13.8 minutes. The theoretical minimum number of stations is:

$$TM = \frac{\sum t}{c} = \frac{13.8}{3} = 4.6 \text{ or } 5 \text{ stations}$$

d.

Balance

Station	Work element	Time	Time left	Ready Work elements
1	A	1.8	1.2	A, B, C
	E	.7	.5	B, C, D, E
	F	.5	0	B, C, D, F
2	C	1.6	1.4	B, C, D
	H	1.4	0	B, D, H
3	D	1.5	1.5	B, D, K
	I	1.4	.1	B, K, I
4	K	.5	2.5	B, K
	B	.4	2.1	B
	G	.8	1.3	G
5	J	1.4	1.6	J
	L	1	.6	L
6	M	.8	2.2	M

Summary Statistics

Cycle time =	3 minutes
Min (theoretical) # of stations =	5
Actual # of stations =	6
Time allocated (cyc*sta) =	18 minutes per cycle
Time needed (sum task) =	13.8 minutes per unit
Idle time	4.2 minutes per cycle
Efficiency =	76.67%
Balance Delay =	23.33%

e. The most followers decision rule provides the following solution: S1= {A,B,E}, S2={C,G,F}, S3={D,H}, S4={J,I}, S5={K,L,M}. Since this solution only requires 5 stations, the efficiency is improved. The POM for Windows solution follows.

Balance

Station	Work element	Time	Time left	Ready Work elements
1	A	1.8	1.2	A(7), B(4), C(3)
	B	.4	.8	B(4), C(3), D(2), E(4)
	E	.7	.1	C(3), D(2), E(4), G(3)
2	C	1.6	1.4	C(3), D(2), G(3), F(3)
	G	.8	.6	D(2), G(3), F(3), H(2)
	F	.5	.1	D(2), F(3), H(2)
3	D	1.5	1.5	D(2), H(2), J(2)
	H	1.4	.1	H(2), J(2), I(1)
4	J	1.4	1.6	J(2), I(1), K(1)
	I	1.4	.2	I(1), K(1), L(1)
5	K	.5	2.5	K(1), L(1)
	L	1	1.5	L(1)
	M	.8	.7	M(0)

Summary Statistics

Cycle time =	3 minutes
Min (theoretical) # of stations =	5
Actual # of stations =	5
Time allocated (cyc*sta) =	15 minutes per cycle
Time needed (sum task) =	13.8 minutes per unit
Idle time	1.2 minutes per cycle
Efficiency =	92%
Balance Delay =	8%

8. Penny's Pie Shop

- a. Output rate equals 50/week which is 50/40 or 1.25 per hour
Cycle time = 1/ 1.25 hours per unit or 48 minutes per unit

b. $TM = \frac{\sum t}{c} = \frac{70 \text{ min}}{48 \text{ min}} = 1.458 \text{ or } 2$

- c. Efficiency with 4 workstations

Efficiency = $\frac{\sum t}{c} (100\%) = \frac{70 \text{ min}}{4(48 \text{ min})} (100\%) = 36.46\%$

9. Melissa's Photo Studio

- a. $5 + (5+7)2 + 20 + 7 = 38 \text{ min}$
b. Taking group portraits is the bottleneck for the entire process. Only 3 group portraits can be taken per hour.
c. Groups bottleneck is taking the portrait the bottleneck time is 20 min which yields a capacity of 60/20 or 3 per hour. Individuals bottleneck is taking the portrait which has a processing time of 15 min, which yields a capacity of 60/15 or 4 per hour.

10. YPI Bottleneck

Station W is the bottleneck

Work Station	A	B	C	Total Load
W	12*60= 720	9*80= 720	20*60= 1200	2640
X	10*60= 600	0	10*60 = 600	1200
Y	0	15*80=1200	5*60 = 300	1500
Z	12*60= 720	10*80=800	0	1520

11. YPI profits by traditional method:

	A	B	C
Price	105	95	110
Raw and Purchased Parts	16	12	19
Contribution Margin	89	83	91

Order would be C-A-B

60C (1200 minutes) 60 A (720 minutes) 53 B (477 minutes)

Product	Overhead	Raw Mat'l	Labor	Purchase Parts	Total Costs	Revenues
A		60 x 11 = 660		60 x 5 = 300		60 x \$105 = 6300
B		53 x 8 = 424		53 x 4 = 212		53 x \$95 = 5035
C		60 x 14 = 840		60 x 5 = 300		60 x \$110 = 6600
Totals	9000	1924	4 x 40 x 15 = 2400	812	14,136	17,935

Revenue – costs = profit

\$17,935 – \$14,136 = \$3,799 by traditional method

Bottleneck-based approach

	A	B	C
Contribution Margin	89	83	91
Time at bottleneck	12	9	20
Contribution margin per minute	7.42	9.22	4.55

Order would be B-A-C

80B (720 minutes) 60 A (720 minutes) 48 C (960 minutes)

Product	Overhead	Raw Mat'l	Labor	Purchase Parts	Total Costs	Revenues
A		60 x 11 = 660		60 x 5 = 300		60 x \$105 = 6300
B		80 x 8 = 640		80 x 4 = 320		80 x \$95 = 7600
C		48 x 14 = 672		48 x 5 = 240		48 x \$110 = 5280
Totals	9000	1972	4 x 40 x 15 = 2400	860	14,232	19,180

Revenue – costs = profit

\$19,180 – \$14,232 = \$4,948 by bottleneck-based method

Using the bottleneck approach profits would increase by \$4,948 – \$3,799 = \$1,149.00 per week.

12. A.J.'s Bird Feeders

a. Traditional Method

	Deluxe	Super Duper
Price	\$81	\$80
Material Cost	-15	-10
Contribution Margin	\$66	\$70

When ordered highest to lowest, the contribution margin per unit sequence of these products is Super Duper and then Deluxe.

Work Center	Minutes at the Start	Minutes Left after Making 60 Super Duper	Can only make 40 Deluxe
Station X	2400	600	0
Station Y	2400	1200	600
Station Z	2400	1800	600

The best product mix using the traditional approach is then 60 Super Duper and 40 Deluxe.

Profit

Revenue = (60 x \$80) + (40 x \$81) = \$8,040

Materials = (60 x \$10.00) + (40 x \$15) = -\$1,200

Labor = 3 workers x 40 hours per week x \$16/hour = -\$1,920

Overhead = -\$2,000

Profit = \$8,040 - \$1,200 - \$1,920 - \$2,000 = \$2,920 per week

b. Bottleneck-based Method

	Deluxe	Super Duper
Contribution Margin	\$66	\$70
Time at Bottleneck	15	30
Contribution margin per minute	\$4.40	\$2.33

Based on the bottleneck method the manufacturing sequence should be Deluxe then Super Duper

Work Center	Minutes at the Start	Minutes Left after Making 50 Deluxe	Can only make 55 Super Duper
Station X	2400	1650	0
Station Y	2400	1650	550
Station Z	2400	900	350

The best product mix according to the bottleneck method is 50 Deluxe and 55 Super Duper.

$$\text{Revenue} = (55 \times \$80) + (50 \times \$81) = \$8,450$$

$$\text{Materials} = (55 \times \$10.00) + (50 \times \$15) = \$1,300$$

$$\text{Labor} = 3 \text{ workers} \times 40 \text{ hours per week} \times \$16/\text{hour} = \$1,920$$

$$\text{Overhead} = \$2,000$$

$$\text{Profit} = \$8,450 - \$1,300 - \$1,920 - \$2,000 = \$3,230 \text{ per week}$$

13. Cooper River Glass Works (CRGW)

- a. Only 8640 minutes are available for production next month ($20 \times 8 \times 60 \times (1 - .1) = 8640$). As seen in the following Excel spreadsheet, Station 2 has the largest load which exceeds available capacity and is thereby the bottleneck.

Identify the bottleneck

Product	Station 1	Station 2	Station 3	Station 4	Demand
Alpha	10 min	5 min	15 min	10 min	200 units
Bravo		20 min	10 min		250 units
Charlie	5 min	15 min	5 min	20 min	150 units
Delta	20 min	5 min	10 min	10 min	225 units
Load	7250 min	9375 min	8500 min	7250 min	

- b. The profit produced from the traditional method is \$52,620. All demand is for products Alpha, Bravo, and Charlie is satisfied, but only enough capacity remains to produce 78 units of Delta.

Traditional Method

Product	Margin	Production	Capacity	Station 1	Station 2	Station 3	Station 4	Profit
			Initial	8640 min	8640 min	8640 min	8640 min	
Bravo	\$ 85.00	250 units	Remaining	8640 min	3640 min	6140 min	8640 min	\$ 21,250
Charlie	\$ 82.00	150 units		7890 min	1390 min	5390 min	5640 min	\$ 12,300
Alpha	\$ 70.00	200 units		5890 min	390 min	2390 min	3640 min	\$ 14,000
Delta	\$ 65.00	78 units		4330 min	0 min	1610 min	2860 min	\$ 5,070
								\$ 52,620

- c. The profit produced from the bottleneck method is \$59,030. All demand is for products Alpha, Charlie and Delta is satisfied, but only enough capacity remains to produce 213 units of Bravo.

Bottleneck Method

Product	Margin	Production	Capacity	Station 1	Station 2	Station 3	Station 4	Profit
			Initial	8640 min	8640 min	8640 min	8640 min	
Alpha	\$ 70.00	200 units	Remaining	6640 min	7640 min	5640 min	6640 min	\$ 14,000
Delta	\$ 65.00	225 units		2140 min	6515 min	3390 min	4390 min	\$ 14,625
Charlie	\$ 82.00	150 units		1390 min	4265 min	2640 min	1390 min	\$ 12,300
Bravo	\$ 85.00	213 units		1390 min	5 min	510 min	1390 min	\$ 18,105
								\$ 59,030

14. Davis Watercraft

a.

	A	B	C
Price	\$450	\$400	\$500
Material Cost	-50.00	-40.00	-110.00
Contribution Margin	\$400	\$360	\$390

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

Work Center	Minutes at the Start	Minutes Left after Making 100 A	Can only make 16 C	Can still Make 75 B
Station 1	6480	480	0	0
Station 2	6480	6480	5520	5520
Station 3	6480	5480	5480	980
Station 4	6480	4480	3840	1590

The best product mix using the traditional approach is then 100 A, 16 C and 75 B.

Revenue = $(100 \times \$450) + (16 \times \$500) + (75 \times \$400) = \$83,000$

Materials = $(100 \times \$50) + (16 \times \$110) + (75 \times \$40) = -\$9,760$

Labor = $10 \text{ workers} \times 18 \text{ hours per day} \times 6 \text{ days per week} \times \$25/\text{hour} = -\$27,000$

Overhead = $-\$35,000$

Profit = $\$83,000 - \$9,760 - \$27,000 - \$35,000 = \$11,240$ per week

b.

	A	B	C
Contribution Margin	\$400	\$360	\$390
Time at Bottleneck	60	0	30
Contribution margin per minute	\$6.66	Not Defined	\$13.00

Based on the bottleneck method the manufacturing sequence should be B, C and A. Model B is scheduled first because it does not consume any resources at the bottleneck.

Work Center	Minutes at the Start	Minutes Left after Making 75 B	Minutes Left after Making 40 C	Can only Make 88 A
Station 1	6480	6480	5280	0
Station 2	6480	6480	4080	4080
Station 3	6480	1980	1980	1100
Station 4	6480	4230	2630	870

The best product mix according to the bottleneck method is 75B, 40C and 88A.

Profit

$$\text{Revenue} = (88 \times \$450) + (40 \times \$500) + (75 \times \$400) = \$89,600$$

$$\text{Materials} = (88 \times \$50) + (40 \times \$110) + (75 \times \$40) = \$11,800$$

$$\text{Labor} = 10 \text{ workers} \times 18 \text{ hours per day} \times 6 \text{ days per week} \times \$25/\text{hour} = \$27,000$$

$$\text{Overhead} = \$35,000$$

$$\text{Profit} = \$89,600 - \$11,800 - \$27,000 - \$35,000 = \$15,800 \text{ per week}$$

15. Calculators

- a. Maximum hourly output rate.

Station	Total Time per Cycle	Station Slack
S1	2.7	0.3
S2	1.5	1.5
S3	3.0	0.0
S4	2.3	0.7
S5	2.2	0.8
S6	<u>2.4</u>	<u>0.6</u>
Total 14.1		3.9

The busiest station is S3, which takes 3.0 minutes per unit. Therefore, the maximum output of the whole line is:

$$(60 \text{ min/hr}) / (3.0 \text{ min/unit}) = 20 \text{ units/hr}$$

- b. The cycle time would be 3 minutes, allowing no idle time for the “bottleneck” station S3.
- c. Idle time is 3.9 minutes per cycle. Because 20 units are made each hour, the total idle time lost over a 10-hour shift is:
 $(3.9 \text{ min/unit})(20 \text{ units/hr})(10 \text{ hr/shift}) = 780 \text{ min/shift}$, or 13 hr/shift
- d. Efficiency = $[(14.1)/(6)(3)]100 = 78.3\%$

16. Jane’s Custom Cards

- a. Output rate equals 10/ 8 hours which is 1.25 per hour
 Cycle time = 1/ 1.25 hours per unit or 48 minutes per unit
- b.

$$TM = \frac{\sum t}{c} = \frac{70 \text{ min}}{48 \text{ min}} = 1.46 \text{ or } 2$$

- c. Efficiency with 5 workstations

$$\text{Efficiency} = \frac{\sum t}{c} (100\%) = \frac{70 \text{ min}}{5(48 \text{ min})} (100\%) = 29.167\%$$

$$\text{Balance Delay} = 100 - 29.167 = 70.833 \text{ percent}$$

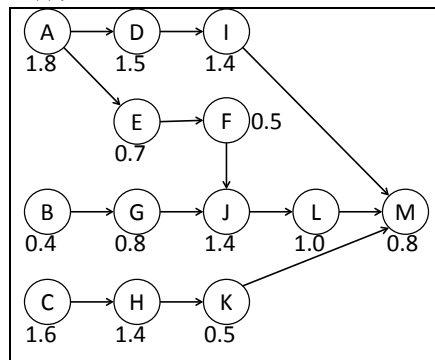
- d. The cycle time would increase from 48 minutes to 96 minutes. The new theoretical minimum would be $70/96$ or $.729$ or 1 . This is a decrease of approximately 50% from the previous TM of 1.46 .

17. Six Points Saco

- a. With one employee, the cycle time = total of all task times (because one person has to do all tasks) = 177 seconds / customer
Hourly production capacity = $(3,600 \text{ seconds/hr}) / (177 \text{ seconds/order}) = \underline{20.33 \text{ customers/hr}}$
- b. Output rate equals $3600\text{sec}/45 \text{ customers}$ or 80 sec/customer . The minimum number of employees will then be $177/80 = 2.21$ or 3 employees.
- c. Using trial and error the maximum output with 3 workstations is 53
- d. The total production capacity corresponding to the cycle time of 35 (longest single task) seconds is $(3,600 \text{ seconds/hr}) / (35 \text{ seconds/car}) = \underline{102.5 \text{ customer cars/hr}}$.
- e. From part d, we know that the bottleneck task is Task C (35 seconds). Thus, Greg should add one worker to help out with task C, thereby reducing the effective task time for C to 17.5 seconds. But when we change task time for C to 17.5 seconds, the next bottleneck task is Task D (32 seconds). If we compute with a “Given Cycle Time = 32 seconds”, then the best staffing possible is 7 workers. In reality this means we need 8 workers to support a cycle time of 32 seconds (because task C really requires two workers to maintain an effective task time of 17.5 seconds).
Thus, the conclusion is that we cannot increase the output capacity of the drive-thru with just one additional worker beyond what we obtained using part d. staffing configuration.

18. Trim line at PW (part 2)

Precedence diagram for PW.



The trim line must handle 20 cars per hour. This translates into 3 minutes per car.

Thus, the cycle time is 3 minutes.

The total work content is 13.8 secs. The theoretical minimum number of stations is:

$$TM = \frac{\sum t}{c} = \frac{13.8}{3} = 4.6 \text{ or } 5 \text{ stations}$$

Using the precedence diagram as a guide, packing each station as close as possible to the cycle time, and considering the two zoning constraints, the following solution results:

Station	Work Elements Assigned	Total Content	Station Slack
S1	A, B, E	2.9	0.1
S2	C, F, G	2.9	0.1
S3	D, H	2.9	0.1
S4	I, J	2.8	0.2
S5	K, L, M	2.3	0.7

The following solution works with the same results:

S1={A,E,B}, S2={C,H}, S3={D,I}, S4={G,F,J}, S5={L,K,M}

$$\text{Efficiency} = [(138)/(5)(3)]100 = 92\%$$

EXPERIENTIAL LEARNING: MIN-YO GARMENT COMPANY

A. Synopsis

The Min-Yo Garment simulation case is intended to be used in conjunction with Chapter 7. The case describes a company that has established a sound reputation in the garment industry but has not established a consistent market strategy. The company is opportunistic, trying to maintain the make-to-stock business on which it had built its reputation while branching out into more lucrative markets. Its manufacturing strategy is to build flexibility in the production process. This was accomplished by investing in a machine that can produce every product the firm manufactures. However, the machine is not a perfect match for any of the markets the firm is pursuing. Profits are declining, and delivery performance is deteriorating. The company must do a better job of aligning its market strategy with its manufacturing strategy using the theory of constraints.

Because the case is a simulation involving teams, it can be used to emphasize the need for collaboration between the marketing and manufacturing functions. Team members can represent Marketing, Manufacturing, and Accounting/Finance. It could also be used at the end of the course to emphasize the interrelatedness of manufacturing strategy, inventory management, and master scheduling. The case provides the basis for a discussion of the theory of constraints and how it can be used to identify the markets the manufacturing system can best support.

B. Simulation

The simulation is designed for one class period. The number of weeks the simulation can cover is up to the instructor, depending on the time available. The recommended procedure is to assign the case and make the team assignments the session before the simulation is to be conducted, asking the students to read the case and think about the

possible strategies that might be successful. On class day, the introduction to the case and review of exhibits will take about 20 minutes. The first period of play takes the longest time, with each successive period requiring less time. Be prepared to answer many questions about the details of the simulation in the first few periods of play. The analysis of the results will take another 20 minutes, depending on the depth the instructor wants to discuss. All together, a simulation of 6 weeks should take about 100 minutes, including introduction and analysis. If 100 minutes is too long, consider discussing the analysis in the following period.

If your class is only 75 minutes long, consider making the team assignments the class before the simulation day. Go through the first four points listed below to preserve time for specific questions and game play. The assignment for the teams is to prepare the first week's production schedule before game day.

The following is a suggested outline for the simulation, including ten periods of demand/order information.

1. *Review the game instructions in the case.* Provide all students with the Min-Yo Guide prior to simulation day (see below). Assign students to teams if you have not already done so. Get each member of the team to play one of the following roles: Marketing, Manufacturing, or Accounting/Finance. Teams of three are ideal, but four members are fine. Rather than using teams with five members, consider using teams of two and three.
2. *Distribute the company report to each team.* The company report contains the changeover times for each product on the garment maker. The report has the changeover times for Dragon Shirts high, thereby making smaller orders of Dragon Shirts a bad choice for Min-Yo. The instructor can change the setup times to create a different environment for the simulation.
3. *Review Exhibit 1, Exhibit 2, Exhibit 3 and Exhibit 4.* Make sure everyone is comfortable with the mechanics of working with the Min-Yo Tables spreadsheet and the Open Order file, Profit & Loss statement, Production Schedule, and Summary. Use the following trial period data for the demonstration of the spreadsheet:
 - Suppose there are Dragon order opportunities as follows:

Order 1	50	due wk 1
Order 2	95	due wk 2
Order 3	80	due wk 2
Order 4	100	due wk 3
Thunder Order	150	due wk 2
 - Suppose you decide to accept the Thunder Shirt order and Dragon Orders 1 and 4. (See Exhibit 1).
 - Show Exhibit 2, which shows the Week 1 schedule. Notice that Order 1 of Dragons and the past-due order of Thunders are automatically entered. The past-due order of Thunders (see case) does not have to be put in the Open Order file.
 - Make a production decision for Muscle shirts based upon a forecast. Suppose it is 450 units. Enter it into the schedule sheet (see Exhibit 2). Note that this quantity is automatically entered into the Open Order file (see Exhibit 1) for record keeping purposes. The spreadsheet keeps track of total production hours. If they exceed 120 hours, the program will not update the P&L statement. Note also that the machine was set for Thunder shirt production last period (see case),

so we do not have to schedule a setup for Thunders. We do have to set up for the Muscle Shirts and all Dragon Shirt orders.

- Show Exhibit 3, which has the P&L statement. It is automatically updated for all decisions and now awaits the instructor's information on Muscle Demand for the week. Suppose it is 500 units. Show the completed P&L statement.
 - Show Exhibit 4, which keeps track of the team's profit performance over the course of the simulation.
4. *Explain the importance of the open order file in Exhibit 1.* Any order entered in the file is considered a commitment by the firm and must be honored. The spreadsheet is driven by the Open Order file for Thunder and Dragon orders. The file also has a row for the production schedule for Muscle Shirts. Currently there is a past due demand of 200 Thunder Shirts due in week 1. Other points to make at this time include:
- (1) Enter only the orders you want to accept in the week they are due.
 - (2) Excess demand for Muscle Shirts are merely lost sales with no penalties. No backorder possibilities exist. However, extended poor performance will force the licensor to find another manufacturer to work with.
 - (3) Because each order for Dragon Shirts is unique, Min-Yo cannot use inventory from overproducing one order to satisfy the demand for another order. However, an order for Dragon shirts can be started one week and finished the following week to take advantage of changeover times and excess capacity in a particular week.
 - (4) Orders for Dragon Shirts cannot be shipped until all shirts have been produced. However, partial shipments are possible for Muscle Shirts (that is, satisfy only a portion of the total demand in a week with the excess demand being lost sales) and Thunder Shirts (penalty charge just for the past due portion of the shipment).
 - (5) If Min-Yo ever refuses to accept an order for Thunder Shirts, it no longer is in the Thunder Shirt business. Prior commitments must still be honored, however.
5. *Start the simulation.* The following is a week-by-week suggestion for the demands and order sizes for Thunder Shirts and Dragon Shirts. Dragon Shirt opportunities will be announced using an "order number" to emphasize that each order is different. Min-Yo does not have to accept any of these orders, but decisions to accept or reject them must be made. Because order opportunities are known at the start of a week, some orders for Dragon Shirts will manifest themselves in the same week they are due.

Week 1.

- (1) New orders for Dragon Shirts

Order 1	100	Due week 1
Order 2	200	Due week 1
Order 3	150	Due week 2
Order 4	75	Due week 2
- (2) New orders for Thunder Shirts

200	Due week 2
200	Due week 3
- (3) Agree on the orders to accept and complete the production schedule. Do not proceed until all teams have made their decisions.
- (4) Announce the actual demand for Muscle Shirts in week 1: 700 shirts.

Note: Step 3 is the same for each period and will not be repeated. However, the instructor must be sure that the teams have committed to production decisions before announcing the actual demands for Muscle Shirts.

Week 2.

- (1) New orders for Dragon Shirts

Order 5	200	Due week 2
Order 6	180	Due week 2
Order 7	300	Due week 3

- (2) No new orders for Thunder Shirts

- (3) Announce actual demand for Muscle Shirts in week 2: 600 shirts.

Week 3.

- (1) New orders for Dragon Shirts

Order 8	50	Due week 3
Order 9	125	Due week 3
Order 10	150	Due week 4
Order 11	100	Due week 4

- (2) New orders for Thunder Shirts

100	Due week 4
300	Due week 5

- (3) Announce actual demand for Muscle Shirts in week 3: 800 shirts.

Week 4.

- (1) New orders for Dragon Shirts

Order 12	75	Due week 4
Order 13	220	Due week 4
Order 14	150	Due week 5

- (2) New Order for Thunder Shirts

EXPEDITE ORDER	200	Due week 5

This order is over and above the regular order for week 5. If it is rejected, Min-Yo is out of the Thunder Shirt business.

- (3) Announce the actual demand for Muscle Shirts: 1000 shirts.

Week 5.

- (1) New orders for Dragon Shirts

Order 15	200	Due week 5
Order 16	100	Due week 5
Order 17	80	Due week 6

- (2) New orders for Thunder Shirts

250	Due week 6
150	Due week 7

- (3) Announce actual demand for Muscle Shirts: 1100 shirts.

Week 6

- (1) New orders for Dragon Shirts

Order 18	100	Due week 6
Order 19	150	Due week 6
Order 20	130	Due week 6

- (2) No new orders for Thunder Shirts

- (3) Announce actual demands for Muscle Shirts: 1200 shirts.

Week 7

- (1) New orders for Dragon Shirts

Order 21	220	Due week 7
Order 22	280	Due week 8
Order 23	60	Due week 8
- (2) New orders fro Thunder Shirts

	200	Due week 8
	250	Due week 9
- (3) Muscle Shirt demand: 900 shirts.

Week 8

- (1) New orders for Dragon Shirts

Order 24	300	Due week 8
Order 25	75	Due week 8
- (2) No new Thunder Shirt orders
- (3) Muscle Shirt demand: 1300 shirts

Week 9

- (1) New orders for Dragon Shirts

Order 26	80	Due week 9
- (2) New orders for Thunder Shirts

EXPEDITE ORDER	200	Due week 10
- (3) Muscle Shirt demand: 800 shirts

Week 10

- (1) New orders for Dragon Shirt

Order 27	100	Due week 10
Order 28	200	Due week 10
- (2) No new Thunder Shirt orders
- (3) Muscle Shirt demand: 1000 shirts

End of Simulation

Benchmark for 10 periods. Try to beat \$16,813.

C. Discussion and Analysis of Results

The discussion and analysis could be as brief as merely finding the team with the greatest total contribution to profits and asking them to characterize their strategy in light of the material in Chapter 7 or as involved as using the experience as a motivator to learn about

the fit of manufacturing processes to market strategies. This latter use of the simulation can be realized by introducing the concept of contribution margin and how the process (in this case, represented by the changeover times) plays a role in identifying the most lucrative markets for the firm. The following guidelines assume the more elaborate discussion is preferred.

1. Find the best team, as represented by the greatest total contribution to profits. Ask the team(s) to share their strategy for success. Record the essence of the strategy on the board for later recall.
2. What are the marginal contributions to profit of the three product categories produced by Min-Yo?

Students will probably respond with the contributions per *unit*:

Contribution per unit = Price – material

Muscle Shirts = \$6 – \$4 = \$2

Thunder Shirts = \$7 – \$4 = \$3

Dragon Shirts = \$8 – \$4 = \$4

We have not included labor because it is a sunk cost in our simulation.

3. Why not just produce Dragon Shirts, as they have the largest contributions of the product line? The answer is that the changeover times are large. Introduce the concept of contribution per *hour*. See text Examples 7.2 and 7.3.

The implication is that you had better look at the size of the orders (particularly in the Dragon market) before determining if the market will be lucrative. Note that the measure assumes that you are able to use all of your capacity and you have no other attendant costs such as past due penalties or inventory holding costs. If these conditions are not met, the contribution per hour overstates the contribution the firm will actually receive.

4. What business should Min-Yo be in?

It is informative to look at Figure 2, which is a plot of the contribution per hour for various time commitments to available order options, assuming the changeover time for Dragon Shirts is 25 hours. It is clear that if order sizes are greater than 450 (which imply a T value of 70 hours including setup), Dragon Shirts are the most lucrative. However, in the market for Dragon Shirts, the average order size is only 148 shirts (the average of orders offered in the simulation). The contribution per hour for Dragon Shirts at order sizes of 148 units is only \$14.87. Contrast this with the situation for Thunder Shirts and Muscle Shirts. Thunder Shirts average 200 units per order and enjoy a contribution per hour of \$20.00. Muscle Shirts, if produced at an average of 800 shirts per week, have a contribution per hour of \$18.18. The market strategy that is in tune with manufacturing capabilities is to pursue the licensed brands and the customer-owned brands.

Figures 3 and 4 provide further insight. In most situations, you can skip the setup of Muscle Shirts or Thunder Shirts by scheduling them to be the last in sequence the week before. It is clear that Dragon Shirt orders must be even larger to overcome the advantage of Thunder Shirts or Muscle Shirts.

This graphical analysis can also help to develop heuristics for selecting which Dragon Shirt orders to accept. For example, in Figure 3, produce any Thunder Shirts that are available for delivery. deduct the amount of time consumed. Select any Dragon orders that can be produced in the remaining time. Use any left over time for Muscle Shirts.

5. What improvements would you suggest for the garment maker?
Although the answer might depend on the changeover times the instructor used for the simulation, responses would include:
 - a. Shorter changeovers
 - b. Faster production rates
 - c. Continuous improvement programs
 - d. Major investments in machines—separate high- from low-volume businesses.
6. Points to remember:
 - a. Winning strategies require close collaboration between marketing and manufacturing. Deciding which markets to serve requires an understanding of manufacturing capabilities.

- b. Manufacturing strategy is involved in developing the capability to best serve the markets the company chooses to serve.
- c. Manufacturing has the ability to change the size or timing of production runs, but must recognize capacity limits.

D. Frequently Asked Questions

1. Must I incur a setup charge each time I produce a Dragon Shirt order?

ANS: Yes. Each Dragon Shirt order is unique. Overproduction for one order cannot be used to satisfy the demand for another order.

2. Can future orders for Thunder Shirts be combined into one production run?

ANS: Yes. Thunder Shirts can be produced to stock.

3. Are holding costs the same for every product?

ANS: Yes. The cost is \$0.10 per shirt per week. For example, you can produce Dragon Shirts in advance of the delivery date, but you must hold them in inventory until the due date.

4. Can I use some hours at the end of a week to begin a setup that will be completed at the start of the next week?

ANS: Yes.

5. Can I partially ship a Dragon Shirt order?

ANS: No. Dragon Shirts must be shipped in their entirety. However, this restriction does not hold for Muscle or Thunder Shirts.

6. Can I ship Dragon or Thunder Shirts before their due date?

ANS: No. Customers do not want their order early.

REPORT

1. Changeover Improvement Study

The Engineering Department reports that the efforts to reduce the changeover times of the garment maker machine have produced the following results:

Product	Changeover Time
Muscle Shirts	8 hours
Thunder Shirts	10 hours
Dragon Shirts	25 hours

The Engineering Department continues to work on reducing changeover times, but no further improvements are expected in the near future.

2. Inventory Levels

The Materials Management Department indicates that at present there are 600 Muscle Shirts in stock. The finished goods inventories of all other products have been depleted. The Materials Management Department respectfully reminds the Production Department that there is an order for 200 Thunder Shirts that is past due.

3. Notice of Termination

The Min-Yo Garment Company has been purchased by a large international textile company and will cease all operations at the end of **week 6 (or whatever week the simulation will end)**. All employees will be reassigned to other duties in the firm. In the meantime, everyone is expected to do whatever they can to maximize the contribution to profits until then. We regret any inconvenience this may impose.

Min-Yo Guide

MIN-YO Spreadsheet

The spreadsheet is intended to minimize the paper work necessary to conduct the Min-Yo simulation. The simulation is interactive with an environment that is unaffected by other teams. Your team will be making decisions each period with the goal of maximizing your firm's profits by the end of the simulation. The spreadsheet has four major elements:

1. *Open Order File*

The open order file contains your commitments for orders placed by your Thunder shirt and Dragon shirt customers. You do not have to accept all of the orders you have access to, however the orders you do accept must be recorded by entering the quantity into the week that the order is due. For example, given the order possibilities in week 1, if you decide to accept a Thunder shirt order of 100 due in week 3, you must enter 100 in the week 3 column for Thunder shirts. Similarly, if you decide to accept Dragon order #3 for 50 units due in week 2 and Dragon order #5 for 70 units due in week 4, you must enter the quantities in the appropriate weeks for Dragon order #3 and Dragon order #5. You will use this same file for the entire simulation.

2. *Production Schedule*

There is a Production Schedule sheet for each week of the simulation. Enter the production quantities for Muscle shirts, Thunder shirts, and each Dragon shirt order you want to produce this week. For each production quantity, enter a "1" in the changeover column. Zero (or blank) indicates no changeover is required; a 1 indicates a changeover is required. For example, if you want to produce two Dragon shirt orders, you must have a changeover for each one. The same holds true for the Muscle shirts and Thunder shirts with one exception – if you ended production last week on Muscle (Thunder) shirts, you can start the next week on Muscle (Thunder) shirts without incurring a changeover because the machine is already set to go. This does not hold for Dragon shirts because each Dragon order is unique. That is why the Dragon shirt orders have individual numbers. Example: Suppose you want to produce Muscle shirts, Thunder shirts, and two Dragon shirt orders. If last week you ended up producing Muscle shirts, you would have only 3 changeovers this week (one Thunder and two Dragon). The spreadsheet adds the total hours (Changeover and Production) and checks to make sure the sum does not exceed 120 hours for the week. The production quantities are automatically transferred to the Profit and Loss statement if the 120 hour limit is not exceeded.

3. *Profit and Loss Statement (P&L)*

This statement is provided for each week just below the Production Schedule. The spreadsheet will automatically update the demand for Thunder and Dragon orders from the Open Order File. You will have to manually enter the demand for Muscle shirts when the instructor provides that information. All production quantities will be automatically transferred from the Production Schedule to the Profit and Loss (P&L) Statement for that week. The P&L statement will keep track of beginning inventories (which are the ending inventories of the previous week) and calculate the profits for the week.

4. *Summary Sheet*

The spreadsheet will automatically update the summary sheet. It shows weekly production decisions, weekly profit contributions, and cumulative profit contributions. One very important performance measure is cumulative profits for the duration of the simulation.

Simulation Procedure

The simulation proceeds week-to-week until the instructor declares that it is over. Teams should not try to guess the end of the simulation. The simulation can only proceed to the next week if all firms are committed to their decisions for the current week. The first weeks of the simulation typically take longer than the following weeks as you get more familiar with the nature of the decisions you have to make. There are five steps for each week of the simulation:

1. The instructor provides order opportunities for the week. These will be customer orders for Thunder shirts (not every week) and Dragon shirts (each week).
2. Teams decide which of the offered orders to accept. Customers withdraw their order if you do not accept it. Consequently, once an order is “rejected” it cannot be accepted in following weeks. The accepted orders are entered into the Open Order file by entering the required quantity in the week it is due. Keep in mind that if you ever reject an order from your Thunder shirt customer, you are effectively out of business in Thunder shirts. Past orders must be honored, but you cannot accept any future orders.
3. Teams decide on the production quantities for that week. Keep in mind that if you accepted an order for delivery in a future week, you do not have to produce it in the current week. Or, you can produce an order in the current week for delivery in a future week by holding it in inventory. Your Thunder shirt customer and the Dragon shirt customers do not want early shipments of the product.
4. Teams “commit” to their order choices and production schedule for the week. That means no more changes can be made. Once all teams have committed, the simulation can proceed.
5. When all teams have committed, the instructor provides the ACTUAL demand for Muscle shirts. Teams enter that value in the demand column for Muscle shirts in their P&L statement for that week. This ends the play for one week.

Exhibit 1

MIN-YOU GARMENT COMPANY

Open Order File (Record of commitments)

<i>Week Order is Due</i>									
<i>Product</i>	1	2	3	4	5	6	7	8	9
Muscle Productions	450	0	0	0	0	0	0	0	0
Thunder Orders		150							
Dragon Order 1	50								
Dragon Order 2									
Dragon Order 3									
Dragon Order 4			100						
Dragon Order 5									
Dragon Order 6									
Dragon Order 7									
Dragon Order 8									

Exhibit 2

PRODUCT	Changeover	Quantity						
Muscle	1	800						
Hours		88						
Thunder	1	200						
Hours		30						
				Changeover	Quantity		Changeover	Quantity
Dragon Order 1			Dragon Order 11			Dragon Order 21		
Dragon Order 2			Dragon Order 12			Dragon Order 22		
Dragon Order 3			Dragon Order 13			Dragon Order 23		
Dragon Order 4			Dragon Order 14			Dragon Order 24		
Dragon Order 5			Dragon Order 15			Dragon Order 25		
Dragon Order 6			Dragon Order 16			Dragon Order 26		
Dragon Order 7			Dragon Order 17			Dragon Order 27		
Dragon Order 8			Dragon Order 18			Dragon Order 28		
Dragon Order 9			Dragon Order 19			Dragon Order 29		
Dragon Order 10			Dragon Order 20			Dragon Order 30		
Total Dragon Hours		0						
Total Dragon Production		0						
Total Hours scheduled		118						

The two inputs to the production Schedule table are:
 1. The quantity you decide to produce this time period
 2. Whether there is a setup/changeover required (1 or 0)

Is production within capacity Yes

Exhibit 3**P&L STATEMENT**

The input to this table is: Actual demand for the product
 200 units of pending order for Thunder has been added to this week.

Product	Price	Beg Inv	Production	Available	Demand	Sales	End Inv	Inv/Past due costs
Muscle	\$8	600	450	1050	500	3000	550	
Thunder	\$7		200	200	200	1400	0	
Dragon Orders	\$8		50	50	50	400	0	
			700			4800		

		Current	Cumulative
Sales Total		\$4,800	\$10,700
Labor	\$1,200		
Materials	\$2,800		
Inv/Past due	\$55		
Total Cost		\$4,055	
Profit Contribution		\$745	\$1,185

The cumulative sales for week 1 include the sales for week 0.

The cumulative profits for week 1 include the profits from week 0.

Exhibit 4

MIN-YO GARMENT COMPANY

Summary sheet

Week	Muscle		Thunder		Dragon		Sales	Profit
	Hours	Production	Hours	Production	Hours	Production		
0	88	800	30	200	0	0	\$5,900	\$440
1	53	450	20	200	30	50	\$4,800	\$745
2	0	0	0	0	0	0	\$0	\$0
3	0	0	0	0	0	0	\$0	\$0
4	0	0	0	0	0	0	\$0	\$0
5	0	0	0	0	0	0	\$0	\$0
6	0	0	0	0	0	0	\$0	\$0
7	0	0	0	0	0	0	\$0	\$0
8	0	0	0	0	0	0	\$0	\$0
9	0	0	0	0	0	0	\$0	\$0
10	0	0	0	0	0	0	\$0	\$0
Total							\$10,700	\$1,185

Figure 1

Contribution per Hour

How Can I Tell Which Market Will Be Most Profitable?

Contribution per hour

c = contribution to profits and overhead per unit

s = changeover time (hrs.)

p = productivity rate (units per hour)

T = total resource hours required for customer order

C_H = contribution per hour

$$C_H = \frac{cp(T-s)}{T}$$

Figure 2

Contribution per Hour – All Changeovers Required

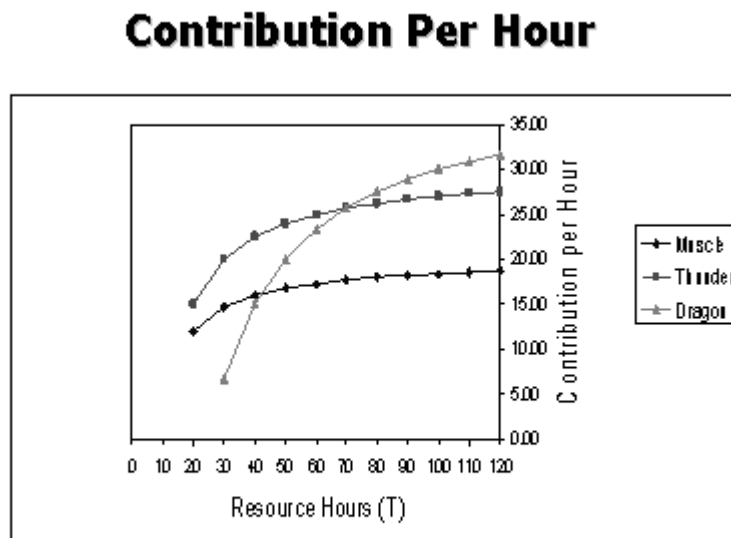


Figure 3

Contribution per Hour – No Thunder Shirt Changeover Required

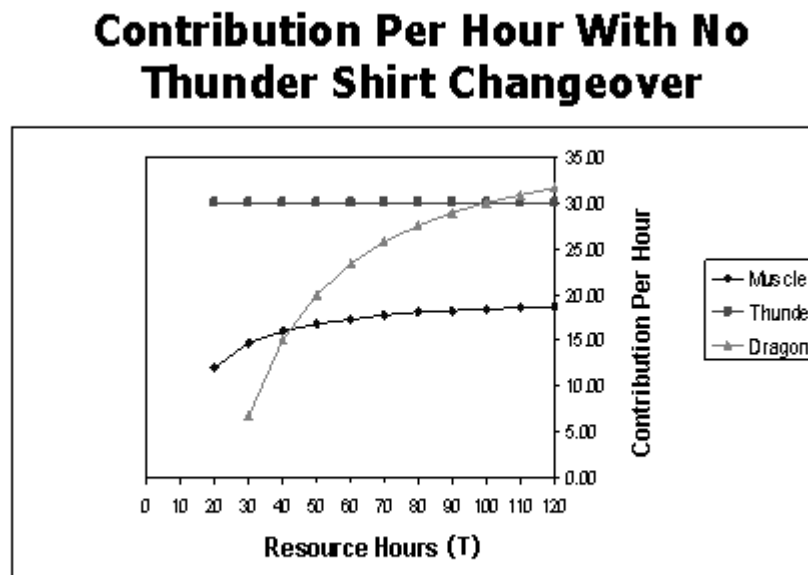
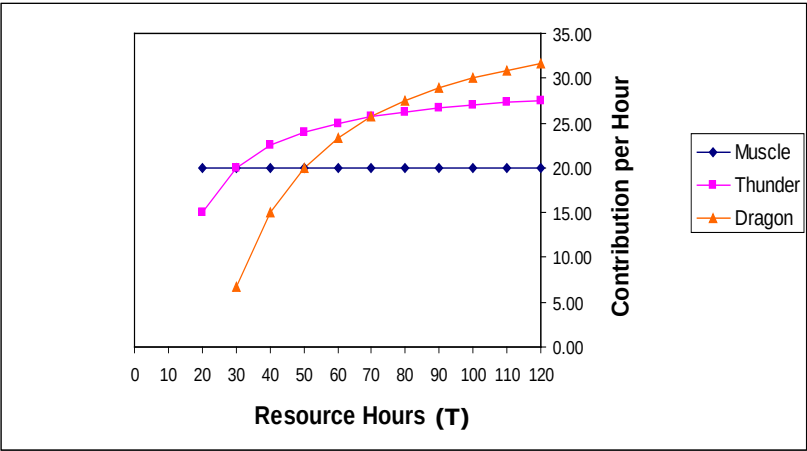


Figure 4

Contribution per Hour – No Muscle Shirt Changeover Required

**Contribution Per Hour With No
Muscle Shirt Changeover**



Chapter

8

Lean Systems

DISCUSSION QUESTIONS

1. Many students buy into lean systems as a philosophy until they are faced with the prospect of having their own work evaluated on the basis of performance of a group rather than as an individual. This discussion will probably uncover any conflicts between the culture the students have been raised in and lean systems philosophy. The discussion might be turned to look for compromises or ways lean systems could be modified to work with their culture.
2. Aspects of lean systems that have proven troublesome for some U.S. users are realignment of managerial reward systems, restrictive labor contracts, plant layouts, and adversarial supplier relationships. Our culture focuses on individuals rather than groups, and our legal system contains hurdles to forming partnerships that restrict competition. Many firms have already overcome these obstacles.
3. A lean system requires a low level of capacity slack and increasingly smaller levels of inventory. In order to reap the waste-reduction benefits of lean uniformly across the supply chain, all members of the supply chain must participate. Otherwise, one tier of the supply chain may be holding increasing levels of inventory to decouple them from their more efficient supply chain partners. This leads to higher costs and greater inefficiency for the entire supply chain. Thus, it is vital to create close, collaborative relationships with supply chain partners to ensure that information planning and problems are shared along the supply chain.

Thus, the pressures of participating in a lean supply chain come from enforcing a discipline of (1) small lots, (2) frequent shipping, (3) short lead times, (4) accurate shipping schedules, and (5) high quality from inbound logistics through operations and outbound logistics. Significant problems within this environment, such as inventory shortages or labor stoppages, will ripple across the supply chain. If not corrected quickly, these problems can shut down the entire supply chain.

4. The answer here will vary. Most students will draw a simple process they are very familiar with. For example ordering an item at a fast food restaurant: Receive order – gather materials (buns, meat, cheese, condiments) – assemble materials – serve order.

PROBLEMS

1. Harvey Motorcycles

- a. What is the cycle time for the assembly line?

$$c = \frac{1}{r} = \frac{7 \text{ hours}}{126 \text{ motorcycles}} = 0.0555 \frac{\text{hours}}{\text{motorcycle}}$$

$$= 3.33 \frac{\text{minutes}}{\text{motorcycle}}$$

- b. If Harvey uses small-lot mixed model production, what is the batch size of each model before the production cycle is repeated? The greatest common divisor of the production requirements for each motorcycle is 6. Therefore,

Golden = 9

LX 2000 = 7

Tiger = 5

- c.
- G L G L T G L G L G L T G L G T G L T G T
- other sequences are possible.

- d. Now the greatest common divisor is 13. Therefore,

Golden = 4

LX 2000 = 3

Tiger = 2

Cheetah = 1

Unless the setup time is reduced, there may be too much loss of capacity in performing additional setups per day. There may also be a shift in demand from the original three motorcycles to the new one, changing the mixed-model required.

2. Spradleys' Sprockets

$$k = \frac{\bar{d}(\bar{w} + \bar{\rho})(1 + \alpha)}{c}$$

$$k = \frac{500(0.20 + 1.80)(1 + 0.05)}{20}$$

$$k = 52.5$$

3. LeWin

- a. Solving for implied policy variable,
- α

$$k = \frac{\bar{d}(\bar{w} + \bar{\rho})(1 + \alpha)}{c}$$

$$12 = \frac{1,800[1.05 + 0.003(300)](1 + a)}{300}$$

$$(1 + a) = \frac{12(300)}{1,800[1.05 + 0.003(300)]} = 1.0256$$

$$\alpha = 1.0256 - 1 = 0.0256$$

- b. Reduction in waiting time

$$11 = \frac{[1,800(\bar{w} + 0.90)(1.0256)]}{300} = \frac{1,846\bar{w} + 1,661.47}{300}$$

$$1,846\bar{w} = 3,300 - 1,661.47$$

$$\bar{w} = 0.888 \text{ days}$$

The reduction in waiting time is:

$$\frac{(1.05 - 0.888)}{1.05} = 15.43\%$$

4. Gadjits and Widjits

- a. Containers for gadjits

$$k = \frac{\bar{d}(\bar{w} + \bar{\rho})(1 + \alpha)}{c}$$

$$k = \frac{800(3)(0.09 + 0.06)(1 + 0.09)}{80} = 4.905$$

$$k = 5$$

- b. Containers for widjits

$$k = \frac{\bar{d}(\bar{w} + \bar{\rho})(1 + \alpha)}{c}$$

$$k = \frac{800(2)(0.14 + 0.20)(1 + 0.08)}{50} = 11.750$$

$$k = 12$$

5. Gestalt, Inc.

$$\bar{\rho} = \frac{150(30)}{8(60)(60)} = 0.156$$

$$\bar{w} = \frac{1.6}{8} = 0.20 \text{ days}$$

$$k = \frac{\bar{d}(\bar{w} + \bar{\rho})(1 + \alpha)}{c}$$

$$8 = \frac{\bar{d}(0.20 + 0.15625)(1.1)}{30}$$

$$\bar{d} = \frac{240}{0.35625(1.1)} = 612.44 \text{ or } 612$$

6. Jittery USPS

$$\bar{\rho} = \frac{375}{8(60)(60)} = 0.01302 \text{ days}$$

$$\bar{w} = \frac{25}{8(60)} = 0.0521 \text{ days}$$

$$k = \frac{\bar{d}(\bar{w} + \bar{\rho})(1 + \alpha)}{c}$$

$$k = \frac{90,000(0.0521 + 0.01302)(1.18)}{375} = 18.44 \text{ or } 19 \text{ containers}$$

7. January's container needs

$$k = \frac{\bar{d}(\bar{w} + \bar{\rho})(1 + \alpha)}{c}$$

$$k = \frac{1,200(4)(0.16 + 0.10)(1 + 0.15)}{200} = 7.16 \text{ or } 8 \text{ containers}$$

February's container needs

$$k = \frac{\bar{d}(\bar{w} + \bar{\rho})(1 + \alpha)}{c}$$

$$k = \frac{(900 \times 4)(0.16 + 0.125)(1 + 0.15)}{200}$$

$$k = 5.8995 \text{ or } 6 \text{ containers per day}$$

8. Jitsmart

11 days(lead time plus processing time) × 36 units(demand) + [0.25(safety stock variable) × 396] = 396 units + 99 units = 495 units

$36(11)(1.25)/48 = 10.31$ containers for 495 units. Rounding up to 11 containers would allow for the “small inventory on the lower shelf”.

9. Markland First National Bank

a. Processing time = 24 min/day

Waiting time = 120 min/day

Total processing and waiting = 144 min/day

Total minutes per day = $24 \times 60 = 1440$ Total processing and waiting in portions of a day = $144/1440 = 0.10$ Let d be the daily demand of checks

$$\frac{[d(.1)1.25]}{50} = 20$$

$$50$$

$$\frac{0.125d}{50} = 20$$

$$50$$

$$0.125d = 1000$$

$$d = 8000$$

Daily demand = 8000 checks

- b. Waiting time is muda and therefore, if eliminated, would leave only 24 mins of processing time. When expressed as portions of a day, 24 min = 0.017 days.

$$\frac{(8000)(0.017)(1.25)}{50} = 3.4 \text{ or } 4 \text{ containers}$$

50

10. Farm-4-Less

- a. Each cycle contains 4SM, 2GC and 2 LT. In total each cycle produces 8 machines. Since Farm-4-Less completes a machine every 2 minutes (takt time), it takes: $8 \times 2 = 16$ minutes to complete the entire cycle sequence.
- b. Per cycle= 4 SM, 2 GC and 2 LT are produced. If there are 480 minutes available, then there are $(480/16) = 30$ cycles per shift. Thus, a total of = $(30 \times 4) = 120$ SM, $(30 \times 2) = 60$ GC and $(30 \times 2) = 60$ LT are produced each shift.

11. Jensen Bearings Inc.

- a. The plant now holds 1 day of raw material.
- b. There are $[(1050+1200)/2500] = 0.9$ weeks or $[0.9 \times 5] = 4.5$ days of work in process inventory is held between Press and Pierce & Form.
- c. There are $[(250+1500)/2500] = 0.7$ weeks or $[0.7 \times 5] = 3.5$ days of work in process inventory is held between Pierce & Form and Finish Grind.
- d. There are $[(500+1200)/2500] = 0.68$ weeks or $[0.68 \times 5] = 3.4$ days of work in process inventory is held between Finish Grind and Shipping.
- e. The value stream's production lead time now equals $[1.0+4.5+3.5+3.4] = 12.4$ days
- f. The value stream's processing time is 60 seconds $[3 + 22 + 35]$.

12. Ormonde Inc.

- a. The cell's current inventory level is $[400+500+200+1000] = 2100$ units
- b. The cell's takt time is 2.37 minutes per unit.
- $(8\text{hrs} \times 60\text{mins} - 45\text{mins}) \times 3\text{shifts} = 1305$ minutes available per day for production.
 - $1305\text{mins} / 550\text{units of demand per day} = 2.37$ minutes per unit.
- c. The cell's production lead time is: $.73 + .91 + .36 + 1.82 = 3.82$ days
- Raw Material lead time = $[400/550] = .73$ days
 - WIP lead time between Cutting and Bend = $[500/550] = .91$ days
 - WIP lead time between Bend and Punch = $[200/550] = .36$ days
 - Finished Goods lead time after Punch = $[1000/550] = 1.82$
- d. The cell's processing time is $[120+250+140] = 510$ seconds.
- e. The cell's capacity is 554.5 units per day (slightly larger than current demand level).
- Given 99% uptime, bending is the bottleneck
 - Availability at bending = $1305 \text{ mins} \times .99 = 1291.95 \text{ mins/day}$
 - Time at bottleneck (with setup)
 $125\text{secs} + 300\text{sec} / 20\text{units} = 140\text{sec/unit}$ or 2.33min/unit
 - Availability/Time at bottleneck = $1291.95 / 2.33 = 554.5$ units

CASE: COPPER KETTLE CATERING *

A. Synopsis

Copper Kettle Catering, owned by Wayne and Janet Williams, is a full-service catering business with services ranging from the delivery of box lunches to the serving of dinner for weddings and large office parties. The case describes the two primary market segments, “deliver only” and “deliver and serve.” Information that details these market segment characteristics along with descriptions of the operations and CKC’s competitive priorities is provided. The business is feeling competitive pressures in the form of shorter lead times to respond to customer demands, increased flexibility of product/service offerings, and increased focus by customers on the value received for their catering dollar. A major issue proposed to the students is whether the concepts of lean systems are applicable to this service business.

B. Purpose

The major purpose of this case is twofold:

1. To provide a framework within which the concepts underlying the lean systems approach to the management of material flows can be discussed.
2. To lead students to the understanding that lean system concepts are applicable to service operations as well as to manufacturing.

Specific issues that students need to address include:

- ☐ Process management considerations
 - Repetitive nature of the tasks
 - Well-defined material flows
 - Close proximity of work-centers layout
- ☐ Inventory management
 - Lot sizes
 - Aggregate levels to maintain
 - Space/spoilage considerations
- ☐ Scheduling of orders and workers
 - Level of stability in the schedule
 - HRM issues, including reward and recognition, skills required, cross training
 - Interaction with suppliers

C. Analysis

For an effective discussion of the case issues, following the assignment questions at the end of the case works best.

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

Question 1

There is a wide range of operations that are conducive to the use of lean systems concepts, including service operations. In general, the focus of lean systems includes high quality with respect to both inputs and outputs of the processes; reduction of waste; quick response times by the reduction of setup times and the simplification of processes; and a reduction in costs by lowering inventory-level requirements and maintaining quality. All of these are consistent with the objectives and improvements the Williams' desire for CKC.

The processes at CKC have several characteristics that support the implementation of lean systems. They include:

- ❑ Having a demand pull system where orders placed by the customer cause materials to be “pulled” through the system. “Deliver only” orders are more reactive, having a relatively short lead time in which to respond. The “deliver and serve” orders are booked much farther in advance, and firm planned schedules can be established on a weekly basis.
- ❑ Workers are very flexible and, for the most part, interchangeable, except maybe for the cooks.
- ❑ The menu is still relatively simple, with limited variety allowing for some standardization.
- ❑ The processes seem to be “visible,” in that workers can see the entire operation and track the flow of materials easily.
- ❑ The processes are repeatable and conducive to standardization.
- ❑ Lot sizes would seem to be small and setup times relatively short.
- ❑ The overall load on the system, that is, orders, is relatively uniform.
- ❑ Quality of materials and output is at a high level.

Question 2

There are a number of possible barriers that CKC may face if the concept of lean systems is pursued.

- ❑ It was mentioned that the facilities were set up in a job process configuration that may be less suitable for lean systems than a line flow configuration.
- ❑ Overall demand is indicated to be stable; however, the variability in each order may inhibit standardization. In some respects this operation may be thought of as a “custom-job shop.”
- ❑ Supplier relationships will be extremely important to maintain both quality and quick response. Some suppliers now require CKC to pick up their orders.
- ❑ The two types of markets, deliver only and deliver and serve, really require two different types of operating systems to focus on different customer requirements. The relative importance of menu variety and response time differ noticeably in each market.

Question 3

There are a number of recommendations students may present that take advantage of the use of lean systems concepts and principles. Some of the ones to expect include:

- ❑ If possible, split the operations to focus independently on the two market segments: deliver only and deliver and serve. Lay out the processes in a flow pattern where the entire process for each market segment is visible to the workers. Also, lay out the necessary tasks and equipment so that cycle times can be reduced to shorten lead times.
- ❑ CKC can begin to employ lean systems signaling techniques for the movement of materials such as color-coded, standard-sized trays.
- ❑ Begin a cross-training program to enhance the flexibility of the workers so they can be assigned where needed.
- ❑ Continue to build supplier relationships by developing supplier alliances, reducing the total number of suppliers, and sharing information on demand patterns and material needs.
- ❑ Try to limit the menu selection, especially for deliver-only orders where response time is more important. This will also help reduce inventory levels.
- ❑ Maintain good housekeeping policies, not only for quality and health safety reasons but also for enhancing visibility within the processes and ensuring the prompt availability of needed tools and materials. It also helps in the development of the proper attitudes about work and the workplace.

These are but a few of the possible recommendations. The students will have many more. The focus of their recommendations usually revolves around these primary areas: process management issue and inventory management.

D. Teaching Suggestions

As mentioned in the analysis section, an effective way to discuss this case is to follow the three case questions. The case is designed to be used as a “cold-call” in-class exercise. It is short enough to read in 10 minutes. Given that the students read the lean systems chapter prior to coming to class, they should be able to discuss the three questions posed at the end of the case. The intent is to have the students discuss the major concepts of lean systems and to recognize appropriate applications.

The case should take no more than 30 minutes to explore fully. Spend the first 10 minutes discussing factors concerning CKC’s operations that are conducive to lean systems. Put these on the left side of the board. Then list the possible barriers to lean systems implementation on the right side of the board. This should take another 10 minutes. Finally, ask for recommendations and put these in the center of the board. You can then quickly relate each recommendation to the implementation factors both pro and con to the left and right. Recommendations should build on the strengths and address the barriers. Exhibit TN.1 shows the layout of the board.

EXHIBIT TN.1

Sample Board Plan Layout

Factors Supporting Lean Systems	Recommended Actions	Barriers to the Implementation of Lean Systems

9 Supply Chain Inventory Management

DISCUSSION QUESTIONS

1. The short answer is that higher inventories do not provide an advantage in *any* of the nine competitive priority categories. The important point is that firms must have the “right amount” of inventory to meet their competitive priorities.
The only relevant costs considered in this chapter are ordering costs, holding costs, and stockout costs. In the economic order quantity (EOQ) model, costs of placing replenishment orders tradeoff against the costs of holding inventory. Under the assumptions of the EOQ, average inventory is one-half of the order quantity. The number of orders placed per year varies inversely with order quantity. When we consider stockout costs, an additional inventory (safety stock), is held to trade-off costs of poor customer service or costs for expediting shipments from unreliable suppliers.
In the lean systems chapter, we see order quantities (lot sizes) that are much smaller than the “ideal” suggested by the EOQ model. As a result, lean systems average inventory is also much lower. Are there some other relevant costs of holding inventory that we have not considered in the EOQ model? If there are, a firm that ignores these costs will make the wrong inventory decisions. These wrong decisions will make the firm less competitive.
Let’s examine the relationships between inventory and the nine competitive priorities discussed in the “Using Operations to Compete” chapter. We compare competitors H and L. They are similar in all respects except H maintains much higher inventory than does L.
 1. **Low-cost operations.** Costs include materials, scrap, labor, and equipment capacity that are wasted when products are defective. When a process drifts out of control, competitor H’s large lot sizes tend to result in large quantities of defectives. The EOQ does not consider the cost of defectives, and erroneously assumes that setup costs are constant. Small lots cause frequent setups, but the cost per setup decreases due to the learning curve. Competitor L will enjoy competitive advantages with lower setup, materials, labor, equipment, and inventory holding costs.
 2. **Top quality.** Superior features, durability, safety, and convenience result from improved designs. High inventories force competitor H to choose between scrapping obsolete designs or delaying introduction of product improvements until the old inventory is consumed. In either case, L gains a competitive advantage.
 3. **Consistent quality.** Consistency in conforming to design specifications requires consistency in supplied materials, setups, and processes. Small lots made frequently tend to increase consistency. Again, advantage goes to L.
 4. **Delivery speed.** Large lots take longer to produce than small lots. A customer will wait less time for competitor L to set up and produce orders made in small batches.

5. **On-time delivery.** Contrary to expectations, large inventories do not equate to on-time delivery. It's more like, lots of inventory equals lots of chaos. Big lots make big scheduling problems. Big lots get dropped, mishandled, and pilfered. Most lean companies experience dramatic improvement in on-time delivery.
6. **Development speed.** This response is similar to that given for top quality. Low inventories result in getting new designs to the market more quickly.
7. **Customization.** Lean companies usually don't claim an advantage in customization. However, large inventories provide no advantage with regard to customization either. It remains unlikely that a customized product will be found in inventory, no matter how large.
8. **Variety.** Mass customizers compete on service or product variety. They will keep products at raw material or component levels until a customer orders a specific configuration. Inventories are at as low a level as possible.
9. **Volume flexibility.** Lean (low inventory) companies tend to produce the same quantity of every product every day, but they claim considerable volume flexibility from month to month. On the other hand, a large finished goods inventory can be used to absorb volume fluctuations.

In summary, a case can be made that several competitive priorities are not considered in the EOQ model. It is sometimes difficult to place a dollar value on these competitive advantages, but the advantages invariably go to the low-inventory, small lot-size firm. So if the EOQ is too large, what is the "ideal" lot size? According to the lean philosophy, the "ideal" lot size is one.

2. The continuous review system requires the determination of two parameters: the order quantity and the reorder point. The ordering cost for each firm will decrease, which means that the economic order quantities will decrease. Because of this, there may be some implications for the logistics system. Smaller, more frequent shipments could require more costly less-than-truckload shipments. In addition, while the order quantities will decrease, the reorder points will also decrease because the lead times will be smaller. The supply chain should experience smaller pipeline inventories as a consequence.

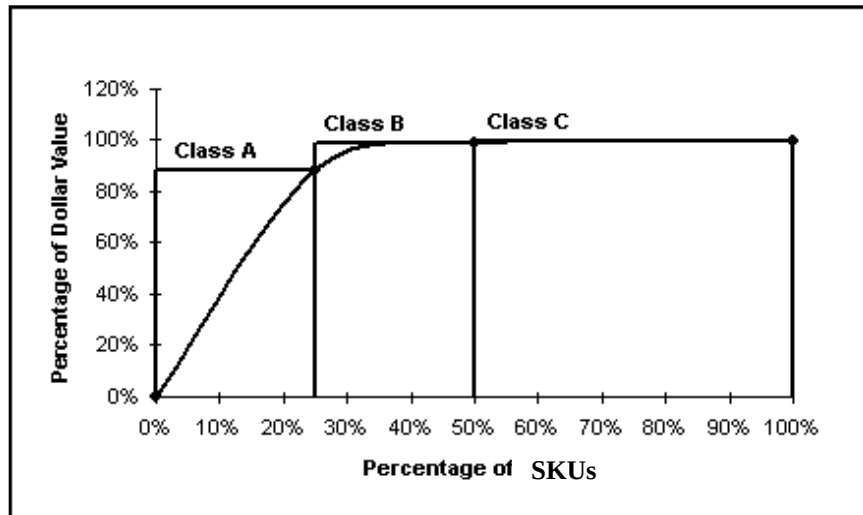
If the new information system also reduces the variance of demand or lead times, there can be additional safety stock savings. However, all of these benefits will come at some additional expense for the incorporation of the new system. There will be capital costs for equipment and potential training costs involved.

3. Organizations will never get to the point where inventories are unneeded. Inventories provide many functions and should be managed, not eliminated. It is impossible to eliminate uncertainties in the provision of products or services. In addition, unless materials can be transported instantaneously, there will always be pipeline inventories. Cycle inventories will exist unless we universally get to the point where production of single units is feasible.

PROBLEMS

1. A part
 - a. Average cycle inventory $= Q/2$
 $= 1000/2 = 500$ units
 Value of cycle inventory $= (500 \text{ units}) (\$50 + \$60)$
 $= \$55,000$
 - b. Pipeline inventory $= dL$
 $[(3800 \text{ units/year}) / (50 \text{ wks/yr})] (6 \text{ weeks})$
 $= 456$ units
 Value of the pipeline inventory $= (456 \text{ units}) (\$50 + \$30)$
 $= \$36,480$
2. Prince Electronics
 - a. Value of each DC's pipeline inventory
 $= (75 \text{ units/wk}) (2 \text{ wk}) (\$350/\text{unit})$
 $= \$52,500$
 - b. Total inventory $= \text{cycle} + \text{safety} + \text{pipeline}$
 $= 5[(400/2) + (2*75) + (2*75)]$
 $= 2,500$ units
3. Terminator Inc.
 - a. Average cycle inventory $= Q/2$
 $= 250/2$
 $= 125$ units
 Value of cycle inventory $= (125 \text{ units}) (\$450)$
 $= \$56,250$
 - b. Pipeline inventory $= dL = \left\{ \frac{(4,000 \text{ units/yr})}{50 \text{ wk/yr}} \right\} (3 \text{ wk})$
 $= 240$ units
 Value of pipeline inventory $= (240 \text{ units}) (\$150 + \$300/2)$
 $= \$72,000$
4. Oakwood Hospital
 First we rank the SKUs from top to bottom on the basis of their dollar usage. Then we partition them into classes. The analysis was done using OM Explorer Tutor 9.2—ABC Analysis.

SKU #	Description	Qty Used/Year	Value	Dollar Usage	Pct of Total	Cumulative % of Dollar Value	Cumulative % of SKUs	Class
4		44,000	\$1.00	\$44,000	60.0%	60.0%	12.5%	A
7		70,000	\$0.30	\$21,000	28.6%	88.7%	25.0%	A
5		900	\$4.50	\$4,050	5.5%	94.2%	37.5%	B
2		120,000	\$0.03	\$3,600	4.9%	99.1%	50.0%	B
6		350	\$0.90	\$315	0.4%	99.5%	62.5%	C
8		200	\$1.50	\$300	0.4%	99.9%	75.0%	C
3		100	\$0.45	\$45	0.1%	100.0%	87.5%	C
1		1,200	\$0.01	\$12	0.0%	100.0%	100.0%	C
Total				\$73,322				



The dollar usage percentages don't exactly match the predictions of ABC analysis. For example, Class A SKUs account for 88.7% of the total, rather than 80%. Nonetheless, the important finding is that ABC analysis did find the "significant few." For the items sampled, particularly close control is needed for SKUs 4 and 7.

5. Southern Markets Inc.

- a. Typically, we expect A items to account for 20% of the items and 80% of the total dollar usage.

A items: $20,000 \times .20 = 4000$ items with an annual dollar usage of
 $\$10,000,000 \times .80 = \$8,000,000$

Typically, we expect B items to account for 30% of the items and 15% of the total dollar usage.

B items: $20,000 \times .30 = 6000$ items with an annual dollar usage of
 $\$10,000,000 \times .15 = \$1,500,000$

Typically, we expect C items to account for 50% of the items and 5% of the total dollar usage.

C items: $20,000 \times .50 = 10,000$ items with an annual dollar usage of
 $\$10,000,000 \times .05 = \$500,000$

- b. First we rank the SKUs from top to bottom on the basis of their annual dollar usage. Then we partition them into classes. The analysis was done using Excel.

SKU Code	Unit Value	Demand (units)	Annual Dollar Usage	Cumulative Percentage of Dollar Usage	Item Category
A104	\$2.10	2500	\$5,250.00	81.65%	A
X205	\$0.35	1020	\$357.00	87.21%	A
X104	\$0.85	350	\$297.50	91.83%	B
L104	\$4.25	50	\$212.50	95.14%	B
S104	\$0.02	4000	\$80.00	96.38%	C
D205	\$2.50	30	\$75.00	97.55%	C
L205	\$4.75	20	\$95.00	99.03%	C
U404	\$0.25	250	\$62.50	100.00%	C
Sum			\$6,429.50		

The dollar usage percentages closely match the predictions of ABC analysis. For example, Class A SKUs account for 87.21% of the total. For the items sampled, particularly close control is needed for SKU A104 and X205.

6. Yellow Press, Inc.

- a. Economic order quantity

$$D = 2500 \text{ rolls}$$

$$\text{Price} = \$800/\text{roll}$$

$$H = 15\%(\$800) = \$120/\text{roll-year}$$

$$S = \$50$$

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2500 \text{ rolls/year})(\$50)}{\$120/\text{roll-year}}} = \sqrt{2083.33} = 45.64 \text{ or } 46 \text{ rolls}$$

- b. Time between orders

$$\frac{Q}{D} = \frac{46}{2500} = 0.0184 \text{ year, or every 4.6 days}$$

if there are 250 working days in a year

7. Babble Inc.

- a.

$$D = (400 \text{ tapes/month})(12 \text{ months/yr}) = 4,800 \text{ tapes/year}$$

$$H = \$0.12$$

$$S = \$12.50$$

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(4,800)(\$12.50)}{\$0.12}} = \sqrt{1,000,000} = 1000 \text{ tapes}$$

- b.

Time between orders

$$\frac{Q}{D} = \frac{1,000}{4,800} = 0.2083 \text{ years or 2.5 months}$$

8. Dot Com

a. $EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(32,000)(\$10)}{\$4}} = 400 \text{ books}$

b. Optimal number of orders/year = $(32,000)/400 = 80 \text{ orders}$

c. Optimal interval between orders = $300/80 = 3.75 \text{ days}$

d. Demand during lead time = $\bar{d}L = (5 \text{ days})(32,000/300) = 533 \text{ books}$

e. Reorder point = $\bar{d}L + \text{safety stock} = 533 + 0 = 533 \text{ books}$

f. Inventory position = $OH + SR - BO = 533 + 400 - 0 = 933 \text{ books}$

e. Annual holding cost

$$\frac{Q}{2}H = \frac{400}{2}(27\%)(\$11.70) \\ = \$631.80$$

Annual ordering cost

$$\frac{D}{Q}S = \frac{4,680}{400}\$54 \\ = \$631.80$$

Total cost using EOQ is \$1,263.60, which is \$31.59 less than when the order quantity is 500 bags.

11. Sam's Cat Hotel, revisited

a. If the demand is only 60 bags per week, the correct EOQ is:

$$D = (60 \text{ units/wk})(52 \text{ wk/yr}) = 3,120 \text{ bags}$$

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(3,120)(\$54)}{\$3.16}} = \sqrt{106,632.91} = 326.54, \text{ or } 327 \text{ bags}$$

If the demand is incorrectly estimated at 90 bags, the EOQ would be incorrectly calculated (from Problem 10) as 400 bags.

The total cost, working with the actual demand, is:

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

$$C_{327} = \frac{327}{2}(\$3.16) + \frac{3,120}{327}(\$54) = \$1,031.89$$

$$C_{400} = \frac{400}{2}(\$3.16) + \frac{3,120}{400}(\$54) = \$1,053.20$$

We can see clearly now that the cost penalty of Sam's difficulty in foreseeing demand for kitty litter is \$21.31 (\$1,053.20 – \$1,031.89).

b. If $S = \$6$, and $D = 60 \times 52 = 3120$, the correct EOQ is:

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(3,120)(\$6)}{\$3.16}} = \sqrt{11,848.10} = 108.85, \text{ or } 109 \text{ bags}$$

The total cost, working with the actual ordering cost, is

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

$$C_{109} = \frac{109}{2}(\$3.16) + \frac{3,120}{109}(\$6) = \$342.96$$

$$C_{327} = \frac{327}{2}(\$3.16) + \frac{3,120}{327}(\$6) = \$573.91$$

If the reduced ordering cost continues to be unseen, the cost penalty for not updating the EOQ is $(573.91 - 342.96) = \$229.95$.

12. A Q system (also known as a reorder point system)

$$\bar{d} = 300 \text{ pints/week}$$

$$\sigma_d = 15 \text{ pints}$$

a. Standard deviation of demand during the protection interval:

$$\sigma_{dLT} = \sigma_d \sqrt{L} = 15 \sqrt{9} = 45 \text{ pints}$$

- b. Average demand during the protection interval:

$$\text{Demand during protection interval} = \bar{d}L = 300 * 9 = 2700 \text{ pints}$$

- c. Reorder point

$$R = \text{average demand during protection interval} + \text{safety stock}$$

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

When the desired cycle-service level is 99%, $z = 2.33$.

$$\text{Safety stock} = 2.33 * 45 = 104.85 \text{ or } 105 \text{ pints}$$

$$R = 2,700 + 105 - 0 = 2,805 \text{ pints}$$

13. Petromax Enterprises

a.
$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(50,000)(35)}{2}} = 1,323 \text{ units}$$

b.
$$\text{Safety stock} = z\sigma_{dLT} = z\sigma_d\sqrt{L} = (1.28)(125)\sqrt{3} = 277.13 \text{ or } 277 \text{ units}$$

$$\text{Reorder point} = \text{average lead time demand} + \text{safety stock}$$

$$= (3)(50,000/50) + 277$$

$$= 3,277 \text{ units}$$

14. A continuous review system for door knobs.

Find the safety stock reduction when lead time is reduced from five weeks to one week.

Standard deviation of demand during the (five-week) protection interval is $\sigma_d\sqrt{L} = 85$ door knobs.

Desired cycle service level is 99% (therefore $z = 2.33$).

Safety stock required for five-week protection interval:

$$\text{Safety stock} = z\sigma_d\sqrt{L} = 2.33(85) = 198.05, \text{ or } 198 \text{ door knobs}$$

Safety stock required for one-week protection interval

$$\sigma_{dLT} = \sigma_d\sqrt{L} = \sigma_d\sqrt{5} = 85 \text{ door knobs}$$

$$\sigma_d = 85/\sqrt{5} = 38.01 \text{ door knobs.}$$

$$\text{Safety stock} = z\sigma_t = 2.33(38.01) = 88.57 \text{ or } 89 \text{ door knobs}$$

Safety stock reduction

$$\text{Reduction} = 198 - 89 = 109 \text{ door knobs.}$$

15. A two-bin system. "The two-bin system is really a Q system, with the normal level in the second bin being the reorder point R."

- a. Find cycle-service level, given:

$$L = 2 \text{ weeks} \quad \sigma_d = 5 \text{ bolts}$$

$$\bar{d} = 53 \text{ bolts/week} \quad R = 130 \text{ bolts}$$

$$\text{Expected demand over lead time} = 2(53) = 106 \text{ bolts with a standard deviation of } \sigma_{dLT} = \sigma_d\sqrt{L} = 5\sqrt{2} = 7.07 \text{ bolts}$$

The probability that demand exceeds the reorder point R (in units of standard deviation) = $(130-106)/7.07 = 3.39$

When $z = 3.39$, the probability of demand exceeding the reorder point is 100.00% - 99.97% = 0.03%.

- b. Using the same approach as in part (a), given:

$$L = 3 \text{ weeks} \quad \sigma_d = 5 \text{ bolts}$$

$$\bar{d} = 53 \text{ bolts/week} \quad R = 130 \text{ bolts}$$

Expected demand over lead time in this case = $3(53) = 159$ bolts

with a standard deviation of $\sigma_{dLT} = \sigma_d \sqrt{L} = 5\sqrt{3} = 8.66$ bolts

The probability that demand exceeds the reorder point R (in units of standard deviation) = $(130-159)/8.66 = -3.35$

When $z = -3.35$, the probability that demand exceeds the reorder point is 99.96% or if the shipment is delayed by 1 week, a stockout is almost a certainty!

16. Nationwide Auto Parts

- a. Protection interval (PI) $= P + L = 6 + 3 = 9$ weeks
 Average demand during PI $= 9(100) = 900$ units
 Standard deviation during PI $= \sqrt{9} \cdot (20) = 60$ units
- b. Target inventory $= \bar{d}(P+L) + z\sigma_{P+L}$
 $= 900 + (1.96)(60) = 1,018$
- c. Order quantity $= \text{Target inventory} - \text{IP}$
 $= 1,018 - 350 = 668$ units presuming no SR or BO

17. P system (also known as a periodic review system) for weed killer.

- a. Find cycle-service level, given:
 $L = 2$ weeks, $P = 1$ week
 $\bar{d}(P+L) = 218$
 $\sigma_{P+L} = 40$ boxes
 $T = 300$ boxes
 $T = \text{Average demand during protection interval} + \text{Safety stock}$
 $T = 218 + z(40) = 300$ boxes
 $z = (300 - 218)/40 = 2.05$
 When $z = 2.05$, cycle-service level is 97.98 or 98%.
- b. Find the cycle-service level, given:
 $L = 2$ weeks, $P = 1$ week
 $\bar{d}(P+L) = 180$
 $\sigma_{P+L} = 50$ boxes
 $T = 300$ boxes
 $T = \text{Average demand during protection interval} + \text{Safety stock}$
 $T = 180 + z(50) = 300$ boxes
 $z = (300 - 180)/50 = 2.40$
 When $z = 2.40$, cycle-service level is 99.18 or 99%.

18. A Successful Product

Annual Demand, $D = (200)(50) = 10,000$ units, $H = ((0.20)(12.50)) = 2.50$

a. Optimal ordering quantity $= \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(10,000)(50)}{2.5}} = 633$ units

b. Safety stock $= z\sigma_d\sqrt{L}$
 $= (2.33)(16)\sqrt{(4)} = 74.56$ or 75 units

c. Safety stock will now be: $(2.33)(16)\sqrt{(2)} = 52.72$ or 53 units

% reduction in safety stock $= (75 - 53)/75 = 29.33\%$

d. Safety stock will be $= (2.33)(8)\sqrt{(4)} = 37.28$ or 38 units

% reduction in safety stock $= (75 - 38)/75 = 49.33\%$

19. Sam's Cat Hotel with a P system

- a. Referring to Problem 10, the EOQ is 400 bags. When the demand rate is 15 per day, the average time between orders is $(400/15) = 26.67$ or about 27 days. The lead time is 3 weeks $\times$ 6 days per week = 18 days. If the review period is set equal to the EOQ 's average time between orders (27 days), then the protection interval $(P + L) = (27 + 18) = 45$ days.

For an 80% cycle-service level

$$z = 0.84$$

$$\sigma_{P+L} = \sigma_d \sqrt{P + L}$$

$$\sigma_{P+L} = (6.124)\sqrt{27 + 18} = 41.08$$

$$\text{Safety stock} = z\sigma_{P+L} = 0.84(41.08) = 34.51 \text{ or } 35 \text{ bags}$$

T = Average demand during the protection interval + Safety stock

$$T = (15 \times 45) + 35 = 710$$

- b. In Problem 10, the Q system required a safety stock of 22 bags to achieve an 80% cycle-service level. Therefore, the P system requires a safety stock that is larger by $(35 - 22) = 13$ bags.
- c. From Problem 10, inventory position, $IP = 320$.
 The amount to reorder is $T - IP = 710 - 320 = 390$.

20. Continuous review system.

- a. Economic order quantity.

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2,000)(40)}{2}} = 894.4 \text{ or } 894 \text{ units}$$

$$\text{Time between orders (TBO)} = Q/D = 894/20,000 = 0.0447 \text{ years} = 2.32 \text{ weeks}$$

- b. Weekly demand $= 20,000/52 = 385$ units

For a 95% cycle-service level, $z = 1.65$

$$\text{Safety stock: } z\sigma_d\sqrt{L} = (1.65)(100)\sqrt{2} = 233.34, \text{ or } 233 \text{ units}$$

Now solve for R , as

$$R = \bar{d}L + \text{Safety stock} = 385(2) + 233 = 1,003 \text{ units}$$

- c. i. Annual holding cost of cycle inventory

$$\frac{Q}{2}H = \frac{894}{2}(2) = \$894.00$$

- ii. Annual ordering cost

$$\frac{D}{Q}S = \frac{20,000}{894}\$40 = \$894.85$$

- d. With the 15-unit withdrawal, IP drops from 1,040 to 1,025 units. Because this level is above the reorder point ($1,025 > 1,003$), a new order is not placed.

21. Periodic review system

- a. Economic order quantity.

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(15,080)(125)}{3}} = 1121 \text{ units}$$

- b. Continuous Review System

Weekly demand = $15,080/52 = 290$ units

For a 95% cycle-service level, $z = 1.65$

Safety stock: $z\sigma_d\sqrt{L} = (1.65)(64)\sqrt{5} = 236.13$, or 236 units

Now solve for R , as

$$R = \bar{d}L + \text{Safety stock} = 290(5) + 236 = 1,686 \text{ units}$$

Thus, under a continuous review system, order 1121 units whenever the inventory level drops to 1686 units

Periodic Review System

Number of orders per year = $D/Q = 15,080/1,121 = 13.5$ orders per year or $52/13.5 = 3.85$ weeks. P is rounded to 4 weeks.

For a 95% cycle-service level, $z = 1.65$. Therefore Safety stock = $z\sigma_{P+L}$

$$\sigma_{P+L} = \sigma_d\sqrt{P+L} = (64)\sqrt{4+5} = 192 \text{ units}$$

Safety stock = $1.65(192) = 316.8$ or 317 units,

T = Average demand during the protection interval + Safety stock

$$T = (290 * 9) + 317 = 2,927 \text{ units}$$

Thus, under a periodic review system, order up to 2927 units every 4 weeks.

- c. The periodic review system has a longer protection interval and thereby requires more safety stock. In this case: $317 - 236 = 81$ units

22. Continuous review system

- a. Economic order quantity

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(64)(52)(50)}{13}} = 160 \text{ units}$$

- b. Safety stock.

When cycle-service level is 88%, $z = 1.18$.

$$\text{Safety stock} = z\sigma_d\sqrt{L} = (1.18)(12)\sqrt{2} = 20.03, \text{ or } 20 \text{ units}$$

- c. Reorder point

$$R = \bar{d}L + \text{Safety stock} = 64(2) + 20 = 148 \text{ units.}$$

d. If $Q = 200$ and $R = 180$, average inventory investment is higher than necessary to achieve an 88% cycle-service level. The larger order quantity increases average cycle stock by 20 units, and the higher reorder point increases safety stock by 32 units.

23. Periodic review system

a. From Problem 22, $EOQ = 160$

$$P = \frac{EOQ}{\bar{d}} = \frac{160}{64} = 2.5 \text{ weeks}$$

P is rounded to 3 weeks.

b. For an 88% cycle-service level, $z = 1.18$. Therefore

$$\text{Safety stock} = z\sigma_{P+L}$$

$$\sigma_{P+L} = \sigma_d \sqrt{P+L}$$

$$\sigma_{P+L} = (12)\sqrt{3+2} = 26.83 \text{ units.}$$

$$\text{Safety stock} = 1.18(26.83) = 31.66, \text{ or } 32 \text{ units}$$

$$T = \text{average demand during the protection interval} + \text{Safety stock}$$

$$T = (64 * 5) + 32 = 352 \text{ units}$$

24. Wood County Hospital

a. $D = (1000 \text{ boxes/wk})(52 \text{ wk/yr}) = 52,000 \text{ boxes}$

$$H = (0.15)(\$35/\text{box}) = \$5.25/\text{box}$$

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(52,000)(\$15)}{\$5.25}} = 545.1 \text{ or } 545 \text{ boxes}$$

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

$$C_{900} = \frac{900}{2}\$5.25 + \frac{52,000}{900}\$15.00 = \$3,229.16$$

$$C_{545} = \frac{545}{2}\$5.25 + \frac{52,000}{545}\$15.00 = \$2,861.82$$

The savings would be $\$3,229.16 - \$2,861.82 = \$367.34$.

b. When the cycle-service level is 97%, $z = 1.88$. Therefore,

$$\text{Safety stock} = z\sigma_d \sqrt{L} = (1.88)(100)\sqrt{2} = 1.88(141.42) = 265.87, \text{ or } 266 \text{ boxes}$$

$$R = \bar{d}L + \text{Safety stock} = 1000(2) + 266 = 2,266 \text{ boxes}$$

c. In a periodic review system, find target inventory T , given:

$$P = 2 \text{ weeks}$$

$$L = 2 \text{ weeks}$$

$$\text{Safety stock} = z\sigma_{P+L}$$

$$\sigma_{P+L} = \sigma_d \sqrt{P+L}$$

$$\sigma_{P+L} = (100)\sqrt{2+2} = 200 \text{ units.}$$

$$\text{Safety stock} = 1.88(200) = 376 \text{ units}$$

$$T = \text{Average demand during the protection interval} + \text{Safety stock}$$

$$T = 1000(2 + 2) + 376$$

$$T = 4,376 \text{ units}$$

The table below is derived from OM Explorer Solver—Inventory Systems. Notice that the total cost for the Q system is much less than that of the P system. The reason is that the optimal value of P was not used here. The optimal value is $P = 0.55$ weeks.

Continuous Review (Q) system		Periodic Review (P) System	
	$z =$	1.88	Time Between Reviews (P) 2.00 Weeks
			☒ Enter manually
Safety Stock		266	Standard Deviation of Demand During Protection Interval 200
Reorder Point		2266	Safety Stock 376
Annual Cost	\$4,258.32		Average Demand During Protection Interval 4000
			Target Inventory Level (T) 4376
			Annual Cost \$7,614.00

25. Golf specialty wholesaler
a. Periodic Review System

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2000)(40)}{5}} = 178.88 \text{ or } 179 \text{ 1-irons}$$

$$P = \frac{EOQ}{D} = \frac{179}{2000} = 0.0895 \text{ years} = 4.475 \text{ or } 4.0 \text{ weeks}$$

When cycle-service level is 90%, $z = 1.28$.

Weekly demand is $(2,000 \text{ units/yr}) / (50 \text{ wk/yr}) = 40 \text{ units/wk}$

$L = 4$ weeks

Safety stock:

$$z \sigma_{P+L} = z \sigma_d \sqrt{P+L} = (1.28)(3)\sqrt{4+4} = 10.86, \text{ or } 11 \text{ irons}$$

$$T = \bar{d}(P+L) + \text{Safety stock} \\ = 40(4+4) + 11 = 331 \text{ irons.}$$

- b. Continuous review system

$$\text{Safety stock} = z \sigma_d \sqrt{L} = (1.28)(3)\sqrt{4} = 1.28(3)(2) = 7.68, \text{ or } 8 \text{ irons}$$

$$R = \bar{d}L + \text{Safety stock} = 40(4) + 8 = 168 \text{ irons}$$

26. Osprey Sports.
a. The economic order quantity is

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(350)(4)(\$30)}{\$1}} = \sqrt{84,000} = 289.83, \text{ or } 290 \text{ lures.}$$

- b. The safety stock and reorder point are

$$\sigma_{dLT} = \sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_{LT}^2} = \sqrt{(10)(1)^2 + (4)^2(3)^2} = 12.41 \text{ lures}$$

The z value for a 97 percent cycle-service level = 1.88.

The safety stock = 1.88 (12.41) = 23.33, or 23 lures

The reorder point = $\bar{d}\bar{L}$ + Safety stock = (4)(10) + 23 = 63 lures.

- c. The total annual cost for this continuous review system is

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) + (H)(\text{Safety stock}) = \frac{290}{2}(\$1) + \frac{350(4)}{290}(\$30) + (\$1)(23). \\ = \$312.83$$

27. Farmer's Wife

- a. The continuous review system is specified by the fixed order quantity and the reorder point. We will use the EOQ for the order quantity.

The order quantity is:

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(30)(50)(\$15)}{\$0.75}} = \sqrt{60,000} = 244.95, \text{ or } 245 \text{ cows.}$$

The safety stock is:

$$\sigma_{dLT} = \sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_{LT}^2} = \sqrt{(8)(5)^2 + (30)^2(2)^2} = 61.64 \text{ cows.}$$

The z value for a 90 percent cycle-service level = 1.28.

The safety stock = 1.28 (61.64) = 78.90, or 79 cows.

The reorder point = $\bar{d}\bar{L}$ + Safety stock = (30)(8) + 79 = 319 cows

- b. The system would operate as follows: Whenever the stock of cows drops to 319, order 245 more cows.

- c. The total annual cost for this continuous review system is

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) + (H)(\text{Safety stock}) = \frac{245}{2}(\$0.75) + \frac{30(250)}{245}(\$15) + (\$0.75)(79). \\ = \$243.06$$

28. Muscle Bound

To find the cycle-service level, we must determine the standard deviation of demand during lead time and then use the equation for total annual cost to solve for z. We will use the EOQ for the ordering quantity.

The standard deviation of demand during lead time is

$$\sigma_{dLT} = \sqrt{\bar{L}\sigma_d^2 + \bar{d}^2\sigma_{LT}^2} = \sqrt{(35)(150)^2 + (1000)^2(5)^2} = 5,078.14 \text{ barbells}$$

The economic order quantity is

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(1000)(313)(\$40)}{\$2}} = \sqrt{12,520,000} = 3,538.36, \text{ or } 3,538 \text{ barbells}$$

The total annual cost (with z as a variable) is

$$C = \frac{Q}{2}(H) + \frac{D}{Q}(S) + (H)(\text{Safety stock}) = \\ \frac{3,538}{2}(\$2) + \frac{1000(313)}{3,538}(\$40) + (\$2)(z)(5,078.14) = \$16,000$$

We now solve for z

$$z = \frac{\$16,000 - (\$3,538) - (3,538.72)}{(\$2)(5,078.14)} = 0.8785, \text{ or } 0.88.$$

This value of z corresponds to a cycle-service level of 81 percent.

29. Georgia Lighting Center.

Using the demand data given in the problem statement, we extended text Table 9.2 below the dashed line in the following way. The beginning inventory for day 7 is the ending inventory for day 6, which is 27 units. The demand for day 7 is 7 units, which leaves 20 units in inventory at the end of day 7. No orders are open to the supplier; consequently the inventory position is 20 units. Because 20 units exceeds the reorder point of 15 units, no new order is placed. Continuing in this manner, the inventory position at the end of day 9 drops below the reorder point; consequently a new order for 40 units is placed. That order will be received three business days later, or day 12. The complete simulation results with $Q = 40$ and $R = 15$ are:

Day	Beginning Inventory	Open Orders Received	Daily Demand	Ending Inventory	Inventory Position	Amount Ordered	
1	19	0	5	14	14	40	
2	14	0	3	11	51		
3	11	0	4	7	47		
4	7	40	1	46	46		
5	46	0	10	36	36		
Sat 6	36	0	9	27	27		
Mon7	27	0	7	20	20	40	
8	20	0	4	16	16		
9	16	0	2	14	14		
10	14	0	7	7	47		
11	7	0	3	4	44		
12	4	40	6	38	38		
13	38	0	10	28	28	40	
14	28	0	0	28	28		
15	28	0	5	23	23		
16	23	0	10	13	13		
17	13	0	4	9	49		
18	9	0	7	2	42		
TOTAL				343			
AVERAGE				19.06			

- a. The average ending inventory is:

$$\frac{343}{18} = 19.06 \text{ or } 19 \text{ units}$$

No stockouts occurred during any of the three cycles.

b. Assuming a $Q=30$, $R=20$ system is used, the following simulation results:

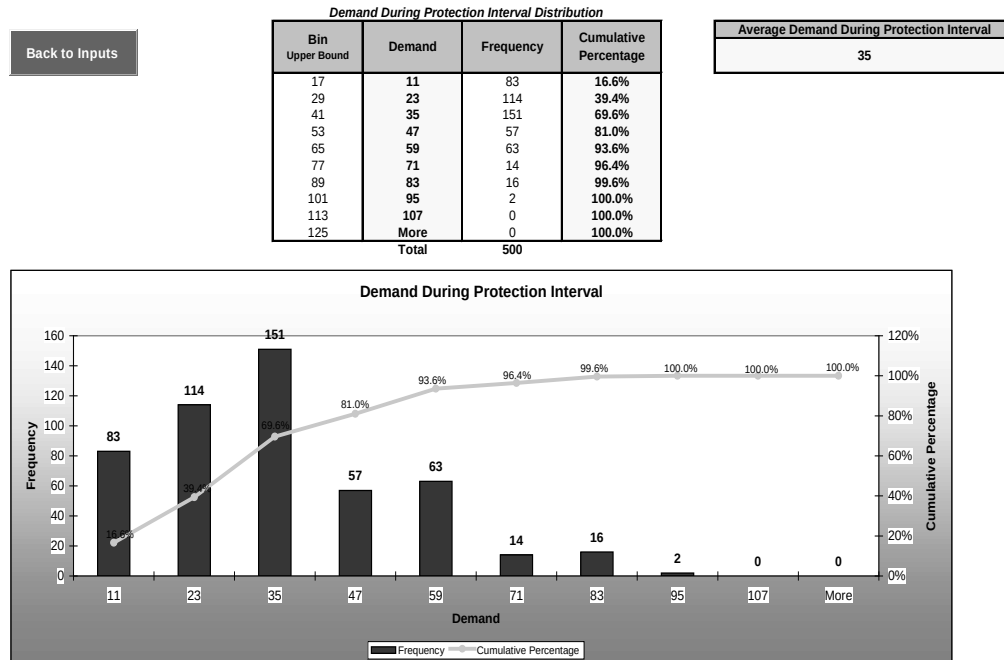
Day	Beginning Inventory	Open Orders Received	Daily Demand	Ending Inventory	Inventory Position	Amount Ordered
1	19	0	5	14	14	30
2	14	0	3	11	41	
3	11	0	4	7	37	
4	7	30	1	36	36	
5	36	0	10	26	26	
Sat 6	26	0	9	17	17	30
Mon 7	17	0	7	10	40	
8	10	0	4	6	36	
9	6	30	2	34	34	
10	34	0	7	27	27	
11	27	0	3	24	24	
12	24	0	6	18	18	30
13	18	0	10	8	38	
14	8	0	0	8	38	
15	8	30	5	33	33	
16	33	0	10	23	23	
17	23	0	4	19	19	30
18	19	0	7	12	42	
TOTAL				333		
AVERAGE				18.50		

The average level of ending inventory is 18.5 units and no stockouts occur. However, one additional order is placed.

myomlab ADVANCED PROBLEMS

1. Office Supply Shop

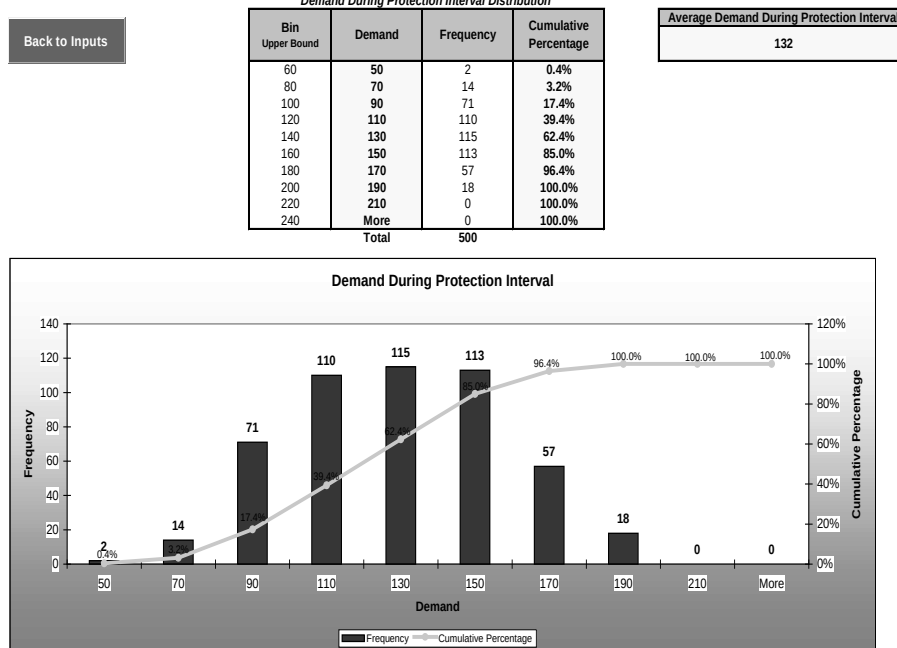
The screen shot below is taken from OM Explorer Solver – Demand During Protection Interval Simulator. It shows the results of 500 trials.



- a. Given the simulation, the value of R must yield a service level that meets or exceeds the desired value of 95%. That value of R is 71 pens, which will yield a cycle service level of 96.4%.
- b. The average demand during the protection interval is 35 pens. Since the reorder point is 71, the safety stock must be $71 - 35 = 36$ pens. The high level of safety stock is necessary because of the high variance in the demand during protection interval distribution and the high variance in lead time.

2. Grocery store.

- a. The target level (T) should be 150 tubes of Happy Breath Toothpaste. This result comes from OM Explorer Solver – Demand During Protection Interval Simulator.

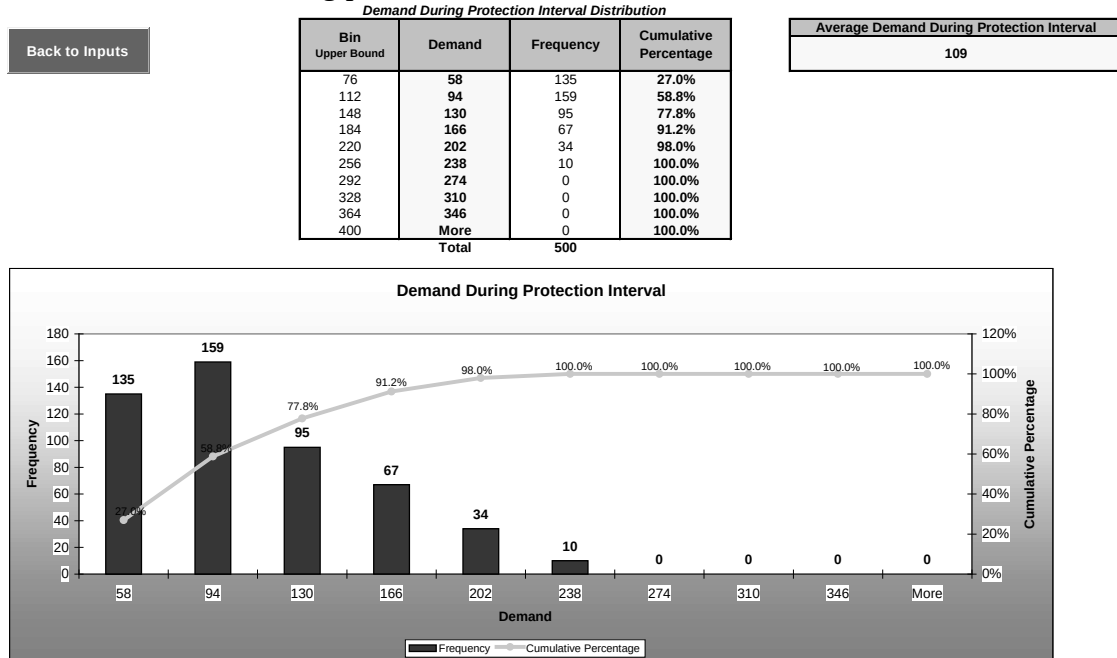


- b. Using OM Explorer once again, the cycle-service level for $T = 150$ would be 97.8%. Eliminating the variance in supply lead times will significantly increase the cycle service level of the inventory.

3. Floral shop
- a. The EOQ for the continuous review system would be as follows.

$$Q = \sqrt{\frac{2(2550)(\$30)}{\$1}} = 391$$

The demand during protection interval distribution is shown below.



To attain at least a 90% cycle service level, the florist needs to set the reorder point at 166 baskets.

- b. As the output from OM Explorer Solver – Q-System Simulator shows, the average cost per day is \$274.74.

Probability of Weekly Demand

Probability of Demand	Lower Range Probability	Demand (Units)
0.40	0.00	40
0.30	0.40	50
0.15	0.70	60
0.10	0.85	70
0.05	0.95	80
1.00		

Probability of Lead Time

Probability of Lead Time	Lower Range Probability	Lead Time (Periods)
0.30	0.00	1
0.40	0.30	2
0.20	0.70	3
0.10	0.90	4
0.00	1.00	5
1.00		

Holding Cost (\$/unit/period) \$ 1.0
 Order Cost (\$/order) \$ 30
 Stockout Cost (\$/unit) \$ 10

Order Size 391
 Reorder Point 166
 Beginning Inventory 300

Random Numbers

RN I Demand	RN II Lead Time
0.6586	0.8794
0.4101	0.2609
0.8676	0.5330
0.2831	0.8584
0.4569	0.8724
0.9689	0.9560
0.1591	0.2470
0.9864	0.9519
0.4978	0.8590
0.0223	0.7551
0.5906	0.2691
0.8835	0.4734
0.1373	0.4465
0.0001	0.4061
0.7819	0.4404
0.9917	0.8927
0.5232	0.2572
0.7593	0.2128
0.3090	0.8100
0.5006	0.6821
0.4173	0.5249
0.8148	0.4963
0.2962	0.2767
0.3003	0.1054
0.3560	0.7946
0.9473	0.9374
0.7621	0.0953
0.4240	0.2803
0.9240	0.2087
0.3494	0.8918
0.9098	0.0755
0.0235	0.3544
0.2316	0.1659
0.6310	0.8530
0.8768	0.9013
0.8892	0.4419
0.4683	0.6197
0.3062	0.4341
0.3298	0.9087
0.1754	0.7790
0.2214	0.3099
0.8985	0.4848
0.8108	0.2892
0.7581	0.4780
0.7205	0.4660
0.1673	0.4669
0.7142	0.3310
0.8320	0.0554
0.9648	0.1822
0.5548	0.1393

Simulation of 50 Weeks

Week	Beginning Inventory	Simulated Demand	Ending Inventory	Stockout Units	Place Order?	Simulated Lead Time	Days to Receive Order	Holding Cost	Ordering Cost	Stockout Cost	Total Cost
1	300	50	250	0	No	-	-	\$ 275	\$ -	\$ -	\$ 275
2	250	50	200	0	No	-	-	\$ 225	\$ -	\$ -	\$ 225
3	200	70	130	0	Yes	2	2	\$ 165	\$ 30	\$ -	\$ 195
4	130	40	90	0	No	-	1	\$ 110	\$ -	\$ -	\$ 110
5	481	50	431	0	No	-	0	\$ 456	\$ -	\$ -	\$ 456
6	431	70	361	0	No	-	-	\$ 396	\$ -	\$ -	\$ 396
7	361	40	321	0	No	-	-	\$ 341	\$ -	\$ -	\$ 341
8	321	80	241	0	No	-	-	\$ 281	\$ -	\$ -	\$ 281
9	241	50	191	0	No	-	-	\$ 216	\$ -	\$ -	\$ 216
10	191	40	151	0	Yes	3	3	\$ 171	\$ 30	\$ -	\$ 201
11	151	50	101	0	No	-	2	\$ 126	\$ -	\$ -	\$ 126
12	101	70	31	0	No	-	1	\$ 66	\$ -	\$ -	\$ 66
13	422	40	382	0	No	-	0	\$ 402	\$ -	\$ -	\$ 402
14	382	40	342	0	No	-	-	\$ 362	\$ -	\$ -	\$ 362
15	342	60	282	0	No	-	-	\$ 312	\$ -	\$ -	\$ 312
16	282	80	202	0	No	-	-	\$ 242	\$ -	\$ -	\$ 242
17	202	50	152	0	Yes	1	1	\$ 177	\$ 30	\$ -	\$ 207
18	543	60	483	0	No	-	0	\$ 513	\$ -	\$ -	\$ 513
19	483	40	443	0	No	-	-	\$ 463	\$ -	\$ -	\$ 463
20	443	50	393	0	No	-	-	\$ 418	\$ -	\$ -	\$ 418
21	393	50	343	0	No	-	-	\$ 368	\$ -	\$ -	\$ 368
22	343	60	283	0	No	-	-	\$ 313	\$ -	\$ -	\$ 313
23	283	40	243	0	No	-	-	\$ 263	\$ -	\$ -	\$ 263
24	243	40	203	0	No	-	-	\$ 223	\$ -	\$ -	\$ 223
25	203	40	163	0	Yes	3	3	\$ 183	\$ 30	\$ -	\$ 213
26	163	70	93	0	No	-	2	\$ 128	\$ -	\$ -	\$ 128
27	93	60	33	0	No	-	1	\$ 63	\$ -	\$ -	\$ 63
28	424	50	374	0	No	-	0	\$ 399	\$ -	\$ -	\$ 399
29	374	70	304	0	No	-	-	\$ 339	\$ -	\$ -	\$ 339
30	304	40	264	0	No	-	-	\$ 284	\$ -	\$ -	\$ 284
31	264	70	194	0	No	-	-	\$ 229	\$ -	\$ -	\$ 229
32	194	40	154	0	Yes	2	2	\$ 174	\$ 30	\$ -	\$ 204
33	154	40	114	0	No	-	1	\$ 134	\$ -	\$ -	\$ 134
34	505	50	455	0	No	-	0	\$ 480	\$ -	\$ -	\$ 480
35	455	70	385	0	No	-	-	\$ 420	\$ -	\$ -	\$ 420
36	385	70	315	0	No	-	-	\$ 350	\$ -	\$ -	\$ 350
37	315	50	265	0	No	-	-	\$ 290	\$ -	\$ -	\$ 290
38	265	40	225	0	No	-	-	\$ 245	\$ -	\$ -	\$ 245
39	225	40	185	0	No	-	-	\$ 205	\$ -	\$ -	\$ 205
40	185	40	145	0	Yes	3	3	\$ 165	\$ 30	\$ -	\$ 195
41	145	40	105	0	No	-	2	\$ 125	\$ -	\$ -	\$ 125
42	105	70	35	0	No	-	1	\$ 70	\$ -	\$ -	\$ 70
43	426	60	366	0	No	-	0	\$ 396	\$ -	\$ -	\$ 396
44	366	60	306	0	No	-	-	\$ 336	\$ -	\$ -	\$ 336
45	306	60	246	0	No	-	-	\$ 276	\$ -	\$ -	\$ 276
46	246	40	206	0	No	-	-	\$ 226	\$ -	\$ -	\$ 226
47	206	60	146	0	Yes	2	2	\$ 176	\$ 30	\$ -	\$ 206
48	146	60	86	0	No	-	1	\$ 116	\$ -	\$ -	\$ 116
49	477	80	397	0	No	-	0	\$ 437	\$ -	\$ -	\$ 437
50	397	50	347	0	No	-	-	\$ 372	\$ -	\$ -	\$ 372
Averages	296.94	53.80	243.14	0.00		2.29		\$270.04	\$4.20	\$0.00	\$274.24

EXPERIENTIAL LEARNING: SWIFT ELECTRONIC SUPPLY, INC.

This in-class exercise allows students to test an inventory system of their design against a new demand set. On the day of the simulation, students should come with sufficient copies of Table 1.

TABLE 1	Simulation Evaluation Sheet									
Day	1	2	3	4	5	6	7	8	9	10
Beginning inventory position										
Number ordered										
Daily demand										
Day-ending inventory										
Ordering costs (\$200 per order)										
Holding costs (\$0.05 per piece per day)										
Shortage costs (\$2 per piece)										
Total cost for day										
Cumulative cost from last day										
Cumulative costs to date										

It is best to precede the simulation with a brief overview of the simulation process and the calculation of costs. The instructor may decide to require students to bring a computer to class and use a spreadsheet of their design to accomplish the tasks embodied in Table 1.

Once everyone understands the simulation procedure, the instructor uses the “actual” demands in TN1, one at a time, and proceeding at a pace such that students have a chance to decide whether or not to order that period, how much to order, and calculate relevant costs. The instructor can stop at any point, using TN2 to benchmark students’ results against any of the four provided systems in this manual. A good idea is to stop at the halfway point in the simulation and ask students what their total costs are. The variance is often quite high. The same benchmarking comparisons can be done at the end of the simulation. The instructor can use the students’ results to discuss differences in the systems tried, the importance of using safety stocks, and the value of perfect information. One of the provided systems in this manual utilizes the Wagner-Whitin (WW) approach, which is optimal for perfect forecasts.

The variance in student results will be greater if this exercise is used as a prelude to a discussion of formal inventory systems (such as the *Q*-system or *P*-system). Alternatively, the exercise can be used after a presentation of the formal systems to give students a practicum for the theory.

TN3 shows the cost structure and system parameters for the EOQ-system, *Q*-system and *P*-system. All the relevant case information and derived data are on the left side of the sheet, and key computed parameters for three systems are presented on the right side of the sheet. There are some other points that need to be addressed about TN3 through TN7:

- “Average Demand/day” and “Standard Deviation” come from a statistical analysis of the historical demand data in Table 9.3.
- All the ordering quantities are rounded up as integers. Consequently, the associated costs might differ a little from what they actually are.
- The review time in the EOQ-system is actually up to the student. In TN4 we have used the EOQ divided by average daily demand.

TN4 through TN6 show the application of the provided systems for the demand data in TN1. TN7 shows the results from WW system. In all of our reported results, inventory levels at the start of the day are used to make inventory decisions. This is consistent with the daily purchasing routine at Swift.

Economic Order Quantity (EOQ) System

Under this system, students order the EOQ each and every review period, which using the case data would be 3 days, without any forecasts of future demand or consideration of demand variability. TN4 shows the performance of this system. Students may elect to use varying review periods. If so, their results will differ from TN4.

Q-system

This system assumes that inventory levels are checked on a daily basis and compared to a “Reorder Point (RP).” If actual inventory level goes below the RP, an order of EOQ is placed; if above, no order will be placed. In the provided results, the RP is calculated by adding safety stock to average demand during the two-day lead time. The safety stock is designed to meet the 95 percent cycle service level. TN5 shows the results of the Q-system.

P-system

The inventory level is reviewed every three days, which is determined by dividing EOQ by average demand. The target inventory level is composed of two parts: “average demand during the protection interval,” which is the review period plus the lead time, and the “safety stock.” Every review period (three days in the provided results), an order is placed to bring the inventory position up to the target inventory level. TN6 shows the performance of the P-system.

Wager-Whitin (WW) System

The WW system is based on dynamic programming and assumes all demands are known with certainty. Consequently, it provides an absolute lower bound on the solution found by the students. The WW system assumes that stockouts are to be avoided. It is interesting to show the difference in total costs between the WW solution and another system because it demonstrates the cost of uncertainty. The solution using the WW system is shown in TN7. Also note that the lot sizes are shown in the day in which they must *arrive*. Actual release dates would be two days earlier. This implies that the first order for 1733 would have been placed in day 0, one day before the actual start of the simulation.

TN 1. Actual Demand Data for Simulation

Day	Demand	Day	Demand	Day	Demand
1	870	21	961	41	993
2	901	22	828	42	1008
3	960	23	764	43	852
4	702	24	933	44	725
5	1068	25	960	45	667
6	975	26	988	46	1015
7	977	27	1028	47	1167
8	662	28	967	48	878
9	1147	29	918	49	824
10	1085	30	965	50	863
11	1041	31	1068	51	1085
12	890	32	996	52	1067
13	1001	33	1123	53	930
14	960	34	855	54	1021
15	863	35	1035	55	828
16	794	36	1085	56	724
17	1109	37	824	57	987
18	948	38	941	58	737
19	1040	39	883	59	750
20	1008	40	828	60	765

TN 2. Total Costs for Four Systems

Day	Demand	EOQ System	Q-System	P-System	WW Solution
1	870	\$ 241.50	\$ 241.50	\$ 241.50	\$ 41.50
2	901	\$ 383.50	\$ 383.50	\$ 383.50	\$ 324.60
3	960	\$ 471.70	\$ 671.70	\$ 548.95	\$ 359.70
4	702	\$ 724.80	\$ 724.80	\$ 879.30	\$ 359.70
5	1068	\$ 736.80	\$ 860.70	\$ 956.25	\$ 690.40
6	975	\$ 824.25	\$ 1,147.85	\$ 1,109.05	\$ 772.35
7	977	\$ 1,062.85	\$ 1,186.15	\$ 1,413.00	\$ 805.45
8	662	\$ 1,068.35	\$ 1,327.55	\$ 1,483.85	\$ 805.45
9	1147	\$ 1,152.70	\$ 1,611.60	\$ 1,648.35	\$ 1,059.70
10	1085	\$ 1,382.80	\$ 1,641.40	\$ 1,958.60	\$ 1,059.70
11	1041	\$ 2,260.80	\$ 1,755.35	\$ 2,016.80	\$ 1,354.25
12	890	\$ 2,352.50	\$ 2,024.80	\$ 2,175.20	\$ 1,404.30
13	1001	\$ 2,594.15	\$ 2,044.20	\$ 2,483.55	\$ 1,404.30
14	960	\$ 2,848.15	\$ 2,151.80	\$ 2,543.90	\$ 1,687.15
15	863	\$ 2,941.20	\$ 2,416.25	\$ 2,707.70	\$ 1,726.85
16	794	\$ 3,194.55	\$ 2,441.00	\$ 3,031.80	\$ 1,726.85
17	1109	\$ 3,278.55	\$ 2,746.50	\$ 3,100.45	\$ 2,026.25
18	948	\$ 3,367.35	\$ 2,804.60	\$ 3,252.55	\$ 2,078.25
19	1040	\$ 3,604.15	\$ 2,946.90	\$ 3,552.65	\$ 2,078.25
20	1008	\$ 4,148.15	\$ 3,238.80	\$ 3,602.35	\$ 2,367.70
21	961	\$ 4,236.30	\$ 3,282.65	\$ 3,758.85	\$ 2,409.10
22	828	\$ 4,483.05	\$ 3,421.30	\$ 4,073.95	\$ 2,409.10
23	764	\$ 4,491.60	\$ 3,721.75	\$ 4,150.85	\$ 2,703.75
24	933	\$ 4,589.70	\$ 3,775.55	\$ 4,320.95	\$ 2,751.75
25	960	\$ 4,839.80	\$ 3,917.55	\$ 4,643.05	\$ 2,751.75
26	988	\$ 4,840.50	\$ 4,210.15	\$ 4,715.75	\$ 3,051.50
27	1028	\$ 4,926.00	\$ 4,251.35	\$ 4,869.90	\$ 3,099.85
28	967	\$ 5,163.15	\$ 4,380.40	\$ 5,175.70	\$ 3,099.85
29	918	\$ 5,513.15	\$ 4,663.55	\$ 5,235.60	\$ 3,401.50
30	965	\$ 5,601.10	\$ 4,698.45	\$ 5,396.40	\$ 3,454.90
31	1068	\$ 5,835.65	\$ 4,816.15	\$ 5,703.80	\$ 3,454.90
32	996	\$ 6,445.65	\$ 5,084.05	\$ 5,761.40	\$ 3,753.80
33	1123	\$ 6,525.70	\$ 5,095.80	\$ 5,910.40	\$ 3,796.55
34	855	\$ 6,763.00	\$ 5,401.00	\$ 6,216.65	\$ 3,796.55
35	1035	\$ 7,341.00	\$ 5,454.45	\$ 6,271.15	\$ 4,092.00
36	1085	\$ 7,422.95	\$ 5,589.85	\$ 6,420.10	\$ 4,133.20
37	824	\$ 7,663.70	\$ 5,884.05	\$ 6,727.85	\$ 4,133.20
38	941	\$ 7,915.70	\$ 5,931.20	\$ 6,788.55	\$ 4,418.75
39	883	\$ 8,007.75	\$ 6,070.40	\$ 6,952.30	\$ 4,460.15
40	828	\$ 8,258.40	\$ 6,368.20	\$ 7,274.65	\$ 4,460.15
41	993	\$ 8,259.40	\$ 6,416.35	\$ 7,347.35	\$ 4,753.15
42	1008	\$ 8,346.20	\$ 6,550.30	\$ 7,502.25	\$ 4,795.75
43	852	\$ 8,590.40	\$ 6,841.65	\$ 7,814.55	\$ 4,795.75
44	725	\$ 8,598.35	\$ 6,896.75	\$ 7,890.60	\$ 5,079.85
45	667	\$ 8,709.15	\$ 7,054.70	\$ 8,075.95	\$ 5,130.60
46	1015	\$ 8,969.20	\$ 7,361.90	\$ 8,410.55	\$ 5,130.60
47	1167	\$ 8,970.90	\$ 7,410.75	\$ 8,486.80	\$ 5,458.85
48	878	\$ 9,064.90	\$ 7,551.90	\$ 8,639.50	\$ 5,543.20
49	824	\$ 9,317.70	\$ 7,851.85	\$ 8,951.00	\$ 5,586.35
50	863	\$ 9,327.35	\$ 7,908.65	\$ 9,019.35	\$ 5,586.35
51	1085	\$ 9,418.95	\$ 8,047.40	\$ 9,176.90	\$ 5,886.20
52	1067	\$ 9,657.20	\$ 8,332.80	\$ 9,481.10	\$ 5,932.70
53	930	\$ 9,987.20	\$ 8,371.70	\$ 9,538.80	\$ 5,932.70
54	1021	\$ 10,072.35	\$ 8,495.75	\$ 9,696.20	\$ 6,210.30
55	828	\$ 10,316.10	\$ 8,778.40	\$ 10,012.20	\$ 6,246.50
56	724	\$ 10,323.65	\$ 8,824.85	\$ 10,092.00	\$ 6,246.50
57	987	\$ 10,418.05	\$ 8,958.15	\$ 10,261.40	\$ 6,559.10
58	737	\$ 10,675.60	\$ 9,254.60	\$ 10,593.95	\$ 6,634.85
59	750	\$ 10,695.65	\$ 9,313.55	\$ 10,689.00	\$ 6,673.10
60	765	\$ 10,813.65	\$ 9,470.45	\$ 10,868.20	\$ 6,673.10

TN 3. Cost Structure and System Parameters**In-case information**

Cost of DRAM/piece	\$	10.00
Ordering cost/lot (S)	\$	200.00
Stockout cost/piece per day	\$	2.00
Holding Cost (% of Cost of DRAM per day)		0.50%
Beginning balance		1700
The cycle inventory service level		95%
Lead time (Days)		2

Data referred

Z value at 95% confidence interval		1.645
Average Demand/day		927
Standard Deviation		126
Holding Cost/day	\$	0.05
EOQ		2724

EOQ System

Average time between orders	3
Order Amount	2724
Review time in EOQ system	3

Q system

Average demand during lead time	1854
Safety stock	294
Reorder Point for Q system	2148

P system

Average demand during the protection interval	4635
Safety stock	464
Review Period	3
Targeted Inventory Level	5099

TN 4. EOQ System

Day	Demand	Order quantity	Beginning Inventory	Ending Inventory with Back orders	Actual Ending Inventory	Holding Cost	Stockout Cost	Order Cost	Daily total Cost	Accumulative Costs from Last Day	Accumulative Cost to Date
1	870	2724	1700	830	830	\$ 41.50	\$ -	\$ 200.00	\$ 241.50	\$ -	\$ 241.50
2	901		830	-71	0	\$ -	\$ 142.00	\$ -	\$ 142.00	\$ 241.50	\$ 383.50
3	960		2724	1764	1764	\$ 88.20	\$ -	\$ -	\$ 88.20	\$ 383.50	\$ 471.70
4	702	2724	1764	1062	1062	\$ 53.10	\$ -	\$ 200.00	\$ 253.10	\$ 471.70	\$ 724.80
5	1068		1062	-6	0	\$ -	\$ 12.00	\$ -	\$ 12.00	\$ 724.80	\$ 736.80
6	975		2724	1749	1749	\$ 87.45	\$ -	\$ -	\$ 87.45	\$ 736.80	\$ 824.25
7	977	2724	1749	772	772	\$ 38.60	\$ -	\$ 200.00	\$ 238.60	\$ 824.25	\$ 1,062.85
8	662		772	110	110	\$ 5.50	\$ -	\$ -	\$ 5.50	\$ 1,062.85	\$ 1,068.35
9	1147		2834	1687	1687	\$ 84.35	\$ -	\$ -	\$ 84.35	\$ 1,068.35	\$ 1,152.70
10	1085	2724	1687	602	602	\$ 30.10	\$ -	\$ 200.00	\$ 230.10	\$ 1,152.70	\$ 1,382.80
11	1041		602	-439	0	\$ -	\$ 878.00	\$ -	\$ 878.00	\$ 1,382.80	\$ 2,260.80
12	890		2724	1834	1834	\$ 91.70	\$ -	\$ -	\$ 91.70	\$ 2,260.80	\$ 2,352.50
13	1001	2724	1834	833	833	\$ 41.65	\$ -	\$ 200.00	\$ 241.65	\$ 2,352.50	\$ 2,594.15
14	960		833	-127	0	\$ -	\$ 254.00	\$ -	\$ 254.00	\$ 2,594.15	\$ 2,848.15
15	863		2724	1861	1861	\$ 93.05	\$ -	\$ -	\$ 93.05	\$ 2,848.15	\$ 2,941.20
16	794	2724	1861	1067	1067	\$ 53.35	\$ -	\$ 200.00	\$ 253.35	\$ 2,941.20	\$ 3,194.55
17	1109		1067	-42	0	\$ -	\$ 84.00	\$ -	\$ 84.00	\$ 3,194.55	\$ 3,278.55
18	948		2724	1776	1776	\$ 88.80	\$ -	\$ -	\$ 88.80	\$ 3,278.55	\$ 3,367.35
19	1040	2724	1776	736	736	\$ 36.80	\$ -	\$ 200.00	\$ 236.80	\$ 3,367.35	\$ 3,604.15
20	1008		736	-272	0	\$ -	\$ 544.00	\$ -	\$ 544.00	\$ 3,604.15	\$ 4,148.15
21	961		2724	1763	1763	\$ 88.15	\$ -	\$ -	\$ 88.15	\$ 4,148.15	\$ 4,236.30
22	828	2724	1763	935	935	\$ 46.75	\$ -	\$ 200.00	\$ 246.75	\$ 4,236.30	\$ 4,483.05
23	764		935	171	171	\$ 8.55	\$ -	\$ -	\$ 8.55	\$ 4,483.05	\$ 4,491.60
24	933		2895	1962	1962	\$ 98.10	\$ -	\$ -	\$ 98.10	\$ 4,491.60	\$ 4,589.70
25	960	2724	1962	1002	1002	\$ 50.10	\$ -	\$ 200.00	\$ 250.10	\$ 4,589.70	\$ 4,839.80
26	988		1002	14	14	\$ 0.70	\$ -	\$ -	\$ 0.70	\$ 4,839.80	\$ 4,840.50
27	1028		2738	1710	1710	\$ 85.50	\$ -	\$ -	\$ 85.50	\$ 4,840.50	\$ 4,926.00
28	967	2724	1710	743	743	\$ 37.15	\$ -	\$ 200.00	\$ 237.15	\$ 4,926.00	\$ 5,163.15
29	918		743	-175	0	\$ -	\$ 350.00	\$ -	\$ 350.00	\$ 5,163.15	\$ 5,513.15
30	965		2724	1759	1759	\$ 87.95	\$ -	\$ -	\$ 87.95	\$ 5,513.15	\$ 5,601.10
31	1068	2724	1759	691	691	\$ 34.55	\$ -	\$ 200.00	\$ 234.55	\$ 5,601.10	\$ 5,835.65
32	996		691	-305	0	\$ -	\$ 610.00	\$ -	\$ 610.00	\$ 5,835.65	\$ 6,445.65
33	1123		2724	1601	1601	\$ 80.05	\$ -	\$ -	\$ 80.05	\$ 6,445.65	\$ 6,525.70
34	855	2724	1601	746	746	\$ 37.30	\$ -	\$ 200.00	\$ 237.30	\$ 6,525.70	\$ 6,763.00
35	1035		746	-289	0	\$ -	\$ 578.00	\$ -	\$ 578.00	\$ 6,763.00	\$ 7,341.00
36	1085		2724	1639	1639	\$ 81.95	\$ -	\$ -	\$ 81.95	\$ 7,341.00	\$ 7,422.95
37	824	2724	1639	815	815	\$ 40.75	\$ -	\$ 200.00	\$ 240.75	\$ 7,422.95	\$ 7,663.70
38	941		815	-126	0	\$ -	\$ 252.00	\$ -	\$ 252.00	\$ 7,663.70	\$ 7,915.70
39	883		2724	1841	1841	\$ 92.05	\$ -	\$ -	\$ 92.05	\$ 7,915.70	\$ 8,007.75
40	828	2724	1841	1013	1013	\$ 50.65	\$ -	\$ 200.00	\$ 250.65	\$ 8,007.75	\$ 8,258.40
41	993		1013	20	20	\$ 1.00	\$ -	\$ -	\$ 1.00	\$ 8,258.40	\$ 8,259.40
42	1008		2744	1736	1736	\$ 86.80	\$ -	\$ -	\$ 86.80	\$ 8,259.40	\$ 8,346.20
43	852	2724	1736	884	884	\$ 44.20	\$ -	\$ 200.00	\$ 244.20	\$ 8,346.20	\$ 8,590.40
44	725		884	159	159	\$ 7.95	\$ -	\$ -	\$ 7.95	\$ 8,590.40	\$ 8,598.35
45	667		2883	2216	2216	\$ 110.80	\$ -	\$ -	\$ 110.80	\$ 8,598.35	\$ 8,709.15
46	1015	2724	2216	1201	1201	\$ 60.05	\$ -	\$ 200.00	\$ 260.05	\$ 8,709.15	\$ 8,969.20
47	1167		1201	34	34	\$ 1.70	\$ -	\$ -	\$ 1.70	\$ 8,969.20	\$ 8,970.90
48	878		2758	1880	1880	\$ 94.00	\$ -	\$ -	\$ 94.00	\$ 8,970.90	\$ 9,064.90
49	824	2724	1880	1056	1056	\$ 52.80	\$ -	\$ 200.00	\$ 252.80	\$ 9,064.90	\$ 9,317.70
50	863		1056	193	193	\$ 9.65	\$ -	\$ -	\$ 9.65	\$ 9,317.70	\$ 9,327.35
51	1085		2917	1832	1832	\$ 91.60	\$ -	\$ -	\$ 91.60	\$ 9,327.35	\$ 9,418.95
52	1067	2724	1832	765	765	\$ 38.25	\$ -	\$ 200.00	\$ 238.25	\$ 9,418.95	\$ 9,657.20
53	930		765	-165	0	\$ -	\$ 330.00	\$ -	\$ 330.00	\$ 9,657.20	\$ 9,987.20
54	1021		2724	1703	1703	\$ 85.15	\$ -	\$ -	\$ 85.15	\$ 9,987.20	\$ 10,072.35
55	828	2724	1703	875	875	\$ 43.75	\$ -	\$ 200.00	\$ 243.75	\$ 10,072.35	\$ 10,316.10
56	724		875	151	151	\$ 7.55	\$ -	\$ -	\$ 7.55	\$ 10,316.10	\$ 10,323.65
57	987		2875	1888	1888	\$ 94.40	\$ -	\$ -	\$ 94.40	\$ 10,323.65	\$ 10,418.05
58	737	2724	1888	1151	1151	\$ 57.55	\$ -	\$ 200.00	\$ 257.55	\$ 10,418.05	\$ 10,675.60
59	750		1151	401	401	\$ 20.05	\$ -	\$ -	\$ 20.05	\$ 10,675.60	\$ 10,695.65
60	765		3125	2360	2360	\$ 118.00	\$ -	\$ -	\$ 118.00	\$ 10,695.65	\$ 10,813.65
Average					927	\$ 46.33	\$ 67.23	\$ 66.67	\$ 180.23		
EOQ		2724									

TN 5. Q-System

Day	Beginning Inventory	Demand	Ending Inventory with Back Orders	Actual Ending Inventory	Inventory Position	Order Quantity	Holding Cost	Stockout Cost	Ordering Cost	Daily Total Cost	Accumulative Costs from Last Day	Accumulative Cost to Date
1	1700	870	830	830	830	2724	\$ 41.50	\$ -	\$ 200.00	\$ 241.50	\$ -	\$ 241.50
2	830	901	-71	0	2724	0	\$ -	\$ 142.00	\$ -	\$ 142.00	\$ 241.50	\$ 383.50
3	2724	960	1764	1764	1764	2724	\$ 88.20	\$ -	\$ 200.00	\$ 288.20	\$ 383.50	\$ 671.70
4	1764	702	1062	1062	3786	0	\$ 53.10	\$ -	\$ -	\$ 53.10	\$ 671.70	\$ 724.80
5	3786	1068	2718	2718	2718	0	\$ 135.90	\$ -	\$ -	\$ 135.90	\$ 724.80	\$ 860.70
6	2718	975	1743	1743	1743	2724	\$ 87.15	\$ -	\$ 200.00	\$ 287.15	\$ 860.70	\$ 1,147.85
7	1743	977	766	766	3490	0	\$ 38.30	\$ -	\$ -	\$ 38.30	\$ 1,147.85	\$ 1,186.15
8	3490	662	2828	2828	2828	0	\$ 141.40	\$ -	\$ -	\$ 141.40	\$ 1,186.15	\$ 1,327.55
9	2828	1147	1681	1681	1681	2724	\$ 84.05	\$ -	\$ 200.00	\$ 284.05	\$ 1,327.55	\$ 1,611.60
10	1681	1085	596	596	3320	0	\$ 29.80	\$ -	\$ -	\$ 29.80	\$ 1,611.60	\$ 1,641.40
11	3320	1041	2279	2279	2279	0	\$ 113.95	\$ -	\$ -	\$ 113.95	\$ 1,641.40	\$ 1,755.35
12	2279	890	1389	1389	1389	2724	\$ 69.45	\$ -	\$ 200.00	\$ 269.45	\$ 1,755.35	\$ 2,024.80
13	1389	1001	388	388	3112	0	\$ 19.40	\$ -	\$ -	\$ 19.40	\$ 2,024.80	\$ 2,044.20
14	3112	960	2152	2152	2152	0	\$ 107.60	\$ -	\$ -	\$ 107.60	\$ 2,044.20	\$ 2,151.80
15	2152	863	1289	1289	1289	2724	\$ 64.45	\$ -	\$ 200.00	\$ 264.45	\$ 2,151.80	\$ 2,416.25
16	1289	794	495	495	3219	0	\$ 24.75	\$ -	\$ -	\$ 24.75	\$ 2,416.25	\$ 2,441.00
17	3219	1109	2110	2110	2110	2724	\$ 105.50	\$ -	\$ 200.00	\$ 305.50	\$ 2,441.00	\$ 2,746.50
18	2110	948	1162	1162	3886	0	\$ 58.10	\$ -	\$ -	\$ 58.10	\$ 2,746.50	\$ 2,804.60
19	3886	1040	2846	2846	2846	0	\$ 142.30	\$ -	\$ -	\$ 142.30	\$ 2,804.60	\$ 2,946.90
20	2846	1008	1838	1838	1838	2724	\$ 91.90	\$ -	\$ 200.00	\$ 291.90	\$ 2,946.90	\$ 3,238.80
21	1838	961	877	877	3601	0	\$ 43.85	\$ -	\$ -	\$ 43.85	\$ 3,238.80	\$ 3,282.65
22	3601	828	2773	2773	2773	0	\$ 138.65	\$ -	\$ -	\$ 138.65	\$ 3,282.65	\$ 3,421.30
23	2773	764	2009	2009	2009	2724	\$ 100.45	\$ -	\$ 200.00	\$ 300.45	\$ 3,421.30	\$ 3,721.75
24	2009	933	1076	1076	3800	0	\$ 53.80	\$ -	\$ -	\$ 53.80	\$ 3,721.75	\$ 3,775.55
25	3800	960	2840	2840	2840	0	\$ 142.00	\$ -	\$ -	\$ 142.00	\$ 3,775.55	\$ 3,917.55
26	2840	988	1852	1852	1852	2724	\$ 92.60	\$ -	\$ 200.00	\$ 292.60	\$ 3,917.55	\$ 4,210.15
27	1852	1028	824	824	3548	0	\$ 41.20	\$ -	\$ -	\$ 41.20	\$ 4,210.15	\$ 4,251.35
28	3548	967	2581	2581	2581	0	\$ 129.05	\$ -	\$ -	\$ 129.05	\$ 4,251.35	\$ 4,380.40
29	2581	918	1663	1663	1663	2724	\$ 83.15	\$ -	\$ 200.00	\$ 283.15	\$ 4,380.40	\$ 4,663.55
30	1663	965	698	698	3422	0	\$ 34.90	\$ -	\$ -	\$ 34.90	\$ 4,663.55	\$ 4,698.45
31	3422	1068	2354	2354	2354	0	\$ 117.70	\$ -	\$ -	\$ 117.70	\$ 4,698.45	\$ 4,816.15
32	2354	996	1358	1358	1358	2724	\$ 67.90	\$ -	\$ 200.00	\$ 267.90	\$ 4,816.15	\$ 5,084.05
33	1358	1123	235	235	2959	0	\$ 11.75	\$ -	\$ -	\$ 11.75	\$ 5,084.05	\$ 5,095.80
34	2959	855	2104	2104	2104	2724	\$ 105.20	\$ -	\$ 200.00	\$ 305.20	\$ 5,095.80	\$ 5,401.00
35	2104	1035	1069	1069	3793	0	\$ 53.45	\$ -	\$ -	\$ 53.45	\$ 5,401.00	\$ 5,454.45
36	3793	1085	2708	2708	2708	0	\$ 135.40	\$ -	\$ -	\$ 135.40	\$ 5,454.45	\$ 5,589.85
37	2708	824	1884	1884	1884	2724	\$ 94.20	\$ -	\$ 200.00	\$ 294.20	\$ 5,589.85	\$ 5,884.05
38	1884	941	943	943	3667	0	\$ 47.15	\$ -	\$ -	\$ 47.15	\$ 5,884.05	\$ 5,931.20
39	3667	883	2784	2784	2784	0	\$ 139.20	\$ -	\$ -	\$ 139.20	\$ 5,931.20	\$ 6,070.40
40	2784	828	1956	1956	1956	2724	\$ 97.80	\$ -	\$ 200.00	\$ 297.80	\$ 6,070.40	\$ 6,368.20
41	1956	993	963	963	3687	0	\$ 48.15	\$ -	\$ -	\$ 48.15	\$ 6,368.20	\$ 6,416.35
42	3687	1008	2679	2679	2679	0	\$ 133.95	\$ -	\$ -	\$ 133.95	\$ 6,416.35	\$ 6,550.30
43	2679	852	1827	1827	1827	2724	\$ 91.35	\$ -	\$ 200.00	\$ 291.35	\$ 6,550.30	\$ 6,841.65
44	1827	725	1102	1102	3826	0	\$ 55.10	\$ -	\$ -	\$ 55.10	\$ 6,841.65	\$ 6,896.75
45	3826	667	3159	3159	3159	0	\$ 157.95	\$ -	\$ -	\$ 157.95	\$ 6,896.75	\$ 7,054.70
46	3159	1015	2144	2144	2144	2724	\$ 107.20	\$ -	\$ 200.00	\$ 307.20	\$ 7,054.70	\$ 7,361.90
47	2144	1167	977	977	3701	0	\$ 48.85	\$ -	\$ -	\$ 48.85	\$ 7,361.90	\$ 7,410.75
48	3701	878	2823	2823	2823	0	\$ 141.15	\$ -	\$ -	\$ 141.15	\$ 7,410.75	\$ 7,551.90
49	2823	824	1999	1999	1999	2724	\$ 99.95	\$ -	\$ 200.00	\$ 299.95	\$ 7,551.90	\$ 7,851.85
50	1999	863	1136	1136	3860	0	\$ 56.80	\$ -	\$ -	\$ 56.80	\$ 7,851.85	\$ 7,908.65
51	3860	1085	2775	2775	2775	0	\$ 138.75	\$ -	\$ -	\$ 138.75	\$ 7,908.65	\$ 8,047.40
52	2775	1067	1708	1708	1708	2724	\$ 85.40	\$ -	\$ 200.00	\$ 285.40	\$ 8,047.40	\$ 8,332.80
53	1708	930	778	778	3502	0	\$ 38.90	\$ -	\$ -	\$ 38.90	\$ 8,332.80	\$ 8,371.70
54	3502	1021	2481	2481	2481	0	\$ 124.05	\$ -	\$ -	\$ 124.05	\$ 8,371.70	\$ 8,495.75
55	2481	828	1653	1653	1653	2724	\$ 82.65	\$ -	\$ 200.00	\$ 282.65	\$ 8,495.75	\$ 8,778.40
56	1653	724	929	929	3653	0	\$ 46.45	\$ -	\$ -	\$ 46.45	\$ 8,778.40	\$ 8,824.85
57	3653	987	2666	2666	2666	0	\$ 133.30	\$ -	\$ -	\$ 133.30	\$ 8,824.85	\$ 8,958.15
58	2666	737	1929	1929	1929	2724	\$ 96.45	\$ -	\$ 200.00	\$ 296.45	\$ 8,958.15	\$ 9,254.60
59	1929	750	1179	1179	3903	0	\$ 58.95	\$ -	\$ -	\$ 58.95	\$ 9,254.60	\$ 9,313.55
60	3903	765	3138	3138	3138	0	\$ 156.90	\$ -	\$ -	\$ 156.90	\$ 9,313.55	\$ 9,470.45
Average				1709.48	2662.88	953.40	85.47	2.37	70.00	157.84		
Reorder Point for Q System			2148									
Order Quantity			2724									



TN 6. P-System

Day	Beginning Inventory	Demand	Ending Inventory with Back orders	Actual Ending Inventory	Inventory Position	Order quantity	Holding Cost	Stockout Cost	Ordering Cost	Daily total Cost	Accumulative Costs from Last Day	Accumulative Cost to Date
1	1700	870	830	830	830	4269	\$ 41.50	\$ -	\$ 200.00	\$ 241.50	\$ -	\$ 241.50
2	830	901	-71	0	4269		\$ -	\$ 142.00	\$ -	\$ 142.00	\$ 241.50	\$ 383.50
3	4269	960	3309	3309	3309		\$ 165.45	\$ -	\$ -	\$ 165.45	\$ 383.50	\$ 548.95
4	3309	702	2607	2607	2607	2492	\$ 130.35	\$ -	\$ 200.00	\$ 330.35	\$ 548.95	\$ 879.30
5	2607	1068	1539	1539	4031		\$ 76.95	\$ -	\$ -	\$ 76.95	\$ 879.30	\$ 956.25
6	4031	975	3056	3056	3056		\$ 152.80	\$ -	\$ -	\$ 152.80	\$ 956.25	\$ 1,109.05
7	3056	977	2079	2079	2079	3020	\$ 103.95	\$ -	\$ 200.00	\$ 303.95	\$ 1,109.05	\$ 1,413.00
8	2079	662	1417	1417	4437		\$ 70.85	\$ -	\$ -	\$ 70.85	\$ 1,413.00	\$ 1,483.85
9	4437	1147	3290	3290	3290		\$ 164.50	\$ -	\$ -	\$ 164.50	\$ 1,483.85	\$ 1,648.35
10	3290	1085	2205	2205	2205	2894	\$ 110.25	\$ -	\$ 200.00	\$ 310.25	\$ 1,648.35	\$ 1,958.60
11	2205	1041	1164	1164	4058		\$ 58.20	\$ -	\$ -	\$ 58.20	\$ 1,958.60	\$ 2,016.80
12	4058	890	3168	3168	3168		\$ 158.40	\$ -	\$ -	\$ 158.40	\$ 2,016.80	\$ 2,175.20
13	3168	1001	2167	2167	2167	2932	\$ 108.35	\$ -	\$ 200.00	\$ 308.35	\$ 2,175.20	\$ 2,483.55
14	2167	960	1207	1207	4139		\$ 60.35	\$ -	\$ -	\$ 60.35	\$ 2,483.55	\$ 2,543.90
15	4139	863	3276	3276	3276		\$ 163.80	\$ -	\$ -	\$ 163.80	\$ 2,543.90	\$ 2,707.70
16	3276	794	2482	2482	2482	2617	\$ 124.10	\$ -	\$ 200.00	\$ 324.10	\$ 2,707.70	\$ 3,031.80
17	2482	1109	1373	1373	3990		\$ 68.65	\$ -	\$ -	\$ 68.65	\$ 3,031.80	\$ 3,100.45
18	3990	948	3042	3042	3042		\$ 152.10	\$ -	\$ -	\$ 152.10	\$ 3,100.45	\$ 3,252.55
19	3042	1040	2002	2002	2002	3097	\$ 100.10	\$ -	\$ 200.00	\$ 300.10	\$ 3,252.55	\$ 3,552.65
20	2002	1008	994	994	4091		\$ 49.70	\$ -	\$ -	\$ 49.70	\$ 3,552.65	\$ 3,602.35
21	4091	961	3130	3130	3130		\$ 156.50	\$ -	\$ -	\$ 156.50	\$ 3,602.35	\$ 3,758.85
22	3130	828	2302	2302	2302	2797	\$ 115.10	\$ -	\$ 200.00	\$ 315.10	\$ 3,758.85	\$ 4,073.95
23	2302	764	1538	1538	4335		\$ 76.90	\$ -	\$ -	\$ 76.90	\$ 4,073.95	\$ 4,150.85
24	4335	933	3402	3402	3402		\$ 170.10	\$ -	\$ -	\$ 170.10	\$ 4,150.85	\$ 4,320.95
25	3402	960	2442	2442	2442	2657	\$ 122.10	\$ -	\$ 200.00	\$ 322.10	\$ 4,320.95	\$ 4,643.05
26	2442	988	1454	1454	4111		\$ 72.70	\$ -	\$ -	\$ 72.70	\$ 4,643.05	\$ 4,715.75
27	4111	1028	3083	3083	3083		\$ 154.15	\$ -	\$ -	\$ 154.15	\$ 4,715.75	\$ 4,869.90
28	3083	967	2116	2116	2116	2983	\$ 105.80	\$ -	\$ 200.00	\$ 305.80	\$ 4,869.90	\$ 5,175.70
29	2116	918	1198	1198	4181		\$ 59.90	\$ -	\$ -	\$ 59.90	\$ 5,175.70	\$ 5,235.60
30	4181	965	3216	3216	3216		\$ 160.80	\$ -	\$ -	\$ 160.80	\$ 5,235.60	\$ 5,396.40
31	3216	1068	2148	2148	2148	2951	\$ 107.40	\$ -	\$ 200.00	\$ 307.40	\$ 5,396.40	\$ 5,703.80
32	2148	996	1152	1152	4103		\$ 57.60	\$ -	\$ -	\$ 57.60	\$ 5,703.80	\$ 5,761.40
33	4103	1123	2980	2980	2980		\$ 149.00	\$ -	\$ -	\$ 149.00	\$ 5,761.40	\$ 5,910.40
34	2980	855	2125	2125	2125	2974	\$ 106.25	\$ -	\$ 200.00	\$ 306.25	\$ 5,910.40	\$ 6,216.65
35	2125	1035	1090	1090	4064		\$ 54.50	\$ -	\$ -	\$ 54.50	\$ 6,216.65	\$ 6,271.15
36	4064	1085	2979	2979	2979		\$ 148.95	\$ -	\$ -	\$ 148.95	\$ 6,271.15	\$ 6,420.10
37	2979	824	2155	2155	2155	2944	\$ 107.75	\$ -	\$ 200.00	\$ 307.75	\$ 6,420.10	\$ 6,727.85
38	2155	941	1214	1214	4158		\$ 60.70	\$ -	\$ -	\$ 60.70	\$ 6,727.85	\$ 6,788.55
39	4158	883	3275	3275	3275		\$ 163.75	\$ -	\$ -	\$ 163.75	\$ 6,788.55	\$ 6,952.30
40	3275	828	2447	2447	2447	2652	\$ 122.35	\$ -	\$ 200.00	\$ 322.35	\$ 6,952.30	\$ 7,274.65
41	2447	993	1454	1454	4106		\$ 72.70	\$ -	\$ -	\$ 72.70	\$ 7,274.65	\$ 7,347.35
42	4106	1008	3098	3098	3098		\$ 154.90	\$ -	\$ -	\$ 154.90	\$ 7,347.35	\$ 7,502.25
43	3098	852	2246	2246	2246	2853	\$ 112.30	\$ -	\$ 200.00	\$ 312.30	\$ 7,502.25	\$ 7,814.55
44	2246	725	1521	1521	4374		\$ 76.05	\$ -	\$ -	\$ 76.05	\$ 7,814.55	\$ 7,890.60
45	4374	667	3707	3707	3707		\$ 185.35	\$ -	\$ -	\$ 185.35	\$ 7,890.60	\$ 8,075.95
46	3707	1015	2692	2692	2692	2407	\$ 134.60	\$ -	\$ 200.00	\$ 334.60	\$ 8,075.95	\$ 8,410.55
47	2692	1167	1525	1525	3932		\$ 76.25	\$ -	\$ -	\$ 76.25	\$ 8,410.55	\$ 8,486.80
48	3932	878	3054	3054	3054		\$ 152.70	\$ -	\$ -	\$ 152.70	\$ 8,486.80	\$ 8,639.50
49	3054	824	2230	2230	2230	2869	\$ 111.50	\$ -	\$ 200.00	\$ 311.50	\$ 8,639.50	\$ 8,951.00
50	2230	863	1367	1367	4236		\$ 68.35	\$ -	\$ -	\$ 68.35	\$ 8,951.00	\$ 9,019.35
51	4236	1085	3151	3151	3151		\$ 157.55	\$ -	\$ -	\$ 157.55	\$ 9,019.35	\$ 9,176.90
52	3151	1067	2084	2084	2084	3015	\$ 104.20	\$ -	\$ 200.00	\$ 304.20	\$ 9,176.90	\$ 9,481.10
53	2084	930	1154	1154	4169		\$ 57.70	\$ -	\$ -	\$ 57.70	\$ 9,481.10	\$ 9,538.80
54	4169	1021	3148	3148	3148		\$ 157.40	\$ -	\$ -	\$ 157.40	\$ 9,538.80	\$ 9,696.20
55	3148	828	2320	2320	2320	2779	\$ 116.00	\$ -	\$ 200.00	\$ 316.00	\$ 9,696.20	\$ 10,012.20
56	2320	724	1596	1596	4375		\$ 79.80	\$ -	\$ -	\$ 79.80	\$ 10,012.20	\$ 10,092.00
57	4375	987	3388	3388	3388		\$ 169.40	\$ -	\$ -	\$ 169.40	\$ 10,092.00	\$ 10,261.40
58	3388	737	2651	2651	2651	2448	\$ 132.55	\$ -	\$ 200.00	\$ 332.55	\$ 10,261.40	\$ 10,593.95
59	2651	750	1901	1901	4349		\$ 95.05	\$ -	\$ -	\$ 95.05	\$ 10,593.95	\$ 10,689.00
60	4349	765	3584	3584	3584		\$ 179.20	\$ -	\$ -	\$ 179.20	\$ 10,689.00	\$ 10,868.20
Average				2219	3196.441	2882.5	\$ 110.97	\$ 2.41	\$ 66.67	\$ 181.17		

Target
Inventory
Level

5099



TN 7. Wagner-Whitin (WW) Solution

Period	Demand	Lot Size	End Inventory	End Backorder	Cum. Cost
			1700		
1	870	0	830	0	41.5
2	901	1733	1662	0	324.6
3	960	0	702	0	359.7
4	702	0	0	0	359.7
5	1068	3682	2614	0	690.4
6	975	0	1639	0	772.35
7	977	0	662	0	805.45
8	662	0	0	0	805.45
9	1147	2232	1085	0	1059.7
10	1085	0	0	0	1059.7
11	1041	2932	1891	0	1354.25
12	890	0	1001	0	1404.3
13	1001	0	0	0	1404.3
14	960	2617	1657	0	1687.15
15	863	0	794	0	1726.85
16	794	0	0	0	1726.85
17	1109	3097	1988	0	2026.25
18	948	0	1040	0	2078.25
19	1040	0	0	0	2078.25
20	1008	2797	1789	0	2367.7
21	961	0	828	0	2409.1
22	828	0	0	0	2409.1
23	764	2657	1893	0	2703.75
24	933	0	960	0	2751.75
25	960	0	0	0	2751.75
26	988	2983	1995	0	3051.5
27	1028	0	967	0	3099.85
28	967	0	0	0	3099.85
29	918	2951	2033	0	3401.5
30	965	0	1068	0	3454.9
31	1068	0	0	0	3454.9
32	996	2974	1978	0	3753.8
33	1123	0	855	0	3796.55
34	855	0	0	0	3796.55
35	1035	2944	1909	0	4092
36	1085	0	824	0	4133.2
37	824	0	0	0	4133.2
38	941	2652	1711	0	4418.75
39	883	0	828	0	4460.149
40	828	0	0	0	4460.149
41	993	2853	1860	0	4753.149
42	1008	0	852	0	4795.75
43	852	0	0	0	4795.75
44	725	2407	1682	0	5079.85
45	667	0	1015	0	5130.6
46	1015	0	0	0	5130.6
47	1167	3732	2565	0	5458.85
48	878	0	1687	0	5543.2
49	824	0	863	0	5586.35
50	863	0	0	0	5586.35
51	1085	3082	1997	0	5886.2
52	1067	0	930	0	5932.7
53	930	0	0	0	5932.7
54	1021	2573	1552	0	6210.3
55	828	0	724	0	6246.5
56	724	0	0	0	6246.5
57	987	3239	2252	0	6559.1
58	737	0	1515	0	6634.85
59	750	0	765	0	6673.1
60	765	0	0	0	6673.1
Average		902.3	973.9		

Minimum Total Cost 6673.10

CASE: PARTS EMPORIUM *

A. Synopsis

This case describes the problems facing Sue McCaskey, the new materials manager of a wholesale distributor of auto parts. She seeks ways to cut the bloated inventories while improving customer service. Back orders with excessive lost sales are all too frequent. Inventories were much higher than expected when the new facility was built, even though sales have not increased. Summary data on inventory statistics, such as inventory turns, are not available. McCaskey decides to begin with a sample of two products to uncover the nature of the problems—the EG151 exhaust gasket and the DB032 drive belt.

B. Purpose

The purpose of this case is to allow the student to put together a plan, using either a continuous review system (Q system) or a periodic review system (P system), for two inventory SKUs. Enough information is available to determine the EOQ and R for a continuous review system (or P and T for a periodic review system). Because stockouts are costly relative to inventory holding costs, a 95% cycle-service level is recommended. Inventory holding costs are 21% of the value of each item (expressed at cost). The ordering costs (\$20 for exhaust gaskets and \$10 for drive belts) should not be increased to include charges for making customer deliveries. These charges are independent of the inventory replenishment at the warehouse and are reflected in the pricing policy.

C. Analysis

We now find appropriate policies for a Q system, beginning with the exhaust gasket. Shown here are the calculations of the EOQ and R , followed by a cost comparison between this continuous review system and the one now being used. The difference is what can be realized by a better inventory control system. Reducing lost sales due to back orders is surely the biggest benefit.

1. EG151 Exhaust Gasket

a. New plan

Begin by estimating annual demand and the variability in the demand during the lead time for this first item. Working with the weekly demands for the first 21 weeks of this year and assuming 52 business weeks per year, we find the EOQ as follows:

Weekly demand average = 102 gaskets/week

Annual demand (D) = $102(52) = 5304$ gaskets

Holding cost = \$1.85 per gasket per year (or $0.21 \times 0.68 \times \$12.99$)

Ordering cost = \$20 per order

$$\text{EOQ} = \sqrt{2(5,304)(\$20)/\$1.85} = 339 \text{ gaskets}$$

* This case was prepared by Dr. Rob Bregman, University of Houston, as a basis for classroom discussion.

Turning to R , the Normal Distribution appendix shows that a 95% cycle-service level corresponds to a $z = 1.65$. We then use the EG151 data to find the standard deviation of demand.

Standard deviation in weekly demand (σ_d) = 2.86 gaskets

Standard deviation in demand during lead time $\sigma_{dLT} = 2.86\sqrt{2} = 4.04$

R = Average demand during the lead time + Safety stock

= $2(102) + 1.65(4.04) = 210.66$, or 211 gaskets

b. Cost comparison

After developing their plan, students can compare its annual cost with what would be experienced with current policies.

Cost Category	Current Plan	Proposed Plan
Ordering cost	\$707	\$313
Holding cost (cycle inventory)	<u>139</u>	<u>314</u>
TOTAL	\$846	\$627

The total of these two costs for the gasket is reduced by 26 percent (from \$846 to \$627) per year. The safety stock with the proposed plan may be higher than the current plan, if the reason for the excess back orders is that no safety stock is now being held (inaccurate inventory records or a faulty replenishment system are other explanations). We cannot determine the safety stock level (if any) in the current system. The extra cost of safety stock for the proposed system is minimal, however. Only seven gaskets are being proposed as safety stock, and their annual holding cost is just another $1.85(7) = \$12.95$.

Surely the lost sales due to back orders are substantial with the current plan and will be much less with the proposed plan. One symptom of such losses is that 11 units are on back order in week 21. A lost sale costs a minimum of \$4.16 per gasket ($0.32 \times \$12.99$). If 10 percent of annual sales were lost with the current policy, this cost would be $\$4.16(0.10)(5,304) = \$2,206$ per year. Such a loss would be much reduced with the 95% cycle-service level implemented with the proposed plan.

2. DB032 Drive Belt

a. New plan

The following demand estimates are based on weeks 13 through 21. Weeks 11 and 12 are excluded from the analysis because the new product's start-up makes them unrepresentative. We find the EOQ as follows:

Weekly demand average = 52 belts/week

Annual demand (D) = $52(52) = 2704$ belts

Holding cost \$0.97 per belt per year (or $0.21 \times 0.52 \times \$8.89$)

Ordering cost \$10 per order

$EOQ = \sqrt{2(2,704)(\$10)/\$0.97} = 236$ gaskets

Turning now to R , where z remains at 1.65, we use the data in the DB032 table to find:

Standard deviation in weekly demand (σ_d) = 1.76 belts

Standard deviation in demand during lead time $\sigma_{dLT} = 1.76\sqrt{3} = 3.05$ belts

R = Average demand during the lead time + Safety stock

$$= 3(52) + 1.65(3.05) = 161.03, \text{ or } 161 \text{ belts}$$

b. **Cost comparison**

After developing their plan, students again can compare the cost for the belts with what would be experienced with current policies.

Cost Category	Current Plan	Proposed Plan
Ordering cost	\$ 27	\$115
Holding cost (cycle inventory)	485	114
TOTAL	\$512	\$229

With the belt, the total of these two costs is reduced by 55 percent. The safety stock with the proposed plan may be higher than the current system, as with the gaskets, but added cost for safety stock is only $\$0.97(5) = \$4.85$.

The big cost once again is the lost sales due to back orders with the current plan. A lost sale costs a minimum of \$4.27 per belt ($0.48 \times \$8.89$). If 10 percent of annual sales were lost, the cost with the current policy would be $\$4.27(0.10)(2,704) = \$1,155$. Such a loss would be much less with the 95% cycle-service level implemented with the proposed plan.

D. Recommendations

For the gasket, the recommendation is to implement a continuous review system with $Q = 339$ and $R = 211$. For the belt, the recommendation is to implement a continuous review system with $Q = 236$ and $R = 161$.

E. Teaching Strategy

This case can be used as a “cold-call” case or as a short case prepared in advance of the class meeting. If used without prior student preparation, it works best as a team assignment. Each team can have a different assignment (P or Q system, gasket or belt). When used as a cold-call case and time is a concern, the instructor should provide the mean and standard deviation of the weekly demand for the two products.

Begin with a general discussion of how to do the analysis and then work through the analysis. If done with teams, give each time to follow through. After the teams develop their policies, have them make the cost comparison. It brings back the fundamental notions of cycle inventory and ordering costs that were introduced in this Inventory Management chapter. The discussion at the end can broaden into other issues, such as applying the notion of inventory levers and the use of systems other than a Q system to control inventories.

If time permits, the instructor can have the class hand-simulate their policies, using the actual demand data in the first 21 weeks of this year for the gaskets and the last 9 weeks of this year for the belts. Use a form to record the simulation, either as a handout or transparency. The starting conditions on back orders, scheduled receipts, and on-hand inventory can be what is mentioned in the case for week 21.

Supplement

C Special Inventory Models

PROBLEMS

1. Bold Vision Inc.

$$\begin{aligned} \text{ELS} &= \sqrt{\frac{2DS}{H}} \sqrt{\frac{p}{p-d}} \\ &= \sqrt{\frac{2(625)(52)(100)}{.2(130)}} \sqrt{\frac{1,736}{1,736-625}} \\ &= \sqrt{250,000} \sqrt{1.5626} = (500)(1.25) \\ &= 625 \text{ toner cartridges} \end{aligned}$$

2. Sharpe Cutter

$$\begin{aligned} \text{a. ELS} &= \sqrt{\frac{2DS}{H}} \sqrt{\frac{p}{p-d}} \\ &= \sqrt{\frac{2(100,000)(300)}{1.20}} \sqrt{\frac{450}{(450-400)}} \\ &= (7,071.07)(3) = 21,213 \text{ knives} \end{aligned}$$

- b. Total annual cost

$$\begin{aligned} C &= \frac{Q}{2} \left(\frac{p-d}{p} \right) (H) + \frac{D}{Q} (S) \\ &= \frac{21,213}{2} \left(\frac{450-400}{450} \right) (1.20) + \frac{100,000}{21,213} (300) \\ &= \$1,414.21 + \$1,414.22 = \$2,828.44 \end{aligned}$$

$$\text{c. TBO} = \frac{\text{ELS}}{D} (250 \text{ days/year}) = \frac{21,213}{100,000} (250) = 53 \text{ days}$$

$$\text{d. Production time/lot} = \frac{\text{ELS}}{p} = \frac{21,213}{450} = 47.1 \text{ days}$$

3. Sud's Bottling Company

$$\begin{aligned}
 ELS &= \sqrt{\frac{2DS}{H}} \sqrt{\frac{p}{p-d}} \\
 &= \sqrt{\frac{2(600)(52)(800)}{.30(12.50)}} \sqrt{\frac{2400}{2,400-600}} \\
 &= \sqrt{13,312,000} \sqrt{1.333} = (3,648.56)(1.1547) \\
 &= 4,213 \text{ cases}
 \end{aligned}$$

4. Bucks Grande major-league baseball. Results from POM for Windows Software:

Demand rate(D)	17500		
Setup/Ordering cost(S)	100		
Holding@38%			
Price Ranges	From	To	Price
	1	999	7.5
	1000	4999	7.25
	5000	999999	6.5

Results

Optimal order quantity (Q*)	5000
Maximum Inventory Level (Imax)	5000
Average inventory	2500
Orders per period(year)	3.5
Annual Setup cost	\$350
Annual Holding cost	\$6175
Unit costs (PD)	\$113750
Total Cost	\$120275

Details -----

Range	Quantity	Setup Cost	Holding Cost	Unit Cost	Total Cost
1 to 999					
1000 to 4999	1127.13	1552.62	1552.62	126875	129980.2
5000 to 999999	5000	350	6175	113750	120275

Step 1: Calculate the EOQ at the lowest price (\$6.50):

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(350)(50)(100)}{.38(6.5)}} = 1190.4 \text{ or } 1190 \text{ balls}$$

This solution is infeasible. We cannot buy 1190 balls at a price of \$6.50 each. Therefore we calculate the EOQ at the next lowest price (\$7.25):

$$EOQ = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(350)(50)(100)}{.38(7.25)}} = 1127.13 \text{ or } 1127 \text{ balls}$$

This solution is feasible.

Step 2: Calculate total costs at the feasible EOQ and at higher discount quantities:

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

$$C_{1127} = \frac{1,127}{2} [.38(\$7.25)] + \frac{17,500}{1,127} (\$100) + \$7.25(17,500)$$

$$C_{1127} = \$1,552.44 + \$1,552.79 + \$126,875.00 = \$129,980.23$$

$$C_{5000} = \frac{5,000}{2} [.38(\$6.50)] + \frac{17,500}{5,000} (\$100) + \$6.50(17,500)$$

$$C_{5000} = \$6,175.00 + \$350.00 + \$113,750.00 = \$120,275.00$$

- It is less costly on an annual basis to buy 5,000 baseballs at a time.
- The total annual costs associated with buying 5,000 balls at a time are \$120,275.00
- No, the Bucks should not change their order quantity. The total annual cost associated with buying 5,000 balls at a time of \$120,275.00 is still the lowest. Results from POM for Windows Software for this analysis follows:

Demand rate(D)	17500
Setup/Ordering cost(S)	100
Holding@38%	
Price Ranges	From To Price
	1 999 7.5
	1000 4999 7.25
	5000 14999 6.5
	15000 999999 6.25

Results	
Optimal order quantity (Q*)	5000
Maximum Inventory Level (Imax)	5000
Average inventory	2500
Orders per period(year)	3.5
Annual Setup cost	\$350
Annual Holding cost	\$6175
Unit costs (PD)	\$113750
Total Cost	\$120275

Details -----

Range	Quantity	Setup Cost	Holding Cost	Unit Cost	Total Cost
1 to 999					
1000 to 4999	1127.13	1552.62	1552.62	126875	129980.2
5000 to 14999	5000	350	6175	113750	120275
15000 to 999999	15000	116.67	17812.5	109375	127304.2

5. Pfisher. The EOQ at the lowest price (\$49.00) remains infeasible and the EOQ at the next lowest price (\$50.25) remains at 79 packages. The total annual cost of buying disposable surgical packages also remains at \$25,416.44 per year. Now we calculate the annual cost associated with ordering 500 at a time:

$$C_{500} = \frac{500}{2}(.2 \times \$47.80) + \frac{490}{500}(\$64) + \$47.80(490)$$

$$C_{500} = \$2,390 + \$62.72 + \$23,422$$

$$C_{500} = \$25,874.72$$

The quantity discount is not sufficient to cause Pfisher to buy the larger order quantity.

6. University Bookstore

Step 1: Calculate the EOQ at the lowest price (\$3.25)

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2,500)10}{(0.3)(3.25)}} = 226.45, \text{ or } 226$$

This solution is infeasible; we cannot buy 226 pencils at \$3.25 a piece. Therefore, we calculate the EOQ at the next lowest price (\$3.50).

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2,500)10}{(0.30)(3.50)}} = 218.21, \text{ or } 218$$

This solution is feasible.

Step 2: Calculate total costs at the feasible EOQ and at higher discount quantities.

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

$$\begin{aligned} C_{218} &= \frac{218}{2}(0.30)(3.50) + \frac{2,500}{218}(\$10) + (\$3.50)(2,500) \\ &= \$114.45 + \$114.67 + \$8,750 \\ &= \$8,979.12 \end{aligned}$$

$$\begin{aligned} C_{2,001} &= \frac{2,001}{2}(0.30)(3.25) + \frac{2,500}{2,001}(\$10) + (\$3.25)(2,500) \\ &= \$975.49 + \$12.49 + \$8,125 \\ &= \$9,112.98 \end{aligned}$$

The best order quantity is 218 units.

7. Mac-in-the-Box, Inc.

Step 1: Calculate the EOQ at the lowest price (\$400):

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(1,200)(300)}{.16(400)}} = 106.06 \text{ or } 106 \text{ scanners}$$

This solution is infeasible. We cannot buy 106 scanners at a price of \$400 each. Therefore, we calculate the EOQ at the next lowest price (\$500).

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(1,200)(300)}{.16(500)}} = 94.86 \text{ or } 95 \text{ scanners}$$

This solution is feasible.

Step 2: Calculate total costs at the feasible EOQ and at higher discount quantities.

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

$$C_{95} = \frac{95}{2} [.16(\$500)] + \frac{(1,200)}{95} (\$300) + \$500(1200)$$

$$C_{95} = \$3,800 + \$3,800 + \$600,000$$

$$C_{95} = \$607,600.00$$

$$C_{144} = \frac{144}{2} [.16(\$400)] + \frac{(1,200)}{144} (\$300) + \$400(1200)$$

$$C_{144} = \$4,608.88 + \$2,500.00 + \$480,000$$

$$C_{144} = \$487,108.00$$

The order quantity should be 144 scanners.

8. Order quantity for “an item”

Step 1: Calculate the EOQ at the lowest price (\$2.00).

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2,000)(20)}{.2(2.00)}} = 447.2 \text{ or } 447 \text{ units}$$

This solution is infeasible. We cannot buy 447 units at a price of \$2.00 each. Therefore, we calculate the EOQ at the next lowest price (\$2.25).

$$\text{EOQ} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2,000)(20)}{.2(2.25)}} = 421.6 \text{ or } 422 \text{ units}$$

This solution is feasible.

Step 2: Calculate total costs at the feasible EOQ and at higher discount quantities.

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

$$C_{422} = \frac{422}{2} [.2(\$2.25)] + \frac{(2,000)}{422} (\$20) + \$2.25(2,000)$$

$$C_{422} = \$94.95 + \$94.79 + \$4,500.00$$

$$C_{422} = \$4,689.74$$

$$C_{1000} = \frac{1000}{2} [.2(\$2.00)] + \frac{(2,000)}{1,000} (\$20) + \$2.00(2,000)$$

$$C_{1000} = \$200.00 + \$40.00 + \$4,000$$

$$C_{1000} = \$4,240.00$$

The order quantity should be 1,000 units.

9. Downtown Health Clinic

- a. Order 5000 vaccines with an expected profit of \$43,800. The following table comes from the *One-Period Inventory Decision Solver* in OM Explorer.

Profit	\$11.00	(if sold during preferred period)
Loss	\$3.00	(if sold after preferred period)

					
Demand	2000	3000	4000	5000	6000
Probability	0.05	0.2	0.25	0.4	0.1

Payoff Table

		Demand				
		2000	3000	4000	5000	6000
Quantity	2000	22000	22000	22000	22000	22000
	3000	19000	33000	33000	33000	33000
	4000	16000	30000	44000	44000	44000
	5000	13000	27000	41000	55000	55000
	6000	10000	24000	38000	52000	66000

Weighted Payoffs

Order Quantity	Expected Payoff		
2000	22000	Greatest Expected Payoff	43800
3000	32300		
4000	39800		
5000	43800	Associated with Order Quantity	5000
6000	42200		

- b. If the Clinic participates in this Federal program, their profit maximizing solution is to order 5000 vaccines with an expected profit of \$32,800; an \$11,000 drop in expected profitability from part (a) (\$43,800 – \$32,800 = \$11,000). The following table comes from the *One-Period Inventory Decision Solver* in OM Explorer

Profit	\$8.00	(if sold during preferred period)				
Loss	\$1.00	(if sold after preferred period)				
						
Demand		2000	3000	4000	5000	6000
Probability		0.05	0.2	0.25	0.4	0.1

Payoff Table

		Demand				
		2000	3000	4000	5000	6000
Quantity	2000	16000	16000	16000	16000	16000
	3000	15000	24000	24000	24000	24000
	4000	14000	23000	32000	32000	32000
	5000	13000	22000	31000	40000	40000
	6000	12000	21000	30000	39000	48000

Weighted Payoffs

Order Quantity	Expected Payoff		
2000	16000	Greatest Expected Payoff	32800
3000	23550		
4000	29300		
5000	32800	Associated with Order Quantity	5000
6000	32700		

10. Dorothy's Pastries

The following payoff matrix was constructed, where

$$\text{Payoff} = \begin{cases} 0.40Q & \text{if } Q \leq D \\ 0.40D - 0.30(Q - D) & \text{if } Q > D \end{cases}$$

		<i>D</i>	
<i>Q</i>	50	150	200
50	\$20	\$20	\$20
150	(\$10)	\$60	\$60
200	(\$25)	\$45	\$80

Now we can compute the expected payoff for each baking quantity Q .

Order Quantity	Expected Payoff		
50	0.25(20) + 0.50(20)	+	0.25(20) = \$20.00
150	0.25(–10) + 0.50(60)	+	0.25(60) = \$42.50
200	0.25(–25) + 0.50(45)	+	0.25(80) = \$36.25

Therefore, 150 pastries should be baked each day.

11. Aggies versus Tech

The following payoff matrix was constructed, where

$$\text{Payoff} = \begin{cases} 1.50Q & \text{if } Q \leq D \\ 1.50D - 1.00(Q - D) & \text{if } Q > D \end{cases}$$

	D				
Q	2,000	3,000	4,000	5,000	6,000
2,000	\$3,000	\$3,000	\$3,000	\$3,000	\$3,000
3,000	\$2,000	\$4,500	\$4,500	\$4,500	\$4,500
4,000	\$1,000	\$3,500	\$6,000	\$6,000	\$6,000
5,000	\$ 0	\$2,500	\$5,000	\$7,500	\$7,500
6,000	(\$1,000)	\$1,500	\$4,000	\$6,500	\$9,000

Now we can compute the expected payoff for each baking quantity Q .

Order Quantity	Expected Payoff					
2,000	0.10(3,000)	+ 0.30(3,000)	+ 0.30(3,000)	+ 0.20(3,000)	+ 0.10(3,000)	= \$3,000
3,000	0.10(2,000)	+ 0.30(4,500)	+ 0.30(4,500)	+ 0.20(4,500)	+ 0.10(4,500)	= \$4,250
4,000	0.10(1,000)	+ 0.30(3,500)	+ 0.30(6,000)	+ 0.20(6,000)	+ 0.10(6,000)	= \$4,750
5,000	0.10(0)	+ 0.30(2,500)	+ 0.30(5,000)	+ 0.20(7,500)	+ 0.10(7,500)	= \$4,500
6,000	0.10(-1,000)	+ 0.30(1,500)	+ 0.30(4,000)	+ 0.20(6,500)	+ 0.10(9,000)	= \$3,750

Order 4,000 hot dogs.

12. Bold Vision Inc.

Bold Vision Inc's current batch size = 625 toner cartridges

$$\begin{aligned} \text{ELS} &= \sqrt{\frac{2DS}{H}} \sqrt{\frac{p}{p-d}} \\ &= \sqrt{\frac{2(625)(52)(100)}{.2(130)}} \sqrt{\frac{1,736}{1,736 - 625}} \\ &= \sqrt{250,000} \sqrt{1.5626} = (500)(1.25) \\ &= 625 \text{ toner cartridges} \end{aligned}$$

Yearly cost of this strategy:

$$\begin{aligned} C &= \frac{Q}{2} \left(\frac{p-d}{p} \right) H + \frac{D}{Q} S + PD \\ \frac{625}{2} \left(\frac{1736 - 625}{1736} \right) (.2)(130) &+ \frac{625(52)}{625} 100 + 130(625)(52) = 5,200 + 5,200 + 4,225,000 = \$4,235,400 \end{aligned}$$

Yearly cost including the \$2.00 discount:

$$\begin{aligned} C &= \frac{Q}{2} \left(\frac{p-d}{p} \right) H + \frac{D}{Q} S + PD \\ \frac{2000}{2} \left(\frac{1736 - 625}{1736} \right) (.2)(128) &+ \frac{625(52)}{2000} 100 + 128(625)(52) = 16,384 + 1,625 + 4,160,000 = \$4,178,009 \end{aligned}$$

Yes, Bold Vision should increase their batch size to 2000 units and thereby save
\$4,235,400 - \$4,178,009 = \$57,391 per year.

Chapter

10 Supply Chain Design

DISCUSSION QUESTIONS

1. For any supply chain there is a theoretical efficiency curve that maps the relationship between total costs and performance. Most firms, if their actual costs and performance are plotted, will be in a position where total costs exceed those indicated by the efficiency curve for a given level of performance. Firms can move closer to the efficiency curve through better forecasting, inventory management, operations planning and scheduling, and resource planning. All of these tactics can reduce costs while improving performance. However, quantum levels of improvement can be had by improving the design of the supply chain itself. Improvements can be made in inventory placement, mass customization strategies, outsourcing, and facility location.
2. Walmart's approach is to generate a competitive situation between suppliers and to drive down prices. One of the major competitive priorities in Walmart's business is low cost, thereby keeping retail prices to a minimum. Walmart is dealing with standardized goods in high volumes, and consequently uses an efficient supply chain. The Limited deals with fashion goods that have shorter life cycles. Therefore, the Limited needs a more flexible supply chain and also more control over the supply channels. Mast Industries provides the capability to produce fashion goods quickly.
3. Canon has chosen to keep its manufacturing process close to its manufacturing process to take advantage of concurrent engineering. They have chosen a strategy of speedy introduction of new products. Separating the manufacturing process by offshoring to a low cost country (such as China) would delay the introduction of new products, even though manufacturing costs would be less. Locating design engineers close to the manufacturing process allows for quick changes to new designs to overcome initial production problems. GM has initiated the joint venture with Shanghai Auto Industry Corporation to gain a foothold in a growing market for cars. The lower labor rates enable margins to be maintained and they overcome any additional logistical costs for shipping components to China or for exporting the cars to other countries. The need for fast reactions to new product introductions is not great because new product introductions are not as frequent as is the case for Canon. GM is competing on price and not on new product development speed. GM runs the risk of technology transfer and the possibility of setting up SAIC as a competitor.

PROBLEMS

1. EBI Solar
 - a. Inventory turnover = (Annual sales at cost)/(Average aggregate inventory value)
 Thus, $4.50 = 2,500,000 / \text{Average aggregate inventory value}$
 Average aggregate inventory value = \$555,556
 Weekly sales = Cost of goods sold / 52 = $2,500,000/52 = \$48,077$
 Weeks of supply = Average aggregate inventory value / weekly sales =
 $555,556/48,077 = 11.56$ weeks of supply
 - b. Average aggregate inventory value = raw material + work-in-process + finished goods = $\$100,500 + \$25,800 + \$16,200 = \$142,500$
 Inventory turnover = (Annual sales at cost)/(Average aggregate inventory value) = $2,500,000/\$142,500 = 17.54$
 Weeks of supply = Average aggregate inventory value / weekly sales =
 $\$142,500/48,077 = 2.96$ weeks of supply
2. Buzzrite Company
 - a. Current Year's average aggregate inventory value
 = $\$48,000,000/6 = \$8,000,000$
 Next year's average aggregate inventory value
 = $(\$48,000,000 \times 1.25)/6 = \$10,000,000$
 Increase in the average aggregate inventory value
 = $(\$10,000,000 - 8,000,000) = \$2,000,000$
 - b. Number of turns to support next year's sales with no increase in inventory value
 = $(1.25)(6) = 7.5$ turns.
3. Precision Enterprises. Average aggregate inventory value
 = Raw materials + WIP + Finished goods
 = $\$3,129,500 + \$6,237,000 + \$2,686,500$
 = \$12,053,000
 - a. Sales per week
 = Cost of goods sold/52 weeks per year
 = $\$32,500,000/52$
 = \$625,000
 Weeks of supply
 = Average aggregate inventory value/
 Weekly sales
 = $\$12,053,000/\$625,000$
 = 19.28 wk
 - b. Inventory turnover
 = (Annual sales at cost)/(Average aggregate inventory value)
 = $\$32,500,000/\$12,053,000$
 = 2.6964 turns/year

4. One product line

$$\text{Inventory turnover} = (\text{Annual sales at cost}) / (\text{Average aggregate inventory value})$$

$$10.0 = \$985,000 / \text{Average aggregate inventory value}$$

$$\text{Average aggregate inventory value} = \$985,000 / 10 = \$98,500$$

5. Bawl Corporation. Average aggregate inventory value can be calculated as: Average aggregate inventory value

$$\begin{aligned} &= \text{Raw materials} + \text{WIP} + \text{Finished goods} \\ &= \$2,470,000 + \$1,566,000 + \$1,200,000 \\ &= \$5,236,000 \end{aligned}$$

$$\begin{aligned} \text{a. Sales per week} &= \text{Cost of goods sold} / 52 \text{ weeks per year} \\ &= \$48,000,000 / 52 \\ &= \$923,077 \end{aligned}$$

$$\begin{aligned} \text{Weeks of supply} &= \text{Average aggregate inventory value} / \text{Weekly sales (at cost)} \\ &= \$5,236,000 / \$923,077 \\ &= 5.7 \text{ wk} \end{aligned}$$

$$\begin{aligned} \text{b. Inventory turnover} &= (\text{Annual sales at cost}) / (\text{Average aggregate inventory value}) \\ &= \$48,000,000 / \$5,236,000 \\ &= 9.17 \text{ turns/year} \end{aligned}$$

6. A retailer

$$\begin{aligned} \text{a. a. Sales per week} &= \text{Cost of goods sold} / 52 \text{ weeks per year} \\ &= \$3,500,000 / 52 \\ &= \$67,308 \end{aligned}$$

$$\begin{aligned} \text{Weeks of supply} &= \text{Average aggregate inventory value} / \text{Weekly sales (at cost)} \\ &= \$1,200,000 / \$67,308 \\ &= 17.8 \text{ wk} \end{aligned}$$

$$\begin{aligned} \text{b. Inventory turnover} &= (\text{Annual sales at cost}) / (\text{Average aggregate inventory value}) \\ &= \$3,500,000 / \$1,200,000 \\ &= 2.9 \text{ turns/year} \end{aligned}$$

7. Sterling Inc.

Part Number	Average		
	Inventory (units)	Value (\$/unit)	Total Value (\$)
RM-1	20,000	1.00	20,000
RM-2	5,000	5.00	25,000
RM-3	3,000	6.00	18,000
RM-4	1,000	8.00	8,000
WIP-1	6,000	10.00	60,000
WIP-2	8,000	12.00	96,000
FG-1	1,000	65.00	65,000
FG-2	500	88.00	44,000

Average aggregate inventory value: \$336,000

- b. Average weekly sales at cost = \$6,500,000/52
 = \$125,000
 Weeks of supply = \$336,000/\$125,000
 = 2.688 weeks.
- c. Inventory turnover = Annual sales (at cost) / Average aggregate inventory value
 = \$6,500,000/\$336,000
 = 19.34 turns.

8. Large global automobile manufacturer

- a. We must use the break-even equation for evaluating processes:

$$Q = \frac{F_m - F_b}{c_b - c_m}$$

$Q = (\$6 \text{ million} - \$4 \text{ million}) / (\$8.00 - \$5.00) = 666,667 \text{ solenoids.}$
 Consequently, the automobile manufacturer would need to use 666,667 or more solenoids to make a financial case to retain manufacture of them in-house.

- b. If the projection is for less than 666,667 solenoids, the use of the subcontractor becomes a possibility. However, in doing so, the manufacturer loses some control over the production of that part. If that part is critical to the end product, relinquishing direct oversight may not be a good idea. The ability of the subcontractor to deliver on time and with high quality are also factors to consider. Also, once out of the manufacturing of that part, it typically will take quite a while to start it back up again, raising issues of labor skills and equipment. Ethical issues, such as the potential layoffs and the effect on the community, should also be considered.

9. Dogs-R-Us versus K-9 Inc.

- a. The following Excel spreadsheet provides the total average inventory value by inventory category for both firms. The average aggregate inventory value = the sum of the total inventory value of all categories.

	Dogs-R-Us			K-9 Inc.		
Cost of Goods Sold	\$560,000.00			\$640,000.00		
Category	Average Inventory in Units	Value per Unit	Total Value	Average Inventory in Units	Value per Unit	Total Value
Dog Beds	200	\$55.00	\$11,000.00	140	\$55.00	\$7,700.00
Dog Bones & Treats	1200	\$2.50	\$3,000.00	250	\$2.50	\$625.00
Pet Feeders	50	\$12.50	\$625.00	20	\$12.50	\$250.00
Flea & Tick	350	\$7.50	\$2,625.00	75	\$7.50	\$562.50
Dog Kennels	10	\$65.00	\$650.00	2	\$65.00	\$130.00
Dog Pens	10	\$220.00	\$2,200.00	3	\$220.00	\$660.00
Patio Pet Doors	5	\$120.00	\$600.00	2	\$120.00	\$240.00
Dog Ramps	5	\$150.00	\$750.00	2	\$150.00	\$300.00
Pet Strollers	10	\$40.00	\$400.00	2	\$40.00	\$80.00
Pet Supplements	1400	\$4.50	\$6,300.00	150	\$4.50	\$675.00
Dog Toys	250	\$2.20	\$550.00	100	\$2.20	\$220.00
Average Aggregate Inventory Value			\$28,700.00			\$11,442.50

b. Average Weekly Sales at Cost	Dogs-R-Us = \$560,000/52 = \$10,769.23
	K-9 Inc. = \$640,000/52 = \$12,307.69
Weeks of Supply	Dogs-R-Us = \$28,700.00/\$10,769.23 = 2.67
	K-9 Inc. = \$11,442.50/\$12,307.69 = 0.93
c. Inventory Turnover	Dogs-R-Us = \$560,000/\$28,700 = 19.51
	K-9 Inc. = \$640,000/\$11,442.50 = 55.93

10. Black Bear Outfitters.

We must use the break-even equation for evaluating processes:

$$Q = \frac{F_m - F_b}{c_b - c_m}$$

$Q = (\$16 \text{ million} - \$9 \text{ million}) / (\$15.00 - \$6.00) = 777,778$ packages. Consequently, Black Bear Outfitters must ship more than 777,778 packages to make the vertical integration into warehouse operations cost effective.

11. BlueFin Bank

We use the break-even equation for evaluating two processes:

$$Q = \frac{F_m - F_b}{c_b - c_m}$$

The key is to solve for the fixed costs of the “make” option,

$$F_m = F_b + (c_b - c_m)Q$$

$F_m = \$12 \text{ million} + 0.02(\$20 \text{ million}) = \$12,400,000$. Consequently, if the fixed annual costs to do the transactions in-house exceed, \$12,400,000, BlueFin would be better off using DataEase.

12. Global Manufacturer of Electrical Switching Equipment

a. We must use the break-even equation for evaluating processes:

$$Q = \frac{F_m - F_b}{c_b - c_m}$$

$Q = (\$8 \text{ million} - \$0 \text{ million}) / (\$16.00 - \$11.00) = 1,600,000$ breakers. Consequently, the manufacturer would need to use 1,600,000 or more breakers to make a financial case to retain manufacture of them in-house.

b. We must use the break-even equation for evaluating processes:

$$Q = \frac{F_m - F_b}{c_b - c_m}$$

$Q = (\$8 \text{ million} - \$5 \text{ million}) / (\$12.00 - \$11.00) = 3,000,000$ breakers. Consequently, the manufacturer would need to use 3,000,000 or more breakers to make a financial case to retain manufacture of them in-house.

c. Calculate the total cost of each option:

- Make in-house: $\$8,000,000 + \$11(1,500,000) = \$24,500,000$
- Use subcontractor without sharing in the cost of equipment:
 $\$16(1,500,000) = \$24,000,000$
- Use subcontractor with sharing in the cost of equipment:
 $\$5,000,000 + \$12(1,500,000) = \$23,000,000$

Option 3, use subcontractor with sharing in the cost of equipment, is least costly at \$23,000,000

EXPERIENTIAL LEARNING: SONIC DISTRIBUTORS

A. Synopsis

The purpose of this exercise is to provide a situation in which students can observe how supply-chain management affects the efficiency and effectiveness of a distribution network. It is designed to be quite flexible. In its simplest form it can be a “quick hit” to give the students an initial exposure to supply chains and thus set them up for a more productive lecture and discussion of the chapter. Alternatively, complexity can be added so the efficient and the responsive distribution chains can be compared or more freedom can be allowed making it an analytical simulation to observe and measure the effects of changes to the system. In this last format, students can configure the supply chain for efficiency or responsiveness (or anywhere in between) and then operate it while measuring its supply-chain performance.

Many lessons can be brought out from a discussion of the results of this exercise. It demonstrates the complexities of managing an enterprise where there are multiple parties and information requirements involved. It brings forth the trade-offs that must be made when conflicting goals exist with different costs or benefits. It shows the cost implications of managerial decisions such as establishing safety stock policies and setting production lot sizes. And, it shows the role of time delay on the overall system performance.

The results of this exercise can also lead to further discussions: The distribution of demand for the distribution centers (and thus for the factory) depends not only on the nature of the demand at the retail stores but also on the ordering policies of the retailer and the distribution center. This can lead to a discussion of dependent demand, which sets the stage for Chapter 16, “Resource Planning.” As a tie-in to applied statistics, the smoothing effect of grouping several independent demands, and perhaps, even the central limit theorem can be teased out of the results. An outline of some of the topics from Chapters 10 and 12 that spring from this exercise can be found at the end of this teaching note.

B. Preparation Materials

- ❑ Retail and Distributor Purchase Order Forms (one set for each retail store and one set for each of the two distribution centers). A set is made up of one form for each simulated day the game is to be played.
- ❑ Manufacturing Work Order Sheet (one set for the factory). The set for the factory contains as many forms as the proposed length of the simulation times the number of distributors it serves.
- ❑ Factory and Distributor Material Delivery Forms (one set for the factory and one set for each distribution center that the factory supplies). The size of the set for a

distributor is the proposed number of days times the number of retail stores each is to serve.

- ❑ Inventory Position Worksheets (one for each retail store, each distribution center, and the factory)
- ❑ A random demand generator such as a pair of dice, a deck of playing cards for each team (with all face cards removed) or slips of paper with the numbers 1 to 10 written on them, random number table, a simple computer program, etc.

Preparation Time Required

Instructor: It will take a couple of hours to read through the material and fully understand the procedure that the students will enact. It is suggested that the instructor personally play several rounds before presenting it in class to the students. The instructor should play the part of all participants (retail stores, distribution centers, and the factory) to best grasp each student's role. Although it appears complex at first, the procedure is fairly simple.

Preclass preparation consists of devising the random demand generators, one for each company (team). If only one type of CD is to be produced (Quick-Hit version), a pair of dice works well (one pair for each retail store is best but a pair can be shared by the stores in a team). If the demonstration is to include all four types of CD demands, an easy demand generator is a shuffled deck of playing cards with all the face cards and jokers removed.

Inventory position and cost calculation worksheets need to be photocopied, one for each retail outlet, distributor, and factory. Likewise, sets of Retail Store and Distribution Center Purchase Order Forms, Factory Work Order Forms, and Factory and Distribution Center Material Delivery Forms need to be photocopied.

Students: Prereading the exercise is suggested; it reduces the startup time. It should take the students only 15 minutes or so to read and understand the instructions. Indicate to the students how the exercise will be run (the "Quick Hit" version in the text or the "Efficient versus Responsive Comparison" or the "Analytical Simulation" versions in this teaching note).

Class Time Required

As with any business simulation, there is a trade-off between realism and feasibility. More detail can yield a more realistic estimate of what true distribution chain costs are. This realism comes at the cost of more effort on the part of the student to perform the exercise. It also can cause more confusion when trying to explain the rationale behind each cost and how to account for it when calculating total cost. Therefore, three versions of the exercise are suggested to allow whatever level of realism the instructor chooses; other configurations are easily devised, depending on the objectives of the instructor.

In its simplest form, the "Quick Hit" version can take as little as 45 minutes to run. This has enough detail for the students to observe the dynamics of a supply chain. The "Efficient versus Responsive Comparison" version takes about 75 minutes. The "Analytical Simulation" version generates the most realistic total costs and allows the students to try several configurations. Therefore, it can take two hours or more plus additional time for postexercise debriefing and discussion. This longer configuration works best for a one-night-per-week class or if the debriefing and

discussion session can take place during the following class. It could also be given as a multiple session exercise if the goal of the instructor is to cover distribution chain performance in depth.

Setting Up

This exercise works well when two or more companies are formed. In any case, companies should be configured with no fewer than two retail outlets drawing from each distributor (more than one can be used). Although this is the minimum, more than two retail outlets to each distributor are better because they more clearly demonstrate the effect of averaging stochastic demand at the distributors.

The following parameters need to be established for each team:

1. Starting conditions:

Initial inventory of each of the four artist's CDs at the:

Retail stores—the text suggests 15

Distribution center—the text suggests 25

Factory—the text suggests 100

Outstanding orders (or backorders—if any) for each of the four CDs at the:

Distribution centers—the text suggests none

Factory—the text suggests none

Note: There will be no backorders at the Retail Stores because any stockout results in a lost sale.

2. Operating considerations:

Demand patterns—will a quantity of only one artist's CD be sold at a given retail store each day (i.e., each retailer will generate only one random number for demand per round—as for the Quick Hit version) or will several artist's CDs be sold (i.e., each retailer will generate several different random numbers to determine demand)?

3. Costs

Transportation costs and holding costs in the inventory pipeline are expressly ignored in the Quick Hit version for simplicity.

Holding cost per unit per day—may be different for each of the stages in the distribution chain.¹ The text suggests:

Retail outlets—\$1.00/day

Distribution center—\$0.50/day

Factory—\$0.25/day

Ordering/setup cost—may be different for each of the stages in the distribution chain. The text suggests:

Retail outlets—\$20.00/order

Distribution center—\$20.00/order

Factory setup—\$50 per order. For other versions with a capacity limited factory, the setup cost does not recur in subsequent days of production until another order is called for.

¹ These holding costs differentials are designed to dissuade students from positioning too much forward inventory at the retail outlets. See a discussion of other possibilities in the parameter list for the Efficient vs. Responsive version, later on.

Stockout cost (may be different for each stage—will be equivalent to the contribution margin of a lost sale for the retail stores) the text suggests \$8.00 for each CD short in a period.

Expediting cost (for example, shipping an order by UPS instead of normal freight). The text doesn't suggest a cost for the Quick Hit version.

4. Delays

Ordering delay—time from when a purchase order (PO) is issued until it is received. The text suggests one day.

Delivery delay—time required to assemble, pack, and transport an order once the PO is received. The text suggests one day.

Production time—time from receiving an order until it is ready for shipment (may be determined by factory production lot sizes). The text suggests one day. If the factory is capacity limited, the delivery delay will be as long as it takes to run the entire order. Partial production runs are not shipped.

5. Lot sizing restrictions—

Retail Store orders—the text indicates there are none.

Distribution Center orders—the text indicates there are none.

Factory production lot sizes and capacity. Also, the factory may be able to produce multiple types simultaneously or be restricted to producing only one type of CD at a time. For the Quick Hit version, the text suggests a minimum lot size of 20 and an upper limit of 200, which is well above any required production. For the Quick Hit version, this large capacity eliminates the complexity needing to extend a production run over several days.

6. Storage capacity restrictions—the text does not mention any for the Quick Hit version.

All of these parameters will be preset by the instructor for the “Quick Hit” and the “Efficient versus Responsive Comparison” versions. The “Analytical Simulation” version allows students to adjust many of the operating considerations by making lot sizing and cost/performance trade-off decisions.

C. Conducting the Exercise

Break the class into teams and have them sit together so that communication among the team members will be convenient. They can be seated in an area of the classroom or around a large table. Let them arrange themselves to establish effective and efficient transmission chains for the required information (POs and material delivery forms). To include delays in the transmission of POs to suppliers or in the delivery of goods from suppliers, provide a place where the POs and delivery forms can be placed for the required delay periods. If the team is seated at a table, $8\frac{1}{2} \times 11$ pieces of paper (one for each source and destination pair) can be fastened on the table and marked as delay stations. If the students are sitting in chairs, an empty chair between the various pairs within the team can serve as a delay station.

Specify the values for the parameters (listed previously) that will be followed for the exercise. Review the sequence of play. If a deck of cards or slips of paper are used to determine demand, specify that at the end of each round (day) the cards or slips that were drawn should be returned to the deck and the deck reshuffled. Go over the items that are to be recorded on the worksheets. Start off with a few practice rounds

to be sure each student understands his or her task, how the data are gathered, and how play progresses.

To simplify record keeping, have the students adopt a “midpoint convention” for recording transactions. This assumes all transactions occur simultaneously in the middle of the day—scheduled receipts arrive, demand is determined and met, and any shortages occur, all at noon. Inventory recorded in the inventory position worksheet is the ending inventory after all these transactions occur.

Regardless of the version, for each simulated day the sequence of play goes as follows:

Retailer:

- a. Each retailer receives any shipment due in from their distributor (one day after shipment) and places it into sales inventory (adds the quantity indicated on any incoming Material Delivery Form from the distributor—after its one-day delay—to the current inventory level on the Retailer’s Inventory Position Worksheet). Note: for the first day of the exercise no order will be coming in.
- b. The retailers each determine the day’s retail demand (the quantity of CDs requested) by rolling a pair of dice. The roll determines the number demanded.
- c. Retailers fill demand from available stock if possible. Demand is filled by subtracting it from the current inventory level indicated on the worksheet. If demand exceeds supply, sales are lost. Record all lost sales on the worksheet.
- d. Retailers determine whether a replenishment order should be placed. If an order is required, the desired quantity of CDs is written on a Retail Store Purchase Order, which is forwarded to the distributor (who receives it after a one-day delay). If an order is made, it should be noted on the worksheet. Retailers may also desire to keep track of outstanding orders separately.

Distributor:

- a. The distributor receives any shipment due in from the factory and places the CDs in available inventory (adds the quantity indicated on any incoming Material Delivery Form from the factory—after its one-day delay—to the current inventory level on the distributor’s Inventory Position Worksheet).
- b. All outstanding back orders are filled (the quantity is subtracted from the current inventory level indicated on the worksheet) and prepared for shipment. CDs are shipped by filling out a Distribution Center Material Delivery Form indicating the quantity of CDs to be delivered.
- c. The distributor uses the purchase orders received from the retail stores (after the designated one-day delay) to prepare shipments for delivery from available inventory. Quantities shipped are subtracted from the current inventory level on the worksheet. If insufficient supply exists, back orders are generated.
- d. The distributor determines whether a replenishment order should be placed. If an order is required, the quantity of CDs is written on a Distribution Center Purchase Order, which is forwarded to the factory (after a one-day delay). If an order is made, it should be noted on the worksheet. The distributor may also desire to keep track of outstanding orders separately.

Factory:

- a. The factory places any available new production into inventory (adds the items produced the previous day to the current inventory level on the Factory Inventory Position Worksheet).
- b. All outstanding back orders are filled (the quantity is subtracted from the current inventory level indicated on the worksheet) and prepared for shipment. CDs are shipped by filling out a Factory Material Delivery Form, indicating the quantity of CDs to be delivered.
- c. The factory obtains the incoming distributor's purchase orders (after the designated one-day delay) and ships them from stock if it can. These amounts are subtracted from the current values on the inventory worksheet. Any unfilled orders become back orders for the next day.
- d. The factory decides whether to issue a work order to produce CDs either to stock or to order. If production is required, a Factory Work Order is issued and the order is noted on the inventory worksheet. Remember that the setup cost is for each *production* order. It is important to keep careful track of all production in process.

When all parties have completed and recorded their day's transactions, go back to Retailer Step (a.) and repeat. Make the students aware that, once an order is placed, it cannot be changed (unless, of course, you wish to simulate the ability to amend orders).

The exercise must be run long enough in order for the interactions within the system to be revealed. The number of rounds required will depend on the parameters that are selected. In general, if feedback is sluggish (the time between issuing a PO and the receipt of inventory is two or more days), as many as 40 simulated days may be required to see the effects of the system dynamics. If feedback time is short, the number of required rounds may be reduced at the expense of fully developing the dynamic characteristics in the system.

When the exercise is concluded, have each entity (retailer(s), distributor, and the factory) calculate the total cost of operation.

For retail stores, find the total of:

1. The cumulative amount of inventory of each type of CD (there will be only one type of CD if the Quick Hit version is run). Add the inventory position numbers in each of the two columns on the worksheet for each type of CD and then multiply the total by the holding cost per CD per day.
2. The total ordering cost. Count the number of times an order was placed and multiply by the ordering cost.
3. The total stockout cost. Add the numbers in each of the two columns on the worksheet for stockouts and multiply the total by the cost per lost sale.
4. For distribution centers, find the total of:
 - i. The cumulative amount of inventory of each type of CD (only one type if Quick Hit version). Add the numbers in each of the two columns on the worksheet for each type of CD and then multiply the total by the holding cost per CD per day.
 - ii. The total ordering cost. Count the number of times an order was placed and multiply by the ordering cost.

For the factory, find the total of:

- i. The cumulative amount of inventory of each type of CD (only one type if Quick Hit version). Add the numbers in each of the two columns on the worksheet for each type of CD and then multiply the total by the holding cost per CD per day.
- ii. The total setup cost. Count the number of times a production order was placed and multiply by the setup cost.

Then add up the costs of all the entities. The lower the total cost, the better the team operated the distribution chain.

D. “Quick Hit” Version (the version in the text)

In this version, only one type of CD is produced and there is only one Distribution Center. The team breakout, procedures, costs, and conditions for this version are given in the text. Distribute the materials to each team (the worksheets, order and delivery forms, and the random demand generator). Assuming that they have already read the exercise description and instructions, briefly review the sequence of steps they will follow in each round (simulated day). Remind them of the values they need to use for each of the operating parameters (costs and conditions).

Allow the students to complete a couple of practice rounds so that each person knows his or her task. Then have them reset to the starting conditions (no pipeline inventory and the initial quantities in stock) and begin the exercise. Let them go until most teams have at least 25 rounds completed, more if you have time.

When completed, have them determine the total cost of their operation. Discussion can then begin.

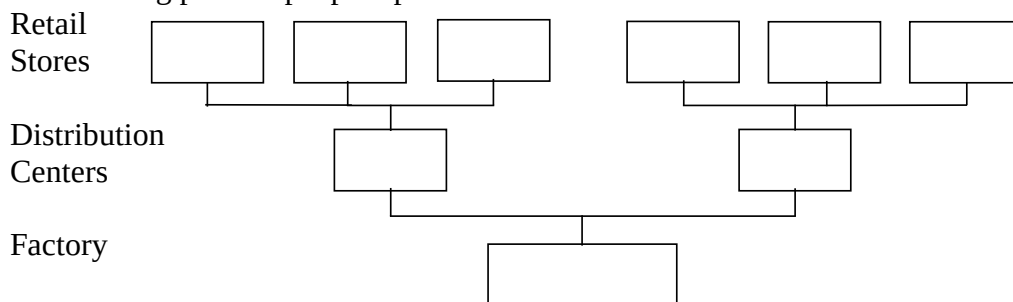
E. Efficient Versus Responsive Comparison

Divide the class into two companies (teams) of 16 to 26 or so, although, if necessary, as few as 7 can form a team:

2 people schedule production at the factory

2 people operate each of the two distribution centers

The remaining pairs of people operate the retail stores



At each of the distribution centers and retail stores, one person determines demand and fills the orders while the other records and graphs inventory levels as play progresses. Both help decide when and how much to order. The goal is to achieve the lowest total operating costs for the entire distribution chain.

In these expanded versions **four** groups currently have top-10 recordings being sold. They are: Jake Spade and the Diggers, The Heartmenders, Diamonds in the Ruff, and Kulture Klub. Consequently, playing cards make a convenient way of

determining demand. When using cards, the daily retail demand for a given group's recording at a given retail outlet is determined by drawing a playing card. The suit determines which group's CDs sold that day and the pip (the number) indicates how many were sold.

Briefly review the sequence of steps they will follow in each round. Then give the students the following parameters for their production:

Starting conditions for both teams:

Initial inventory of each of the four artist's CDs at the:

Retail stores—10 CDs of each artist

Distribution centers—25 CDs of each artist

Factory—50 CDs of each artist

Team 1—Efficient Supply Chain

Costs:

Holding cost per unit per day:²

Retail outlets: \$1.00/CD/day

Distribution centers: \$0.50/CD/day

Factory: \$0.25/CD/day

Pipeline inventory cost: These costs can be ignored or added in depending on the level of realism desired (because they are linear, they don't affect the best decisions to make, only the total cost that is generated). If you choose to include them, add another column to the inventory position worksheets for the DCs and the factory next to the inventory column. Explain that the DC pays inventory holding costs on open orders (inventory shipped to the retailers but not yet received), and the factory pays inventory costs for open orders sent to the DCs.

Ordering cost (retailers and distributors): \$20/order for single or mixed types.

Factory setup cost (to run an order): \$50 (unless the subsequent order is for the same type CD as the preceding order).

Stockout (lost margin) cost for retail stores: \$8 per CD sale lost in a period.

Back orders: There is no cost for back orders due to shortages from the factory or the distribution centers, although all back orders must be filled first before shipping new orders.

Shipping cost: One alternative is to ignore this cost by using the rationale that, as other products are already being distributed through this chain and CDs are light and take up little volume, the cost is essentially zero. If you desire more realism, a per shipment (or per unit) shipping cost can be included.

Expediting cost (for example, shipping an order by UPS instead of normal freight): \$1 per CD.

Outstanding orders:

² As with the Quick Hit version, these cost differentials are designed to prevent too much forward placement of inventory. One possibility is to make the costs more equal, but impose capacity limits on how much a retailer is willing to hold. Another possibility is to make the lead time from the factory longer than from the DC to the retailers.

Retail outlets and distribution centers: no orders.

Existing factory order: 200 Kulture Klub CDs in production, the first 50 to be delivered next period.

Lot sizing restrictions:

Retail store orders—minimum order: 20 of each artist. More may be ordered if desired.

Distribution center orders—minimum order: 100 of each artist. More may be ordered if desired.

Factory production lot sizes and capacity: Limited to only one type CD at a time. Produce in lots of 200 at the rate of 50 per day (i.e., an order takes four days to complete but 50 units are available the day after production starts).³

Delays

Ordering delay: 1 day transit time for orders between retail stores and distributors and between distributors and the factory. Note: As an alternative, you may wish to allow this “efficient” firm to employ electronic data interchange (EDI) and allow the team to electronically forward orders with no delay. This capability is provided to the other “responsive” firm.

It takes one day to start up production (i.e., a one-day delay) if the factory has not been producing anything the previous day. There is no delay if immediately starting a second order of an existing CD or switching to a new type CD.

Delivery delay: 1-day delivery time between distributors and retail stores and between the factory and the distributors.

Team 2—Responsive Supply Chain

Costs:

Holding cost per unit per day (see footnote 2 above):

Retail outlets: \$2.00/CD/day

Distribution Centers: \$1.00/CD/day

Factory: \$0.50/CD/day

Pipeline inventory cost: These costs can be ignored or added in depending on the level of realism desired (as they are linear, they don’t affect the best decisions to make, only the total cost that is generated). If you choose to include them, add another column to the inventory position worksheets for the DCs and the factory next to the inventory column. Explain that the DC pays inventory holding costs on open orders (inventory shipped to the retailers but not yet received), and the factory pays inventory costs for open orders sent to the DCs.

Ordering cost (retailers and distributors): \$20/order for single or mixed types

³ The factory capacities should be adjusted upward if there are more than six retail stores drawing off a single factory’s production. Using playing cards, the average demand is 5.5 CDs per store per day. With four retail stores the factory will experience a mean demand of 22 CDs per day, and the peak demand can occasionally approach 40. Having a production capacity of 50/day makes meeting demand without a lot of forward placed inventory a challenge. With more than four retail outlets, the capacity cushion becomes very thin. Six retail outlets give a mean demand of 33 with a peak of 60. Although the increased number of retail outlets reduces the variability of the demand experienced by the factory, it becomes very hard to avoid stockouts. More than six retail outlets require increased capacity at the factory.

Factory setup cost (to run an order): \$25 (unless the subsequent order is for the same type CD as the preceding order).

Stockout (lost margin) cost—retail store: \$16 per CD sale lost in a period.

There is no cost for back orders for shortages from the factory or the distribution centers, although all back orders must be filled first before shipping new orders.

Expediting cost (for example, shipping an order by UPS instead of normal freight): \$.50 per CD. (This is suggested to be lower than for the efficient chain using the rationale; this is planned for and, thus, can be contracted at a lower cost.)

Lot sizing restrictions—none: all orders may be made lot-for-lot including factory production lot sizes.

Factory capacity: 50 units/day, may be of mixed types (see footnote 3).

Outstanding orders: no orders for retail outlets, distribution centers, or the factory.

Delays

Ordering delay: none. Using EDI, orders placed in one period can be acted on the following period. This includes the factory. Furthermore, the factory should be informed about all retail store purchase orders at the time they are made, although they do not ship to the distribution centers until a request for inventory has been issued.

Delivery delay: orders received are shipped the same day. They are available for use the following day. Note: As an alternative, you may wish to maintain a delivery delay, say, of one day.

Have the two teams run 30 to 40 rounds and then allow the students to compare the performance of the two different types of supply chains using the data gathered on their worksheets. To focus the discussion, suggest to the students that they use Tables 10.2 and 10.3 found in the text as a guide for comparison.

F. “Analytical Simulation” Version

This version allows the students to see how the various distribution chain parameters (see the list under “Setting Up” in Section B) affect performance. It can be run by forming two or more teams, each designing a distribution system by selecting values for their

distribution system’s parameters based on their understanding of the chapter material. The teams run their various systems simultaneously (like in the “Efficient Versus Responsive Comparison” version). After sufficient periods have been simulated, the teams come together to discuss and compare the effectiveness of their distribution system designs.

Alternatively, it can be run with the class operating as one team. Have them select the way they want to design the distribution system and then run it for a while to establish how well it performs. They can then discuss the results, adjust various parameters, and rerun the exercise to see if performance has been improved. This alternative works best for smaller sized classes.

In either case, the instructor will need to establish values for the various operating costs and set limits over which the other parameters can reasonably range. Other variations can be included as well. For instance, it could be permissible to allow the factory or DCs to position inventory forward (as anticipation inventory) rather than waiting for a purchase order to better synchronize the entire distribution chain. It is also possible to allow for partial shipments to better allocate scarce resources.

G. Debriefing/Discussion

When any of the versions of the game have been completed, there will be an opportunity to discuss many of the topics that are covered in Chapters 10 and 12 of the text. Some of the more relevant of these topics are outlined below. Furthermore, any of these topics can become issues to include for investigation when playing the analytical version of the game.

Possible disruptions to model:

- External supply chain causes

- Volume changes

- Product mix changes

- Delivery delays

- Partial shipments

- Internal supply chain causes

- Production failure

- Product modifications

- New products

- Promotional demand peaks

- Information

- Value analysis

- Where to stock

- Forward placement

- Backward placement (Even out variations in demand—inventory pooling. This could be simulated by developing a bimodal demand generator—include face cards and have them worth 25 CDs.)

- Holding costs

- Aggregate inventory value (the different types of CDs could be valued differently)

- Week's supply

- Inventory turns

- Production costs:

- Setups

- Lot sizes

- Material purchases (quantity and supplier lead-time)

- Defects—yield (relate to required speed of delivery and length of run)

- Transport (shipping) costs

- Truckload vs. LTL common carrier vs. UPS

- Tardiness costs

- Time delay

- Lost sales, back orders (measured as percent on-time delivery)

Students can also be shown the imbalance that exists between a flow shop production and a product that needs to be flexible by decreeing that the factory only produce in large, multiday runs.

It may also be instructive to have the students graph their inventory positions over the duration of the exercise to better display the supply chain dynamics. It will become evident that the greater the delays in the delivery of the POs and the shipment of the CDs, the more wild the resulting inventory level excursions.

Some students may wish to write a computer simulation to replicate this exercise. By doing so and then experimenting with the model, they will develop a deeper appreciation for the system dynamics that evolve from adjusting various parameters. Although a simulation is an interesting tool, most students will not gain much by playing with a model created by someone else. The inner workings are not clear enough to develop a full understanding of the interactions that take place. However by participating in the in-class exercise, these interactions become more evident and can be better appreciated.

H. Worksheets

Two sets are provided; one for the single product version (“Quick Hit”), and one for the other two multiple product versions. Duplicate as many of these as needed (see “Materials” section of the instructions).

One thing expressly left out of the worksheets is a column for keeping track of what has been ordered but not yet delivered. This is to allow the students to discover, on their own, the importance of keeping track of outstanding orders so that double ordering does not occur. If you do not wish this to be a self-discovery exercise, you can add a column to the Inventory Position Worksheets for this information to be recorded.

Forms for Single Product (Quick Hit) Version:

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
Quantity:		

Forms for Single Product (Quick Hit) Version:

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

DISTRIBUTION CENTER P. 0.	
Day Sent:	Day Rec'd.:
Quantity:	

Forms for Single Product (Quick Hit) Version:

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
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FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
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Day Placed:	Day Complete:
Quantity:	

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Day Placed:	Day Complete:
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FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
Quantity:	

Forms for Single Product (Quick Hit) Version:

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

FACTORY MATL. DELIVERY FORM	
Day Shipped:	Day Rec'd.:
Quantity:	

Forms for Single Product (Quick Hit) Version:

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
Quantity:		

Retailer Inventory Position Worksheet—One for each Retail Store

INVENTORY POSITION				RETAIL STORE #			
Day	Ending Inven- tory	Stock- outs	Quantity Ordered	Day	Ending Inven- tory	Stock- outs	Quantity Ordered
1				21			
2				22			
3				23			
4				24			
5				25			
6				26			
7				27			
8				28			
9				29			
10				30			
11				31			
12				32			
13				33			
14				34			
15				35			
16				36			
17				37			
18				38			
19				39			
20				40			
Cumulative sum of both columns for each category							
Total number of check marks for orders							
Holding cost/day/unit in first column, stockout cost (lost sale per unit) in second column, ordering cost/order in last column							
Cumulative holding, ordering, and stockout costs							
Total operating cost (sum of all costs)							

Distributor Inventory Position Worksheet—One for each Distribution Center

DISTRIBUTION CENTER INVENTORY POSITION							
Day	Ending Inven- tory	Back Orders	Quantity Ordered	Day	Ending Inven- tory	Back Orders	Quantity Ordered
1				21			
2				22			
3				23			
4				24			
5				25			
6				26			
7				27			
8				28			
9				29			
10				30			
11				31			
12				32			
13				33			
14				34			
15				35			
16				36			
17				37			
18				38			
19				39			
20				40			
Cumulative sum of both columns for each category Total number of check marks for orders							
Holding cost/day/unit in first column, ordering cost/order in last column						0	
Resulting cumulative holding and ordering costs							
Total operating cost (sum of both costs)							

Factory Inventory Position Worksheet

FACTORY INVENTORY POSITION							
Day	Ending Inventory	Back Orders	Production Order	Day	Ending Inventory	Back Orders	Production Order
1				21			
2				22			
3				23			
4				24			
5				25			
6				26			
7				27			
8				28			
9				29			
10				30			
11				31			
12				32			
13				33			
14				34			
15				35			
16				36			
17				37			
18				38			
19				39			
20				40			
Cumulative sum of both columns for each category							
Total number of check marks for orders							
Holding cost/day/unit in first column, production order cost/order in last column						0	
Resulting cumulative holding and ordering costs							
Total operating cost (sum of both costs)							

Forms for Multiple Product Versions:

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
CD Artist:	Quantity:	
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
CD Artist:	Quantity:	
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
CD Artist:	Quantity:	
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
CD Artist:	Quantity:	
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
CD Artist:	Quantity:	
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
CD Artist:	Quantity:	
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
CD Artist:	Quantity:	
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

RETAIL STORE PURCHASE ORDER		
Retailer:	Day Sent:	Day Rec.:
CD Artist:	Quantity:	
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

Forms for Multiple Product Versions:

DISTRIBUTION CENTER P. 0.		
Center:	Day Sent:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DISTRIBUTION CENTER P. 0.		
Center:	Day Sent:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DISTRIBUTION CENTER P. 0.		
Center:	Day Sent:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DISTRIBUTION CENTER P. 0.		
Center:	Day Sent:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DISTRIBUTION CENTER P. 0.		
Center:	Day Sent:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DISTRIBUTION CENTER P. 0.		
Center:	Day Sent:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

Forms for Multiple Product Versions:

FACTORY WORK ORDER	
Day Placed:	Day Complete:
CD Artist—Check One:	Quantity:
Jake Spade and the Diggers	
The Heartmenders	
Diamonds in the Ruff	
Kulture Klub	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
CD Artist—Check One:	Quantity:
Jake Spade and the Diggers	
The Heartmenders	
Diamonds in the Ruff	
Kulture Klub	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
CD Artist—Check One:	Quantity:
Jake Spade and the Diggers	
The Heartmenders	
Diamonds in the Ruff	
Kulture Klub	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
CD Artist—Check One:	Quantity:
Jake Spade and the Diggers	
The Heartmenders	
Diamonds in the Ruff	
Kulture Klub	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
CD Artist—Check One:	Quantity:
Jake Spade and the Diggers	
The Heartmenders	
Diamonds in the Ruff	
Kulture Klub	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
CD Artist—Check One:	Quantity:
Jake Spade and the Diggers	
The Heartmenders	
Diamonds in the Ruff	
Kulture Klub	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
CD Artist—Check One:	Quantity:
Jake Spade and the Diggers	
The Heartmenders	
Diamonds in the Ruff	
Kulture Klub	

FACTORY WORK ORDER	
Day Placed:	Day Complete:
CD Artist—Check One:	Quantity:
Jake Spade and the Diggers	
The Heartmenders	
Diamonds in the Ruff	
Kulture Klub	

Forms for Multiple Product Versions:

FACTORY MATL. DELIVERY FORM		
To Cntr:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

FACTORY MATL. DELIVERY FORM		
To Cntr:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

FACTORY MATL. DELIVERY FORM		
To Cntr:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

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To Cntr:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
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To Cntr:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
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Diamonds in the Ruff		
Kulture Klub		

FACTORY MATL. DELIVERY FORM		
To Cntr:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

FACTORY MATL. DELIVERY FORM		
To Cntr:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

FACTORY MATL. DELIVERY FORM		
To Cntr:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

Forms for Multiple Product Versions:

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

DIST. CNTR. MATL. DELIV. FORM		
To Store:	Day Ship:	Day Rec.:
CD Artist:		Quantity:
Jake Spade and the Diggers		
The Heartmenders		
Diamonds in the Ruff		
Kulture Klub		

Retailer Inventory Position Worksheet—One for each Retail Store

RETAIL STORE INVENTORY POSITION WORKSHEET							RETAIL STORE #						
	Ending Inventory				Stock-outs	Order Quantity		Ending Inventory				Stock-outs	Order Quantity
Day	«	a	©	»			Day	«	a	©	»		
1							21						
2							22						
3							23						
4							24						
5							25						
6							26						
7							27						
8							28						
9							29						
10							30						
11							31						
12							32						
13							33						
14							34						
15							35						
16							36						
17							37						
18							38						
19							39						
20							40						
Cumulative sum of both columns for each category													
Total number of check marks for orders													
Cost/unit (supplied by instructor).													
Holding cost/day/unit in first four columns,													
stockout cost (lost sale per unit) in fifth column,													
ordering cost/order in last column													
Cumulative holding, ordering, and stockout costs													
Total operating cost (sum of all costs)													

Distributor Inventory Position Worksheet—One for each Distribution Center

DISTRIBUTION CENTER INVENTORY POSITION WORKSHEET							CENTER #						
Ending Inventory					Back Orders	Order Quantity	Ending Inventory					Back Orders	Order Quantity
Day	«	a	©	»			Day	«	a	©	»		
1							21						
2							22						
3							23						
4							24						
5							25						
6							26						
7							27						
8							28						
9							29						
10							30						
11							31						
12							32						
13							33						
14							34						
15							35						
16							36						
17							37						
18							38						
19							39						
20							40						
Cumulative sum of both columns for each category													
Total number of check marks for orders													
Cost/unit (supplied by instructor)													
Holding cost/day/unit in first four columns, ordering cost/order in last column.													
Resulting cumulative holding and ordering costs													
Total operating cost (sum of all costs)													

Factory Inventory Position Worksheet

FACTORY INVENTORY POSITION WORKSHEET													
	Ending Inventory				Back Orders	Production Order					Back Orders	Production Order	
Day	«	a	©	»			Day	«	a	©	»		
1							21						
2							22						
3							23						
4							24						
5							25						
6							26						
7							27						
8							28						
9							29						
10							30						
11							31						
12							32						
13							33						
14							34						
15							35						
16							36						
17							37						
18							38						
19							39						
20							40						
Cumulative sum of both columns for each category													
Total number of check marks for orders													
Cost/unit (supplied by instructor)													
Holding cost/day/unit in first four columns, production order cost/order in last column													
Resulting cumulative holding and production costs													
Total operating cost (sum of all costs)													

CASE: BRUNSWICK DISTRIBUTORS

There are two options that need to be considered in the analysis of Brunswick Distribution, Inc. (BDI). Students will need to perform an NPV analysis to completely analyze the case. This case offers a good opportunity to team teach its analysis with a finance professor. The following information in the students' assignment will facilitate a financial analysis of the options.

- Use a weighted average cost of capital of 12 percent as the discount rate.
- Use the Modified Accelerated Cost Recovery System (MACRS) for depreciation charges. The **Financial Analysis Solver**, in OM Explorer, uses MACRS in the Net Present Value Analysis. The starting year for the investments is year zero.
- Assume that the MACRS recovery period for both options is 10 years.
- The warehouse building and equipment can be sold for \$7.50 million after 10 years (which comes at the middle of year 11 with MACRS). The land can be sold for its book value of \$2 million. This information is needed so that a comparison can be made between the two options, the warehouse with an economic life of 20 years and the new infrastructure with a life of 10 years. The new infrastructure has no terminal value.

For a more elaborate analysis of this case, students could use the Financial Measures Analyzer Solver, which is found in OM Explorer under Supply Chain Design. The implications of the investments on a multitude of financial measures can be addressed with the program. A summary of the conclusions from a more simplified, less-involved, analysis of the two options posed in the case follows.

Option 1: New warehouse facilities overview

- Inventory turnover is $\text{COGS} / \text{Aggregate Inventory Value} = \$23,337 / \$7,200 = 3.24$, which indicates that this option will not solve the problem of low inventory turnover.
- Net income goes up slightly. Using Figure 9.8 in the text, and using the average depreciation over the 10 year recovery period of \$1,000, the ROA can be calculated to be $\$2,820 / \$43,551 = 6.5$ percent; or, if it is preferred to use earnings before interest and taxes (EBIT) the ROA is $\$6,496 / \$43,551 = 14.9$ percent. See the Income Statement below for the Warehouse option.
- Using MACRS and a 10-year recovery period, the net present value (NPV) for this option is \$1.52 million, which makes it a viable alternative to consider. The internal rate of return is 14.4%, and the payback period is 5.92 years. See the Financial Analysis Solver spreadsheet for the Warehouse option.
- The investment would put Brunswick in a precarious debt to equity situation.

Option 2: New infrastructure overview.

- Inventory turnover is $\text{COGS} / \text{Aggregate Inventory Value} = \$19,115 / \$4,500 = 4.2$, which at least is larger than option 1.
- Net income goes up slightly. The ROA using Figure 9.8 is $\$2,960 / \$35,932 = 8.2$ percent. Using EBIT for the calculation instead, the ROA is $\$6,092 / \$35,932 = 17.0$ percent. See the Income statement below for the new infrastructure option.

- The NPV for this option is \$1.47 million, which is less than option 1. However, the internal rate of return of 16.6% and the payback period of 4.72 years are better than option 1.

While Option 2 – new infrastructure – dominates Option 1 from the perspective of inventory turnover, ROA, internal rate of return, and payback period, it is slightly worse off in NPV and it does not increase revenues or improve market share. Nonetheless, this option may improve customer service and drive increases in customer demands in the future. The analysis of these two options shows the tradeoff in attempting to build market share (Option 1) and becoming more efficient (Option 2). It should be pointed out to the students that it is debatable which of the two options may have more long-term benefits.

Educational objectives

- To critically examine the inter-related activities of marketing, finance and operations.
- To link supply chain design decisions to the net present value analysis.
- To study how seemingly small changes in various aspects of the business affect return on assets and financial measures.
- To emphasize that supply chain design changes can affect the cost of goods sold (such as direct materials costs or labor costs) or other operational expenses in an income statement can have an effect on the important performance measures for a business.

DISCUSSION

Option 1

Income statement

- This option increases annual revenue by \$4.426 million.
- This option would increase costs by a total of \$1,717,000, split up between shipping (\$955 thousand), direct material (\$358 thousand), and direct labor cost (\$404 thousand).
- Using MACRS, depreciation is accelerated over the early years of the asset. This will allow for lower corporate taxes; however the net income figures for the early years will decline due to the large depreciation amounts. The average annual depreciation works out to be \$1,000,000, which is based on the capital cost portion of the investment only because land cannot be depreciated. The asset is assumed to have a 10-year recovery period using MACRS. We used the average depreciation in the calculation of annual net income and EBIT for use in the ROA calculation to get on overall sense of the returns to be expected over the life of the warehouse.
- Annual interest is computed at the rate of 11%. ($11\% \times 12 \text{ million} = \$1,320,000$)

Net present value

- The NPV analysis assumes the investment can be liquidated after 10 years (actually in year 11 to correspond to MACRS assumptions) in order to be able to compare this investment to that of the distribution system improvements, which has a life of only 10 years. The liquidation value of the warehouse and equipment in 10 years is assumed to be \$7.50 million, which must be taxed at the corporate rate because it has been fully depreciated. The land, which is not depreciated, is assumed to have the same liquidation value as its book value of \$2 million; consequently it is not taxed.

- The revenue in year 1 and year 11 is one-half the annual revenue increase, or \$2.213 million. The revenue in year 11 is augmented for the sale of the warehouse asset of \$7.50 million; the total revenue becomes \$9.713 million. The liquidation value of the land, \$2 million, is added to the Total Cash Flow figure for year 11 as a lump sum.

See the spreadsheet reports below.

Option 2

The improved infrastructure option would contribute 16% in direct cost savings in shipping and direct labor which is computed as $16\% * (\$8,931,000 + \$6,726,000)$. This works out to be \$1,429,000 in shipping and \$1,076,000 for direct labor.

Income statement

- We use the average annual depreciation, which works out to be \$700,000, to calculate the typical net income over the years of the asset. This net income figure is used for the ROA calculation. See the income statement for the new infrastructure option.
- Fixed expenses are \$500,000 for the training/year.
- Annual interest is computed at the rate of 10%. $10\% * \$7 \text{ million} = \$700,000$.

Net present value

- The benefits are all from cost reduction; there are no increases in revenues from this option. The asset is assumed to have no value at the end of its recovery period; consequently there is no liquidation value.

See the spreadsheet reports below.

If the financial analysis is the only consideration, the new infrastructure option is a good choice. However, the discussion should raise the question of which competitive priorities should Brunswick pursue. Get the class to agree on a set of competitive priorities. Given that agreement, which of the two options does the best job of addressing those competitive priorities? While the final direction of the discussion may take several paths, the important point to make is that it is the strategic contribution of the asset that is important, subject to its financial merits. If the warehouse option meets minimum financial hurdles, it should be kept in the list of viable options when considering the strategic implications.

OTHER ISSUES TO DISCUSS

One of the biggest issues facing BDI is the predictability of sales. Since orders do not come in from retailers in a timely fashion, considerable emphasis is placed on forecasting sales for manufacturers. This forecasting is largely historical and therefore does not reflect the changes that have occurred over the past two years. In order to better determine levels of safety stock, a better integration of the supply chain is required. Getting the end customer involved by showcasing the product in a kitchen-like setting and acquiring forward-looking information from the end user might help Brunswick in determining demand.

With the additional business, and the extra product lines, BDI has acquired some deadweight. The company already supplies the majority of high-end appliances and the new lines have cut into the profit margins that the company has historically observed.

OPTION 1 – Warehouse**Income Statement**

Inc. Stmt.	Before Investments		Change	After Investment
	\$000's	\$000's	\$000's	
Revenue		\$33,074	\$4,426	\$37,500
Cost of Goods Sold				
Shipping costs	\$8,931		\$955	\$9,886
Direct materials	\$5,963		\$358	\$6,321
Direct Labor & other	\$3,726		\$404	\$7,130
Total	\$21,620			\$23,337
Gross Profit		\$11,454		\$14,163
Operating Expenses				
Selling Expnses	\$2,232			\$2,232
Fixed Expenses	\$2,641			\$2,641
Depreciation	\$1,794		\$1,000	\$2,794
Total	\$6,667			\$7,667
Earnings Before Interest and Taxes		\$4,787		\$6,496
Interest Expense	\$838		\$1,320	\$2,158
Earnings Before Taxes		\$3,949		\$4,338
Taxes @	35%	\$1,382		\$1,518
Net Income		\$2,567		\$2,820
Dividends	\$0			\$0
Contribution to Retained Earnings		\$2,567		\$2,820
# of Shares Outstanding	350			350
Current Stock Price	\$60.00			\$60.00
Par value of stocke	\$5.00			

NPV – Warehouse

Investment amount (non land)	\$ 10.00	Net Present Value	\$1.52
Investment (land)	\$ 2.00	Internal Rate of Return	14.4%
Starting year	0	Payback Period	5.92 years
Depreciation type	10-Year MACRS		
Years	10		
Discount rate	12.0%		
Tax Rate (as percent)	35%		

	1	2	3	4	5	6	7	8	9	10	11
Revenue	2.21	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	4.43	9.71
Expenses: Variable	0.86	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	1.72	0.86
Expenses: Fixed	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Depreciation (D)	1.00	1.80	1.44	1.14	0.92	0.74	0.66	0.66	0.66	0.66	0.33
Pre-tax income	0.35	0.91	1.27	1.56	1.79	1.97	2.05	2.05	2.05	2.05	8.53
Taxes (35%)	0.12	0.32	0.44	0.54	0.63	0.69	0.72	0.72	0.72	0.72	2.98
Net Operating Income (NOI)	0.23	0.59	0.82	1.01	1.16	1.28	1.34	1.34	1.34	1.34	5.54
Total Cash Flow (NOI + D)	1.23	2.39	2.26	2.16	2.08	2.02	1.99	1.99	1.99	1.99	7.87

OPTION 2 – Improve Distribution System

Income Statement

Inc. Stmt.	Before Investments	Change \$000's	After Investment
Revenue	\$33,074		\$33,074
Cost of Goods Sold			
Shipping costs	\$8,931	(\$1,429)	\$7,502
Direct materials	\$5,963		\$5,963
Direct Labor & other	\$3,726	(\$1,076)	\$5,650
Total	\$21,620		\$19,115
Gross Profit	\$11,454		\$13,959
Operating Expenses			
Selling Expenses	\$2,232		\$2,232
Fixed Expenses	\$2,641	\$500	\$3,141
Depreciation	\$1,794	\$700	\$2,494
Total	\$6,667		\$7,867
Earnings Before Interest and Taxes	\$4,787		\$6,092
Interest Expense	\$838	\$700	\$1,538
Earnings Before Taxes	\$3,949		\$4,554
Taxes @ 35%	\$1,382		\$1,594
Net Income	\$2,567		\$2,960
Dividends	\$0		\$0
Contribution to Retained Earnings	\$2,567		\$2,960
# of Shares Outstanding	350		350
Current Stock Price	\$60.00		\$60.00
Par value of stock	\$5.00		

NPV – Improve Distribution System

Investment amount (non land)	\$ 7.00	Net Present Value	\$1.52
Investment (land)		Internal Rate of Return	14.4%
Starting year	0	Payback Period	5.92 years
Depreciation type	10-Year MACRS		
Years	10		
Discount rate	12.0%		
Tax Rate (as percent)	35%		

	1	2	3	4	5	6	7	8	9	10	11
Revenue											
Expenses: Variable	-1.25	-2.51	-2.51	-2.51	-2.51	-2.51	-2.51	-2.51	-2.51	-2.51	-1.25
Expenses: Fixed	0.25	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.25
Depreciation (D)	0.70	1.26	1.01	0.81	0.65	0.52	0.46	0.46	0.46	0.46	0.23
Pre-tax income	0.30	0.75	1.00	1.20	1.36	1.49	1.55	1.55	1.55	1.55	0.77
Taxes (35%)	0.11	0.26	0.35	0.42	0.48	0.52	0.54	0.54	0.54	0.54	0.27
Net Operating Income (NOI)	0.20	0.49	0.65	0.78	0.89	0.94	1.01	1.01	1.01	1.01	0.50
Total Cash Flow (NOI + D)	0.90	1.75	1.66	1.59	1.53	1.49	1.47	1.47	1.47	1.47	0.73

Chapter

11 Supply Chain Location Decisions

DISCUSSION QUESTIONS

1. Answers depend on the specific organizations and industries selected by the teams. Some expected tendencies for *manufacturers* are:

Favorable labor climate	Textiles, furniture, consumer electronics
Proximity to markets	Paper, plastic pipe, cars, heavy metals, and food processing
Quality of life	High technology and research firms
Proximity to suppliers and resources	Paper mills, food processors, and cement manufacturers
Proximity to company's other facilities	Feeder plants and certain product lines in computer manufacturing industry

For *service providers*, the usually dominant location factor is proximity to customers, which is related to revenues. Other factors that also can be crucial are transportation costs and proximity to markets (such as for distribution centers and warehouses), location of competitors, and site-specific factors such as retail activity and residential density for retailers. Data collection relates to the factors selected, which can be collected with on-site visits or from consultants, chambers of commerce, governmental agencies, banks, and the like.

For locations in other countries, additional information is needed about differences in political differences, labor laws, tax laws, regulatory requirements, and cultural differences. It is also important to assess how much control the home office should retain, and the extent to which new techniques will be accepted.

2. The “rust belt” city has made long-term investments in the stadium, roads, zoning, and planning to the benefit of the baseball team (an entertainment service). Leaving the rust belt city leaves the city with these long-term obligations with no means to pay for them. For example, when General Motors closed a large facility in a small community, the results were so devastating that the community sued GM for damages. Retailers in the vicinity have built facilities and operate stores that may not be viable any longer if the team moves. Baseball fans also may not be too sympathetic with the baseball owner.
3. The firm would be well advised to consider both the current state of affairs and potential future action required should the firm finalize this plant location decision. Once the plant is purchased, the firm may take on responsibility for remediating previous plant-management decisions.

Regarding the environmental impact of current practices, the firm should consider such aspects as (1) the plant's current carbon footprint and the costs to reduce, (2) the carbon footprint of suppliers that may be used should this location be selected, (3) overall plant energy costs, (4) contamination that may need to be remediated, (5) any known hazardous conditions that will have to be corrected, and , (6) long term health concerns for employees and local populations due to prior hazardous pollution.

Regarding workplace safety, unless the firm will repurpose the plant, it will need to consider all current practices that it will use once the plant is purchased. The new firm will need to (1) review all employment policies and procedures to ensure compliance with their company policies, (2) review any pre-employment screening protocols such as random drug and alcohol testing (3) ensure that previous management has complied with the relevant federal law such as providing medical leave for employees or nondiscrimination in the workplace (4) ensure the plant has maintained adequate records, for example in instances of employees discharged for misconduct, and (5) consider the cost and time needed for process redesign and/or addition of safety equipment to bring safety requirements up to the OSHA standards.

PROBLEMS

1. Preference matrix location for A, B, C, or D

Location Factor	Factor Weight	Factor Score for Each Location							
		A		B		C		D	
1. Labor climate	5	5	25	4	20	3	15	5	25
2. Quality of life	30	2	60	3	90	5	150	1	30
3. Transportation system	5	3	15	4	20	3	15	5	25
4. Proximity to markets	25	5	125	3	75	4	100	4	100
5. Proximity to materials	5	3	15	2	10	3	15	5	25
6. Taxes	15	2	30	5	75	5	75	4	60
7. Utilities	<u>15</u>	5	<u>75</u>	4	<u>60</u>	2	<u>30</u>	1	<u>15</u>
Total	100		345		350		400		280

Location C, with 400 points.

2. John and Jane Darling

Location Factor	Factor Weight	Factor Score for Each Location							
		A		B		C		D	
1. Rent	25	3	75	1	25	2	50	5	125
2. Quality of life	20	2	40	5	100	5	100	4	80
3. Schools	5	3	15	5	25	3	15	1	5
4. Proximity to work	10	5	50	3	30	4	40	3	30
5. Proximity to recreation	15	4	60	4	60	5	75	2	30
6. Neighborhood security	15	2	30	4	60	4	60	4	60
7. Utilities	<u>10</u>	4	<u>40</u>	2	<u>20</u>	3	<u>30</u>	5	<u>50</u>
Total	100		310		320		370		380

Location D, the in-laws' downstairs apartment, is indicated by the highest score. This points out a criticism of the technique: the Darlings did not include or give weight to a relevant factor.

3. Jackson or Dayton locations

Jackson —

$$\begin{aligned} \$250(30,000) - [\$1,500,000 + (\$50 \times 30,000)] &= \$7,500,000 - \$3,000,000 \\ &= \$4,500,000 \end{aligned}$$

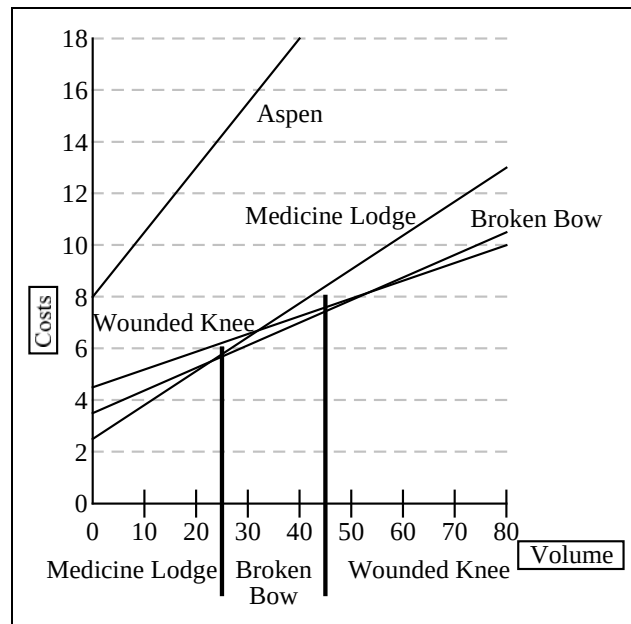
Dayton —

$$\begin{aligned} \$250(40,000) - [\$2,800,000 + (\$85 \times 40,000)] &= \$10,000,000 - \$6,200,000 \\ &= \$3,800,000 \end{aligned}$$

Jackson yields higher total profit per year.

4. Fall-Line, Inc.

- a. Plot of total costs (in \$ millions) versus volume (in thousands)



- b. Medicine Lodge is the lowest-cost location for volumes up to 25,000 pairs per year. Broken Bow is the best choice over the range of 25,000 to 44,000 pairs per year. Wounded Knee is the lowest-cost location for volumes over 44,000 pairs per year. Aspen is not the low-cost location at any volume.

- c. Aspen —

$$\begin{aligned} \$500(60,000) - [\$8,000,000 + (\$250 \times 60,000)] &= \$30,000,000 - \$23,000,000 \\ &= \$7,000,000 \end{aligned}$$

Medicine Lodge —

$$\begin{aligned} \$350(45,000) - [\$2,400,000 + (\$130 \times 45,000)] &= \$15,750,000 - \$8,250,000 \\ &= \$7,500,000 \end{aligned}$$

Broken Bow —

$$\begin{aligned} \$350(43,000) - [\$3,400,000 + (\$90 \times 43,000)] &= \$15,050,000 - \$7,270,000 \\ &= \$7,780,000 \end{aligned}$$

Wounded Knee—

$$\begin{aligned} \$350(40,000) - [\$4,500,000 + (\$65 \times 40,000)] &= \$14,000,000 - \$7,100,000 \\ &= \$6,900,000 \end{aligned}$$

- d. Aspen would surpass Broken Bow when the Aspen profit is \$7,780,000.

$$\$500Q - (\$8,000,000 + (\$250Q)) = \$7,780,000$$

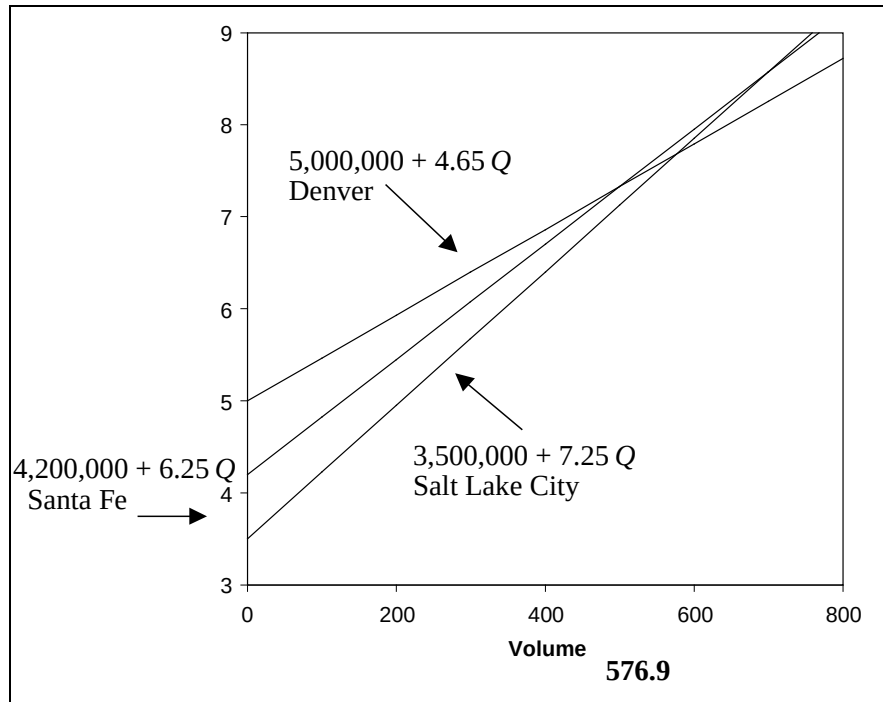
$$\$250Q = 15,780,000$$

$$Q = 63,120$$

Aspen would be the best location if sales would exceed 63,120 pairs per year. Holding all other sales volumes constant.

5. Wiebe Trucking, Inc.

- a. Plot of total costs (in \$ millions) versus volume (in thousands)



- b. For up to 576,923 shipments per year, Salt Lake City is the best location. Beyond that, Denver is the best location.

6. Sam's Bagels

Expected annual profits from "Downtown" location:

$$30,000(3.25 - 1.50) - 12,000 = \$40,500$$

Expected annual profits from "Suburban" location:

$$25,000(2.85 - 1.00) - 8,000 = \$38,250$$

Recommend "Downtown" location.

7. Distance between three points

Point A = (20, 20)

Point B = (50, 10)

Point C = (50, 60)

- a. Euclidean distance
- $d_{AB} = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2}$

$$d_{AB} = \sqrt{(20 - 50)^2 + (20 - 10)^2}$$

$$= \sqrt{(900 + 100)}$$

$$= 31.62$$

$$d_{AC} = \sqrt{(20 - 50)^2 + (20 - 60)^2}$$

$$= \sqrt{(900 + 1600)}$$

$$= 50.0$$

$$d_{BC} = \sqrt{(50 - 50)^2 + (10 - 60)^2}$$

$$= \sqrt{(0 + 2500)}$$

$$= 50$$

- b. Rectilinear distances $d_{AB} = |x_A - x_B| + |y_A - y_B|$
 $d_{AB} = 30 + 10 = 40$
 $d_{BC} = 0 + 50 = 50$
 $d_{AC} = 30 + 40 = 70$

8. West Gorham High School

- a. The weighted latitude and longitude calculations are found in the following Excel spreadsheet.

	Population	Latitude	Longitude	Weighted Latitude	Weighted Longitude
	L	x	y	lx	ly
Westbrook	16,000	43.6769	70.3717	698,830	1,125,947
Scarborough	22,000	43.5781	70.3222	958,718	1,547,088
Gorham	36,500	43.6795	70.4447	1,594,302	2,571,232
Sum	74,500			3,251,850	5,244,267

x^*	43.6490
y^*	70.3928

Optimal latitude and longitude follow are calculated as follows:

$$x^* = \frac{\sum_i l_i x_i}{\sum_i l_i} = \frac{698,830 + 958,718 + 1,594,302}{74,500} = 43.6490$$

$$y^* = \frac{\sum_i l_i y_i}{\sum_i l_i} = \frac{1,125,947 + 1,547,088 + 2,571,232}{74,500} = 70.3928$$

- b. The rectilinear distance from the optimal location to the available land parcels are:

Distance to Baker's Field =

$$d_i = |x_i - x^*| + |y_i - y^*| = |43.6784 - 43.6490| + |70.3827 - 70.3928| = 0.0395$$

Distance to Lonesome Acres =

$$d_i = |x_i - x^*| + |y_i - y^*| = |43.5119 - 43.6490| + |70.3856 - 70.3928| = 0.1443$$

Baker's Field is closer to the optimal location.

9. Prescott Industries

The cost minimizing solution is to ship 8000 loads from Odessa to Abilene, 10000 loads from Bryan to Tyler, and 4000 loads from Odessa to San Angelo. Total cost of this optimal allocation pattern is \$940,000. The Transportation Method Module of the POM for Windows software may be used to solve this problem.

Solution from POM for Windows

Module/submodel: Transportation Method (Location)

Problem title: Prescott Industries

Objective: Minimize

Data and Results -----

Original Data

	Abilene	Tyler	San Angelo	Capacity
Odessa	60	50	40	12000
Bryan	70	30	90	10000
DEMAND	8000	10000	4000	

Shipments

	Abilene	Tyler	San Angelo
Odessa	8000		4000
Bryan	0	10000	

Total cost = 940000

10. Winston Company

- a. The sum of supply capacities equals the sum of demands, so no dummy wholesaler or distribution center is needed. The capacity is fully utilized and the demand is fully satisfied. For example, the 70,000-gallon supply of Wholesaler 2 is allocated to A, B, and C ($40 + 10 + 20 = 70$). Similarly, the 60,000-gallon demand by Distribution Center B is satisfied by Wholesalers 1 and 2 ($50 + 10 = 60$). The following screens were obtained with the Transportation Method (Location) in POM for Windows.

POM for Windows Data Input Screen

	A	B	C	D	SUPPLY
Wholesaler 1	1.3	1.4	1.8	1.6	50
Wholesaler 2	1.3	1.5	1.8	1.6	70
Wholesaler 3	1.6	1.4	1.7	1.5	60
DEMAND	40	60	30	50	

POM for Windows Solution Screen

Optimal cost = \$265	A	B	C	D
Wholesaler 1		50		
Wholesaler 2	40	10	20	
Wholesaler 3			10	50

- b. Total cost of the preceding solution (in \$000) is
 $(50 \times 1.4) + (40 \times 1.3) + (10 \times 1.5) + (20 \times 1.8) + (10 \times 1.7) + (50 \times 1.5) = \$265$

11. Val's Pizza

Treating the southwest corner of the plot as the origin and estimating the coordinates,

Point A location (1.00, 1.75), demand = 4000

Point B location (3.75, 2.00), demand = 1000

Point C location (4.75, 2.50), demand = 1000

Point D location (5.00, 0.00), demand = 1000

Point E location (0.75, 0.50), demand = 500

$$a. \quad x^* = \frac{\sum_i l_i x_i}{\sum_i l_i} \quad \text{and} \quad y^* = \frac{\sum_i l_i y_i}{\sum_i l_i}$$

$$x^* = \frac{(4000 \times 1.00) + (1000 \times 3.75) + (1000 \times 4.75) + (1000 \times 5.00) + (500 \times 0.75)}{(4000 + 1000 + 1000 + 1000 + 500)}$$

$$x^* = \frac{17,875}{7500} = 2.38$$

$$y^* = \frac{(4000 \times 1.75) + (1000 \times 2.00) + (1000 \times 2.50) + (1000 \times 0.00) + (500 \times 0.50)}{(4000 + 1000 + 1000 + 1000 + 500)}$$

$$y^* = \frac{11750}{7500} = 1.57$$

Val's should start looking for locations at about 30th and "O" streets, say at (2.5, 1.5).

- b. Rectilinear load-distance score. Assuming Val's location at (2.5, 1.5).

Location	Load	Distance	ld score
Point A	4000	1.75	7000
Point B	1000	1.75	1750
Point C	1000	3.25	3250
Point D	1000	4.00	4000
Point E	500	2.75	<u>1375</u>
			17,375

- c. Rectilinear distance from Val's (at 2.5, 1.5) to the farthest point D (5.0, 0.0) is 4 miles. At two minutes per mile, the travel time is eight minutes.

12. Davis, California, Post Office

- a. Center of Gravity

$$x^* = \frac{\sum_i l_i x_i}{\sum_i l_i} \text{ and } y^* = \frac{\sum_i l_i y_i}{\sum_i l_i}$$

$$x^* = \frac{(6 \times 2) + (3 \times 6) + (3 \times 8) + (3 \times 13) + (2 \times 15) + (7 \times 6) + (5 \times 18) + (3 \times 10)}{(6 + 3 + 3 + 3 + 2 + 7 + 5 + 3)}$$

$$x^* = \frac{285}{32} = 8.9$$

$$y^* = \frac{(6 \times 8) + (3 \times 1) + (3 \times 5) + (3 \times 3) + (2 \times 10) + (7 \times 14) + (5 \times 1) + (3 \times 3)}{(6 + 3 + 3 + 3 + 2 + 7 + 5 + 3)}$$

$$y^* = \frac{207}{32} = 6.5$$

- b. Load distance scores

Mail Source Point	Round Trips per Day (<i>l</i>)	xy-Coord	Load-distance to M: (10, 3)	Load-distance to CG: (8.9, 6.5)
1	6	(2, 8)	$6(8 + 5) = 78$	$6(6.9 + 1.5) = 50.4$
2	3	(6, 1)	$3(4 + 2) = 18$	$3(2.9 + 5.5) = 25.2$
3	3	(8, 5)	$3(2 + 2) = 12$	$3(0.9 + 1.5) = 7.2$
4	3	(13, 3)	$3(3 + 0) = 9$	$3(4.1 + 3.5) = 22.8$
5	2	(15, 10)	$2(5 + 7) = 24$	$2(6.1 + 3.5) = 19.2$
6	7	(6, 14)	$7(4 + 11) = 105$	$7(2.9 + 7.5) = 72.8$
7	5	(18, 1)	$5(8 + 2) = 50$	$5(9.1 + 5.5) = 73.0$
M	3	(10, 3)	$3(0 + 0) = 0$	$3(1.1 + 3.5) = 13.8$
			Total = 296	Total = 284.4

13. Rauschenberg Manufacturing

a. Euclidean distance $d_{AB} = \sqrt{(x_A - x_B)^2 + (y_A - y_B)^2}$

$$d_{AB} = \sqrt{(100 - 400)^2 + (200 - 100)^2}$$

$$= \sqrt{(90,000 + 10,000)}$$

$$d_{AB} = 316.2$$

$$d_{BC} = \sqrt{(400 - 100)^2 + (100 - 100)^2}$$

$$= \sqrt{(90,000)}$$

$$d_{BC} = 300$$

$$d_{AC} = \sqrt{(100 - 100)^2 + (200 - 100)^2}$$

$$= \sqrt{(10,000)}$$

$$d_{AC} = 100$$

Location A

— A	8(0)	=	0.0
— B	4(316.2)	=	1,264.8
— C	3(100)	=	<u>300.0</u>
			1,564.8

Location B

— A	8(316.2)	=	2,529.6
— B	4(0)	=	0.0
— C	3(300)	=	<u>900.0</u>
			3,429.6

Location C

— A	8(100)	=	800.0
— B	4(300)	=	1,200.0
— C	3(0)	=	<u>0.0</u>
			2,000.0

↑ shortest transportation distance

b. Rectilinear distances $d_{AB} = |x_A - x_B| + |y_A - y_B|$

$$d_{AB} = |100 - 400| + |200 - 100|$$

$$d_{AB} = 400$$

$$d_{BC} = |400 - 100| + |100 - 100|$$

$$d_{BC} = 300$$

$$d_{AC} = |100 - 100| + |200 - 100|$$

$$d_{AC} = 100$$

Location A

— A	8(0)	=	0.0
— B	4(400)	=	1,600.0
— C	3(100)	=	<u>300.0</u>
			1,900.0

Location B

— A	8(400)	=	3,200.0
— B	4(0)	=	0.0
— C	3(300)	=	<u>900.0</u>
			4,100.0

Location C

— A	8(100)	=	800.0
— B	4(300)	=	1200.0
— C	3(0)	=	<u>0.0</u>
			2,000.0

↑ **Location A is indicated**

c. Center of gravity (180.0, 153.3)

$$x^* = \frac{\sum l_i x_i}{\sum l_i} \text{ and } y^* = \frac{\sum l_i y_i}{\sum l_i}$$

$$x^* = \frac{(8 \times 100) + (4 \times 400) + (3 \times 100)}{(15)}$$

$$x^* = \frac{2,700}{15} = 180.0$$

$$y^* = \frac{(8 \times 200) + (4 \times 100) + (3 \times 100)}{(15)}$$

$$y^* = \frac{2,300}{15} = 153.3$$

14. Personal computer manufacturer

From port at Los Angeles:

To Chicago:	\$0.0017/mile 1,800 miles	=	\$3.06/unit
To Atlanta:	\$0.0017/mile 2,600 miles	=	\$4.42/unit
To New York:	\$0.0017/mile 3,200 miles	=	\$5.44/unit

From port at San Francisco:

To Chicago:	\$0.0020/mile 1,700 miles	=	\$3.40/unit
To Atlanta:	\$0.0020/mile 2,800 miles	=	\$5.60/unit
To New York:	\$0.0020/mile 3,000 miles	=	\$6.00/unit

Now we use the load-distance method to evaluate each port, where $ld = \sum l_i d_i$

Cost of port at Los Angeles:

$$\$3.06(10,000) + \$4.42(7,500) + \$5.44(12,500) = \mathbf{\$131,750}$$

Cost of port at San Francisco:

$$\$3.40(10,000) + \$5.60(7,500) + \$6.00(12,500) = \mathbf{\$151,000}$$

Therefore, the more cost-effective city is Los Angeles.

15. Oscar's Bowling Inc.

a. Center of gravity

City	Population	x	y	Pop * x	Pop * y
Tempe	250,000	5	5	1,250,000	1,250,000
Scottsdale	400,000	5	10	2,000,000	4,000,000
Chandler	300,000	5	0	1,500,000	0
Mesa	700,000	10	1	7,000,000	700,000
Glendale	350,000	1	10	350,000	3,500,000
Total	2,000,000			12,100,000	9,450,000

$$x^* = 12,100,000 / 2,000,000 = 6.05$$

$$y^* = 9,450,000 / 2,000,000 = 4.725$$

b. Closest city

Tempe—closest to (6.05, 4.725)

16. The Acme Company

The optimal solution follows. The total transportation costs are:

$$[(60,000 \times \$1) + (20,000 \times \$3) + (50,000 \times \$1) + (10,000 \times \$4) + (20,000 \times \$3) + (40,000 \times \$1) + (50,000 \times \$2)] = \$410,000$$

Factory	Shipping Cost (\$/case) to Warehouse					Capacity
	W1	W2	W3	W4	W5	
F1	\$1 60,000	\$3 20,000	\$4	\$5	\$6	80,000
F2	\$2	\$2	\$1 50,000	\$4 10,000	\$5	60,000
F3	\$1	\$5	\$1	\$3 20,000	\$1 40,000	60,000
F4	\$5	\$2 50,000	\$4	\$5	\$4	50,000
Demand	60,000	70,000	50,000	30,000	40,000	250,000

These results can be obtained with the *Transportation Method (Location)* module in POMS for Windows:

Data Screen

	W1	W2	W3	W4	W5	SUPPLY
F1	1	3	4	5	6	80,000
F2	2	2	1	4	5	60,000
F3	1	5	1	3	1	60,000
F4	5	2	4	5	4	50,000
DEMAND	60,000	70,000	50,000	30,000	40,000	

Solution Screen

Optimal cost = \$410,000	W1	W2	W3	W4	W5
F1	60,000	20,000		0	
F2			50,000	10,000	
F3				20,000	40,000
F4		50,000			

17. Dennison Manufacturing.

Breakeven quantity between Phoenix and Buffalo =
 $(600,000 - 300,000) / (75 - 60) = 20,000$ units

Break-even quantity between Buffalo and Seattle =
 $(1,500,000 - 600,000) / (60 - 38) = 40,909$ units

No need to include Atlanta at this point because it is dominated in both variable and fixed costs by Seattle.

Choose:

Phoenix for less than 20,000 units

Buffalo for between 20,000 and 40,909 units

Seattle for more than 40,909 units

18. Giant Farmer Company

Buffalo location-optimal solution:

Plant	Distribution Center				Capacity
	Miami	Denver	Lincoln	Jackson	
Chicago	7	2	4	5	100
Houston	3	1	5	2	75
Buffalo	6	9	7	4	80
Requirements	70	90	45	50	255

Total optimal cost = \$82,500.

Atlanta location-optimal solution:

Plant	Shipping cost to Distribution Centers (\$/case)				Capacity (× 100)
	Miami	Denver	Lincoln	Jackson	
Chicago	\$7	\$2	\$4	\$5	100
		55	45		
Houston	\$3	\$1	\$5	\$2	75
		35		40	
Atlanta	\$2	\$10	\$8	\$3	80
	70			10	
Demand (× 100)	70	90	45	50	255

Total optimal cost = \$57,500.

The new plant should be located in Atlanta because the total cost is lower.

19. Thor International Company

Using the *Transportation Method (Location)* module in POMS for Windows, the optimal solution is found to be:

Module/submodel: Transportation Method (Location)
 Problem title: Thor International
 Objective: Minimize

Original Data

	W1	W2	W3	W4	W5	Dummy
F1	2	3	3	2	6	0
F2	2	3	2	4	5	0
F3	4	2	4	2	3	0
F4	3	4	4	5	2	0
DEMAND	45000	30000	30000	35000	50000	60000

Capacity

F1	50000
F2	80000
F3	80000
F4	40000

DEMAND

Shipments

	W1	W2	W3	W4	W5	Dummy
F1						50000
F2	45000		30000			5000
F3		30000		35000	10000	5000
F4					40000	

Total cost = 390000

A dummy warehouse with a demand of 60,000 units was added, because plant capacities exceeded total demand by that amount. Note that Factory 1 ships its entire capacity to the Dummy location and is therefore is not used. Shipments to the Dummy location from F2 and F3 represent unused capacity.

Total Cost:	F2-W1=	45,000(\$2)	=	\$90,000
	F3-W2=	30,000(\$2)	=	\$60,000
	F2-W3=	30,000(\$2)	=	\$60,000
	F3-W4=	35,000(\$2)	=	\$70,000
	F3-W5=	10,000(\$3)	=	\$30,000
	F4-W5=	40,000(\$2)	=	<u>\$80,000</u>
				<u>\$390,000</u>

20. Thor International Company (part 2)

- a. Once again using the *Transportation Method (Location)* module in POMS for Windows, we get the optimal solution shown in the output that follows.

Module/submodel: Transportation Method (Location)
 Problem title: Thor International
 Objective: Minimize

Original Data

	W1	W2	W3	W4	W5	Dummy
F1	2	3	3	2	6	0
F2	2	3	2	4	5	0
F3	4	2	4	2	3	0
DEMAND	45000	30000	30000	35000	50000	20000

Capacity

F1	50000
F2	80000
F3	80000

DEMAND
Shipments

	W1	W2	W3	W4	W5	Dummy
F1				35000		15000
F2	45000		30000			5000
F3		30000			50000	

Total cost = 430000

With this solution, the total cost of the revised problem is greater than the total cost in problem 19. Thus, the logistic manager should get a budget increase.

Total Cost:	F2-W1=	45,000(\$2)	=	\$90,000
	F3-W2=	30,000(\$2)	=	\$60,000
	F2-W3=	30,000(\$2)	=	\$60,000
	F1-W4=	35,000(\$2)	=	\$70,000
	F3-W5=	50,000(\$3)	=	<u>\$150,000</u>
				<u>\$430,000</u>

Total cost, original problem = \$390,000

- b. The logistics manager should receive a budget increase of $(\$430,000 - \$390,000) = \$40,000$ for increased transportation costs. The only shift in the shipping pattern is that W4 is served from F1 and W5 is now served from F3 alone. The increase in costs is less than the \$160,000 requested.

21. Giant Farmer Company: Further Analysis—Memphis Plant

The optimal solution is shown following. The total costs are \$66,500. Because total shipping costs are higher with the Memphis location, this would not change the decision in Problem 18.

Supplier	Shipping cost to Distribution Centers (\$/case)				Capacity ($\times 100$)
	Miami	Denver	Lincoln	Jackson	
Chicago	\$7	\$2	\$4	\$5	100
		65	35		
Houston	\$3	\$1	\$5	\$2	75
		25		50	
Memphis	\$3	\$11	\$6	\$5	80
	70		10		
Demand ($\times 100$)	70	90	45	50	255

Total optimal cost = \$66,500.

22. Chambers Corporation

Using *Transportation Method (Location)* module in POMS for Windows

Alternative 1 (Portland)

Data Screen

	AT	CO	LA	SE	SUPPLY
Baltimore	.35	.2	.85	.75	6,000
Milwaukee	.55	.15	.7	.65	6,000
Portland	.85	.6	.3	.1	6,000
DEMAND	5,000	3,000	6,000	4,000	

Solution Screen

Optimal cost = \$6,050	AT	CO	LA	SE
Baltimore	5,000	1,000		
Milwaukee		2,000	4,000	
Portland			2,000	4,000

Alternative 2 (San Antonio)

Data Screen

	AT	CO	LA	SE	CAPACITY
Baltimore	.35	.2	.85	.75	6,000
Milwaukee	.55	.15	.7	.65	6,000
Portland	.55	.4	.4	.55	6,000
DEMAND	5,000	3,000	6,000	4,000	

Solution Screen

Optimal cost = \$7,250	AT	CO	LA	SE
Baltimore	5,000	1,000		
Milwaukee		2,000	0	4,000
Portland			6,000	

Alternative 3 (Portland and San Antonio)

Data Screen

	AT	CO	LA	SE	CAPACITY
Baltimore	.35	.2	.85	.75	6,000
Milwaukee	.55	.15	.7	.65	6,000
Portland	.85	.6	.3	.1	3,000
San Antonio	.55	.4	.4	.55	3,000
DEMAND	5,000	3,000	6,000	4,000	

Solution Screen

Optimal cost = \$6,500	AT	CO	LA	SE
Baltimore	5,000	1,000		
Milwaukee		2,000	3,000	1,000
Portland				3,000
San Antonio			3,000	

Alternative 1 (Portland) with a minimum total cost of \$605,000 is the best.

Alternative 2 (San Antonio) has a minimum total cost of \$725,000.

Alternative 3 (Portland and San Antonio) has a minimum total cost of \$650,000.

Chapter

12 Supply Chain Integration

DISCUSSION QUESTIONS

1. Supply chain dynamics can be from internal sources or external sources. Dynamics emanating from internal causes should be corrected by addressing the firm's policies on pricing and promotions, ability to provide correct data and information, and the frequency of new service or product introductions, to name a few. Some of the external causes of supply chain disruption can be mitigated by better integration between customers, the firm, and suppliers. However, sometimes the variability in demands is out of the control of the firm. Figure 12.3 shows how a firm's SKUs could look regarding annual demands and weekly demand variability. A new supply chain design could help to mitigate the effects of those products with lower volumes and higher variability. The firm could have an ATO supply chain for those products and a MTS supply chain for the higher volume, more stable products. Splintering the supply chain into two or more individual supply chains should be undertaken only when other approaches outlined in this chapter have been exhausted.
2. The experiences of GM and Chrysler are indicative of two differing approaches to supplier relations. GM's posture is indicative of a competitive orientation because going to lunch at the request of a supplier may give certain suppliers an edge when competing for GM's business. Chrysler's position is indicative of a cooperative approach to supplier relations. If the suppliers have been chosen for a certain product line, the goal is to develop a cooperative working relationship. Going to lunch promotes that atmosphere.
3. Firms with power in a supply relationship can influence the behavior of suppliers in several ways. First, if there is an economic advantage because of the amount of business the buyer gives to the supplier, the buyer can require the supplier to participate in programs such as CFAR or to use technology such as RFID, for example. The threat of losing the business may coerce the supplier into compliance. There are other sources of power that can be applied by a buyer. For example, the buyer may have the ability to reward the supplier with the promise of future business, or the buyer may be an expert in some field (such as technology applied to supply chain integration) and may offer that expertise to the supplier in order to influence behavior on other matters. Of course, the supplier may have the power in a supply relationship, perhaps because it is the only supplier of a critical item to the buyer or may have some expertise in an important aspect of the buyer's business. It is important to emphasize that power can be used to accomplish positive things in a supply chain, not just provide one firm benefits at the expense of another.

4. Many firms have applied the principles of lean systems at the firm level to their supply chains. Small lot sizes, close supplier ties, and quality at the source are all applicable to a supply chain.
- Small lot sizes. We have seen in our total cost analysis that lot sizes have an impact on cycle inventory levels and freight costs because of the options available to transport different quantities of product. Small lot sizes lower cycle inventory requirements (perhaps enabling smaller warehouse space) while requiring more shipments. More shipments may require more oversight and control of the supply relationship, and the potential for supply problems.
 - Close supplier ties. A key to achieving a reliable flow of information and materials is to engender close supplier relationships. As opposed to a competitive orientation, which may be appropriate for short-term relationships, close supplier ties enabled by a cooperative orientation foster long-term relationships, which are the backbone for cooperative programs such as CFAR (see Chapter 14, Forecasting), vendor-managed-inventories, and RFID.
 - Quality at the source. Reliable supplies begin with reliable quality levels. Quality at the source is a concept that discourages passing defects along to a customer, whether that customer is internal or external. Suppliers are typically held to a stated level of quality in their supply contracts; passing along defects will be costly to both the buyer and the supplier.

PROBLEMS

1. Horizon Cellular. We apply the equation for total annual cost analysis to each supplier:

$$\text{Total Annual Cost} = pD + \text{Freight costs} + (Q/2 + \bar{d}L)H + \text{Administrative costs.}$$

The average requirements per day are 200 circuit boards.

For Abbott and a shipping quantity of 10,000, the total annual cost is:

$$\begin{aligned} \text{Total Annual Cost} &= (\$30)(50,000) + \$10,000 + (10,000/2 + 200(4))(\$6) + \$10,000 \\ &= \$1,554,800. \end{aligned}$$

The total annual costs for the other alternatives are given in the following table.

	Shipping Quantity	
	10,000	25,000
Abbott	\$1,554,800	\$1,596,800
Baker	\$1,459,840	\$1,498,840
Carpenter	\$1,602,720	\$1,646,720

Baker, with a shipping quantity of 10,000, is the lowest cost alternative.

2. Eight Flags. We apply the equation for total annual cost analysis to each supplier:

Total Annual Cost = pD + Freight costs + $(Q/2 + \bar{d}L)H$ + Administrative costs.

The average requirements per week are $30,000/50 = 600$ gallons.

For Sharps and a shipping quantity of 5,000, the total annual cost is:

Total Annual Cost = $(\$4)(30,000) + \$5,000 + (5,000/2 + 600(4))(\$0.80) + \$4,000 = \$132,920$.

The total annual costs for the other alternatives are given in the following table.

Shipping Quantity			
Supplier	5,000	10,000	15,000
Sharps	\$132,920	\$132,520	\$133,920
Winkler	\$129,136	\$128,736	\$130,336

Winkler, with a shipping quantity of 10,000, is the lowest cost alternative.

3. Bennet

- a. Each supplier's performance can be calculated as:

Performance Criterion	Weight	Weighted Rating		
		Supplier A	Supplier B	Supplier C
1. Price	0.2	$0.6(0.2) = 0.12$	$0.5(0.2) = 0.10$	$0.9(0.2) = 0.18$
2. Quality	0.2	$0.6(0.2) = 0.12$	$0.4(0.2) = 0.08$	$0.8(0.2) = 0.16$
3. Delivery	0.3	$0.6(0.3) = 0.18$	$0.3(0.3) = 0.09$	$0.8(0.3) = 0.24$
4. Production facilities & capacity	0.1	$0.5(0.1) = 0.05$	$0.9(0.1) = 0.09$	$0.6(0.1) = 0.06$
5. Environmental protection	0.1	$0.7(0.1) = 0.07$	$0.8(0.1) = 0.08$	$0.6(0.1) = 0.06$
6. Financial position	0.1	$0.9(0.1) = \underline{0.09}$	$0.9(0.1) = \underline{0.09}$	$0.7(0.1) = \underline{0.07}$
Total weighted score		0.63	0.53	0.77

- b. Suppliers A and C survived the hurdle. Supplier A would receive 45% of the orders and Supplier C would receive 55% of the orders.
- c. Ben's system provides some assurance that orders are placed with qualified suppliers. The orders are divided between two suppliers, so there is a ready alternative if a strike, fire, or other problem prevents one supplier from performing. The system also rewards suppliers with more orders if they improve performance.

4. Beagle Clothiers. The weights for the four criteria—price, quality, delivery, and flexibility—should be 0.2, 0.2, 0.2, and 0.4, respectively. The weighted scores are

	Supplier A	Supplier B	Supplier C
	$8 \times 0.2 = 1.6$	$6 \times 0.2 = 1.2$	$6 \times 0.2 = 1.2$
	$9 \times 0.2 = 1.8$	$7 \times 0.2 = 1.4$	$7 \times 0.2 = 1.4$
	$7 \times 0.2 = 1.4$	$9 \times 0.2 = 1.8$	$6 \times 0.2 = 1.2$
	$5 \times 0.4 = \underline{2.0}$	$8 \times 0.4 = \underline{3.2}$	$9 \times 0.4 = \underline{3.6}$
Total weighted score	6.8	7.6	7.4

Supplier B should be selected.

5. Wingman Distributing. We use the expected value decision rule. Management has identified three potential levels of demand for the trucks and three corresponding levels of capacity. Consequently, there are three cost possibilities for each capacity level. Costs include the capital costs, variable costs, and rental costs, if applicable. The expected value of a capacity alternative is the probability of a level of demand multiplied by the cost for that level of demand, summed over all possible levels of demand. Take for example the “5 truck” alternative:

$$C(40,000 \text{ miles}) = (\$1,500)(5) + (\$0.90)(40,000) \\ = \$43,500.$$

$$C(80,000 \text{ miles}) = (\$1,500)(5) + (\$0.90)(40,000) + (\$1.40)(80,000 - 40,000) \\ = \$99,500.$$

$$C(120,000 \text{ miles}) = (\$1,500)(5) + (\$0.90)(40,000) + (\$1.40)(120,000 - 40,000) \\ = \$155,500.$$

The expected value for the “5 truck” alternative is:

$$\text{Expected value (5 trucks)} = (0.3)(\$43,500) + (0.4)(\$99,500) + (0.3)(\$155,500) \\ = \$99,500.$$

The expected values for all alternatives are:

Probabilities				
	0.3	0.4	0.3	
Alternatives	40,000 miles	80,000 miles	120,000 miles	Expected Value
5 trucks	\$43,500	\$99,500	\$155,500	\$99,500
10 trucks	\$51,000	\$87,000	\$143,000	\$93,000
15 trucks	\$58,500	\$94,500	\$130,500	\$94,500

The lowest expected cost is attributed to the “10 truck” option.

6. Sanchez Trucking. We use the expected value decision rule. Management has identified four potential levels of demand for teams and four corresponding levels of capacity. Consequently, there are four cost possibilities for each capacity alternative. Costs include the wages and benefits for the teams to be on the payroll and the cost of using short-term employees to cover for capacity shortages. The expected value of an alternative is the probability of a level of demand times the corresponding cost if that demand materializes, summed over all possible levels of demand. Take for example the “3 team” alternative:

$$C(720 \text{ hours}) = (\$3,200)(3 \text{ crews}) = \$9,600.$$

$$C(960 \text{ hours}) = (\$3,200)(3 \text{ crews}) + (\$5,000)(2 \text{ crews} - 1 \text{ crew}) = \$14,600.$$

$$C(1,200 \text{ hours}) = (\$3,200)(3 \text{ crews}) + (\$5,000)(3 \text{ crews} - 1 \text{ crew}) = \$19,600.$$

$$C(1,440 \text{ hours}) = (\$3,200)(3 \text{ crews}) + (\$5,000)(4 \text{ crews} - 1 \text{ crew}) = \$24,600$$

The expected value for the “3 crew” alternative is:

$$\text{Expected value (3 crews)} = (0.2)(\$9,600) + (0.4)(\$14,600) + (0.3)(\$19,600) + (0.1)(\$24,600) = \$16,100.$$

The expected values for all alternatives are:

Probabilities					
	0.2	0.4	0.3	0.1	
Alternatives	720 hours	960 hours	1,200 hours	1,440 hours	Expected Value
3 crews	\$9,600	\$14,600	\$19,600	\$24,600	\$16,100
4 crews	\$12,800	\$12,800	\$17,800	\$22,800	\$15,300
5 crews	\$16,000	\$16,000	\$16,000	\$21,000	\$16,500
6 crews	\$19,200	\$19,200	\$19,200	\$19,200	\$19,200

The lowest expected cost is attributed to the “4 crew” option.

ADVANCED PROBLEMS

7. Weekend Projects.

- a. We apply the equation for total annual cost analysis to each supplier:

$$\text{Total Annual Cost} = pD + \text{Freight costs} + (Q/2 + \bar{d}L)H + \text{Administrative costs.}$$

The average requirements per week are $100,000/50 = 2,000$ tool sets.

For Bradley and a shipping quantity of 10,000, the total annual cost is:

$$\text{Total Annual Cost} = (\$8.10)(100,000) + \$35,000 + (10,000/2 + 2,000(6))(\$1.62) + \$10,000 = \$882,540.$$

The total annual costs for the other alternatives are given in the following table.

Shipping Quantity			
Supplier	10,000	25,000	50,000
Bradley	\$882,540	\$884,690	\$897,940
Alexander	\$886,060	\$886,210	\$897,460

Bradley, with a shipping quantity of 10,000, is the lowest cost alternative.

- b. The target indifference point is \$882,540, which is Bradley's lowest cost. However, the best shipping size for Zelda may not be 10,000 tools sets as it was for Bradley. Consequently, each shipping quantity must be evaluated for Zelda. We begin by finding the total annual costs for Zelda for each shipping quantity *without the annual administrative costs*.

$$C(Q \text{ sets}) = pD + \text{Freight costs} + (Q/2 + \bar{d}L)H$$

$$C(10,000 \text{ sets}) = (\$8.00)(100,000) + \$45,000 + (10,000/2 + 2,000(7))(1.60) = \$875,400.$$

$$C(25,000 \text{ sets}) = (\$8.00)(100,000) + \$25,000 + (25,000/2 + 2,000(7))(1.60) = \$867,400.$$

$$C(50,000 \text{ sets}) = (\$8.00)(100,000) + \$17,000 + (50,000/2 + 2,000(7))(1.60) = \$879,400.$$

We can see that the lowest cost for Zelda will come at a shipping quantity of 25,000 sets. Now we can find the lowest annual administrative cost that would make the decision between Zelda and Bradley a toss up:

$$\text{Administrative costs for Zelda} = \$882,540 - \$867,400 = \$15,140.$$

Consequently, with total annual costs as the criterion, if the estimate for administrative costs for Zelda comes in below \$15,140, Zelda will be chosen with a shipping quantity of 25,000 sets.

8. Wanda Lux.

- a. We first determine the total annual cost for each supplier using the following equation:

$$\text{Total Annual Cost} = pD + \text{Freight costs} + (Q/2 + \bar{d}L)H + \text{Administrative costs.}$$

The average requirements per day are $40,000/250 = 160$ bottles.

$$\text{Total Annual Cost (Dover)} = (\$5.10)(40,000) + \$3,500 + (20,000/2 + 160(15))(\$1.02) + \$4,000 = \$224,148$$

$$\text{Total Annual Cost (Evan)} = (\$5.05)(40,000) + \$3,000 + (20,000/2 + 160(12))(\$1.01) + \$6,000 = \$223,039$$

$$\text{Total Annual Cost (Farley)} = (\$5.00)(40,000) + \$4,500 + (20,000/2 + 160(20))(\$1.00) + \$3,000 = \$220,700$$

Consequently, Farley is the lowest cost supplier of the three alternatives.

- b. We can now rank the three suppliers with regard to total annual cost and assign a score:

$$\text{Farley} = 10; \text{ Evan} = 8.5; \text{ Dover} = 7$$

The weighted scores for each supplier are contained in the following table:

Performance Score

Criterion	Weight	Dover	Evan	Farley
Total Cost	30	7	8.5	10
Consistent Quality	30	9	9	7
On-Time Delivery	20	8	9	9
Environment	20	8	7	7
Total Weighted Score		800	845	830

Consequently, Evan & Sons should get the supply contract from Wanda Lux.

9. Adelie Enterprises

- a. For each supplier at each demand level, multiply each criterion by the supplier's score and sum. Thus, the local supplier under the assumption of low demand scores a 7.65 $(.35(8)+.15(9)+.25(5)+.25(9))$. As shown in the Excel table below:

Under low demand the Local Supplier has the highest ranking

Under moderate demand the National Supplier has the highest ranking

Under high demand the International Supplier has the highest ranking

		Supplier Rating Under Low, Moderate and High Levels of Demand								
		Local Supplier			National Supplier			International Supplier		
	Weight	Low	Moderate	High	Low	Moderate	High	Low	Moderate	High
Product Quality	0.35	8	6	5	7	7	7	6	6	6
Delivery Speed	0.15	9	7	3	6	6	6	4	5	7
Product Price	0.25	5	5	3	5	7	9	7	7	9
Environmental Impact	0.25	9	9	9	7	7	7	8	8	8
Weighted Rankings		<u>7.65</u>	6.65	5.20	6.35	<u>6.85</u>	7.35	6.45	6.60	<u>7.40</u>

- b. Using a Maximin decision criterion, the company would select the International Supplier. This supplier's smallest ranking (6.45 under low demand) is greater than the Local Supplier's (5.20 at high demand) and the National Supplier's (6.35 under low demand).

	Low	Moderate	High	Min Ranking
Local Supplier	7.65	6.65	5.20	5.20
National Supplier	6.35	6.85	7.35	6.35
International Supplier	6.45	6.60	7.40	6.45

- c. For each supplier, multiply the probability of each demand level with the supplier's ranking at that demand level and sum. For example, the expected ranking for the local supplier is 6.71 $(.35(7.65) + .45(6.65) + .20(5.2))$.

The following POM for Windows Decision Analysis printout provides the solution to which supplier achieves the highest expected ranking

Module/submodel: Decision Making/Decision Tables				
Results -----				
Expected				
	Low	Moderate	High	Value

Probabilities	.35	.45	.2	
Local	7.65	6.65	5.2	6.71
National	6.35	6.85	7.35	6.78
International	6.45	6.6	7.4	6.71

Column best				6.78

The maximum expected monetary value is 6.78 given by the National Supplier

10. Adelle Enterprises part 2.

- a. The total costs for the local supplier at a low level of demand are assessed as follows:

Material cost = Demand x unit price

For the Local Supplier at a Low rate of demand:

$$50,000(\$1.25) = \$62,500$$

Freight cost = Demand/10,000 x Freight cost

For the Local Supplier at a Low rate of demand:

$$(50,000/10,000)\$20.00 = \$1,000$$

Inventory cost = $(\text{Order Size}/2 + \text{Demand}/250) \times \text{Carrying Cost}$

For the Local Supplier at a Low rate of demand:

$$(10,000/2 + 50,000/250)\$0.10 = \$520$$

Administrative Cost = as provided in the table

For the Local Supplier at a Low rate of demand:

$$\$15,000$$

Total cost = Material cost + Freight cost + Inventory cost + Administrative Cost

For the Local Supplier at a Low rate of demand:

$$\$62,500 + \$1,000 + \$520 + \$15,000 = \$79,020$$

The following Excel Table provides cost calculations of both suppliers across all levels of demand.

	Demand Level	Costs				
		Material Cost	Freight Cost	Inventory Cost	Admin Cost	Total Cost
Local Supplier	Low	\$62,500.	\$1,000.	\$520.	\$15,000.	\$79,020.
	Moderate	\$125,000.	\$2,000.	\$540.	\$15,000.	\$142,540.
	High	\$312,500.	\$5,000.	\$600.	\$15,000.	\$333,100.
National Supplier	Low	\$67,500.	\$6,000.	\$800.	\$12,500.	\$86,800.
	Moderate	\$125,000.	\$12,000.	\$1,100.	\$12,500.	\$150,600.
	High	\$250,000.	\$30,000.	\$2,000.	\$12,500.	\$294,500.

Thus the Local Supplier minimizes total cost for both the Low and Moderate demand levels. The National Supplier minimizes total cost for High demand levels.

- b. The following POM for Windows Decision Analysis printout provides the solution to which supplier achieves the lowest expected cost.

Module/submodel: Decision Making/Decision Tables

Results -----

	Low	Moderate	High	Expected Value
Probabilities	.35	.45	.2	
Local	\$79,020	\$142,540	\$333,100	\$158,420
National	\$86,800	\$150,600	\$294,500	\$157,050
Column best				\$157,050

The minimum expected monetary value is \$157,050 given by the National supplier,

CASE: WOLF MOTORS *

A. Synopsis

Wolf Motors has just expanded its network of auto dealerships to include its first auto supermarket where three different makes of cars are sold at the same facility. John Wolf, the president and owner of the dealership, has identified three factors that have contributed to the success of the dealerships: volume, “one price-lowest price” concept of pricing, and after-the-sale service to the cars sold. Focusing on the service aspect, three components are critical to providing quality after-the-sale service: well-trained technicians, the latest equipment technologies, and an adequate supply of service parts and materials. Currently each dealership is responsible for ordering and managing its inventory of parts and service materials. The recent growth has brought with it both space and financial resource constraints. John is now wondering what, if anything, can be done with respect to the purchasing of service parts and materials that would help address some of these concerns.

B. Purpose

This case provides students with the opportunity to investigate the supplier relationship process of an organization in the service sector. Students begin to see that the effective management of materials is not only essential in manufacturing environments but is also critical in supporting the delivery of quality services. Students are confronted by a number of issues as they are asked to recommend a suitable structure for the supplier relationship process. Included among them are the following:

1. Given the growth in the number of dealerships in the network, should the supplier relationship process be centralized to take advantage of certain economies of scale, or should it remain decentralized in each separate dealership?
2. Given the different categories of service parts that are purchased, supplier management issues are raised. Some parts may be more appropriately purchased through single-source contracting, whereas others may be competitively bid on by multiple suppliers. Bid awards don’t necessarily have to be awarded on the basis of low cost alone. Also some items may be grouped and purchased from the same supplier using blanket orders.
3. Limited space for inventory storage and limited investment dollars complicate the issues. Fast, reliable service in repairing and servicing cars is a key factor in the success of the dealership, but space and dollars limit service part availability to some extent.
4. Finally, students have the opportunity to conceptually bring into play basic inventory management concepts such as an ABC analysis to help determine appropriate levels of inventory investment and inventory stocking policies. This

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

case can be used as a lead-in to Chapter 9, “Supply Chain Inventory Management.”

C. Analysis

The analysis of this case can be accomplished in three logical steps. Students should first address the issue of restructuring the supplier relationship process. Then the inherent policies and procedures to carry out the purchasing processes can be addressed, followed by an analysis of specific inventory management issues that help lead into Chapter 9, “Supply Chain Inventory Management.”

Major factors to consider in addressing these steps include:

- ❑ Currently each individual dealership handles its own purchase and management of service parts and materials.
- ❑ The new dealership is an auto supermarket with three different makes of cars sold at the same location. The purchase of this dealership has led to a tightening of financial resources. Having three different makes of cars to service has also created a space constraint in stocking service parts.
- ❑ Wolf Motors is trying to reduce the total operating costs in order to compete effectively in a very price competitive market with its “one price-lowest price” strategy, while at the same time it needs to maintain a high level of service. High service levels have traditionally been linked to high levels of inventory of spare parts.
- ❑ There is a need to maintain timely delivery of service parts due to the limited space available.
- ❑ There are various categories of parts and materials. One key distinction is that some parts are available only from the auto manufacturer or its certified dealer/wholesaler. Other parts and materials (i.e., oil, lubricants, fan belts, and so on) are more generic and can be purchased from a number of sources, including local vendors.
- ❑ Parts are not only used to service and repair cars but are also sold over-the-counter to the do-it-yourself mechanic or other repair garages. Therefore, the overall levels of demand and supporting inventory must be coordinated among service needs, sales, and special promotions such as free brake inspections or discounts on oil changes and air-conditioner service. Weather also plays a role in the demand for parts: extreme cold affects the electrical/ignition systems, heat affects the air-conditioning, and rain affects the wipers.

1. *Structural Issues:* Students should first address the structural issues that face Wolf Motors pertaining to the purchase of parts and materials. These issues include two categories of decisions: (1) centralized purchasing versus continuing a decentralized model of letting each dealership purchase and manage its own inventories and (2) the responsibility relationships purchasing should maintain with inventory management and control, including the distribution of parts for service and over-the-counter sales.

Although there is some advantage to be gained by maintaining a decentralized, local purchasing function, it appears that Wolf Motors has grown to the point where a more formal central purchasing function is warranted. Wolf’s size

should give it some economy of scale leverage to help maintain low costs and timely deliveries.

Within the supplier relationship process, personnel could be assigned specific responsibilities for vendors such as:

- ☐ Specific auto manufacturers or their certified distributors
- ☐ Wholesale distributors of generic parts such as alternators, carburetors, or brake pads
- ☐ Wholesale distributors of consumable materials such as oils, lubricants, or filters

The second structural issue pertains to the level of integration that needs to be structured and maintained between purchasing, inventory stocking and control, and parts distribution. Should these be separate functions that “hand off” the responsibility for materials as they flow through the system, or should an integrated supply chain be implemented? The issue is one of being able to balance the purchasing costs, inventory carrying costs, distribution/logistics costs, and target service levels.

2. *Policies and Procedures:* After the structural issues have been discussed, students should consider alternative purchasing options that are available for procuring parts. Given that the parts and materials being purchased differ quite a bit with respect to availability, usage, costs, and delivery lead time, the policies and procedures used to order various parts may be different. Alternative policies that may be used include:

- ☐ Competitive bidding
- ☐ Single-source contracting
- ☐ Blanket orders
- ☐ Open-ended orders

Of course, these approaches are not mutually exclusive and may be combined for certain categories of parts. Students should discuss how each of these alternatives may be used for different groups of parts and materials. Going out for competitive bids would be most appropriate for “commodity” type items that are readily available from a number of vendors. Given that other aspects of the service, such as reliability and dependability, are comparable, then a competitive bid will help reduce purchase costs. Where the quality of the parts and/or service provided differs, then a single-source contract may be warranted. This should lead to a partnership arrangement that is beneficial to both parties.

Blanket orders are used when a number of parts are to be purchased from a single supplier. Blanket orders help reduce the overall ordering and distribution costs by grouping items under a single order. This may be an appropriate procedure for purchasing oils and lubricants from a local supplier or for ordering “factory certified” parts from a manufacturer or its designated distributor.

Open-ended orders provide flexibility in allowing items to be added or deleted from an order or for the time period of the order to be extended, such as in a blanket order of oil. Through this discussion students will begin to see that all items should not be ordered by the same procedure. Factors such as the item’s availability, relative importance, usage levels, and costs will have a significant impact on the way the item should be procured. This has implications also in

determining how the supplier relationship process's performance should be measured and evaluated. Just getting the lowest price is no longer good enough. Other measures of performance, such as product quality, reliable on-time delivery, and ordering flexibility with respect to the size and timing of the order, may be more important than price. This is an important lesson the students should understand.

3. *Inventory Management Issues:* The financial resource and space constraint issues brought out in the case provide the opportunity to discuss the close relationship and necessary integration that purchasing must have with inventory management. Suggested inventory management policies that can be discussed include the three important factors in making inventory stocking-level decisions. These include costs, delivery lead time, and space required/available. Students should see that each of these factors can be used to prioritize the different parts and materials to be inventoried.

- ❑ You can discuss the different costs incurred in ordering and carrying inventory to reinforce the trade-offs in these costs discussed in Chapter 10, "Supply Chain Design."
- ❑ You can bring out the issue of total investment in inventory over time to open the door for a discussion of the ABC analysis in Chapter 9, "Supply Chain Inventory Management."
- ❑ There is the issue of where to stock different parts in the storeroom or warehouse. Frequently used material should be stored in easily accessed locations, and a random location system will minimize space requirements.
- ❑ You could also introduce how inventories can be categorized, such as building anticipation stocks for promotions and seasonal use.
- ❑ Finally, perhaps implementing an effective EDI link between locations and suppliers would reduce delivery lead time.

The amount of time and depth of analysis pertaining to the discussion of inventory management issues will depend on how you wish to lead into Chapter 9, "Supply Chain Inventory Management." You should at least make sure the students see the necessary integration between purchasing and inventory management policies.

D. Recommendations

How the case is used will determine the level of detail you should expect with respect to any recommendations students may make. When used as an in-class exercise without any prior preparation by the students, the focus of the case should be on discussing the issues and recognizing the trade-offs that need to be made in the decisions. If given more time to read and analyze the case, typical recommendations to expect include:

1. Some form of centralization of the purchasing function
2. Development of partnership agreements for "key" parts that perhaps may lead to single sourcing
3. The use of blanket orders to reduce ordering costs and to limit the number of suppliers

4. Open-ended ordering agreements, especially in the “commodity” type materials that can be sourced locally to reduce lead times and minimize inventory investment
5. Perhaps the establishment of a central warehouse facility to reduce overall space requirements while maintaining parts availability in a timely manner
6. Conducting an analysis of inventory cost trade-offs to minimize total costs of inventory policies

E. Teaching Suggestions

This case can be used as either an in-class “cold-call” exercise or an overnight reading and analysis exercise. In either case the class discussion flows well when the instructor follows the order of the discussion questions at the end of the case. The level of detail necessary to make this a good decision case is not present. The case was designed to act as a vehicle to introduce the issues that pertain to the supplier relationship process and to show students that the issues are similar in both services and manufacturing. Therefore, it is best to begin the discussion by first focusing on how the supplier relationship process should be organized. Then focus the students on specific policies and procedures that Wolf may implement for different categories of parts. Finally, if time permits, you can begin to introduce some inventory management issues and show how the inventory function interacts with purchasing.

Chapter

13 Supply Chain Sustainability and Humanitarian Logistics

DISCUSSION QUESTIONS

1. Supply chains aimed at disaster relief evolve over time. Early on, during response operations, supplies must be “pushed” to the disaster location because actual needs are not known with precision. Nonetheless, supply chains must be responsive and flexible because of all the unknown elements. Lead times must be short. Fast delivery, volume flexibility, and of, course high levels of quality are necessary. Forward placement of inventories (as FedEx did with Hart to Hart International) can reduce the lead times in future disasters. During recovery operations, supply chains begin to “pull” supplies because the needs are better known. More efficiency in supply chain design is desirable. The challenge is that often the disaster relief supply chain must be created after the disaster. That is why firms like FedEx can be very helpful because their supply chains are already in place. The management of a disaster relief supply chain must have the ability to integrate the help (and supply chains) of many organizations.
2. Focusing on energy efficiency typically reduces energy costs and may improve delivery performance if distance travelled is a factor. Both of these are competitive priorities and can enhance the financial performance of a firm. Nonetheless, making decisions on the basis of energy efficiency can pose ethical dilemmas if such decisions actually detract from the financial performance of a company or damage the environment. For example, requiring fewer, but larger, shipments of an item from suppliers might save energy consumption but increase inventory costs beyond the savings in energy. Or, locating a plant so that distances travelled to and from the plant for employees, or shipments to customers or from suppliers, are minimized may reduce energy but it may place the plant in an environmentally sensitive area. Pushing forward to satisfy the investors of a firm, especially in a third-world country without economic or political power in the world market, is an ethical issue.
3. There are several financial implications involved with developing a reverse logistics supply chain. First, reverse logistics supply chains are costly to own and operate, typically much more than forward flow supply chains. Second, there is the fear that remanufactured products will cannibalize the sale of the firm’s new products. Third, the firm faces the opportunity cost for not remanufacturing its products. Other firms can pick up used products and remanufacture them in direct competition. Finally, there is the need to have some sort of incentive to ensure recyclable materials enter the reverse logistics supply chain. Incentives would include fees to the user of the

product, deposit fees, take-back programs, trade-in programs, and community recycling activities.

4. As more firms undertake steps to build sustainability in their supply chains, the relationship between buyer and supplier is changing to be more aware of ethical issues. Using programs such as SA8000:2008 firms are selecting suppliers that have a solid understanding of how to operate an ethical workplace. Of course, the buyer's firm must also adhere to those guidelines. Buyers should avoid unethical practices such as expecting gratuities, revealing confidential bids to favored suppliers, requiring reciprocal arrangements, exaggerating situations to get better deals, and using company resources for personal gain. Finally, economic power in the supply chain is a matter of fact. Buyers with power should use it wisely for the betterment of all members in the supply chain, and not just for the betterment of the buying firm. The same rationale goes for powerful suppliers, who should avoid dictating customer ordering policies or requiring exclusive shelf space at the expense of retailer profitability.

PROBLEMS

1 Vampire Van.

- a. The original route (A-B-C-D-E-A) requires a total travel distance of 24.6 miles ($3.0+6.1+4.2+7.2+4.1$)
- b. The new route (A-B-E-C-D-A) requires a total travel distance of 19.1 miles ($3.0+4.3+3.6+4.2+4.0$). This represents a savings of more than 22%.
- c. The new route (E-C-A-B-D-E) requires a total travel distance of 24.3 miles ($3.6+3.5+3.0+7.0+7.2$)

2. Royal Seafood

- a. Starting in Corvallis [A], the Nearest Neighbor technique provides the following route: A-B-C-F-D-E-A with a total of ($93+116+117+106+223+219=$) 874 Miles
- b. The alternative Nearest Neighbor routes are:

Starting City	Route	Total Distance
B	B-A-C-F-D-E-B	$93+102+117+106+223+167=808$ Miles
C	C-A-B-E-F-D-C	$102+93+167+118+106+181=767$ Miles
D	D-F-C-A-B-E-D	$106+117+102+93+167+223=808$ Miles
E	E-F-D-C-A-B-E	$118+106+181+102+93+167=767$ Miles
F	F-D-C-A-B-E-F	$106+181+102+93+167+118=767$ Miles

The best route using this technique is to process as follows:

Corvallis [A] to Roseburg [B] to Lakeview [E] to Burns [F] to Baker [D] to Bend [C] then back to Corvallis [A] Total distance traveled is 767 miles. Note that this is 107 fewer miles than the route found in part a.

3. Traxis Consolidated

- a. The total time required by the company's current route is:

Route: A-F-G-D-E-H-B-C-A : (33+27+30+25+44+73+53+38) = 323 minutes or 5.38 hours

- b. The NN procedure starting from the depot provides the following route:

Route: A-B-F-G-H-D-E-C-A : (26+35+27+21+32+25+45+38) = 249 minutes or 4.15 hours

- c. The NN procedure starting from each customer site provides the following routes:

Starting location	Route	Driving Time Calculation
B:	B-A-D-E-H-G-F-C-B	(26+31+25+44+21+27+68+53) = 296 minutes or 4.93 hours
C:	C-A-B-F-G-H-D-E-C	(38+26+35+27+21+32+25+45) = 249 minutes or 4.15 hours
D:	D-E-H-G-F-A-B-C-D	(25+44+21+27+33+26+53+46) = 275 minutes or 4.58 hours
E:	E-D-G-H-F-A-B-C-E	(25+30+21+50+33+26+53+45) = 283 minutes or 4.72 hours
F:	F-G-H-D-E-C-A-B-F	(27+21+32+25+45+38+26+35) = 249 minutes or 4.15 hours
G:	G-H-D-E-C-A-B-F-G	(21+32+25+45+38+26+35+27) = 249 minutes or 4.15 hours
H:	H-G-F-A-B-C-E-D-H	(21+27+33+26+53+45+25+32) = 262 minutes or 4.37 hours

The best route found by using the NN procedure is:

Route: A-B-F-G-H-D-E-C-A

Which requires a drive time of 249 minutes (or 4.15 hours) a 1.23 hour reduction in drive time from the original route.

4. Big Jim

- a. First, the Euclidean distances between each location must be calculated. This calculation is performed as follows:
- $\sqrt{(X_i - X_j)^2 + (Y_i - Y_j)^2}$
- for the distance

between (0,0) and (10,40) $\sqrt{(0 - 10)^2 + (0 - 40)^2} = 41.2$

			A	B	C	D	E	F
To/From			0	10	22	35	40	50
			0	40	20	37	25	40
A	0	0	0.0	41.2	29.7	50.9	47.2	64.0
B	10	40	41.2	0.0	23.3	25.2	33.5	40.0
C	22	20	29.7	23.3	0.0	21.4	18.7	34.4
D	35	37	50.9	25.2	21.4	0.0	13.0	15.3
E	40	25	47.2	33.5	18.7	13.0	0.0	18.0
F	50	40	64.0	40.0	34.4	15.3	18.0	0.0

Next, use these distances and the NN procedure to form routes.

Starting location	Route	Distance Calculation
A (0,0)	A-C-E-D-F-B-A	$(29.7+18.7+13.0+15.3+40.0+41.2) = 157.9$ * BEST
B(10,40)	B-C-E-D-F-A-B	$(23.3+18.7+13.0+15.3+64.0+41.2) = 175.5$
C(22,20)	C-E-D-F-B-A-C	$(18.7+13.0+15.3+40.0+41.2+29.7) = 157.9$ * BEST
D(35,37)	D-E-F-C-B-A-D	$(13.0+18.0+34.4+23.3+41.2+50.9) = 180.8$
E(40,25)	E-D-F-C-B-A-E	$(13.0+15.3+34.4+23.3+41.2+47.2) = 174.4$
F(50,40)	F-D-E-C-B-A-F	$(15.3+13.0+18.7+23.3+41.2+64.0) = 175.5$

- b. First, the rectilinear distances between each location must be calculated. This calculation is performed as follows: $|X_i - X_j| + |Y_i - Y_j|$ for the distance between (0,0) and (10,40) $|0 - 10| + |0 - 40| = 50.0$

			A	B	C	D	E	F
To/From			0	10	22	35	40	50
			0	40	20	37	25	40
A	0	0	0.0	50.0	42.0	72.0	65.0	90.0
B	10	40	50.0	0.0	32.0	28.0	45.0	40.0
C	22	20	42.0	32.0	0.0	30.0	23.0	48.0
D	35	37	72.0	28.0	30.0	0.0	17.0	18.0
E	40	25	65.0	45.0	23.0	17.0	0.0	25.0
F	50	40	90.0	40.0	48.0	18.0	25.0	0.0

Next, use these distances and the NN procedure to form routes.

Starting location	Route	Distance Calculation
A (0,0)	A-C-E-D-F-B-A	$42+23+17+18+40+50 = 190$ * Best
B(10,40)	B-D-E-C-A-F-B	$28+17+23+42+90+40 = 240$
C(22,20)	C-E-D-F-B-A-C	$23+17+18+40+50+42 = 190$ * Best
D(35,37)	D-E-C-B-F-A-D	$17+23+32+40+90+72 = 274$
E(40,25)	E-D-F-B-C-A-E	$17+18+40+32+42+65 = 214$
F(50,40)	F-D-E-C-B-A-F	$18+17+23+32+50+90 = 230$

Consequently, the method of measuring distances did not matter. The same sequence of cities is chosen for the best route.

5. Arts N Crafts

- a. Currently the company ships (400 units) x(8 pounds)= 3,200 pounds per week
- At a freight classification of 85, using table 13.2, the breakeven weight = $50(26.6)/34.87 = 38.14$ or 3814 pounds, thus the company does not qualify for the lower rate.
 - Total weekly shipping cost = $32(34.87) = \$1,115.84$
 - The packaging changes will not alter the shipping weight. However, the shipping classification will be more favorable.

- At a freight classification of 70, using table 13.2, the breakeven weight = $50(22.88)/29.99 = 38.15$ or 3815 pounds, thus the company still does not qualify for the lower rate.
- Total weekly shipping cost = $32(29.99) = \$959.68$

The new packaging will lower weekly shipping cost by \$156.16

b. If demand increases the company will ship (500 units) x (8 pounds) = 4,000 pounds per week

- At a freight classification of 85, using table 13.2, the breakeven weight = $50(26.6)/34.87 = 38.14$ or 3814 pounds, thus the company now qualifies for the lower rate.
- Total weekly shipping cost = $40(26.60) = \$1,064.00$ (compared with part a., this increase in demand actually lowers overall shipping cost)
- The packaging changes will not alter the shipping weight. However, the shipping classification will be more favorable.
- At a freight classification of 70, using table 13.2, the breakeven weight = $50(22.88)/29.99 = 38.15$ or 3815 pounds, thus the company still qualifies for the lower rate.
- Total weekly shipping cost = $40(22.88) = \$915.20$ (again, compared with part a., a lower shipping cost results)

The new packaging will lower weekly shipping cost by \$148.80

6. Microtech Incorporated

Currently the company ships (10,000 units) x (1.2 pounds) = 12,000 pounds per month .

- At a freight classification of 55, using table 13.2, the breakeven weight = $200(11.58)/17.41 = 133.03$ or 13,303 pounds, thus the company does not qualify for the lower rate.
- Total weekly shipping cost = $120(17.41) = \$2,089.20$
- The change has resulted in a lower weight but less favorable freight classification.
- The new weight to be shipped will be (10,000 units) x (0.5 pounds) = 5,000 pounds per month
- At a freight classification of 70, using table 13.2, the weight is on a weight break.
- Total weekly shipping cost = $50(22.88) = \$1,144.00$

The new packaging will lower monthly shipping cost by \$945.20 – or more than a 45% reduction.

Chapter

14 Forecasting

DISCUSSION QUESTIONS

1.
 - a. There is no apparent trend in the data. The naïve forecast method, exponential smoothing or the simple moving average would be appropriate for estimating the average.
 - b. The primary external factors that can be forecasted three days in advance and can appreciably affect air quality are wind velocity and temperature inversions.
 - c. Weather conditions cannot be forecast two summers in advance. Medium-term causal factors affecting air quality are population, regulations and policies affecting wood burning, mass transit, use of sand and salt on roads, relocation of the airport, and scheduling of major tourism events such as parades, car races, and stock shows.
 - d. In the area of technological forecasting, qualitative methods of forecasting are best. One such approach is the Delphi method, whereby the consensus of a panel of experts is sought. Here we would survey experts in the fields of electric-powered vehicles, coal-fired combustion for electric utilities, and development of alternatives to sand and salt on roads. We hope to determine whether to expect any technological breakthroughs sufficient to affect air quality within the next 10 years.
2. *What's Happening?* Our objective in writing this discussion question is to ensure students recognize the difference between sales and demand. Demand forecasting techniques require demand data. Michael is making the common mistake of using sales data as the basis for demand forecasts. Sales are generally equal to the *lesser* of demand or inventory. Say that inventory matches average demand at a particular location and is 100 newspapers. However, for the current edition, demand is less than average, say 90. Michael enters *sales* (which happens to be equal to demand in this period) into the forecasting system, resulting in an inventory reduction at that location for the next edition. Now suppose that demand for the next edition is 110. But because inventory has been reduced to 90, only 90 newspapers will be sold. Michael would then enter *sales* (which happens to be equal to *inventory*, not demand) into the forecasting system. This approach ratchets downward and tends to starve the distribution system. Because the publication is not reliably available, some customers eventually stop looking for *What's Happening?* and demand truly declines. It is important that data used for demand forecasting are *demand* data, not sales data.

PROBLEMS

1. Printer rentals

- a. The forecast for week 11 is 29 rentals.

Week Forecast Calculated	D_t	Forecast for Following Week (F_{t+1})
5	$\frac{23 + 24 + 32 + 26 + 31}{5}$	= 27.2 or 27
6	$\frac{24 + 32 + 26 + 31 + 28}{5}$	= 28.2 or 28
7	$\frac{32 + 26 + 31 + 28 + 32}{5}$	= 29.8 or 30
8	$\frac{26 + 31 + 28 + 32 + 35}{5}$	= 30.4 or 30
9	$\frac{31 + 28 + 32 + 35 + 26}{5}$	= 30.4 or 30
10	$\frac{28 + 32 + 35 + 26 + 24}{5}$	= 29.0 or 29

- b. The Mean Absolute Deviation is 4 rentals.

Week	Actual	Forecast	Absolute Error
6	28	27	1
7	32	28	4
8	35	30	5
9	26	30	4
10	24	30	6
		TOTAL	20
		MAD	$20/5 = 4$

2. Dalworth Company
 a. Three-month simple moving average

Month	Actual Sales (Thousands)	Three-Month Simple Moving Average Forecast	Absolute Error	Absolute % Error	Squared Error
Jan.	20				
Feb.	24				
Mar.	27				
Apr.	31				
May	37	$(24+27+31)/3 = 27.33$	9.67	26.14	93.51
June	47	$(27+31+37)/3 = 31.67$	15.33	32.62	235.01
July	53	$(31+37+47)/3 = 38.33$	14.67	27.68	215.21
Aug.	62	$(37+47+53)/3 = 45.67$	16.33	26.34	266.67
Sept.	54	$(47+53+62)/3 = 54.00$	0.00	0.00	0.00
Oct.	36	$(53+62+54)/3 = 56.33$	20.33	56.47	413.31
Nov.	32	$(62+54+36)/3 = 50.67$	18.67	58.34	348.57
Dec.	29	$(54+36+32)/3 = 40.67$	11.67	40.24	136.19
Total			106.67	267.83	1,708.47
Average			13.33	33.48	213.56

Such results also can be obtained from the *Time Series Forecasting* Solver of OM Explorer:

Actual Data		3-Period Moving Average		
		Forecast	Error	CFE
1/1/2009	20			
2/1/2009	24			
3/1/2009	27			
4/1/2009	31			
5/1/2009	37	27.33	9.67	9.67
6/1/2009	47	31.67	15.33	25.00
7/1/2009	53	38.33	14.67	39.67
8/1/2009	62	45.67	16.33	56.00
9/1/2009	54	54.00	0.00	56.00
10/1/2009	36	56.33	-20.33	35.67
11/1/2009	32	50.67	-18.67	17.00
12/1/2009	29	40.67	-11.67	5.33

Method 1 - Moving Average:

3 -Period Moving Average

Forecast for 1/1/10 32.33

CFE 5.33

MAD 13.33

MSE 213.56

MAPE 33.48%

b. Four-month simple moving average

Month	Actual Sales (Thousands)	Four-Month Simple Moving Average Forecast	Absolute Error	Absolute % Error	Squared Error
Jan.	20				
Feb.	24				
Mar.	27				
Apr.	31				
May	37	$(20+24+27+31)/4 = 25.5$	11.50	31.08	132.25
June	47	$(24+27+31+37)/4 = 29.75$	17.25	36.70	297.56
July	53	$(27+31+37+47)/4 = 35.5$	17.50	33.02	306.25
Aug.	62	$(31+37+47+53)/4 = 42.00$	20.00	32.26	400.00
Sept.	54	$(37+47+53+62)/4 = 49.75$	4.25	7.87	18.06
Oct.	36	$(47+53+62+54)/4 = 54.00$	18.00	50.00	324.00
Nov.	32	$(53+62+54+36)/4 = 51.25$	19.25	60.16	370.56
Dec.	29	$(62+54+36+32)/4 = 46.00$	<u>17.00</u>	<u>58.62</u>	<u>289.00</u>
Total			124.75	309.71	2,137.68
Average			15.59	38.71	267.21

Similarly, using *Time Series Forecasting Solver* of OM Explorer, we get:

Actual Data		4-Period Moving Average		
		Forecast	Error	CFE
1/1/2009	20			
2/1/2009	24			
3/1/2009	27			
4/1/2009	31			
5/1/2009	37	25.50	11.50	11.50
6/1/2009	47	29.75	17.25	28.75
7/1/2009	53	35.50	17.50	46.25
8/1/2009	62	42.00	20.00	66.25
9/1/2009	54	49.75	4.25	70.50
10/1/2009	36	54.00	-18.00	52.50
11/1/2009	32	51.25	-19.25	33.25
12/1/2009	29	46.00	-17.00	16.25

Method 1 - Moving Average:

4 -Period Moving Average

Forecast for 1/1/10	37.75
CFE	16.25
MAD	15.59
MSE	267.21
MAPE	38.71%

c.–e. Comparison of performance

Question	Measure	3-Month SMA	4-Month SMA	Recommendation
c.	MAD	13.33	15.59	3-month SMA
d.	MAPE	33.48	38.71	3-month SMA
e.	MSE	213.56	267.21	3-month SMA

3. Karl's Copiers

Week Forecast Calculated	Calculation of Forecast for <u>Next</u> Week's Demand	
	$F_{t+1} = \alpha D + (1 - \alpha) F_t$	F_{t+1}
1	$0.20(24) + 0.80(24)$	= 24
2	$0.20(32) + 0.80(24)$	= 25.6 or 26
3	$0.20(36) + 0.80(25.6)$	= 27.68 or 28
4	$0.20(23) + 0.80(27.68)$	= 26.744 or 27
5	$0.20(25) + 0.80(26.744)$	= 26.3952 or 26

Forecasts in each row are for the next week's demand. For example, the calculations done in Week 1 (after the actual demand for Week 1 is known) of 24 units is actually the forecast for Week 2. It happens to be the same as the forecast made for Week 1's demand, because the default initial forecast is set equal to the first week's demand.

The forecast for the week 6 is 26 service calls.

Similarly, using *Time Series Forecasting* Solver of OM Explorer, we get:

Actual Data		Exponential Smoothing		
		Forecast	Error	CFE
1	24	24.00		
2	32	24.00	8.00	8.00
3	36	25.60	10.40	18.40
4	23	27.68	-4.68	13.72
5	25	26.74	-1.74	11.98

The forecasts are for the weeks listed in the row (not for the next week's demand).

Method 3 - Exponential Smoothing:	
α	0.20
Initial Forecast	24.00
Forecast for Week 6	26.40
CFE	11.98
MAD	6.21
MSE	49.28
MAPE	20.30%

4. Dalworth Company (continued)

- a. Three-month weighted moving average (weights of 3/6, 2/6, and 1/6)

Month	Actual Sales (000s)	Three-Month Weighted Moving Average Forecast	Absolute Error	Absolute % Error	Squared Error
Jan.	20				
Feb.	24				
Mar.	27				
Apr.	31	$[(3 \times 27) + (2 \times 24) + (1 \times 20)]/6 = 24.83$	6.17	19.90	38.07
May	37	$[(3 \times 31) + (2 \times 27) + (1 \times 24)]/6 = 28.50$	8.50	22.97	72.25
June	47	$[(3 \times 37) + (2 \times 31) + (1 \times 27)]/6 = 33.33$	13.67	29.09	186.87
July	53	$[(3 \times 47) + (2 \times 37) + (1 \times 31)]/6 = 41.00$	12.00	22.64	144.00
Aug.	62	$[(3 \times 53) + (2 \times 47) + (1 \times 37)]/6 = 48.33$	13.67	22.05	186.87
Sept.	54	$[(3 \times 62) + (2 \times 53) + (1 \times 47)]/6 = 56.50$	2.50	4.63	6.25
Oct.	36	$[(3 \times 54) + (2 \times 62) + (1 \times 53)]/6 = 56.50$	20.50	56.94	420.25
Nov.	32	$[(3 \times 36) + (2 \times 54) + (1 \times 62)]/6 = 46.33$	14.33	44.78	205.35
Dec.	29	$[(3 \times 32) + (2 \times 36) + (1 \times 54)]/6 = 37.00$	8.00	27.59	64.00
Total			99.34	250.59	1,323.91
Average			11.04	27.84	147.09

The results from *Time Series Forecasting Solver* of OM Explorer give the same results:

Actual Data		3-Period Weighted Moving Average		
		Forecast	Error	CFE
1/1/2009	20			
2/1/2009	24			
3/1/2009	27			
4/1/2009	31	24.83	6.17	6.17
5/1/2009	37	28.50	8.50	14.67
6/1/2009	47	33.33	13.67	28.33
7/1/2009	53	41.00	12.00	40.33
8/1/2009	62	48.33	13.67	54.00
9/1/2009	54	56.50	-2.50	51.50
10/1/2009	36	56.50	-20.50	31.00
11/1/2009	32	46.33	-14.33	16.67
12/1/2009	29	37.00	-8.00	8.67

Method 2 - Weighted Moving Average:

3 -Period Weighted Moving Average

Forecast for 1/1/10 31.17

CFE 8.67

MAD 11.04

MSE 147.09

MAPE 27.84%

b. Exponential smoothing ($\alpha = 0.6$)

Month (t)	D_t (millions)	F_t	$F_{t+1} = F_t + \alpha(D_t - F_t)$ (Forecast for Next Month)	Absolute Error	Absolute % Error	Squared Error
Jan.	20	22.00	20.80			
Feb.	24	20.80	22.72			
Mar.	27	22.72	25.29			
Apr.	31	25.29	28.72	5.71	18.41	32.60
May	37	28.72	33.69	8.28	22.38	68.56
June	47	33.69	41.67	13.31	28.32	177.16
July	53	41.67	48.47	11.33	21.38	128.37
Aug.	62	48.47	56.59	13.53	21.82	183.06
Sept.	54	56.59	55.04	2.59	4.80	6.71
Oct.	36	55.04	43.62	19.04	52.88	362.52
Nov.	32	43.62	36.64	11.61	36.28	134.79
Dec.	29	36.64	32.06	<u>7.65</u>	<u>26.38</u>	<u>58.52</u>
Total				93.05	232.65	1,152.29
Average				10.34	25.85	128.03

c.-e. Comparison of performance

Question	Measure	3-Month WMA	Exponential Smoothing	Recommendation
c.	MAD	11.04	10.34	Exponential smoothing
d.	MAPE	27.84	25.85	Exponential smoothing
e.	MSE	147.09	128.03	Exponential smoothing

Exponential smoothing is the better performer on all three criteria.

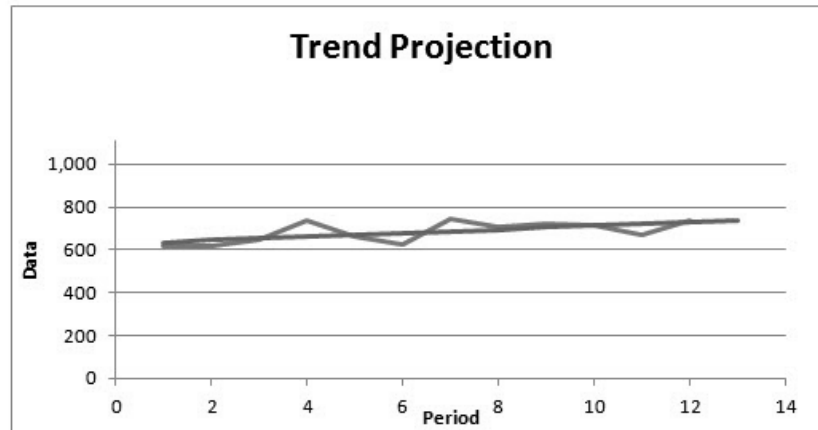
5. Convenience Store

The worksheet calculations from the *Time Series Forecasting Solver* of OM Explorer for both *Exponential Smoothing* and *Trend Projection with Regression* follow:

Period Moving Average	Exponential Smoothing		Trend Projection	
	α	0.40	Intercept	627.09
	Initial Forecast	617	Slope/Trend	8.60
Note: The default for the Initial forecast is set to the initial period's actual demand but can be changed above.		Note: The results in this table use ALL of the data. To see results when using the most recent n-periods of data go to the Trend Projector		

Actual Data		Exponential Smoothing			Trend Projection		
Period		Forecast	Error	CFE	Forecast	Error	CFE
1	617	617.00			635.69	-18.69	-18.69
2	617	617.00			644.29	-27.29	-45.99
3	648	617.00	31.00	31.00	652.90	-4.90	-50.88
4	739	629.40	109.60	140.60	661.50	77.50	26.62
5	659	673.24	-14.24	126.36	670.10	-11.10	15.52
6	623	667.54	-44.54	81.82	678.70	-55.70	-40.17
7	742	649.73	92.27	174.09	687.30	54.70	14.52
8	704	686.64	17.36	191.45	695.90	8.10	22.62
9	724	693.58	30.42	221.87	704.50	19.50	42.12
10	715	705.75	9.25	231.12	713.10	1.90	44.01
11	668	709.45	-41.45	189.67	721.71	-53.71	-9.69
12	740	692.87	47.13	236.80	730.31	9.69	0.00

The results from the *Time Series Forecasting Solver* of OM Explorer for *Trend Projection with Regression*:



<i>a</i> (Y intercept)	627.091
<i>b</i> (slope or trend)	8.601
r^2	0.387
CFE	0.000
MAD	28.564
MSE	1397.523
MAPE	4.18%

Forecast for period 13	738.909

Thus sales are trending up, by 8.60 cans (the slope/trend) per week.

Given a regression equation of $Y=627.091+8.601X$ as provided by the *Time Series Forecasting Solver* of OM Explorer for *Trend Projection with Regression*, these results are supported by Excel calculations as follows on the next page:

Trend Projection with Regression						
Week (t)	Sales	Forecast	Error	Absolute Error	Squared Error	Absolute Percent Error
1	617	635.7	-18.7	18.69	349.37	3.03
2	617	644.3	-27.3	27.29	744.90	4.42
3	648	652.9	-4.9	4.89	23.95	0.76
4	739	661.5	77.5	77.50	6006.93	10.49
5	659	670.1	-11.1	11.10	123.14	1.68
6	623	678.7	-55.7	55.70	3102.31	8.94
7	742	687.3	54.7	54.70	2992.11	7.37
8	704	695.9	8.1	8.10	65.59	1.15
9	724	704.5	19.5	19.50	380.15	2.69
10	715	713.1	1.9	1.90	3.59	0.27
11	668	721.7	-53.7	53.71	2884.27	8.04
12	740	730.3	9.7	9.69	93.96	1.31
Forecast		738.9				
CFE			0.0			
MAD				28.56		
MSE					1397.52	
MAPE						4.18

The results from the *Time Series Forecasting* Solver of OM Explorer for Exponential Smoothing:

Method 3 - Exponential Smoothing:

α	0.40
Initial Forecast	617.00
Forecast for Period 13	711.72
CFE	236.80
MAD	43.73
MSE	2,893
MAPE	6.19%

These results are supported by Excel calculations as follows:

Exponential Smoothing						
Week (t)	Sales	Forecast	Error	Absolute Error	Squared Error	Absolute Percent Error
1	617	617.0	0.0	0.00	0.00	0.00
2	617	617.0	0.0	0.00	0.00	0.00
3	648	617.0	31.0	31.00	961.00	4.78
4	739	629.4	109.6	109.60	12012.16	14.83
5	659	673.2	-14.2	14.24	202.78	2.16
6	623	667.5	-44.5	44.54	1984.17	7.15
7	742	649.7	92.3	92.27	8514.42	12.44
8	704	686.6	17.4	17.36	301.51	2.47
9	724	693.6	30.4	30.42	925.28	4.20
10	715	705.7	9.3	9.25	85.58	1.29
11	668	709.4	-41.4	41.45	1718.05	6.20
12	740	692.9	47.1	47.13	2221.27	6.37
Forecast		711.7				
CFE			236.80			
MAD				43.73		
MSE					2892.62	
MAPE						6.19

Method Comparisons:

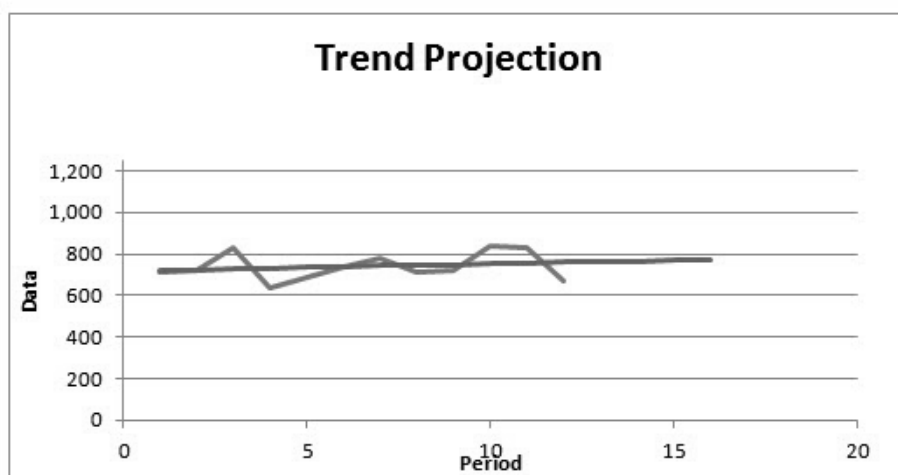
	Trend Projection	Exponential Smoothing
MAD	28.56	43.73
MAPE	4.18	6.19

The Trend Projection with Regression method is superior for both MAD and MAPE. Thus, it appears that a modest trend does exist. Trend component provided through regression analysis = 8.60 cans per week.

6. Community Federal

The results from the *Time Series Forecasting Solver* of OM Explorer for *Trend Projection with Regression* are

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



a (Y intercept)	717.318
b (slope or trend)	3.490
r^2	0.037

CFE	0.000
MAD	49.759
MSE	3775.061
MAPE	6.71%

Forecast for period 13	762.682
Forecast for period 14	766.171
Forecast for period 15	769.661
: Forecast for period 16	773.150

With r^2 so low, the upward trend is negligible.

7. Heartville General Hospital

i. Exponential smoothing, $\alpha = 0.6$

Year	Demand	Exponential Smoothing	Absolute Deviation	Absolute % Deviation	Square Error
1	45	45			
2	50	$45 + .6(45 - 45) = 45$			
3	52	$45 + .6(50 - 45) = 48$	4.00	7.69	16.00
4	56	$48 + .6(52 - 48) = 50.40$	5.60	10.00	31.36
5	58	$50.40 + .6(56 - 50.4) = 53.76$	<u>4.24</u>	<u>7.31</u>	<u>17.98</u>
Totals			13.84	25.00	65.34
Averages			4.61	8.33	21.78

The same forecast (45) is shown for both years 1 and 2, because the default setting makes the initial forecast for the first period equal to its actual year 2 (for year 3) remains at 45.

ii. Exponential smoothing, $\alpha = 0.9$

Year	Demand	Exponential Smoothing	Absolute Deviation	Absolute % Deviation	Squared Error
1	45	45			
2	50	$45 + .9(45 - 45) = 45$			
3	52	$45 + .9(50 - 45) = 49.50$	2.50	4.81	6.25
4	56	$49.50 + .9(52 - 49.5) = 51.75$	4.25	7.59	18.06
5	58	$51.75 + .9(56 - 51.75) = 55.58$	<u>2.43</u>	<u>4.19</u>	<u>5.90</u>
Totals			9.18	16.59	30.21
Averages			3.06	5.53%	10.06

iii. Trend Projection with Regression: model $Y = 42.6 + 3.2X$ obtained from the *Time Series Forecasting Solver* of OM Explorer for *Trend Projection with Regression*:

Year	Demand	Trend Projection	Absolute Deviation	Absolute % Deviation	Squared Error
1	45	$42.6 + 3.2 \times 1 = 45.8$			
2	50	$42.6 + 3.2 \times 2 = 49.0$			
3	52	$42.6 + 3.2 \times 3 = 52.2$	0.20	0.38	0.04
4	56	$42.6 + 3.2 \times 4 = 55.4$	0.60	1.07	0.36
5	58	$42.6 + 3.2 \times 5 = 58.6$	<u>0.60</u>	<u>1.03</u>	<u>0.36</u>
Totals			1.40	2.48	0.76
Averages			0.47	0.83%	0.25

These Excel computations are confirmed by the *Trend Projection with Regression* Solver of OM Explorer:

				CFE	Averages		
				-0.200	MSE 0.253	MAD 0.467	MAPE 0.83%
Period	Actual Demand	Forecast	Error	Running CFE	Error Squared	Absolute Error	Abs % error
1	45						
2	50						
3	52	52	-0.200	-0.200	0.040	0.200	0.38%
4	56	55	0.600	0.400	0.360	0.600	1.07%
5	58	59	-0.600	-0.200	0.360	0.600	1.03%

iv. Two-year moving average

Year	Demand	2-Year Moving Average	Absolute Deviation	Absolute % Deviation	Square Error
1	45				
2	50				
3	52	$(45 + 50)/2 = 47.5$	4.50	8.65	20.25
4	56	$(50 + 52)/2 = 51.0$	5.00	8.93	25.00
5	58	$(52 + 56)/2 = 54.0$	4.00	6.90	16.00
Total			13.50	24.48	61.25
Average			4.50	8.16%	20.42

v. Two-year weighted moving average

Year	Demand	2-Year Weighted Moving Average	Absolute Deviation	Absolute % Deviation	Squared Error
1	45				
2	50				
3	52	$(45(0.4) + 50(0.6)) = 48.0$	4.00	7.69	16.00
4	56	$(50(0.4) + 52(0.6)) = 51.2$	4.80	8.57	23.04
5	58	$(52(0.4) + 56(0.6)) = 54.4$	3.60	6.21	12.96
Totals			12.40	22.47	52.00
Averages			4.13	7.49%	17.33

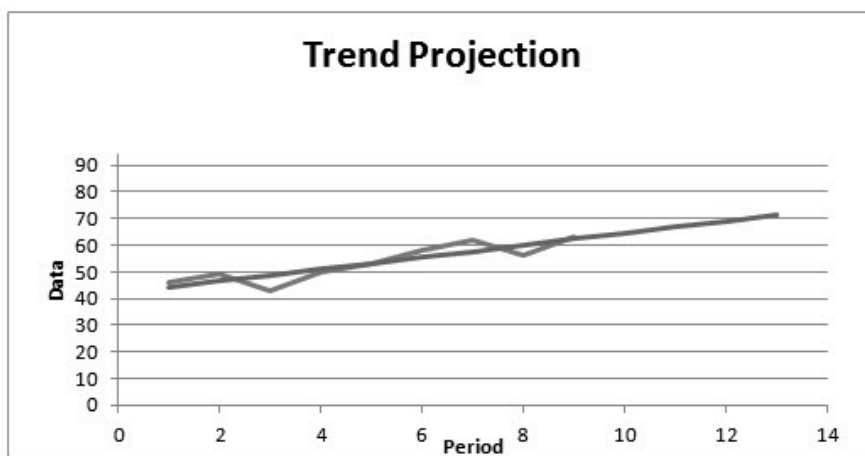
vi-viii Comparison of the forecasting methodologies

Forecast Methodology	MAD	MAPE	MSE
Exponential smoothing $\alpha = .6$	4.61	8.33%	21.78
Exponential smoothing $\alpha = .9$	3.06	5.53%	10.06
Trend Projection with Regression	0.47	0.83%	0.25
Two-year moving average	4.50	8.16%	20.42
Two-year weighted moving average	4.13	7.49%	17.33

The Trend Projection with Regression model methodology works best in this case for all performance criteria.

8. Calculator sales

The *Trend Projection with Regression Solver* of OM Explorer gives the following results:



a (Y intercept) 42.083
 b (slope or trend) 2.250
 r^2 0.783

CFE 0.000
MAD 2.519
MSE 9.361
MAPE 4.91%

Forecast for period 10 64.583
Forecast for period 11 66.833
Forecast for period 12 69.083
Forecast for period 13 71.333

Detailed analysis from the TPWorksheet is::

			Averages				
			CFE	MSE	MAD	MAPE	
			0.000	9.361	2.519	4.91%	
Period	Actual Demand	Forecast	Error	Running CFE	Error Squared	Absolute Error	Abs % error
1	46	44	1.667	1.667	2.778	1.667	3.62%
2	49	47	2.417	4.083	5.840	2.417	4.93%
3	43	49	-5.833	-1.750	34.028	5.833	13.57%
4	50	51	-1.083	-2.833	1.174	1.083	2.17%
5	53	53	-0.333	-3.167	0.111	0.333	0.63%
6	58	56	2.417	-0.750	5.840	2.417	4.17%
7	62	58	4.167	3.417	17.361	4.167	6.72%
8	56	60	-4.083	-0.667	16.674	4.083	7.29%
9	63	62	0.667	0.000	0.444	0.667	1.06%

Trend Projection with Regression: model $Y = 42.083 + 2.250X$ obtained from the *Time Series Forecasting Solver* of OM Explorer for *Trend Projection with Regression*. These results are supported by Excel calculations as follows:

Trend Projection with Regression							
Week	(t)	Sales	Forecast	Error	Absolute Error	Squared Error	Absolute Percent Error
	1	46	44.3	1.7	1.67	2.78	3.62
	2	49	46.6	2.4	2.42	5.84	4.93
	3	43	48.8	-5.8	5.83	34.02	13.57
	4	50	51.1	-1.1	1.08	1.17	2.17
	5	53	53.3	-0.3	0.33	0.11	0.63
	6	58	55.6	2.4	2.42	5.84	4.17
	7	62	57.8	4.2	4.17	17.36	6.72
	8	56	60.1	-4.1	4.08	16.67	7.29
	9	63	62.3	0.7	0.67	0.44	1.06
	10	Forecast	64.6				
	11	Forecast	66.8				
	12	Forecast	69.1				
	13	Forecast	71.3				
Total				0.0	22.7	84.3	44.2
CFE				0.0			
MAD					2.52		
MSE						9.36	
MAPE							4.91
Std Dev						3.25	

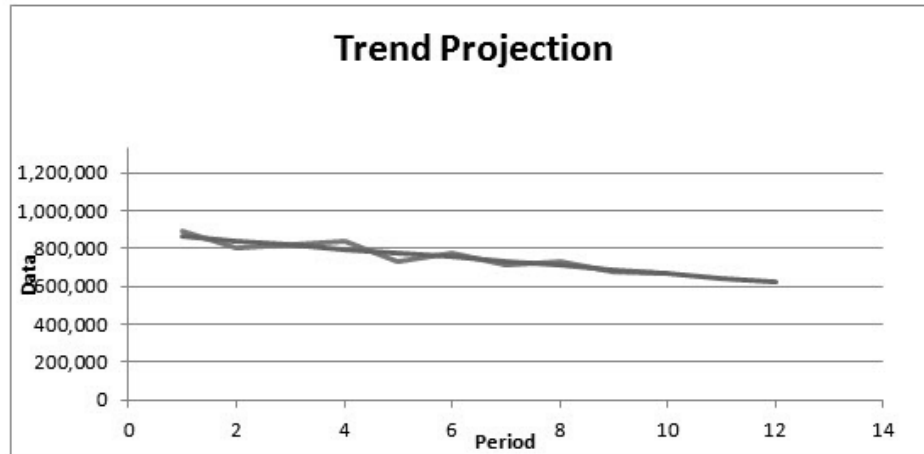
In the above table, σ is “Std Dev” which is calculated as $\sqrt{\frac{\sum (E_t - \bar{E})^2}{n-1}} = \sqrt{\frac{84.3}{9-1}} = 3.25$

The r^2 was calculated as 0.783 by the *Trend Projection with Regression Solver* of OM Explorer.

9. Krispee Crunchies

The *Trend Projection with Regression Solver* of OM Explorer gives the following results:

Regression begins in period	1	check scrollbar
Error analysis begins in period	1	
Number of future forecasts	2	



a (Y intercept)	886,667
b (slope or trend)	-22030
r^2	0.834

CFE	0.000
MAD	23,994
MSE	798,242,424
MAPE	3.09%

Forecast for period 11	644,333
Forecast for period 12	622,303

Detailed analysis from the TPWorksheet is:

				CFE	Averages		
			0.000	0.000	MSE	MAD	MAPE
					798,242,424	23,994	3.09%
Period	Actual Demand	Forecast	Error	Running CFE	Error Squared	Absolute Error	Abs % error
1	890,000	864,636	25363.636	25,363.636	643,314,049.59	25,364	2.85%
2	800,000	842,606	-42606.061	-17,242.424	1,815,276,400.37	42,606	5.33%
3	825,000	820,576	4424.242	-12,818.182	19,573,921.03	4,424	0.54%
4	840,000	798,545	41454.545	28,636.364	1,718,479,338.84	41,455	4.94%
5	730,000	776,515	-46515.152	-17,878.788	2,163,659,320.48	46,515	6.37%
6	780,000	754,485	25515.152	7,636.364	651,022,956.84	25,515	3.27%
7	710,000	732,455	-22454.545	-14,818.182	504,206,611.57	22,455	3.16%
8	730,000	710,424	19575.758	4,757.576	383,210,284.66	19,576	2.68%
9	680,000	688,394	-8393.939	-3,636.364	70,458,218.55	8,394	1.23%
10	670,000	666,364	3636.364	0.000	13,223,140.50	3,636	0.54%

If current conditions remain in place, the r^2 of better than 80% provide some measure of confidence that the downward trend (estimated at 22,030 boxes per month) will continue.

10. Forrest's boxes of chocolates

a. One possible estimated forecast for Year 4:

Quarter	Forecast
1	3,700
2	2,700
3	1,900
4	<u>6,500</u>
	14,800

b. Multiplicative seasonal method

Quarter	Year 1	Seasonal Factor	Year 2	Seasonal Factor	Year 3	Seasonal Factor	Average Seasonal Factor
1	3,000	1.20	3,300	1.1	3502	1.03	1.11
2	1,700	0.68	2,100	0.7	2448	0.72	0.70
3	900	0.36	1,500	0.5	1768	0.52	0.46
4	<u>4,400</u>	1.76	<u>5,100</u>	1.7	<u>5882</u>	1.73	1.73
Totals	10,000		12,000		13,600		
Averages	2,500		3,000		3,400		

Forecast for year 4, 14,800. Average = 3,700.

Quarter	Average	Factor	Forecast
1	3,700	1.11	4,107
2	3,700	0.70	2,590
3	3,700	0.46	1,702
4	3,700	1.73	<u>6,401</u>
			14,800

This technique forecasts that the third-quarter sales *will decrease* compared to sales for the third quarter of the third year. Betcha thought it would increase. Mamma always said: “Life is full of surprises!”

Just to make sure, we find confirmation of our calculations using the *Seasonal Forecasting Solver* of OM Explorer:

Quarter	Seasonal Index	Forecast
1	1.1100	4,107
2	0.7000	2,590
3	0.4600	1,702
4	1.7300	6,401

11. Snyder’s Garden Center

Quarter	Year 1	Seasonal Factor	Year 2	Seasonal Factor	Average Seasonal Factor
1	40	0.179	60	0.218	0.199
2	350	1.573	440	1.600	1.587
3	290	1.303	320	1.164	1.234
4	<u>210</u>	0.944	<u>280</u>	1.018	0.981
Total	890		1,100		
Average	222.50		275.00		

Average quarterly sales in year 3 are expected to be 287.50 (1,150/4). Using the average seasonal factors, the forecasts for year 3 are:

Quarter	Forecast
1	0.199(287.50) 57
2	1.587(287.50) 456
3	1.234(287.50) 355
4	0.981(287.50) 282

With the *Seasonal Forecasting Solver* of OM Explorer, we get the same results

Quarter	Seasonal Index	Forecast
1	0.1990	57
2	1.5865	456
3	1.2335	355
4	0.9810	282

12. Utility company

Quarter	Year 1	Year 2	Year 3	Year 4
1	103.5	94.7	118.6	109.3
2	126.1	116.0	141.2	131.6
3	144.5	137.1	159.0	149.5
4	<u>166.1</u>	<u>152.5</u>	<u>178.2</u>	<u>169.0</u>
Totals	540.2	500.3	597.0	559.4
Averages	135.05	125.075	149.25	139.85

Quarter	Year 1	Year 2	Year 3	Year 4	Average
					Seasonal Index
1	0.7664	0.7571	0.7946	0.7816	0.7749
2	0.9337	0.9274	0.9410	0.9410	0.9371
3	1.0700	1.0961	1.0653	1.0690	1.0751
4	<u>1.2299</u>	<u>1.2193</u>	<u>1.1940</u>	<u>1.2084</u>	<u>1.2129</u>
Totals	4.0	4.0	4.0	4.0	4.0

Forecast for Year 5

Quarter	Average Demand per Quarter	Adjusted Demand
1	150	116.235 = 116
2	150	140.565 = 141
3	150	161.265 = 161
4	150	<u>181.935</u> = 182
	600	600

Turning to the *Seasonal Forecasting* Solver of OM Explorer, we get the same results:

Quarter	Seasonal Index	Forecast
1	0.7749	116
2	0.9371	141
3	1.0751	161
4	1.2129	182

13. Garcia's Garage

a. The results, using the *Regression Analysis* Solver of OM Explorer, are:

R-squared	0.668		
R	0.817		
Constant	42.464		
Standard Error of Estimate	4.572		
Trial X1 Value	9	X1 Coefficient	2.452
		Predicted Y Value	64.532

The regression equation is $Y = 42.464 + 2.452X$

b. Forecasts

$$Y (\text{Sep}) = 42.464 + 2.452 (9) = 64.532 \text{ or } 65$$

$$Y (\text{Oct}) = 42.464 + 2.452 (10) = 66.984 \text{ or } 67$$

$$Y (\text{Nov}) = 42.464 + 2.452 (11) = 71.888 \text{ or } 72$$

14. Hydrocarbon Processing Factory

Using the *Regression Analysis Solver* of OM Explorer, we get:

R-squared	0.450		
R	0.671		
Constant	0.888		
Standard Error of Estimate	0.331		
Trial X1 Value	3.5	X1 Coefficient	0.622
Predicted Y Value			3.065

a. Relationship to forecast Y from X

$$Y = 0.888 + 0.622 X$$

b. Strength of relationship between Y and X is moderate as indicated by

$$R^2 = 0.450$$

$$R = 0.671$$

$$\text{Standard Error of Estimate} = 0.331$$

15. Ohio Swiss Milk

The results from the *Regression Analysis Solver* are:

R-squared	0.888		
R	-0.942		
Constant	1121.212		
Standard Error of Estimate	12.342		
Trial X1 Value	3.5	X1 Coefficient	-0.282
Predicted Y Value			1120.225

a. $Y = 1,121.212. - 0.282 X$ b. $R^2 = 0.888$

$R = -0.942$ indicates a fairly strong negative relationship. Increases in costs explain 89% of the decreases in gallons sold

c. $Y = 1,121.212 - 0.282(325) = 1,029.562$

Because these numbers are in terms of thousands of gallons, the cost per gallon is \$1.03 at this production level.

ADVANCED PROBLEMS

16. Franklin Tooling

(i) Naïve (1-Period Moving Average) Forecasting results

Demand for Component 135.AG	1-Period Moving Average (Naïve) Forecast				
	Forecast	Error	ABS (Error)	Square (Error)	Percent (Error)
137					
136	137.00				
143	136.00				
136	143.00				
141	136.00	5.00	5.00	25.00	3.55
128	141.00	-13.00	13.00	169.00	10.16
149	128.00	21.00	21.00	441.00	14.09
136	149.00	-13.00	13.00	169.00	9.56
134	136.00	-2.00	2.00	4.00	1.49
142	134.00	8.00	8.00	64.00	5.63
125	142.00	-17.00	17.00	289.00	13.60
134	125.00	9.00	9.00	81.00	6.72
118	134.00	-16.00	16.00	256.00	13.56
131	118.00	13.00	13.00	169.00	9.92
132	131.00	1.00	1.00	1.00	0.76
124	132.00	-8.00	8.00	64.00	6.45
121	124.00	-3.00	3.00	9.00	2.48
127	121.00	6.00	6.00	36.00	4.72
118	127.00	-9.00	9.00	81.00	7.63
120	118.00	2.00	2.00	4.00	1.67
115	120.00	-5.00	5.00	25.00	4.35
106	115.00	-9.00	9.00	81.00	8.49
120	106.00	14.00	14.00	196.00	11.67
113	120.00	-7.00	7.00	49.00	6.19
121	113.00	8.00	8.00	64.00	6.61
119	121.00	-2.00	2.00	4.00	1.68
Forecast	119.00				
CFE	-17.00				
MAD	8.68				
MSE	103.68				
MAPE	6.86				

(ii) 3-Period Moving Average

Demand for Component 135.AG	3-Period Moving Average Forecast				
	Forecast	Error	ABS (Error)	Square (Error)	Percent (Error)
137					
136					
143					
136	138.67				
141	138.33	2.67	2.67	7.11	1.89
128	140.00	-12.00	12.00	144.00	9.38
149	135.00	14.00	14.00	196.00	9.40
136	139.33	-3.33	3.33	11.11	2.45
134	137.67	-3.67	3.67	13.44	2.74
142	139.67	2.33	2.33	5.44	1.64
125	137.33	-12.33	12.33	152.11	9.87
134	133.67	0.33	0.33	0.11	0.25
118	133.67	-15.67	15.67	245.44	13.28
131	125.67	5.33	5.33	28.44	4.07
132	127.67	4.33	4.33	18.78	3.28
124	127.00	-3.00	3.00	9.00	2.42
121	129.00	-8.00	8.00	64.00	6.61
127	125.67	1.33	1.33	1.78	1.05
118	124.00	-6.00	6.00	36.00	5.08
120	122.00	-2.00	2.00	4.00	1.67
115	121.67	-6.67	6.67	44.44	5.80
106	117.67	-11.67	11.67	136.11	11.01
120	113.67	6.33	6.33	40.11	5.28
113	113.67	-0.67	0.67	0.44	0.59
121	113.00	8.00	8.00	64.00	6.61
119	118.00	1.00	1.00	1.00	0.84
Forecast	117.67				
CFE	-39.33				
MAD	5.94				
MSE	55.59				
MAPE	4.78				

(iii) Exponential Smoothing, with $\alpha=.28$

Demand for Component 135.AG	Exponential Smoothing Forecast				
	Forecast	Error	ABS (Error)	Square (Error)	Percent (Error)
137	137.00				
136	137.00				
143	136.72				
136	138.48				
141	137.78	3.22	3.22	10.34	2.28
128	138.68	-10.68	10.68	114.17	8.35
149	135.69	13.31	13.31	177.07	8.93
136	139.42	-3.42	3.42	11.69	2.51
134	138.46	-4.46	4.46	19.91	3.33
142	137.21	4.79	4.79	22.92	3.37
125	138.55	-13.55	13.55	183.68	10.84
134	134.76	-0.76	0.76	0.57	0.57
118	134.55	-16.55	16.55	273.76	14.02
131	129.91	1.09	1.09	1.18	0.83
132	130.22	1.78	1.78	3.18	1.35
124	130.72	-6.72	6.72	45.11	5.42
121	128.84	-7.84	7.84	61.40	6.48
127	126.64	0.36	0.36	0.13	0.28
118	126.74	-8.74	8.74	76.42	7.41
120	124.29	-4.29	4.29	18.44	3.58
115	123.09	-8.09	8.09	65.48	7.04
106	120.83	-14.83	14.83	219.82	13.99
120	116.67	3.33	3.33	11.06	2.77
113	117.61	-4.61	4.61	21.21	4.08
121	116.32	4.68	4.68	21.94	3.87
119	117.63	1.37	1.37	1.88	1.15
Forecast	118.01				
CFE	-70.62				
MAD	6.29				
MSE	61.88				
MAPE	5.11				

(iv) Trend Projection with Regression: model $Y=143.1613-1.1289X$ obtained from the *Time Series Forecasting Solver* of OM Explorer for *Trend Projection with Regression*

Demand for Component 135.AG	Trend Projection with Regression				
	Forecast	Error	ABS (Error)	Square (Error)	Percent (Error)
137	142.03				
136	140.90				
143	139.77				
136	138.64				
141	137.52	3.48	3.48	12.12	2.47
128	136.39	-8.39	8.39	70.39	6.55
149	135.26	13.74	13.74	188.76	9.22
136	134.13	1.87	1.87	3.49	1.37
134	133.00	1.00	0.99	1.00	0.74
142	131.87	10.13	10.13	102.53	7.13
125	130.74	-5.74	5.74	32.97	4.59
134	129.62	4.38	4.38	19.22	3.27
118	128.49	-10.49	10.49	109.92	8.89
131	127.36	3.64	3.64	13.26	2.78
132	126.23	5.77	5.77	33.30	4.37
124	125.10	-1.10	1.10	1.21	0.89
121	123.97	-2.97	2.97	8.83	2.45
127	122.84	4.16	4.16	17.28	3.27
118	121.71	-3.71	3.71	13.77	3.14
120	120.59	-0.59	0.59	0.34	0.49
115	119.46	-4.46	4.46	19.86	3.88
106	118.33	-12.33	12.33	151.97	11.63
120	117.20	2.80	2.80	7.85	2.33
113	116.07	-3.07	3.07	9.40	2.72
121	114.94	6.06	6.06	36.71	5.01
119	113.81	5.19	5.19	26.91	4.36
Forecast	112.68				
CFE	9.36				
MAD	5.23				
MSE	40.06				
MAPE	4.16				

These results are confirmed by the output from the *Time Series Forecasting* Solver of OM Explorer:

1-Period Moving Average	3-Period Weighted Moving Average Enter weights Most recent 0.3333333 2nd most recent 0.3333333 3rd most recent 0.3333333	Exponential Smoothing α 0.28 Initial Forecast 137 Note: The default for the initial forecast is set to the initial period's actual demand but can be changed above.	Trend Projection Intercept 143.16 Slope/Trend -1.13 Correlation -0.81 r^2 0.66

Error analysis begins in period 5					Regression begins in period 1								
Combination Weight -->													
Actual Data	1-Period Moving Average			3-Period Weighted Moving Average			Exponential Smoothing			Trend Projection			
Period	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	
1	137						137.00			142.03			
2	136						137.00			140.91			
3	143						136.72			139.78			
4	136			138.67			138.48			138.65			
5	141	136.00	5.00	138.33	2.67	2.67	137.78	3.22	3.22	137.52	3.48	3.48	
6	128	141.00	-13.00	-8.00	140.00	-12.00	-9.33	138.68	-10.68	-7.47	136.39	-8.39	-4.91
7	149	128.00	21.00	13.00	135.00	14.00	4.67	135.69	13.31	5.84	135.26	13.74	8.83
8	136	149.00	-13.00	0.00	139.33	-3.33	1.33	139.42	-3.42	2.42	134.13	1.87	10.70
9	134	136.00	-2.00	-2.00	137.67	-3.67	-2.33	138.46	-4.46	-2.04	133.00	1.00	11.70
10	142	134.00	8.00	6.00	139.67	2.33	0.00	137.21	4.79	2.74	131.87	10.13	21.82
11	125	142.00	-17.00	-11.00	137.33	-12.33	-12.33	138.55	-13.55	-10.81	130.75	-5.75	16.08
12	134	125.00	9.00	-2.00	133.67	0.33	-12.00	134.76	-0.76	-11.57	129.62	4.38	20.46
13	118	134.00	-16.00	-18.00	133.67	-15.67	-27.67	134.55	-16.55	-28.11	128.49	-10.49	9.97
14	131	118.00	13.00	-5.00	125.67	5.33	-22.33	129.91	1.09	-27.03	127.36	3.64	13.61
15	132	131.00	1.00	-4.00	127.67	4.33	-18.00	130.22	1.78	-25.24	126.23	5.77	19.38
16	124	132.00	-8.00	-12.00	127.00	-3.00	-21.00	130.72	-6.72	-31.96	125.10	-1.10	18.28
17	121	124.00	-3.00	-15.00	129.00	-8.00	-29.00	128.84	-7.84	-39.80	123.97	-2.97	15.31
18	127	121.00	6.00	-9.00	125.67	1.33	-27.67	126.64	0.36	-39.44	122.84	4.16	19.47
19	118	127.00	-9.00	-18.00	124.00	-6.00	-33.67	126.74	-8.74	-48.18	121.71	-3.71	15.75
20	120	118.00	2.00	-16.00	122.00	-2.00	-35.67	124.29	-4.29	-52.47	120.59	-0.59	15.17
21	115	120.00	-5.00	-21.00	121.67	-6.67	-42.33	123.09	-8.09	-60.57	119.46	-4.46	10.71
22	106	115.00	-9.00	-30.00	117.67	-11.67	-54.00	120.83	-14.83	-75.39	118.33	-12.33	-1.62
23	120	106.00	14.00	-16.00	113.67	6.33	-47.67	116.67	3.33	-72.07	117.20	2.80	1.19
24	113	120.00	-7.00	-23.00	113.67	-0.67	-48.33	117.61	-4.61	-76.67	116.07	-3.07	-1.88
25	121	113.00	8.00	-15.00	113.00	8.00	-40.33	116.32	4.68	-71.99	114.94	6.06	4.18
26	119	121.00	-2.00	-17.00	118.00	1.00	-39.33	117.63	1.37	-70.62	113.81	5.19	9.36

Error Analysis begins in period 5**Method 1 - Moving Average:****1 -Period Moving Average**

Forecast for Period 27	119.00
CFE	-17.00
MAD	8.68
MSE	103.68
MAPE	6.86%

Method 2 - Weighted Moving Average:**3 -Period Weighted Moving Average**

Forecast for Period 27	117.67
CFE	-39.33
MAD	5.94
MSE	55.59
MAPE	4.78%

Method 3 - Exponential Smoothing:

α	0.28
Initial Forecast	137.00
Forecast for Period 27	118.01
CFE	-70.62
MAD	6.29
MSE	61.88
MAPE	5.11%

Method 4 - Trend Projection

Intercept	143.16
Slope	-1.13
r^2	0.66

Forecast for Period 27	112.68
Forecast for Period 28	111.55
Forecast for Period 29	110.43
Forecast for Period 30	109.30
Forecast for Period 31	108.17
Forecast for Period 32	107.04

CFE	9.36
MAD	5.23
MSE	40.06
MAPE	4.16%

a.-d. As seen in the summary table, the *Trend Projection with Regression* method provides superior results across all performance criteria. The reason that it does not have a CFE of 0.0 is that the regression begins with period 1, but the error analysis begins in period 5.

	CFE	MAD	MSE	MAPE
1-Period Moving Average (Naïve) Forecast	-17.00	8.68	103.68	6.86%
3-Period Moving Average Forecast	-39.33	5.94	55.59	4.78%
Exponential Smoothing Forecast	-70.62	6.29	61.88	5.11%
Trend Projection with Regression	9.36	5.23	40.06	4.16%

17. Combination Forecast for Problem 16

In ranked order, the best methods for Franklin Tool, based on MAD, are Trend Projection with Regression (MAD=5.23), 3-period Moving Average (MAD=5.94), Exponential Smoothing (MAD=6.29), and Naïve (MAD=8.68).

Combination Forecast giving equal weight to all four methods:

Forecasts					Error	Absolute Error	Demand	Absolute Percent Error
Demand	Trend	MA	EA	Naive				
137	142.03							
136	140.91			137.00				
143	139.78			136.00				
136	138.65	138.67		143.00				
141	137.52	138.33	137.78	136.00	137.41	3.59	3.59	12.89
128	136.39	140.00	138.68	141.00	139.02	-11.02	11.02	121.41
149	135.26	135.00	135.69	128.00	133.49	15.51	15.51	240.61
136	134.13	139.33	139.42	149.00	140.47	-4.47	4.47	19.99
134	133.00	137.67	138.46	136.00	136.28	-2.28	2.28	5.21
142	131.87	139.67	137.21	134.00	135.69	6.31	6.31	39.84
125	130.75	137.33	138.55	142.00	137.16	-12.16	12.16	147.81
134	129.62	133.67	134.76	125.00	130.76	3.24	3.24	10.50
118	128.49	133.67	134.55	134.00	132.67	-14.67	14.67	215.35
131	127.36	125.67	129.91	118.00	125.23	5.77	5.77	33.24
132	126.23	127.67	130.22	131.00	128.78	3.22	3.22	10.38
124	125.10	127.00	130.72	132.00	128.70	-4.70	4.70	22.13
121	123.97	129.00	128.84	124.00	126.45	-5.45	5.45	29.72
127	122.84	125.67	126.64	121.00	124.04	2.96	2.96	8.77
118	121.71	124.00	126.74	127.00	124.86	-6.86	6.86	47.11
120	120.59	122.00	124.29	118.00	121.22	-1.22	1.22	1.49
115	119.46	121.67	123.09	120.00	121.05	-6.05	6.05	36.65
106	118.33	117.67	120.83	115.00	117.96	-11.96	11.96	142.92
120	117.20	113.67	116.67	106.00	113.38	6.62	6.62	43.76
113	116.07	113.67	117.61	120.00	116.84	-3.84	3.84	14.71
121	114.94	113.00	116.32	113.00	114.31	6.69	6.69	44.70
119	113.81	118.00	117.63	121.00	117.61	1.39	1.39	1.93
Forecast					115.35			
						-		
CFE					29.40			
MAD						6.36		
MSE							56.87	
MAPE								5.09

These results are confirmed by the output from the *Time Series Forecasting Solver* of OM Explorer:

Error analysis begins in period 5				Regression begins in period 1											
Combination Weight -->															
				0.25			0.25			0.25			0.25		
Actual Data	1-Period Moving Average	3-Period Weighted Moving Average	Exponential Smoothing	Trend Projection			Combination Forecast								
Period	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE
1	137						137.00			142.03					
2	136						137.00			140.91					
3	143						136.72			139.78					
4	136						138.48			138.65					
5	141	5.00	5.00	138.67			137.78	3.22	3.22	137.52	3.48	3.48	137.41	3.59	3.59
6	128	-13.00	-8.00	140.00	-12.00	-9.33	138.68	-10.68	-7.47	136.39	-8.39	-4.91	139.02	-11.02	-7.43
7	149	21.00	13.00	135.00	14.00	4.67	135.69	13.31	5.84	135.26	13.74	8.83	133.49	15.51	8.08
8	136	-13.00	0.00	139.33	-3.33	1.33	139.42	-3.42	2.42	134.13	1.87	10.70	140.47	-4.47	3.61
9	134	-2.00	-2.00	137.67	-3.67	-2.33	138.46	-4.46	-2.04	133.00	1.00	11.70	136.28	-2.28	1.33
10	142	8.00	6.00	139.67	2.33	0.00	137.21	4.79	2.74	131.87	10.13	21.82	135.69	6.31	7.64
11	125	-17.00	-11.00	137.33	-12.33	-12.33	138.55	-13.55	-10.81	130.75	-5.75	16.08	137.16	-12.16	-4.52
12	134	9.00	-2.00	133.67	0.33	-12.00	134.76	-0.76	-11.57	129.62	4.38	20.46	130.76	3.24	-1.28
13	118	-16.00	-18.00	133.67	-15.67	-27.67	134.55	-16.55	-28.11	128.49	-10.49	9.97	132.68	-14.68	-15.95
14	131	13.00	-5.00	125.67	5.33	-22.33	129.91	1.09	-27.03	127.36	3.64	13.61	125.23	5.77	-10.19
15	132	1.00	-4.00	127.67	4.33	-18.00	130.22	1.78	-25.24	126.23	5.77	19.38	128.78	3.22	-6.96
16	124	-8.00	-12.00	127.00	-3.00	-21.00	130.72	-6.72	-31.96	125.10	-1.10	18.28	128.70	-4.70	-11.67
17	121	-3.00	-15.00	129.00	-8.00	-29.00	128.84	-7.84	-39.80	123.97	-2.97	15.31	126.45	-5.45	-17.12
18	127	6.00	-9.00	125.67	1.33	-27.67	126.64	0.36	-39.44	122.84	4.16	19.47	124.04	2.96	-14.16
19	118	-9.00	-18.00	124.00	-6.00	-33.67	126.74	-8.74	-48.18	121.71	-3.71	15.75	124.86	-6.86	-21.02
20	120	2.00	-16.00	122.00	-2.00	-35.67	124.29	-4.29	-52.47	120.59	-0.59	15.17	121.22	-1.22	-22.24
21	115	-5.00	-21.00	121.67	-6.67	-42.33	123.09	-8.09	-60.57	119.46	-4.46	10.71	121.05	-6.05	-28.30
22	106	-9.00	-30.00	117.67	-11.67	-54.00	120.83	-14.83	-75.39	118.33	-12.33	-1.62	117.96	-11.96	-40.25
23	120	14.00	-16.00	113.67	6.33	-47.67	116.67	3.33	-72.07	117.20	2.80	1.19	113.39	6.61	-33.64
24	113	-7.00	-23.00	113.67	-0.67	-48.33	117.61	-4.61	-76.67	116.07	-3.07	-1.88	116.84	-3.84	-37.47
25	121	8.00	-15.00	113.00	8.00	-40.33	116.32	4.68	-71.99	114.94	6.06	4.18	114.31	6.69	-30.79
26	119	-2.00	-17.00	118.00	1.00	-39.33	117.63	1.37	-70.62	113.81	5.19	9.36	117.61	1.39	-29.40

Method 5 - Combination forecast

Forecast for Period 27 **116.84**

CFE **-29.40**
 MAD **6.36**
 MSE **56.87**
 MAPE **5.09%**

Combination Forecast giving equal weight to the best three methods (Trend Projection with Regression, 3-period Moving Average, and Exponential Smoothing):

Forecasts					Error	Absolute Error	Squared Error	Absolute Percent Error
Demand	Trend	MA	EA	Comb of best 3				
137	142.03		137.00					
136	140.91		137.00					
143	139.78		136.72					
136	138.65	138.67	138.48	138.60				
141	137.52	138.33	137.78	137.88	3.12	3.12	9.74	2.21
128	136.39	140.00	138.68	138.36	-10.36	10.36	107.29	8.09
149	135.26	135.00	135.69	135.32	13.68	13.68	187.20	9.18
136	134.13	139.33	139.42	137.63	-1.63	1.63	2.65	1.20
134	133.00	137.67	138.46	136.38	-2.38	2.38	5.65	1.77
142	131.87	139.67	137.21	136.25	5.75	5.75	33.05	4.05
125	130.75	137.33	138.55	135.54	-10.54	10.54	111.17	8.44
134	129.62	133.67	134.76	132.68	1.32	1.32	1.74	0.98
118	128.49	133.67	134.55	132.23	-14.23	14.23	202.59	12.06
131	127.36	125.67	129.91	127.65	3.35	3.35	11.25	2.56
132	126.23	127.67	130.22	128.04	3.96	3.96	15.70	3.00
124	125.10	127.00	130.72	127.61	-3.61	3.61	13.00	2.91
121	123.97	129.00	128.84	127.27	-6.27	6.27	39.30	5.18
127	122.84	125.67	126.64	125.05	1.95	1.95	3.80	1.54
118	121.71	124.00	126.74	124.15	-6.15	6.15	37.85	5.21
120	120.59	122.00	124.29	122.29	-2.29	2.29	5.26	1.91
115	119.46	121.67	123.09	121.40	-6.40	6.40	41.02	5.57
106	118.33	117.67	120.83	118.94	-12.94	12.94	167.44	12.21
120	117.20	113.67	116.67	115.85	4.15	4.15	17.25	3.46
113	116.07	113.67	117.61	115.78	-2.78	2.78	7.73	2.46
121	114.94	113.00	116.32	114.75	6.25	6.25	39.03	5.16
119	113.81	118.00	117.63	116.48	2.52	2.52	6.35	2.12
Forecast				116.12				
CFE					-33.53			
MAD						5.71		
MSE							48.46	
MAPE								4.60

These results are confirmed by the output from the *Time Series Forecasting Solver* of OM Explorer:

1-Period Moving Average		3-Period Weighted Moving Average		Exponential Smoothing			Trend Projection			
		Enter weights			α 0.28			Intercept 143.16		
		Most recent 0.333333			Initial Forecast 137			Slope/Trend -1.13		
		2nd most recent 0.333333			Note: The default for the Initial forecast is set to the initial period's actual demand but can be changed above.			Correlation -0.81		
		3rd most recent 0.333333						r ² 0.66		

Error analysis begins in period 5				Regression begins in period 1												
Combination Weight --> 0.00				0.3333333				0.3333333				0.3333333				
Actual Data		1-Period Moving Average			3-Period Weighted Moving Average			Exponential Smoothing			Trend Projection			Combination Forecast		
Period		Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE
1	137							137.00			142.03					
2	136	137.00						137.00			140.91					
3	143	136.00						136.72			139.78					
4	136	143.00			138.67			138.48			138.65			138.60		
5	141	136.00	5.00	5.00	138.33	2.67	2.67	137.78	3.22	3.22	137.52	3.48	3.48	137.88	3.12	3.12
6	128	141.00	-13.00	-8.00	140.00	-12.00	-9.33	138.68	-10.68	-7.47	136.39	-8.39	-4.91	138.36	-10.36	-7.24
7	149	128.00	21.00	13.00	135.00	14.00	4.67	135.69	13.31	5.84	135.26	13.74	8.83	135.32	13.68	6.45
8	136	149.00	-13.00	0.00	139.33	-3.33	1.33	139.42	-3.42	2.42	134.13	1.87	10.70	137.63	-1.63	4.82
9	134	136.00	-2.00	-2.00	137.67	-3.67	-2.33	138.46	-4.46	-2.04	133.00	1.00	11.70	136.38	-2.38	2.44
10	142	134.00	8.00	6.00	139.67	2.33	0.00	137.21	4.79	2.74	131.87	10.13	21.82	136.25	5.75	8.19
11	125	142.00	-17.00	-11.00	137.33	-12.33	-12.33	138.55	-13.55	-10.81	130.75	-5.75	16.08	135.54	-10.54	-2.36
12	134	125.00	9.00	-2.00	133.67	0.33	-12.00	134.76	-0.76	-11.57	129.62	4.38	20.46	132.68	1.32	-1.04
13	118	134.00	-16.00	-18.00	133.67	-15.67	-27.67	134.55	-16.55	-28.11	128.49	-10.49	9.97	132.23	-14.23	-15.27
14	131	118.00	13.00	-5.00	125.67	5.33	-22.33	129.91	1.09	-27.03	127.36	3.64	13.61	127.65	3.35	-11.91
15	132	131.00	1.00	-4.00	127.67	4.33	-18.00	130.22	1.78	-25.24	126.23	5.77	19.38	128.04	3.96	-7.95
16	124	132.00	-8.00	-12.00	127.00	-3.00	-21.00	130.72	-6.72	-31.96	125.10	-1.10	18.28	127.61	-3.61	-11.56
17	121	124.00	-3.00	-15.00	129.00	-8.00	-29.00	128.84	-7.84	-39.80	123.97	-2.97	15.31	127.27	-6.27	-17.83
18	127	121.00	6.00	-9.00	125.67	1.33	-27.67	126.84	0.36	-39.44	122.84	4.16	19.47	125.05	1.95	-15.88
19	118	127.00	-9.00	-18.00	124.00	-6.00	-33.67	126.74	-8.74	-48.18	121.71	-3.71	15.75	124.15	-6.15	-22.03
20	120	118.00	2.00	-16.00	122.00	-2.00	-35.67	124.29	-4.29	-52.47	120.59	-0.59	15.17	122.29	-2.29	-24.32
21	115	120.00	-5.00	-21.00	121.67	-6.67	-42.33	123.09	-8.09	-60.57	119.46	-4.46	10.71	121.40	-6.40	-30.73
22	106	115.00	-9.00	-30.00	117.67	-11.67	-54.00	120.83	-14.83	-75.39	118.33	-12.33	-1.62	118.94	-12.94	-43.67
23	120	106.00	14.00	-16.00	113.67	6.33	-47.67	116.67	3.33	-72.07	117.20	2.80	1.19	115.85	4.15	-39.52
24	113	120.00	-7.00	-23.00	113.67	-0.67	-48.33	117.61	-4.61	-76.67	116.07	-3.07	-1.88	115.78	-2.78	-42.30
25	121	113.00	8.00	-15.00	113.00	8.00	-40.33	116.32	4.68	-71.99	114.94	6.06	4.18	114.75	6.25	-36.05
26	119	113.00	-2.00	-17.00	118.00	1.00	-39.33	117.63	1.37	-70.62	113.81	5.19	9.36	116.48	2.52	-33.53

Method 5 - Combination forecast

Forecast for Period 27	116.12
CFE	-33.53
MAD	5.71
MSE	48.46
MAPE	4.60%

Combination Forecast giving equal weight to the best two methods (Trend Projection with Regression and 3-period Moving Average):

Forecasts							
Demand	Trend	MA	Comb of best 2	Error	Absolute Error	Squared Error	Absolute Percent Error
137	142.03						
136	140.91						
143	139.78						
136	138.65	138.67	138.66				
141	137.52	138.33	137.93	3.07	3.07	9.45	2.18
128	136.39	140.00	138.19	-10.19	10.19	103.93	7.96
149	135.26	135.00	135.13	13.87	13.87	192.37	9.31
136	134.13	139.33	136.73	-0.73	0.73	0.54	0.54
134	133.00	137.67	135.33	-1.33	1.33	1.78	1.00
142	131.87	139.67	135.77	6.23	6.23	38.81	4.39
125	130.75	137.33	134.04	-9.04	9.04	81.71	7.23
134	129.62	133.67	131.64	2.36	2.36	5.56	1.76
118	128.49	133.67	131.08	-13.08	13.08	171.01	11.08
131	127.36	125.67	126.51	4.49	4.49	20.14	3.43
132	126.23	127.67	126.95	5.05	5.05	25.52	3.83
124	125.10	127.00	126.05	-2.05	2.05	4.20	1.65
121	123.97	129.00	126.49	-5.49	5.49	30.10	4.53
127	122.84	125.67	124.25	2.75	2.75	7.54	2.16
118	121.71	124.00	122.86	-4.86	4.86	23.59	4.12
120	120.59	122.00	121.29	-1.29	1.29	1.67	1.08
115	119.46	121.67	120.56	-5.56	5.56	30.93	4.84
106	118.33	117.67	118.00	-12.00	12.00	143.93	11.32
120	117.20	113.67	115.43	4.57	4.57	20.86	3.81
113	116.07	113.67	114.87	-1.87	1.87	3.49	1.65
121	114.94	113.00	113.97	7.03	7.03	49.42	5.81
119	113.81	118.00	115.91	3.09	3.09	9.57	2.60
Forecast			115.17				
CFE				-14.98			
MAD					5.45		
MSE						44.37	
MAPE							4.38

These results are confirmed by the output from the *Time Series Forecasting Solver* of OM Explorer:

1-Period Moving Average		3-Period Weighted Moving Average					Exponential Smoothing			Trend Projection		
		Enter weights					α 0.05			Intercept 143.16		
		Most recent 0.3333333					Initial Forecast 137			Slope/Trend -1.13		
		2nd most recent 0.3333333					Note: The default for the Initial forecast is set to the initial period's actual demand but can be changed above.			Correlation -0.81		
		3rd most recent 0.3333333								r ² 0.66		

Error analysis begins in period 5							Regression begins in period 1									
Combination Weight -->							0.00 0.50 0.00 0.50									
Actual Data		1-Period Moving Average			3-Period Weighted Moving Average			Exponential Smoothing			Trend Projection			Combination Forecast		
Period		Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE
1	137							137.00			142.03					
2	136	137.00						137.00			140.91					
3	143	136.00						136.95			139.78					
4	136	143.00			138.67			137.25			138.65			138.66		
5	141	136.00	5.00	5.00	138.33	2.67	2.67	137.19	3.81	3.81	137.52	3.48	3.48	137.93	3.07	3.07
6	128	141.00	-13.00	-8.00	140.00	-12.00	-9.33	137.38	-9.38	-5.57	136.39	-8.39	-4.91	138.19	-10.19	-7.12
7	149	128.00	21.00	13.00	135.00	14.00	4.67	136.91	12.09	6.52	135.26	13.74	8.83	135.13	13.87	6.75
8	136	149.00	-13.00	0.00	139.33	-3.33	1.33	137.52	-1.52	5.00	134.13	1.87	10.70	136.73	-0.73	6.02
9	134	136.00	-2.00	-2.00	137.67	-3.67	-2.33	137.44	-3.44	1.56	133.00	1.00	11.70	135.33	-1.33	4.68
10	142	134.00	8.00	6.00	139.67	2.33	0.00	137.27	4.73	6.29	131.87	10.13	21.82	135.77	6.23	10.91
11	125	142.00	-17.00	-11.00	137.33	-12.33	-12.33	137.50	-12.50	-6.21	130.75	-5.75	16.08	134.04	-9.04	1.87
12	134	125.00	9.00	-2.00	133.67	0.33	-12.00	136.88	-2.88	-9.09	129.62	4.38	20.46	131.64	2.36	4.23
13	118	134.00	-16.00	-18.00	133.67	-15.67	-27.67	136.74	-18.74	-27.82	128.49	-10.49	9.97	131.08	-13.08	-8.85
14	131	118.00	13.00	-5.00	125.67	5.33	-22.33	135.80	-4.80	-32.62	127.36	3.64	13.61	126.51	4.49	-4.36
15	132	131.00	1.00	-4.00	127.67	4.33	-18.00	135.56	-3.56	-36.18	126.23	5.77	19.38	126.95	5.05	0.69
16	124	132.00	-8.00	-12.00	127.00	-3.00	-21.00	135.38	-11.38	-47.56	125.10	-1.10	18.28	126.05	-2.05	-1.36
17	121	124.00	-3.00	-15.00	129.00	-8.00	-29.00	134.81	-13.81	-61.37	123.97	-2.97	15.31	126.49	-5.49	-6.84
18	127	121.00	6.00	-9.00	125.67	1.33	-27.67	134.12	-7.12	-68.50	122.84	4.16	19.47	124.25	2.75	-4.10
19	118	127.00	-9.00	-18.00	124.00	-6.00	-33.67	133.77	-15.77	-84.26	121.71	-3.71	15.75	122.86	-4.86	-8.96
20	120	118.00	2.00	-16.00	122.00	-2.00	-35.67	132.98	-12.98	-97.24	120.59	-0.59	15.17	121.29	-1.29	-10.25
21	115	120.00	-5.00	-21.00	121.67	-6.67	-42.33	132.33	-17.33	-114.57	119.46	-4.46	10.71	120.56	-5.56	-15.81
22	106	115.00	-9.00	-30.00	117.67	-11.67	-54.00	131.46	-25.46	-140.03	118.33	-12.33	-1.62	118.00	-12.00	-27.81
23	120	106.00	14.00	-16.00	113.67	6.33	-47.67	130.19	-10.19	-150.22	117.20	2.80	1.19	115.43	4.57	-23.24
24	113	120.00	-7.00	-23.00	113.67	-0.67	-48.33	129.68	-16.68	-166.89	116.07	-3.07	-1.88	114.87	-1.87	-25.11
25	121	113.00	8.00	-15.00	113.00	8.00	-40.33	128.85	-7.85	-174.74	114.94	6.06	4.18	113.97	7.03	-18.08
26	119	121.00	-2.00	-17.00	118.00	1.00	-39.33	128.45	-9.45	-184.19	113.81	5.19	9.36	115.91	3.09	-14.98

Method 5 - Combination forecast

Forecast for Period 27	115.17
CFE	-14.97
MAD	5.45
MSE	44.37
MAPE	4.38%

Of the three Combination Methods, the “best-two” forecast provides superior results. These forecasts are better than the Naïve, Moving Average and Exponential Smoothing methods. However, the Trend Projection with Regression method still provides the best overall result. Combination forecasts are better when they bring in something new, such as judgmental forecasts based on contextual knowledge or salesforce polling information.

18. Large Public Library

Using the *Time Series Forecasting Solver* of OM Explorer, we get the following results by varying the number of periods (n) in the Simple Moving Average method:

n	Forecast for January, Year 4	MAD	CFE
1	2,451	282	604
2	2,299	267	-68
3	2,221	257	-291
4	2,127	242	-524
5	2,037	242	-846
10	2,189	216	-445

In general, as n increases, MAD decreases and CFE (bias) increases. The 10-month average seems to be a good combination of relatively low MAD and low CFE.

19. Large Public Library (continued, using 1,847 as initial average)

Using the *Time Series Forecasting Solver*, we get the following results by varying α in the exponential smoothing model:

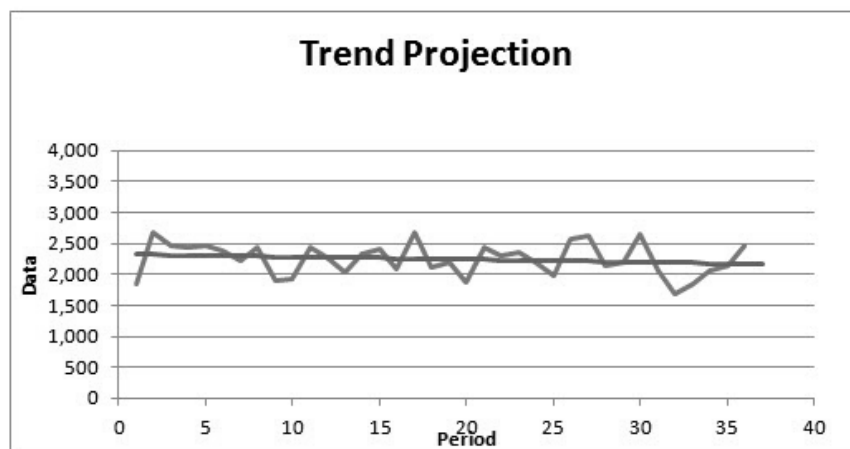
α	Forecast for January, Year 4	MAD	CFE
0.10	2,193	265	3,458
0.20	2,178	256	1,654
0.30	2,186	256	1,131
0.50	2,259	258	823
0.65	2,325	255	736
0.70	2,346	256	713
0.80	2,385	262	673
1.00	2,451	282	604

As α increases, CFE (bias) generally decreases and MAD generally increases. When $\alpha = 0.65$ there seems to be a good combination of low bias and low MAD.

20. Large Public Library (continued)

Using the *Time Series Forecasting Solver* of OM Explorer, we get the following results

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



Intercept	2,328
Slope	-4.37
r^2	0.03
Forecast for Period 37	2,166
Forecast for Period 38	2,162
Forecast for Period 39	2,158
Forecast for Period 40	2,153
Forecast for Period 41	2,149
Forecast for Period 42	2,145
CFE	476.78
MAD	198.02
MSE	59,811
MAPE	8.99%

Trend Projection seems to provide the best forecast because of its low CFE and MAD results, relative to those of the simple moving average or the exponential smoothing methods.

21. Cannister Inc.

a. **Multiplicative Seasonal Method**

Year	1	2	3	4	5
Jan	742	741	896	951	1,030
Feb	697	700	793	861	1,032
Mar	776	774	885	938	1,126
Apr	898	932	1,055	1,109	1,285
May	1,030	1,099	1,204	1,274	1,468
Jun	1,107	1,223	1,326	1,422	1,637
Jul	1,165	1,290	1,303	1,486	1,611
Aug	1,216	1,349	1,436	1,555	1,608
Sep	1,208	1,341	1,473	1,604	1,528
Oct	1,131	1,296	1,453	1,600	1,420
Nov	971	1,066	1,170	1,403	1,119
Dec	783	901	1,023	1,209	1,013
Total	11,724	12,712	14,017	15,412	15,877
Averages	977	1,059.333	1,168.083	1,284.333	1,323.083

Year	1	2	3	4	5	Average Seasonal Index
Jan	0.759	0.699	0.767	0.740	0.778	0.749
Feb	0.713	0.661	0.679	0.670	0.780	0.701
Mar	0.794	0.731	0.758	0.730	0.851	0.773
Apr	0.919	0.880	0.903	0.863	0.971	0.907
May	1.054	1.037	1.031	0.992	1.110	1.045
Jun	1.133	1.154	1.135	1.107	1.237	1.153
Jul	1.192	1.218	1.116	1.157	1.218	1.180
Aug	1.245	1.273	1.229	1.211	1.215	1.235
Sep	1.236	1.266	1.261	1.249	1.155	1.233
Oct	1.158	1.223	1.244	1.246	1.073	1.189
Nov	0.994	1.006	1.002	1.092	0.846	0.988
Dec	0.801	0.851	0.876	0.941	0.766	0.847

b. **Simple Linear Regression Model to forecast annual sales**

$Y = 10,646.6 + 1,100.6X$ obtained from the Time Series Forecasting Solver of OM Explorer for Trend Projection with Regression

c. Forecast for Year 6 (or $X = 6$) is: $Y = 17,250.2$

d. **Monthly Seasonal Forecast for Year 6**

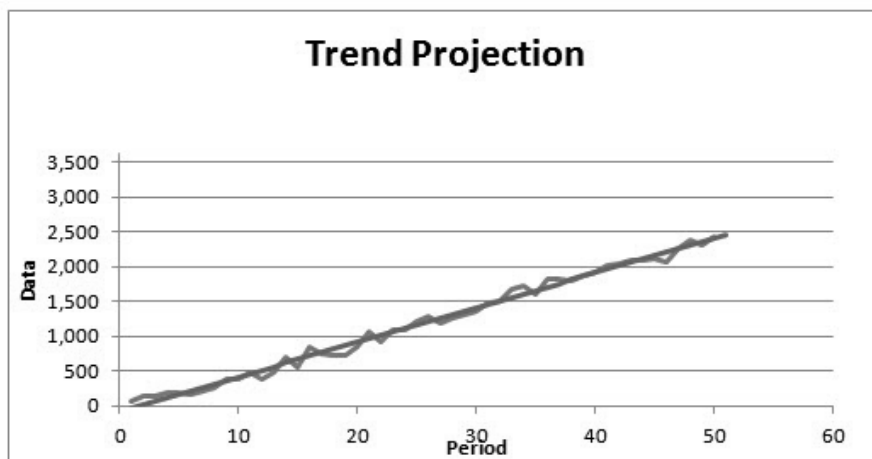
$(17,250/12) \times \text{Average Seasonal Index}$

Jan	1,076.7	Jul	1,696.4
Feb	1,007.3	Aug	1,774.9
Mar	1,110.9	Sep	1,773.1
Apr	1,304.4	Oct	1,708.9
May	1,501.9	Nov	1,420.2
Jun	1,658.1	Dec	1,217.5

22. Midwest Computer Company

a. The results of the *Trend Projection with Regression Solver* of OM Explorer are

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



<i>a</i> (Y intercept)	-78.715
<i>b</i> (slope or trend)	49.696
r^2	0.990

CFE	0.000
MAD	60.577
MSE	5013.638
MAPE	13.23%

Forecast for period 51	2455.795

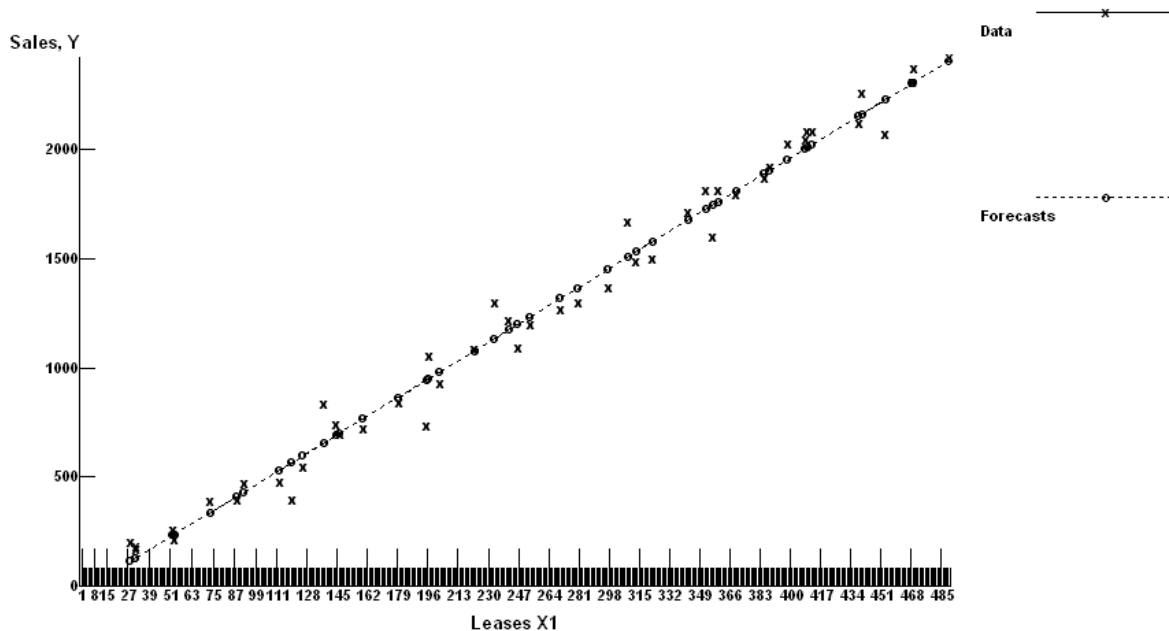
The solver provides a CFE (bias) of 0.00 with a MAD of 60.577 and a correlation coefficient of 0.990. The forecast for week 51 using this method is 2,456.

b. The linear regression model is

$Y = -28.693 + 4.9815 X$ or Sales = -28.693 + 4.9815 (number of leases)
from the Trend Analysis/Time Series Analysis module in *POM for Windows*.

The statistical results and graph are as follows:

Measure	Value
Cumulative forecast error	.00043
Average Forecast Error	.00001
MAD (Mean Absolute Deviation)	65.83693
MSE (Mean Squared Error)	6,917.286
Standard Error (denom=n-1.0=45)	84.99836
MAPE (Mean Absolute Percent	.08463
Regression line	
Sales, $Y = -28.69349$	
$+ 4.9815 * \text{Leases } X_1$	
Statistics	
Correlation coefficient	.99269
Coefficient of determination (r^2)	.98543



The forecast for month 51 (when $X = 496$ from month 48) is $-28.693 + 4.9815 (496) = 2,442$.

c. While both methods provide extremely high coefficients of determination, the *Trend Projection with Regression Solver* has a slightly lower MAD of only 60.577. Therefore, it is slightly more likely to provide better forecasts, based on past experience.

23. P&Q Supermarkets

Numerous methods could be used.

Moving Average

Moving Average Number of Periods	MAD	CFE	Forecast
2	7.09	5.00	39.50
3	6.87	13.67	41.33
4	6.21	12.75	41.50
5	4.52	1.00	44.80
6	4.80	7.00	44.17
7	4.94	7.43	43.43
12	5.15	3.08	43.08

Exponential smoothing

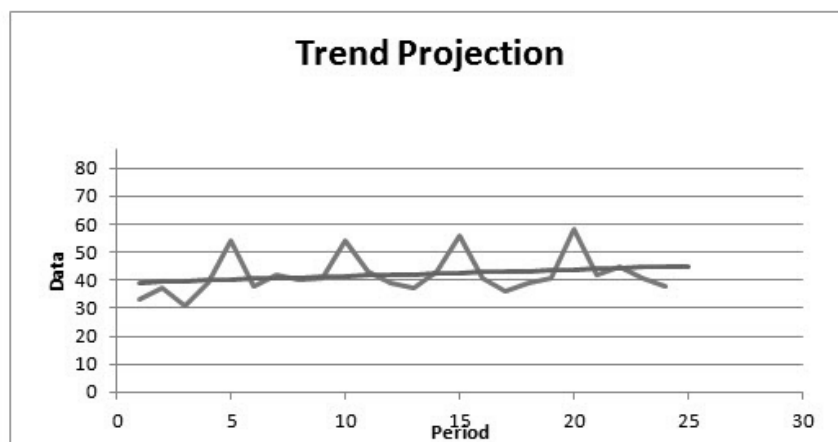
Use $\alpha = 0.20$ for the lowest MAD.

	MAD	CFE	Forecast
$\alpha = 0.20$	5.34	47.62	42.53
$\alpha = 1.00$	7.52	5.00	38

Use $\alpha = 1.00$ (equivalent of naïve model) for the lowest bias.

Trend Projection with Regression

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



a (Y intercept)	38.99
b (slope or trend)	0.24
r^2	0.06

CFE	0.00
MAD	4.84
MSE	43.30
MAPE	11.08%

Forecast for period 25 **45.01**

Combination

Error analysis begins in period 6				Regression begins in period 0.33												
Combination Weight --> 0.33				0.33												
Actual Data		5-Period Moving Average		2-Period Weighted Moving Average			Exponential Smoothing			Trend Projection			Combination Forecast			
Period		Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE
1	33							33.00			39.23					
2	37							33.00			39.47					
3	31				0.00			33.80			39.71					
4	39				0.00			33.24			39.95					
5	54				0.00			34.39			40.19					
6	38	38.80	-0.80	-0.80	0.00	38.00	38.00	38.31	-0.31	-0.31	40.43	-2.43	-2.43	39.18	-1.18	-1.18
7	42	39.80	2.20	1.40	0.00	42.00	80.00	38.25	3.75	3.44	40.68	1.32	-1.11	39.58	2.42	1.24
8	40	40.80	-0.80	0.60	0.00	40.00	120.00	39.00	1.00	4.43	40.92	-0.92	-2.03	40.24	-0.24	1.00
9	41	42.80	-1.60	-1.00	0.00	41.00	161.00	39.20	1.80	6.23	41.16	-0.16	-2.18	40.99	0.01	1.02
10	54	43.00	11.00	10.00	0.00	54.00	215.00	39.56	14.44	20.67	41.40	12.60	10.42	41.32	12.68	13.70
11	43	43.00	0.00	10.00	0.00	43.00	258.00	42.45	0.55	21.23	41.64	1.36	11.78	42.36	0.64	14.34
12	39	44.00	-5.00	5.00	0.00	39.00	297.00	42.56	-3.56	17.67	41.88	-2.88	8.90	42.81	-3.81	10.52
13	37	43.40	-6.40	-1.40	0.00	37.00	334.00	41.85	-4.85	12.82	42.12	-5.12	3.78	42.46	-5.46	5.07
14	43	42.80	0.20	-1.20	0.00	43.00	377.00	40.88	2.12	14.94	42.36	0.64	4.42	42.01	0.99	6.05
15	56	43.20	12.80	11.60	0.00	56.00	433.00	41.30	14.70	29.64	42.60	13.40	17.82	42.37	13.63	19.69
16	41	43.60	-2.60	9.00	0.00	41.00	474.00	44.24	-3.24	26.40	42.84	-1.84	15.97	43.56	-2.56	17.12
17	36	43.20	-7.20	1.80	0.00	36.00	510.00	43.59	-7.59	18.81	43.08	-7.08	8.89	43.29	-7.29	9.83
18	39	42.60	-3.60	-1.80	0.00	39.00	549.00	42.07	-3.07	15.73	43.32	-4.32	4.57	42.67	-3.67	6.17
19	41	43.00	-2.00	-3.80	0.00	41.00	590.00	41.46	-0.46	15.27	43.57	-2.57	2.00	42.68	-1.68	4.49
20	58	42.60	15.40	11.60	0.00	58.00	648.00	41.37	16.63	31.90	43.81	14.19	16.19	42.59	15.41	19.90
21	42	43.00	-1.00	10.60	0.00	42.00	690.00	44.69	-2.69	29.21	44.05	-2.05	14.15	43.91	-1.91	17.98
22	45	43.20	1.80	12.40	0.00	45.00	735.00	44.16	0.84	30.05	44.29	0.71	14.86	43.88	1.12	19.10
23	41	45.00	-4.00	8.40	0.00	41.00	776.00	44.32	-3.32	26.73	44.53	-3.53	11.33	44.62	-3.62	15.49
24	38	45.40	-7.40	1.00	0.00	38.00	814.00	43.66	-5.66	21.07	44.77	-6.77	4.56	44.61	-6.61	8.88

Forecast for Period 25

44.11

CFE

8.88

MAD

4.47

MSE

40.78

MAPE

9.76%

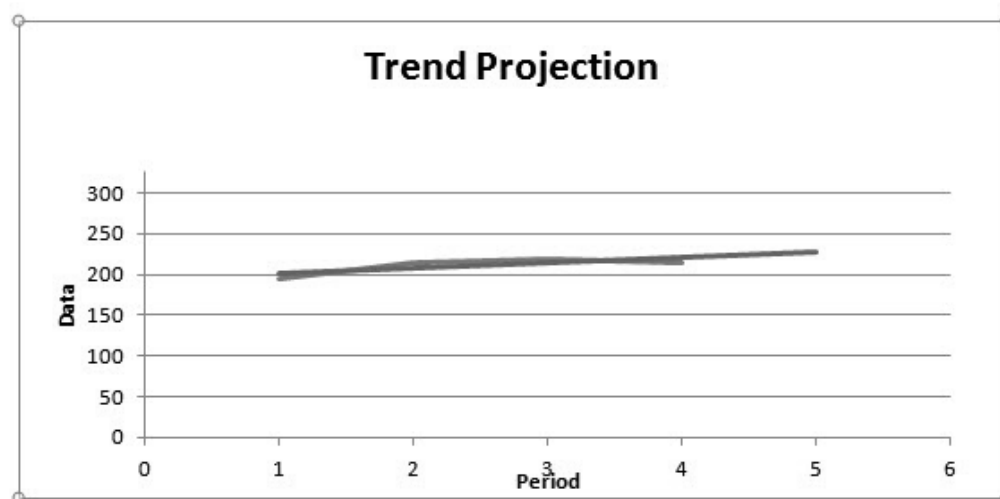
The Combination method gives slightly better forecasts. However, the graphic plot of the data reveals a spike every fifth period in a cycle. None of the methods tried so far reasonably accounts for the fifth-period spike. One way to deal with this cyclical data is to use the multiplicative seasonal method with five periods in a cycle. Unfortunately, OM Explorer's *Seasonal Forecasting Solver* does not allow for a situation where there are 5 periods in a cycle. Therefore if you must do some manual calculations or write your own Excel spreadsheet. Here we do the manual calculations, beginning with the seasonal indexes.

Period	Cycle 1	Seasonal Index	Cycle 2	Seasonal Index	Cycle 3	Seasonal Index	Cycle 4	Seasonal Index	Average Index
1	33	0.8508	38	0.8837	43	0.9862	41	0.9535	0.9186
2	37	0.9536	42	0.9767	39	0.8945	36	0.8372	0.9155
3	31	0.7990	40	0.9302	37	0.8486	39	0.9070	0.8712
4	39	1.0052	41	0.9535	43	0.9862	41	0.9535	0.9746
5	<u>54</u>	1.3918	<u>54</u>	1.2558	<u>56</u>	1.2844	<u>58</u>	1.3488	1.3202
	194		215		218		215		

One way to estimate the total demand for cycle 5 is to use OM Explorer's Trend Projection routine in the *Time Series Solver*. Here we get the following results:

Trend Projection		
Intercept	194.00	
Slope/Trend	6.60	
Note: The results in this table use ALL of the data. To see results when using the most recent n-periods of data go to the Trend Projector		

Trend Projection		
Forecast	Error	CFE
200.60	-6.60	-6.60
207.20	7.80	1.20
213.80	4.20	5.40
220.40	-5.40	0.00



<i>a</i> (Y intercept)	194.00
<i>b</i> (slope or trend)	6.60
<i>r</i>²	0.59
CFE	0.00
MAD	6.00
MSE	37.80
MAPE	2.87%

Forecast for period 5

227

Thus the average demand per period for the 5th cycle is forecast to be $227 / 5 = 45.4$. Applying the seasonal indexes, we get:

Period	Actual Cycle 5	Seasonal Index	Forecast Cycle 5
21	42	0.9186	42
22	45	0.9155	42
23	41	0.8712	39
24	38	0.9746	44
25	??	1.3202	<u>60</u>
			227

To calculate the errors for the multiplicative seasonal method, at least for the first four periods of the 5th cycle, we use the *Error Analysis* module of POM for Windows, with the following results:

Measure	Value
Error Measures	
CFE (Cumulative Forecast Error)	-1
MAD (Mean Absolute Deviation)	2.75
MSE (Mean Squared Error)	12.25
Standard Deviation of Errors	7
MAPE (Mean Absolute Percent Error)	6.834%

At least over this limited sample, the multiplicative seasonal method performs better than the Combination method because it accounts for the peak in the last period of each cycle.

24. Air visibility

a. Below is the analysis using the *Time Series Forecasting Solver* of OM Explorer.

Method 1 - Moving Average:

1 -Period Moving Average	
Forecast for Period 81	105.00
CFE	65.00
MAD	49.03
MSE	3,359
MAPE	46.24%

Method 2 - Weighted Moving Average:

3 -Period Weighted Moving Average	
Forecast for Period 81	103.50
CFE	50.00
MAD	44.21
MSE	2,762
MAPE	44.04%

Method 3 - Exponential Smoothing:

α	0.05
Initial Forecast	125.00
Forecast for Period 81	119.53
CFE	-0.69
MAD	39.17
MSE	2,239
MAPE	41.12%

Method 4 - Trend Projection

Intercept	122.81
Slope	-0.03
r^2	0.00
Forecast for Period 81	120.77
Forecast for Period 82	120.74
Forecast for Period 83	120.72
Forecast for Period 84	120.69
Forecast for Period 85	120.67
Forecast for Period 86	120.64

CFE	0.00
MAD	38.16
MSE	2,154
MAPE	40.04%

Method 5 - Combination forecast

Forecast for Period 81	115.50
CFE	17.08
MAD	37.84
MSE	2,094
MAPE	39.06%

The Trend Projection and Combination models give the best results, but they offer virtually no predictive ability. Note that the r^2 value of the regression is 0.00 and the slope is only - 0.03. MAPE is quite high at around 40 %.

Given the need for a forecast, an estimate of around 117 (above the combination forecast and below the trend projection forecast) seems reasonable.

- b. There is no reason to support expectations for air quality in the third year to be any different from that of the first two years. It will average about 120.5 unless public policy affects transportation, population growth, or utilities burning natural gas rather than coal. That might make a detectable difference in air quality. However, the effects of public policy are not recorded in the database, so qualitative forecasting methods are needed.

25. Flatlands Public Power District

The historical data show both trend and seasonal components. We will use the multiplicative seasonal method to forecast demand for the next year, then look for a low-demand period of two weeks during which the Comstock plant can be serviced. Weeks 7 and 8 look like the best two-week period to schedule maintenance.

Week	Demand Year 1	Seasonal Index	Demand Year 2	Seasonal Index	Demand Year 3	Seasonal Index	Demand Year 4	Seasonal Index	Demand Year 5	Seasonal Index
1	2,050	0.1017	2,000	0.0959	1,950	0.0922	2,100	0.1010	2,275	0.1064
2	1,925	0.0955	2,075	0.0995	1,800	0.0851	2,400	0.1154	2,300	0.1076
3	1,825	0.0906	2,225	0.1067	2,150	0.1017	1,975	0.0950	2,150	0.1006
4	1,525	0.0757	1,800	0.0863	1,725	0.0816	1,675	0.0805	1,525	0.0713
5	1,050	0.0521	1,175	0.0564	1,575	0.0745	1,350	0.0649	1,350	0.0632
6	1,300	0.0645	1,050	0.0504	1,275	0.0603	1,525	0.0733	1,475	0.0690
7	1,200	0.0596	1,250	0.0600	1,325	0.0626	1,500	0.0721	1,475	0.0690
8	1,175	0.0583	1,025	0.0492	1,100	0.0520	1,150	0.0553	1,175	0.0550
9	1,350	0.0670	1,300	0.0624	1,500	0.0709	1,350	0.0649	1,375	0.0643
10	1,525	0.0757	1,425	0.0683	1,550	0.0733	1,225	0.0589	1,400	0.0655
11	1,725	0.0856	1,625	0.0779	1,375	0.0650	1,225	0.0589	1,425	0.0667
12	1,575	0.0782	1,950	0.0935	1,825	0.0863	1,475	0.0709	1,550	0.0725
13	<u>1,925</u>	0.0955	<u>1,950</u>	0.0935	<u>2,000</u>	0.0946	<u>1,850</u>	0.0889	<u>1,900</u>	0.0889
Total	20,150		20,850		21,150		20,800		21,375	

Using regression to forecast the demand for Year 6, we get :

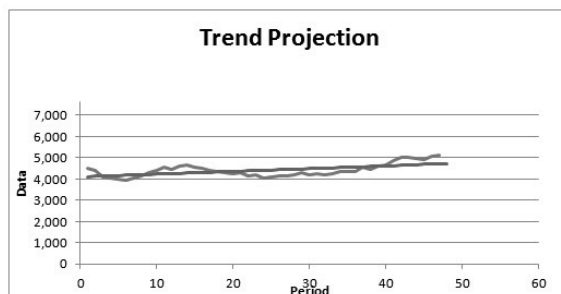
$$Y = 20,145 + 240(X) . \text{ When } X = 6, Y = 21,585 .$$

Using this annual demand forecast, we calculate the weekly breakdown as :

Week	Demand Year 6	Average Seasonal Index
1	2,147	0.0995
2	2,172	0.1006
3	2,135	0.0989
4	1,707	0.0791
5	1,343	0.0622
6	1,371	0.0635
7	1,396	0.0647
8	1,164	0.0539
9	1,422	0.0659
10	1,475	0.0683
11	1,529	0.0708
12	1,733	0.0803
13	<u>1,992</u>	0.0923
Total	21,585	

26. Using the *Trend Projection with Regression Solver*, we get the following results.
- a. The following output makes a forecast of 4,729 units for December of Year 4.

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



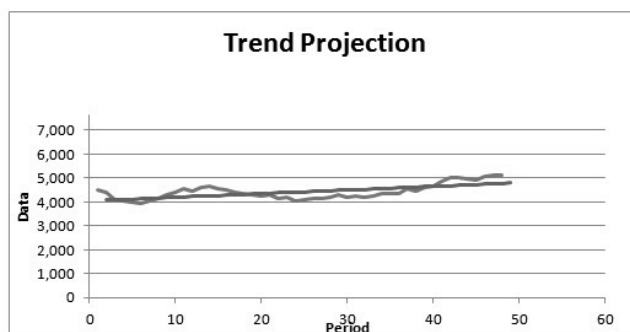
a (Y intercept) 4098.380
 b (slope or trend) 13.133
 r^2 0.359

CFE 0.000
 MAD 210.030
 MSE 56680.943
 MAPE 4.73%

Forecast for period 48 4728.769

- b. The forecast is 4,791 for period 49, up by 63 units. This is quite a jump, and the error measures have also decreased. For example, MAD drops from 210 to 207. These results are somewhat surprising, although the actual demand was quite a bit higher than forecast. Regression can be quite adaptive.

Regression begins in period 2 check scrollbar
 Error analysis begins in period 2
 Number of future forecasts 1



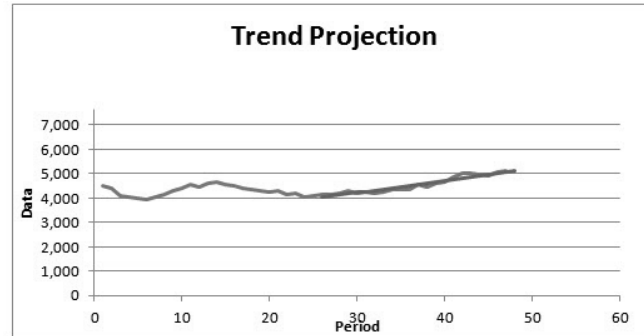
a (Y intercept) 4045.742
 b (slope or trend) 15.218
 r^2 0.434

CFE 0.000
 MAD 207.108
 MSE 55485.200
 MAPE 4.65%

Forecast for period 49 4791.423

- c. Starting again, but with regression beginning with period 25, the forecast for December of Year 4 is 5,114 units, as opposed to the 4,729 units forecast when the regression began with period 1. Error terms are also lower, with MAD down from 210 to 91.

Regression begins in period 26 check scrollbar
 Error analysis begins in period 26
 Number of future forecasts 1

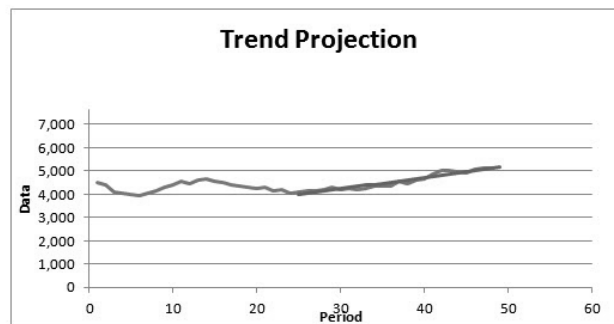


a (Y intercept) 2746.765
b (slope or trend) 49.319
 r^2 0.900
 CFE 0.000
 MAD 90.669
 MSE 10860.418
 MAPE 2.02%

Forecast for period 48 5114.078

When the demand for period 48 is input as 5,100 while starting regression with period 25, the forecast is 5,152 and MAD decreases to 88, the lowest value found. The most reasonable forecast for period 49 is 5,152.

Regression begins in period 25 check scrollbar
 Error analysis begins in period 25
 Number of future forecasts 1

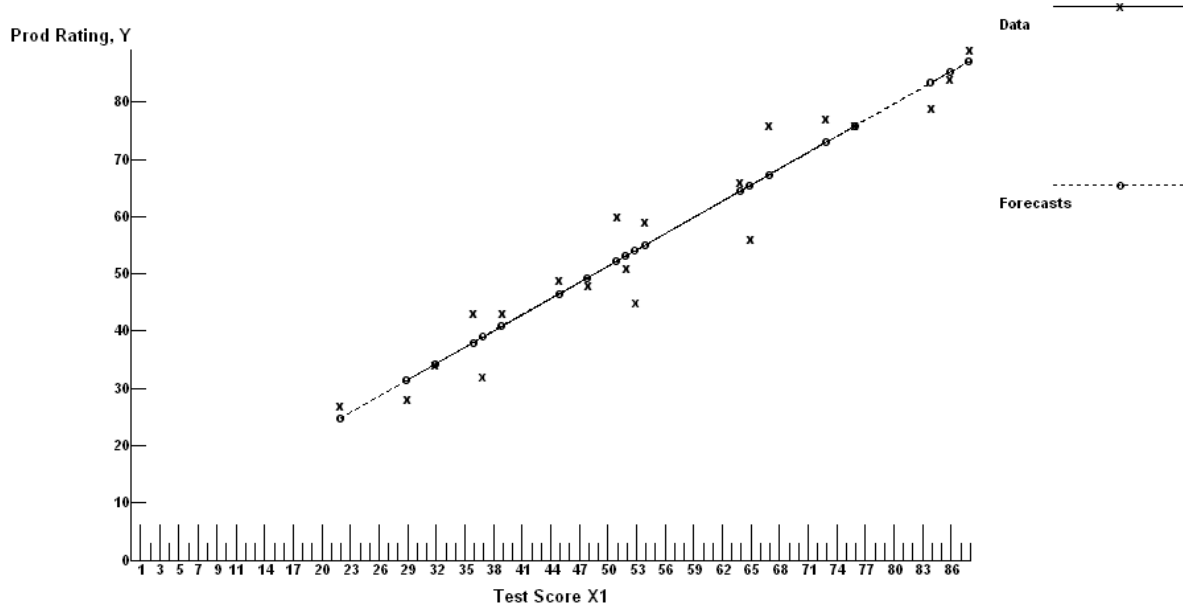


a (Y intercept) 2793.715
b (slope or trend) 48.136
 r^2 0.915
 CFE 0.000
 MAD 88.012
 MSE 10335.340
 MAPE 1.97%

Forecast for period 49 5152.362

27. The results from the *Least Square Linear Regression* module of POM for Windows are:

Measure	Value
Cumulative forecast error	0
Average Forecast Error	0
MAD (Mean Absolute Deviation)	3.899
MSE (Mean Squared Error)	23.649
Standard Error (denom=n-1.0=18)	5.126
MAPE (Mean Absolute Percent	.078
Regression line	
Prod Rating, Y = 4.184	
+ .943 * Test Score X1	
Statistics	
Correlation coefficient	.966
Coefficient of determination (r^2)	.933



- a. From the output, the relationship is

$$\text{Rating} = 4.184 + 0.943 (\text{Score})$$

- b. Score = 80

$$\text{Rating} = 4.184 + 0.943 (80) = 79.624$$

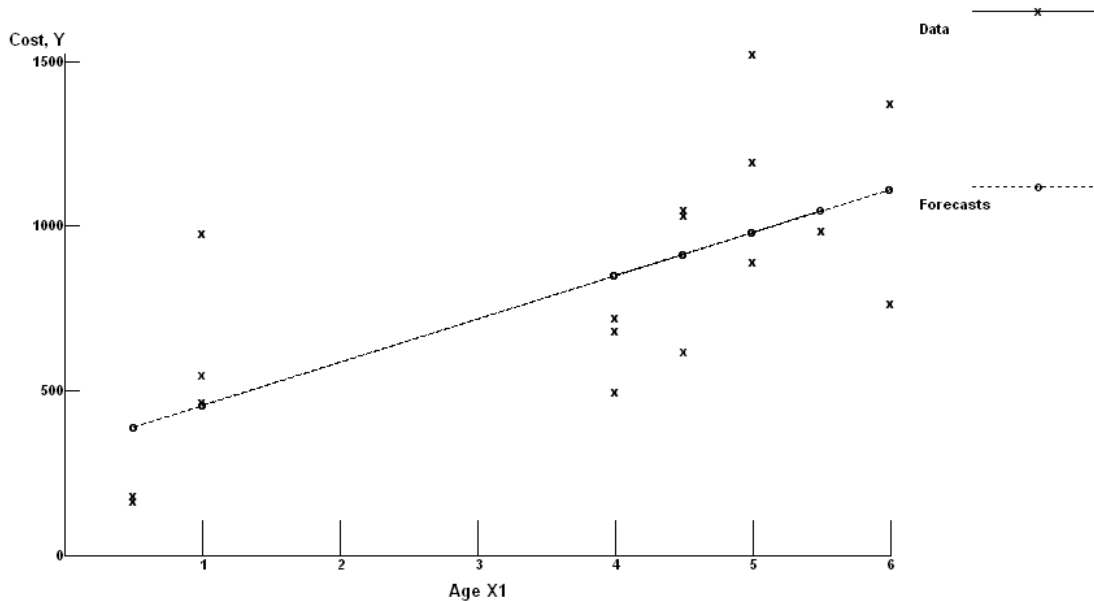
- c. $R = \sqrt{R^2} = \sqrt{0.934} = 0.966$

There is a very strong positive relationship. Increases in scores explain 93% of increases in ratings.

28. Materials handling

The results from the POM for Windows' least squares-linear regression module are:

Measure	Value
Cumulative forecast error	.0001
Average Forecast Error	0
MAD (Mean Absolute Deviation)	221.9953
MSE (Mean Squared Error)	70,906.3
Standard Error (denom=n-1-0=15)	283.4792
MAPE (Mean Absolute Percent	.3803
Regression line	
Cost, Y = 323.6223	
+ 131.7165 * Age X1	
Statistics	
Correlation coefficient	.6907
Coefficient of determination (r ²)	.4771



- From the output shown, the relationship is
Cost = 323.6223 + 131.7165 (Age)
- Annual Cost to maintain a three-year old tractor
 $y = 323.6223 + 131.7165 (3) = \$718.77$
 Annual Cost to maintain a fleet of 20 three-year-old tractors
 $= (20) (\$718.77) = \$14,375.44$

CASE: YANKEE FORK AND HOE COMPANY

A. Synopsis

Yankee Fork and Hoe is a company that produces garden tools for a mature, price-sensitive market in which customers also want on-time delivery. Recently customers have been complaining about late shipments. The president has hired a consultant to look into the problem. The consultant traces the production planning process and its reliance on accurate forecasts. The consultant must make a recommendation to management.

B. Purpose

This case provides the basis for a discussion of the need for accurate forecasts in an industry where low-cost production is critical. It also contains sufficient data to enable the student to generate forecasts for each month of the following year. Specifically, the case can be used to:

1. Discuss the effects of poor forecasts on capacities and schedules.
2. Discuss the choice of the proper data to use for forecasts.
3. Quantitatively analyze forecasting data and provide forecasts for the following year.

C. Analysis

Yankee Fork and Hoe is experiencing two major problems with the current forecasting system. First, the production department is unaware of how marketing arrives at its forecasts. Production views the forecasts as the result of an overinflated estimate of actual customer demand. However, the forecasting technique in use by the marketing department is based on actual *shipments* rather than on actual *demand*. Second, marketing, in its desire to reflect production capacity, is compounding the problems experienced by Yankee Fork and Hoe by trying to rectify past problems. Although marketing adjusts for shortages in the actual shipment data, it is still reflecting past problems and not future demand. If Yankee would move to a system that utilizes past demand to forecast future demand, production would be able to schedule bow rake production more effectively. In addition, production must be aware of how the forecasts are made and what information is being provided so that arbitrary adjustments are no longer needed.

A forecasting system based on actual demands requires careful analysis of Exhibit TN. 1. It is apparent that the bow rake experiences seasonal demand. It is also obvious that there is an upward trend in the annual demand. A forecasting system that recognizes both of these factors is desirable. To arrive at the average monthly demand for year 5, the average increase in the average monthly demands was determined to be 2,589 units. Therefore the average monthly demand for year five is $45,928 + 2,589 = 48,517$. This value is then multiplied by the average seasonal factors (see Exhibit TN.2) to arrive at the forecast shown in Exhibit TN.1. Exhibits TN.3 and TN.4 show graphs of the series.

D. Recommendations

The recommendations to management could include the following:

1. Improve the lines of communication between marketing and production regarding the preparation of forecasts. This will eliminate arbitrary adjustments to the forecasts.
2. Use actual demand data rather than shipment data.
3. Use models that somehow handle seasonality, such as the seasonal forecast method, the weighted moving average (with significant weights placed on time periods lagged by one year), or regression with a trend variable and also dummy variables for the seasons.
4. Consider a combination forecasting approach or possibly focus forecasting, rather than using a single model.

E. Teaching Suggestions: As an Experiential Exercise

This case makes for an excellent team-based experiential exercise, spread over two days. Presumably the basic concepts and techniques of forecasting have already been covered. The exercise might take 45 minutes on the first day and 30 minutes on the second day.

Day 1

Introduce the exercise after the basic concepts and techniques of forecasting have been covered. Students should have read the case beforehand, and each team should bring at least one laptop to class. To get things started, briefly open up and demonstrate three solvers:

1. Regression Analysis (describe how you should use it with one independent variable for the trend, and dummy variables for some of the major seasons)
2. Seasonal Forecasting
3. Time-Series Forecasting (which represents four basic models and countless options in their use)

Have the team members discuss among themselves which forecasting methods might be best, and begin to experiment with some of the models to see how they perform. Have them do their analysis only using data from the first three years, and reserving the fourth year as a holdout sample. They should totally block out that information, as it will provide the “acid test” for their assignment due on the second day. After they get into the project and determine their general approach, give them the assignment for the next day.

Day 2

Between the first day and the second session, each team is to develop combination forecasts for the holdout sample (year 4). They must commit to their combination forecasting procedure (such as which methods to include in the combination and their weights) before they evaluate its results for the holdout sample. They are to prepare a short report on their results.

On the first page of their report, they should describe the approach taken and indicate why they are confident in their forecasts. On the subsequent page(s) they should show a spreadsheet of actual demand, forecasts (from two or more individual methods and then the combination), period-by-period forecast error terms, and summary error measures

(CFE, MAD, MAPE, and MSE). They can manually compute the errors, or develop formulas to make the calculations (perhaps borrowing some of the formulas used in the *Time Series Forecasting Solver*’s “worksheet”). If students use dynamic models, they must “bootstrap” one period at time. If judgment is used as one forecasting technique, the team must control what information the “judgment expert” is given (such as time series model information to date). Actually, a judgment forecasting approach is unlikely to be effective because students have no “contextual knowledge.” It might be convenient to have the teams not only submit hard copy, but also e-mail or post their results to the instructor before class.

If done this way, have the elements in the report combined into one electronic file (such as using the Edit/Paste Special/Picture option to insert spreadsheets and graphs into a Word document).

Based on experience to date, a team typically reports CFE values of plus/minus 20,000 for CFE, 6,000 for MAD, 22% for MAPE, and 85,000,000 for MSE. In all cases to date, the combination forecast did better than any individual forecasting method.

F. Teaching Suggestions: Out-of-Class Exercise

This case should be made an overnight assignment because the students need to develop forecasts for year 5. A computer program can be used to get the forecasts; however, it is not mandatory. The forecasts contained in Exhibit TN.1 were done manually using the multiplicative seasonal method described in the text.

This case is based on an actual company that supplies garden tools to companies such as Sears and Scott's & Sons. The initial discussion should focus on the competitive priorities for Yankee Fork and Hoe (low costs and on-time delivery) and how operations can support these priorities. The need for accurate forecasts in that sort of competitive environment should be emphasized.

The instructor should raise the question, "How would you revise the forecasting system in use at Yankee Fork and Hoe?" This discussion will lead to the issue of which data (shipments or actual demands) to use and how the marketing and production departments can coordinate on the development of the forecasts.

Finally, the students can be asked to present their forecasts (perhaps on blank transparencies provided with the assignment). Discuss how each student's forecast was developed and explore the reasons for the differences between the students' forecasts. The forecast provided in Exhibit TN. I can be used as a benchmark.

G. Board Plan

Board 1	
Competitive Priorities	Management Support
Low costs	Efficient internal schedules
On-time delivery	Proper inventory levels
	Good supplier contracts

Board 2	
Current Forecasting System	Proposed Forecasting System
Based on shipments	Based on actual demands
One month's lead on promotions	Several month's lead on promotions
Marketing passed to production	Coordinated between marketing and production
Second-guessing marketing	Take the forecasts as given

EXHIBIT TN.1

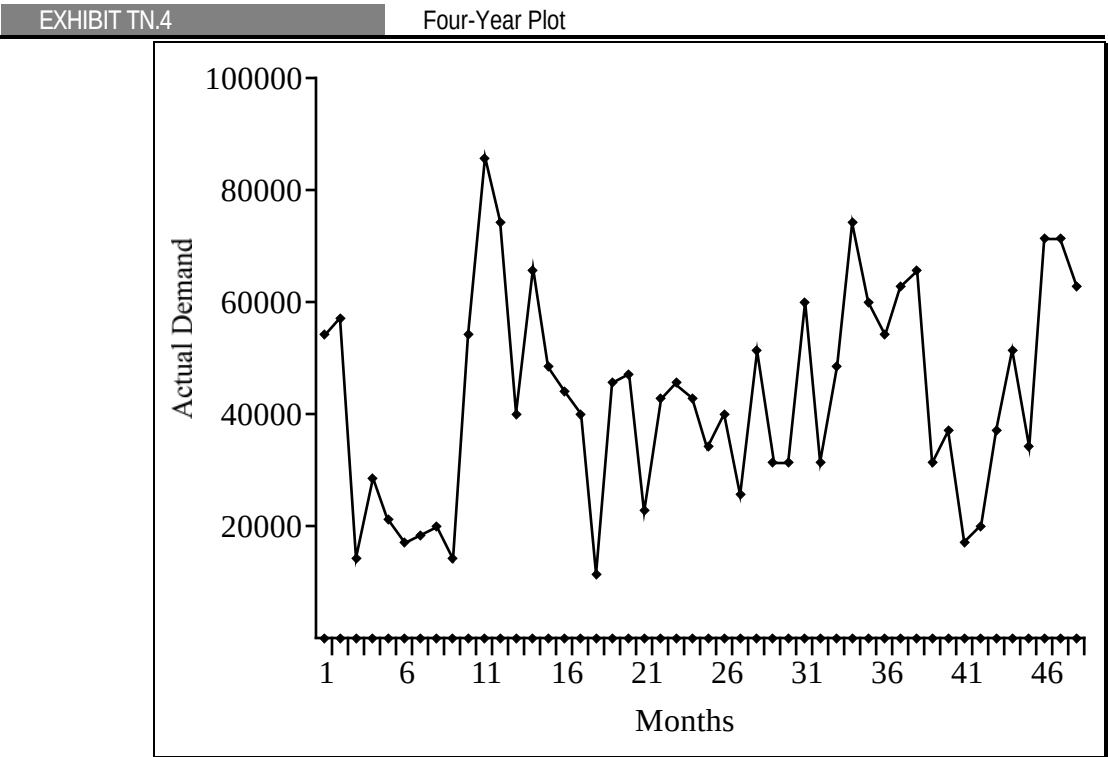
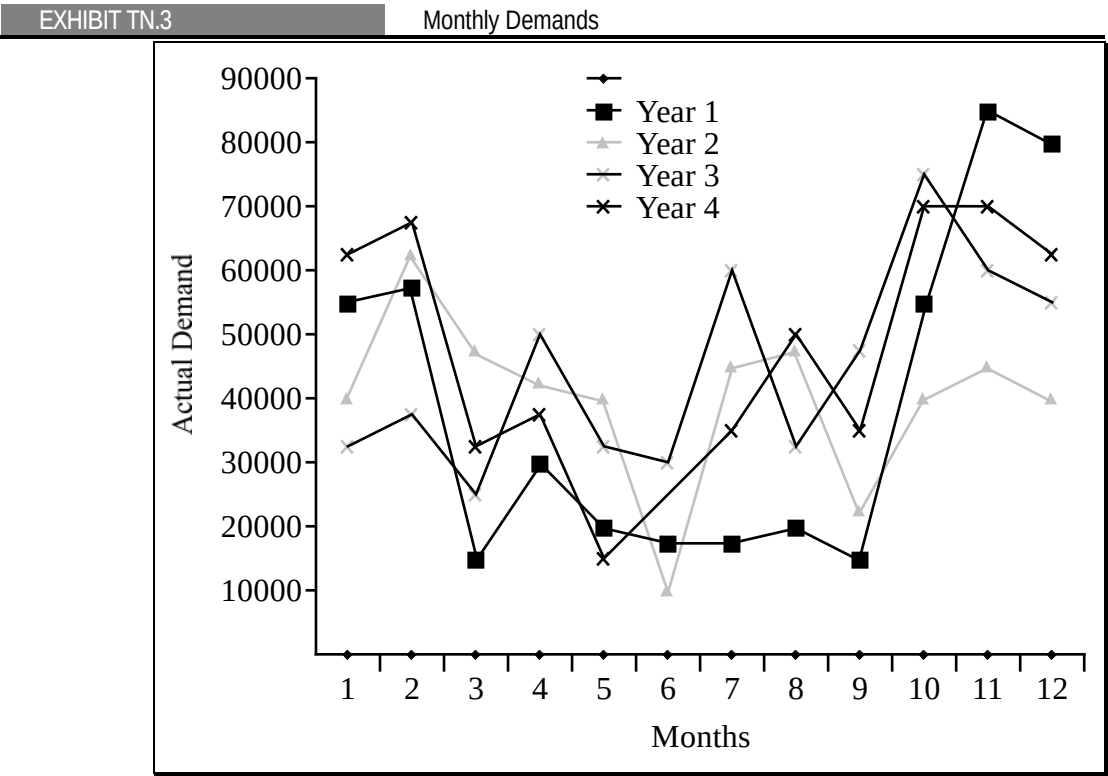
Actual Bow Rake Demands and Forecast

Actual Demands					
Month	Year 1	Year 2	Year 3	Year 4	Forecast
1	55,220	39,875	32,180	62,377	70,203
2	57,350	64,128	38,600	66,501	72,911
3	15,445	47,653	25,020	31,404	19,636
4	27,776	43,050	51,300	36,504	35,312
5	21,408	39,359	31,790	16,888	27,217
6	17,118	10,317	32,100	18,909	21,763
7	18,028	45,194	59,832	35,500	22,920
8	19,883	46,530	30,740	51,250	25,278
9	15,796	22,105	47,800	34,443	20,082
10	53,665	41,350	73,890	68,088	68,226
11	83,269	46,024	60,202	68,175	105,862
12	72,991	41,856	55,200	61,100	92,796
Averages	38,162	40,620	44,805	45,928	48,517

EXHIBIT TN.2

Seasonal Factors

Month	Year 1	Year 2	Year 3	Year 4	Average
1	1.447	0.982	0.718	1.358	1.126
2	1.503	1.579	0.862	1.448	1.348
3	0.405	1.173	0.558	0.684	0.705
4	0.728	1.060	1.145	0.795	0.932
5	0.561	0.969	0.710	0.368	0.652
6	0.449	0.254	0.694	0.412	0.452
7	0.472	1.113	1.335	0.773	0.923
8	0.521	1.145	0.686	1.116	0.867
9	0.414	0.544	1.067	0.750	0.694
10	1.406	1.018	1.649	1.482	1.389
11	2.182	1.133	1.344	1.484	1.536
12	1.913	1.030	1.232	1.330	1.376

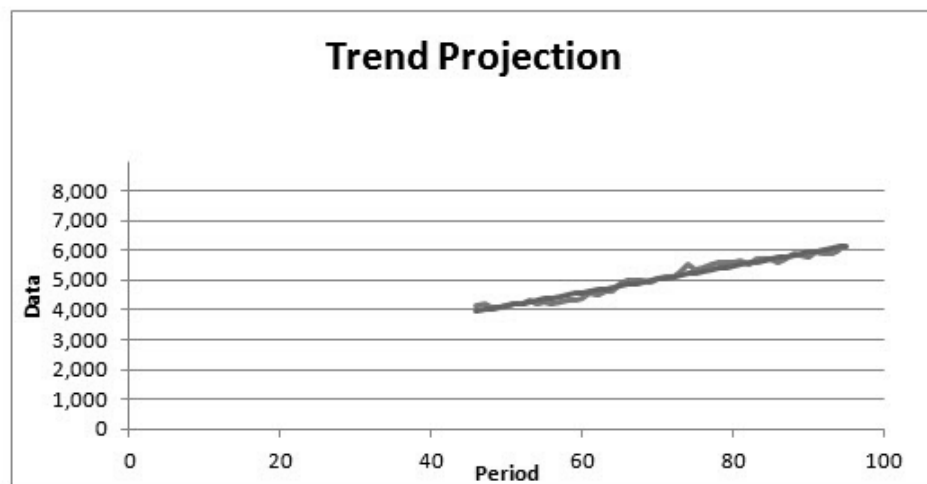


EXPERIENTIAL LEARNING EXERCISE ONE

Forecasting with Holdout Sample

The history file suggests that sales are quite forecastable. The most important demand pattern is the trend, although there is some hint of cycles (Period 1-46 vs. 46-95). The following graph from the *Trend Projection with Regression Solver* of OM Explorer shows that there is a steady upward trend in the last half of the series. Including periods before that time results in worse error measures. While some students may do their analysis for the whole time series, we chose to limit it to the second half of the time series beginning with period 46.

Regression begins in period 46
 Error analysis begins in period 46
 Number of future forecasts 1



a (Y intercept) 1894.491
b (slope or trend) 44.726
 r^2 0.959

CFE 0.000
 MAD 107.315
 MSE 16985.637
 MAPE 2.16%

Forecast for period 95 6143.482

There is no contextual knowledge about this product, and so judgmental forecasts should not be given much importance, unless the forecasters believe another down cycle is beginning or believe one model has been performing particularly well in recent months.

1. Results on History File

After searching through the various models in the *Time Series Forecasting Solver*, four models (including the combination model) are of interest when the error analysis begins in period 46. No moving average model is better than the naïve model, so they are not included.

Model	CFE	MAD	Forecast for November, Year 9
Naïve (Moving Average with $n = 1$)	1,707	90	5987
Weighted Moving Average (0.4, 0.3)	2,361	89	5957
Exponential Smoothing ($\alpha = 0.9$)	1,888	87	5979
Trend Projection with Regression	0	107	6143
Combination	1,177	74	6043

The detailed analysis behind these statistics is as follows:

1 -Period Moving Average	2 -Period Weighted Moving Average Enter weights Most recent 0.60 2nd most recent 0.40	Exponential Smoothing $\alpha = 0.90$ Initial Forecast 3,255 Note: The default for the Initial forecast is set to the initial period's actual demand but can be changed above.	Trend Projection Intercept 1894.49 Slope/Trend 44.73 Correlation 0.98 r^2 0.96

Error analysis begins in period				46				Regression begins in period				46							
Combination Weight -->				0.15				0.15				0.30				0.40			
Actual Data		1-Period Moving Average		2-Period Weighted Moving Average		Exponential Smoothing		Trend Projection		Combination Forecast		Forecast		Error		CFE			
Period	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	Forecast	Error	CFE	
46	4,144	4,280	-136.00	-136.00	4,278	-134.40	-134.40	4,280	-136.00	-136.00	3,952	192.10	192.10	4148.52	-4.52	-4.52			
47	4,219	4,144	75.00	-61.00	4,198	20.60	-113.80	4,158	61.40	-74.60	3,997	222.38	414.48	4097.29	121.71	117.19			
48	4,052	4,219	-167.00	-228.00	4,189	-137.00	-250.80	4,213	-160.86	-235.46	4,041	10.65	425.13	4116.00	-89.60	27.59			
49	4,084	4,052	32.00	-196.00	4,119	-34.80	-285.60	4,068	15.91	-219.55	4,086	-2.08	423.05	4080.48	3.52	31.12			
50	4,158	4,084	74.00	-122.00	4,071	86.80	-198.80	4,082	75.59	-143.96	4,131	27.20	450.25	4100.32	57.68	88.79			
51	4,174	4,158	16.00	-106.00	4,128	45.60	-153.20	4,150	23.56	-120.40	4,176	-1.53	448.72	4158.30	15.70	104.49			
52	4,225	4,174	51.00	-55.00	4,168	57.40	-95.80	4,172	53.36	-67.04	4,220	4.75	453.47	4190.84	34.16	138.66			
53	4,324	4,225	99.00	44.00	4,205	119.40	23.60	4,220	104.34	37.30	4,265	59.02	512.49	4236.33	87.67	226.32			
54	4,220	4,324	-104.00	-60.00	4,284	-64.40	-40.80	4,314	-93.57	-56.27	4,310	-89.71	422.78	4309.21	-89.21	137.11			
55	4,267	4,220	47.00	-13.00	4,262	5.40	-35.40	4,229	37.64	-18.63	4,354	-87.43	335.35	4282.82	-15.82	121.29			
56	4,187	4,267	-80.00	-93.00	4,248	-61.20	-96.60	4,263	-76.24	-34.86	4,399	-212.16	123.19	4315.91	-128.91	-7.62			
57	4,239	4,187	52.00	-41.00	4,219	20.00	-76.60	4,195	44.38	-50.49	4,444	-204.89	-81.70	4296.84	-57.84	-65.46			
58	4,352	4,239	113.00	72.00	4,218	133.80	57.20	4,235	117.44	66.95	4,489	-136.61	-218.31	4334.39	17.61	-47.86			
59	4,331	4,352	-21.00	51.00	4,307	24.20	81.40	4,340	-9.26	57.69	4,533	-202.34	-420.65	4414.23	-83.23	-131.09			
60	4,371	4,331	40.00	91.00	4,339	31.60	113.00	4,332	39.07	96.77	4,578	-207.06	-627.71	4431.36	-60.36	-191.45			
61	4,535	4,371	164.00	255.00	4,355	180.00	293.00	4,367	167.91	264.68	4,623	-87.79	-715.50	4468.14	66.86	-124.60			
62	4,477	4,535	-58.00	197.00	4,469	7.60	300.60	4,518	-41.21	223.47	4,668	-190.52	-906.02	4573.13	-96.13	-220.73			
63	4,601	4,477	124.00	321.00	4,500	100.80	401.40	4,481	119.88	343.35	4,712	-111.24	-1,017	4575.81	25.19	-195.54			
64	4,648	4,601	47.00	368.00	4,551	96.60	498.00	4,589	58.99	402.33	4,757	-108.97	-1,126	4652.35	-4.35	-199.89			
65	4,860	4,648	212.00	580.00	4,629	230.80	728.00	4,642	217.90	620.23	4,802	58.30	-1,068	4704.89	165.11	-44.78			
66	4,998	4,860	138.00	718.00	4,775	222.80	951.60	4,838	159.79	780.02	4,846	151.58	-916.35	4835.31	162.69	117.91			
67	5,003	4,998	5.00	723.00	4,943	60.20	1,012	4,982	20.98	801.00	4,891	111.85	-804.50	4942.19	60.81	178.72			
68	4,960	5,003	-43.00	680.00	5,001	-41.00	970.80	5,001	-40.90	760.10	4,936	24.13	-780.37	4975.22	-15.22	163.50			
69	4,943	4,960	-17.00	663.00	4,977	-34.20	936.60	4,964	-21.09	739.01	4,981	-37.60	-817.97	4972.05	-29.05	134.45			
70	5,052	4,943	109.00	772.00	4,950	102.20	1,039	4,945	106.89	845.90	5,025	26.67	-791.30	4977.58	74.42	208.87			
71	5,107	5,052	55.00	827.00	5,008	98.60	1,137	5,041	65.69	911.59	5,070	36.95	-754.35	5049.47	57.53	266.40			
72	5,100	5,107	-7.00	820.00	5,085	15.00	1,152	5,100	-0.43	911.16	5,115	-14.78	-769.13	5104.84	-4.84	261.56			
73	5,303	5,100	203.00	1,023	5,103	200.20	1,353	5,100	202.96	1,114	5,160	143.49	-625.63	5124.24	178.76	440.32			
74	5,550	5,303	247.00	1,270	5,222	328.20	1,681	5,283	267.30	1,381	5,204	345.77	-279.86	5245.22	304.78	745.10			
75	5,348	5,550	-202.00	1,068	5,451	-103.20	1,578	5,523	-175.27	1,206	5,249	99.04	-180.82	5406.74	-58.74	686.35			
76	5,391	5,348	43.00	1,111	5,429	-37.80	1,540	5,366	25.47	1,232	5,294	97.32	-83.51	5343.65	47.35	733.70			
77	5,519	5,391	128.00	1,239	5,374	145.20	1,685	5,388	130.55	1,362	5,338	180.59	97.08	5366.62	152.38	886.08			
78	5,602	5,519	83.00	1,322	5,468	134.20	1,819	5,506	96.05	1,458	5,383	218.86	315.95	5453.06	148.94	1,035			
79	5,557	5,602	-45.00	1,277	5,569	-11.80	1,807	5,592	-35.39	1,423	5,428	129.14	445.09	5524.48	32.52	1,068			
80	5,608	5,557	51.00	1,328	5,575	33.00	1,840	5,561	47.46	1,470	5,473	135.41	580.50	5527.00	81.00	1,149			
81	5,663	5,608	55.00	1,383	5,588	75.40	1,916	5,603	59.75	1,530	5,517	145.68	726.18	5567.24	95.76	1,244			
82	5,497	5,663	-166.00	1,217	5,641	-144.00	1,772	5,657	-160.03	1,370	5,562	-65.04	661.14	5617.52	-120.52	1,124			
83	5,719	5,497	222.00	1,439	5,563	155.60	1,927	5,513	206.00	1,576	5,607	112.23	773.37	5555.67	163.33	1,287			
84	5,679	5,719	-40.00	1,399	5,630	48.80	1,976	5,698	-19.40	1,557	5,651	27.51	800.88	5672.50	6.50	1,294			
85	5,688	5,679	9.00	1,408	5,695	-7.00	1,969	5,681	7.06	1,564	5,696	-8.22	792.66	5688.87	-0.87	1,293			
86	5,604	5,688	-84.00	1,324	5,684	-80.40	1,889	5,687	-83.29	1,480	5,741	-136.95	655.71	5708.43	-104.43	1,188			
87	5,703	5,604	99.00	1,423	5,638	65.40	1,954	5,612	90.67	1,571	5,786	-82.67	573.04	5684.21	18.79	1,207			
88	5,899	5,703	196.00	1,619	5,663	235.60	2,190	5,694	205.07	1,776	5,830	68.60	641.64	5745.30	153.70	1,361			
89	5,816	5,899	-83.00	1,536	5,821	-4.60	2,185	5,878	-62.49	1,714	5,875	-59.12	582.52	5871.54	-55.54	1,305			
90	5,745	5,816	-71.00	1,465	5,849	-104.20	2,081	5,822	-77.25	1,636	5,920	-174.85	407.67	5864.40	-119.40	1,186			
91	5,821	5,745	76.00	1,641	5,773	147.60	2,229	5,753	168.28	1,805	5,965	-43.58	364.09	5839.41	81.59	1,267			
92	5,900	5,821	-79.00	1,620	5,851	49.40	2,278	5,904	-4.17	1,800	6,009	-109.30	254.79	5940.71	-40.71	1,227			
93	5,911	5,900	11.00	1,631	5,908	2.60	2,281	5,900	10.58	1,811	6,054	-143.03	111.76	5963.00	-52.00	1,175			
94	5,987	5,911	76.00	1,707	5,907	80.40	2,361	5,910	77.06	1,888	6,099	-111.76	0.00	5985.12	1.88	1,177			

The Trend Projection with Regression model has the best fit with the past data in terms of CFE, with the Combination forecast coming in second best. The Combination forecast is best when MAD is the error term. The real test, however, is how well the models predict future demand. We assess that with the 6 periods in the holdout sample. Our forecasts will be based on the Combination forecast, although students may make other forecasts, including those with judgmental adjustments.

Results on Holdout Sample

In class, the computer shows the forecasts for each of the models one month at a time. At this point, the students must make their forecast. Once their forecasts are entered, the instructor announces the actual demand. The actual demands for the holdout sample are:

Month and Year	Actual Demand
Nov, 8	6074
Dec, 8	6045
Jan, 9	6488
Feb, 9	6235
Mar, 9	6440
Apr, 9	6508

Next the computer calculates the forecast errors for each model and for their forecast. It also makes forecasts for each model for the next period, at which time the students must make their forecast for the second period in the holdout sample. The process continues on until the last period in the holdout sample is reached, which is period 100 (April, Year 9).

Shown below are the screens of the Holdout Sample spreadsheet for Periods 95 and 96 (November and December of Year 8). Following it is a table which summarizes the forecasts and errors for all 6 months in the holdout sample.

Screen at Start of Period 95

Combination weights		15.00%		15.00%		30.00%		40.00%					
Actual Data		1-Period Moving Average		2-Period Weighted Moving Average		Exponential Smoothing		Trend Projection		Combination Forecast		Holdout Sample Forecast	
Period		Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error
1	95	5987		5956.60		5979.29		6143.48		6042.72			

Screen at End of Period 95

Combination weights													
		15.00%		15.00%		30.00%		40.00%					
Actual Data		1-Period Moving Average		2-Period Weighted Moving Average		Exponential Smoothing		Trend Projection		Combination Forecast		Holdout Sample Forecast	
Period		Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error
1	95 6074	5987	87.00	5956.60	117.40	5979.29	94.71	6143.48	-69.48	6042.72	31.28	6043.00	31.00
2	96 6074			6039.20		6064.53		6188.21		6111.62			

Screen at End of Period 96

Combination weights													
		15.00%		15.00%		30.00%		40.00%					
Actual Data		1-Period Moving Average		2-Period Weighted Moving Average		Exponential Smoothing		Trend Projection		Combination Forecast		Holdout Sample Forecast	
Period		Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error
1	95 6074	5987	87.00	5956.60	117.40	5979.29	94.71	6143.48	-69.48	6042.72	31.28	6043.00	31.00
2	96 6045	6074	-29.00	6039.20	5.80	6064.53	-19.53	6188.21	-143.21	6111.62	-66.62	6112.00	-67.00
3	97	6045		6056.60		6046.95		6232.93		6122.50			

Screen at End of Period 100

Combination weights													
		15.00%		15.00%		30.00%		40.00%					
Actual Data		1-Period Moving Average		2-Period Weighted Moving Average		Exponential Smoothing		Trend Projection		Combination Forecast		Holdout Sample Forecast	
Period		Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error	Forecast	Error
1	95 6074	5987	87.00	5956.60	117.40	5979.29	94.71	6143.48	-69.48	6042.72	31.28	6043.00	31.00
2	96 6045	6074	-29.00	6039.20	5.80	6064.53	-19.53	6188.21	-143.21	6111.62	-66.62	6112.00	-67.00
3	97 6488	6045	443.00	6056.60	431.40	6046.95	441.05	6232.93	255.07	6122.50	365.50	6122.00	366.00
4	98 6235	6488	-253.00	6310.80	-75.80	6443.90	-208.90	6277.66	-42.66	6364.05	-129.05	6364.00	-129.00
5	99 6440	6235	205.00	6336.20	103.80	6255.89	184.11	6322.39	117.61	6291.40	148.60	6291.00	149.00
6	100 6508	6440	68.00	6358.00	150.00	6421.59	86.41	6367.11	140.89	6393.02	114.98	6393.00	115.00

The following Excel table records the actual demands and forecast for all 6 months in the holdout sample.

Month and Year	Actual Demand	Naïve			Weighted Moving Average			Exp Smooth ($\alpha = 0.90$)			Trend Projection			Combination		
		Forecast	Error	Absolute	Forecast	Error	Absolute	Forecast	Error	Absolute	Forecast	Error	Absolute	Forecast	Error	Absolute
Nov, 8	6074	5987	87.00	87.00	5,957	117.00	117.00	5979	95	95.00	6143	-69.00	69.00	6043	31.00	31.00
Dec, 8	6045	6074	-29.00	29.00	6,039	6.00	6.00	6065	-20.00	20.00	6183	-138.00	138.00	6112	-67.00	67.00
Jan, 9	6488	6045	443.00	443.00	6,057	431.00	431.00	6047	441.00	441.00	6216	272.00	272.00	6122	366.00	366.00
Feb, 9	6235	6488	-253.00	253.00	6,311	(76.00)	76.00	6444	-209.00	209.00	6282	-47.00	47.00	6364	-129.00	129.00
Mar, 9	6440	6235	205.00	205.00	6,336	104.00	104.00	6256	184.00	184.00	6323	117.00	117.00	6291	149.00	149.00
Apr, 9	6508	6440	68.00	68.00	6,358	150.00	150.00	6422	86.00	86.00	6376	132.00	132.00	6393	115.00	115.00
		CFE = 521.00			CFE = 732.00			CFE = 577.00			CFE = 267.00			CFE = 465.00		
		MAD = 180.83			MAD = 147.33			MAD = 172.50			MAD = 129.17			MAD = 142.83		

The results may surprise some students, because the Combination forecast had the lowest MAD for the history file, but was outperformed by Trend Projection with Regression in the Holdout sample. The Trend Projection with Regression had both the lowest CFE and MAD error terms with the holdout sample. The Combination Forecast comes in the next best, with the Exponential smoothing and Naïve models not doing as well. In retrospect, the data has a strong trend, which explains why the naïve model performs better than any moving average model, and the best exponential model has such a high α value.

Comparing Results of History File vs. Holdout File

The following table addresses the real reason for doing a holdout sample. We want to see if the error measures found for the history file give an overly optimistic picture of how well the forecasting techniques will do on data that was not considered when the models were developed.

Forecasting Technique	CFE		MAD	
	History File	Holdout Sample	History File	Holdout Sample
Naive	1,707	521	90	181
Weighted Moving Average	2,361	732	89	147
Exponential Smoothing	1,888	577	87	172
Trend Progression	0	267	107	129
Combination	1,177	465	74	143

These results show surprisingly that the techniques generally do better on the holdout sample than the history file with respect to CFE. Unfortunately, it is a different story with respect to MAD. MAD errors are roughly **double** those experienced with the history file. Developing models using demand data on which their performance is evaluated may indeed overstate the accuracy of the models in forecasting future demand, as opposed to explaining past demand.

This exercise covers considerable territory. Among other things, it

- gets students familiar with the various forecasting techniques,
- requires them to create their own Excel spreadsheets to evaluate errors across models, and
- cautions them against the possibility of over fitting the history file.

EXPERIENTIAL LEARNING EXERCISE TWO

Forecasting East Coast Crude Oil Imports

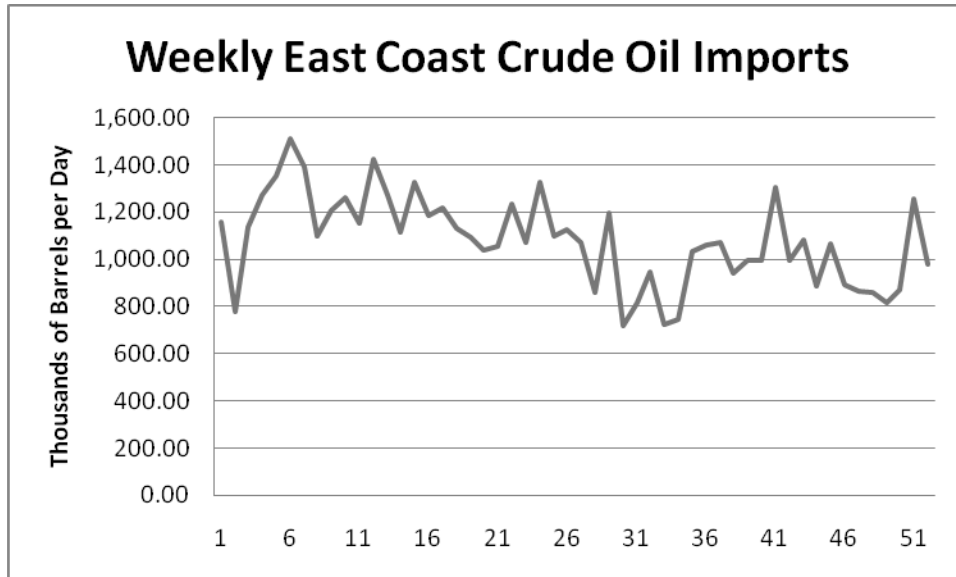
Complete data set including 5-period holdout sample (April 01, 2011 – April 29, 2011)

Quarter 2 2010		Quarter 3 2010		Quarter 4 2010		Quarter 1 2011		Quarter 2 2011	
Time Period	Data	Time Period	Data	Time Period	Data	Time Period	Data	Time Period	Data
Apr 02, 2010	1160	Jul 02, 2010	1116	Oct 01, 2010	1073	Dec 31, 2010	994	Apr 01, 2011	771
Apr 09, 2010	779	Jul 09, 2010	1328	Oct 08, 2010	857	Jan 07, 2011	1307	Apr 08, 2011	709
Apr 16, 2010	1134	Jul 16, 2010	1183	Oct 15, 2010	1197	Jan 14, 2011	997	Apr 15, 2011	562
Apr 23, 2010	1275	Jul 23, 2010	1219	Oct 22, 2010	718	Jan 21, 2011	1082	Apr 22, 2011	1154
Apr 30, 2010	1355	Jul 30, 2010	1132	Oct 29, 2010	817	Jan 28, 2011	887	Apr 29, 2011	998
May 07, 2010	1513	Aug 06, 2010	1094	Nov 05, 2010	946	Feb 04, 2011	1067		
May 14, 2010	1394	Aug 13, 2010	1040	Nov 12, 2010	725	Feb 11, 2011	890		
May 21, 2010	1097	Aug 20, 2010	1053	Nov 19, 2010	748	Feb 18, 2011	865		
May 28, 2010	1206	Aug 27, 2010	1232	Nov 26, 2010	1031	Feb 25, 2011	858		
Jun 04, 2010	1264	Sep 03, 2010	1073	Dec 03, 2010	1061	Mar 04, 2011	814		
Jun 11, 2010	1153	Sep 10, 2010	1329	Dec 10, 2010	1074	Mar 11, 2011	871		
Jun 18, 2010	1424	Sep 17, 2010	1096	Dec 17, 2010	941	Mar 18, 2011	1255		
Jun 25, 2010	1274	Sep 24, 2010	1125	Dec 24, 2010	994	Mar 25, 2011	980		

The Data Set: Weekly East Coast Crude Oil Imports (in Thousand Barrels per Day)
 Source: The US Energy Information Administration
 Excel File Name: psw09.xls
 Available from Web Page: http://www.eia.gov/oil_gas/petroleum/data_publications/weekly_petroleum_status_report/wpsr.html
 Source Web Site: [Energy Information Administration](http://www.eia.gov)
 For Help, Contact: infoctr@eia.gov
 (202) 586-8800

a. Use the Time Series Forecasting Solver of OM Explorer to develop initial forecasts for the history file..

The time series plot shows the week-to-week variation in oil imports. A slight downward trend but no obvious seasonality is evident.



The *Time Series Forecasting* Solver of OM Explorer provides calculation worksheets and results for the each of the models suggested for this exercise.

Naïve Forecast Worksheet

Actual Data		1-Period Moving Average		
Period		Forecast	Error	CFE
1	1,160			
2	779	1,160		
3	1,134	779		
4	1,275	1,134		
5	1,355	1,275	80.00	80.00
6	1,513	1,355	158.00	238.00
7	1,394	1,513	-119.00	119.00
8	1,097	1,394	-297.00	-178.00
9	1,206	1,097	109.00	-69.00
10	1,264	1,206	58.00	-11.00
11	1,153	1,264	-111.00	-122.00
12	1,424	1,153	271.00	149.00
13	1,274	1,424	-150.00	-1.00
14	1,116	1,274	-158.00	-159.00
15	1,328	1,116	212.00	53.00
16	1,183	1,328	-145.00	-92.00
17	1,219	1,183	36.00	-56.00
18	1,132	1,219	-87.00	-143.00
19	1,094	1,132	-38.00	-181.00
20	1,040	1,094	-54.00	-235.00
21	1,053	1,040	13.00	-222.00
22	1,232	1,053	179.00	-43.00
23	1,073	1,232	-159.00	-202.00
24	1,329	1,073	256.00	54.00
25	1,096	1,329	-233.00	-179.00
26	1,125	1,096	29.00	-150.00
27	1,073	1,125	-52.00	-202.00
28	857	1,073	-216.00	-418.00
29	1,197	857	340.00	-78.00
30	718	1,197	-479.00	-557.00
31	817	718	99.00	-458.00
32	946	817	129.00	-329.00
33	725	946	-221.00	-550.00
34	748	725	23.00	-527.00
35	1,031	748	283.00	-244.00
36	1,061	1,031	30.00	-214.00
37	1,074	1,061	13.00	-201.00
38	941	1,074	-133.00	-334.00
39	994	941	53.00	-281.00
40	994	994	0.00	-281.00
41	1,307	994	313.00	32.00
42	997	1,307	-310.00	-278.00
43	1,082	997	85.00	-193.00
44	887	1,082	-195.00	-388.00
45	1,067	887	180.00	-208.00
46	890	1,067	-177.00	-385.00
47	865	890	-25.00	-410.00
48	858	865	-7.00	-417.00
49	814	858	-44.00	-461.00
50	871	814	57.00	-404.00
51	1,255	871	384.00	-20.00
52	980	1,255	-275.00	-295.00

To minimize MAPE, a three-point moving average is a good choice. Additionally, a three-point WMA with weights of .4,.3,.3 works well. It should be noted that in this case, the best weights for the WMA procedure are close to being equivalent. Thus, the WMA procedure provides results almost identical to the simpler moving average procedure.

Moving Average (3-point) and Weighted Moving Average (3-point weights = .4, .3, .3) Forecast Worksheets

Actual Data		3-Period Moving Average			3-Period Weighted Moving Average		
Period	Data	Forecast	Error	CFE	Forecast	Error	CFE
1	1,160						
2	779						
3	1,134						
4	1,275	1,024	250.67	250.67	1,035	239.70	239.70
5	1,355	1,063	292.33	543.00	1,084	271.10	510.80
6	1,513	1,255	258.33	801.33	1,265	248.30	759.10
7	1,394	1,381	13.00	814.33	1,394	-0.20	758.90
8	1,097	1,421	-323.67	490.67	1,418	-321.00	437.90
9	1,206	1,335	-128.67	362.00	1,311	-104.90	333.00
10	1,264	1,232	31.67	393.67	1,230	34.30	367.30
11	1,153	1,189	-36.00	357.67	1,197	-43.50	323.80
12	1,424	1,208	216.33	574.00	1,202	221.80	545.60
13	1,274	1,280	-6.33	567.67	1,295	-20.70	524.90
14	1,116	1,284	-167.67	400.00	1,283	-166.70	358.20
15	1,328	1,271	56.67	456.67	1,256	72.20	430.40
16	1,183	1,239	-56.33	400.33	1,248	-65.20	365.20
17	1,219	1,209	10.00	410.33	1,206	12.60	377.80
18	1,132	1,243	-111.33	299.00	1,241	-108.90	268.90
19	1,094	1,178	-84.00	215.00	1,173	-79.40	189.50
20	1,040	1,148	-108.33	106.67	1,143	-102.90	86.60
21	1,053	1,089	-35.67	71.00	1,084	-30.80	55.80
22	1,232	1,062	169.67	240.67	1,061	170.60	226.40
23	1,073	1,108	-35.33	205.33	1,121	-47.70	178.70
24	1,329	1,119	209.67	415.00	1,115	214.30	393.00
25	1,096	1,211	-115.33	299.67	1,223	-127.10	265.90
26	1,125	1,166	-41.00	258.67	1,159	-34.00	231.90
27	1,073	1,183	-110.33	148.33	1,178	-104.50	127.40
28	857	1,098	-241.00	-92.67	1,096	-238.50	-111.10
29	1,197	1,018	178.67	86.00	1,002	194.80	83.70
30	718	1,042	-324.33	-238.33	1,058	-339.80	-256.10
31	817	924.00	-107.00	-345.33	903.40	-86.40	-342.50
32	946	910.67	35.33	-310.00	901.30	44.70	-297.80
33	725	827.00	-102.00	-412.00	838.90	-113.90	-411.70
34	748	829.33	-81.33	-493.33	818.90	-70.90	-482.60
35	1,031	806.33	224.67	-268.67	800.50	230.50	-252.10
36	1,061	834.67	226.33	-42.33	854.30	206.70	-45.40
37	1,074	946.67	127.33	85.00	958.10	115.90	70.50
38	941	1,055	-114.33	-29.33	1,057	-116.20	-45.70
39	994	1,025	-31.33	-60.67	1,017	-22.90	-68.60
40	994	1,003	-9.00	-69.67	1,002	-8.10	-76.70
41	1,307	976.33	330.67	261.00	978.10	328.90	252.20
42	997	1,098	-101.33	159.67	1,119	-122.20	130.00
43	1,082	1,099	-17.33	142.33	1,089	-7.10	122.90
44	887	1,129	-241.67	-99.33	1,124	-237.00	-114.10
45	1,067	988.67	78.33	-21.00	978.50	88.50	-25.60

46	890	1,012	-122.00	-143.00	1,018	-127.50	-153.10
47	865	948.00	-83.00	-226.00	942.20	-77.20	-230.30
48	858	940.67	-82.67	-308.67	933.10	-75.10	-305.40
49	814	871.00	-57.00	-365.67	869.70	-55.70	-361.10
50	871	845.67	25.33	-340.33	842.50	28.50	-332.60
51	1,255	847.67	407.33	67.00	850.00	405.00	72.40
52	980	980.00	0.00	67.00	1,008	-27.50	44.90

Since the data appear to be moving in a downward direction, students may expect that Trend Projection with Regression should provide some good results.

Trend Projection with Regression Forecast Worksheet

Actual Data		Trend Projection		
Period		Forecast	Error	CFE
1	1,160	1,250	-90.45	-90.45
2	779	1,244	-464.72	-555.16
3	1,134	1,237	-102.98	-658.15
4	1,275	1,230	44.75	-613.40
5	1,355	1,224	131.48	-481.92
6	1,513	1,217	296.21	-185.71
7	1,394	1,210	183.94	-1.76
8	1,097	1,203	-106.33	-108.09
9	1,206	1,197	9.41	-98.68
10	1,264	1,190	74.14	-24.54
11	1,153	1,183	-30.13	-54.67
12	1,424	1,176	247.60	192.93
13	1,274	1,170	104.33	297.26
14	1,116	1,163	-46.93	250.33
15	1,328	1,156	171.80	422.12
16	1,183	1,149	33.53	455.65
17	1,219	1,143	76.26	531.91
18	1,132	1,136	-4.01	527.90
19	1,094	1,129	-35.28	492.63
20	1,040	1,123	-82.54	410.08
21	1,053	1,116	-62.81	347.27
22	1,232	1,109	122.92	470.19
23	1,073	1,102	-29.35	440.84
24	1,329	1,096	233.38	674.22
25	1,096	1,089	7.11	681.34
26	1,125	1,082	42.85	724.18
27	1,073	1,075	-2.42	721.76
28	857	1,069	-211.69	510.07
29	1,197	1,062	135.04	645.11
30	718	1,055	-337.23	307.88
31	817	1,048	-231.50	76.39
32	946	1,042	-95.76	-19.38
33	725	1,035	-310.03	-329.41
34	748	1,028	-280.30	-609.71
35	1,031	1,022	9.43	-600.28
36	1,061	1,015	46.16	-554.12
37	1,074	1,008	65.89	-488.22
38	941	1,001	-60.37	-548.60
39	994	994.64	-0.64	-549.24
40	994	987.91	6.09	-543.15
41	1,307	981.18	325.82	-217.33
42	997	974.45	22.55	-194.77
43	1,082	967.72	114.28	-80.49
44	887	960.98	-73.98	-154.47
45	1,067	954.25	112.75	-41.72
46	890	947.52	-57.52	-99.24
47	865	940.79	-75.79	-175.03
48	858	934.06	-76.06	-251.09
49	814	927.33	-113.33	-364.42
50	871	920.59	-49.59	-414.01
51	1,255	913.86	341.14	-72.87
52	980	907.13	72.87	0.00

Results screen for each method used indicate that:
 Naïve forecasting method has the highest MAD, MSE and MAPE.
 MA and WMA perform similarly in terms of MAPE

Method 1 - Moving Average (Naïve):

1 -Period Moving Average	
Forecast for Period 53	980.00
CFE	-295.00
MAD	147.40
MSE	34,238
MAPE	14.02%

Method 2 - Moving Average:

3 -Period Moving Average	
Forecast for Period 53	1,035
CFE	-183.67
MAD	124.31
MSE	25,643
MAPE	11.72%

Method 3 - Weighted Moving Average:

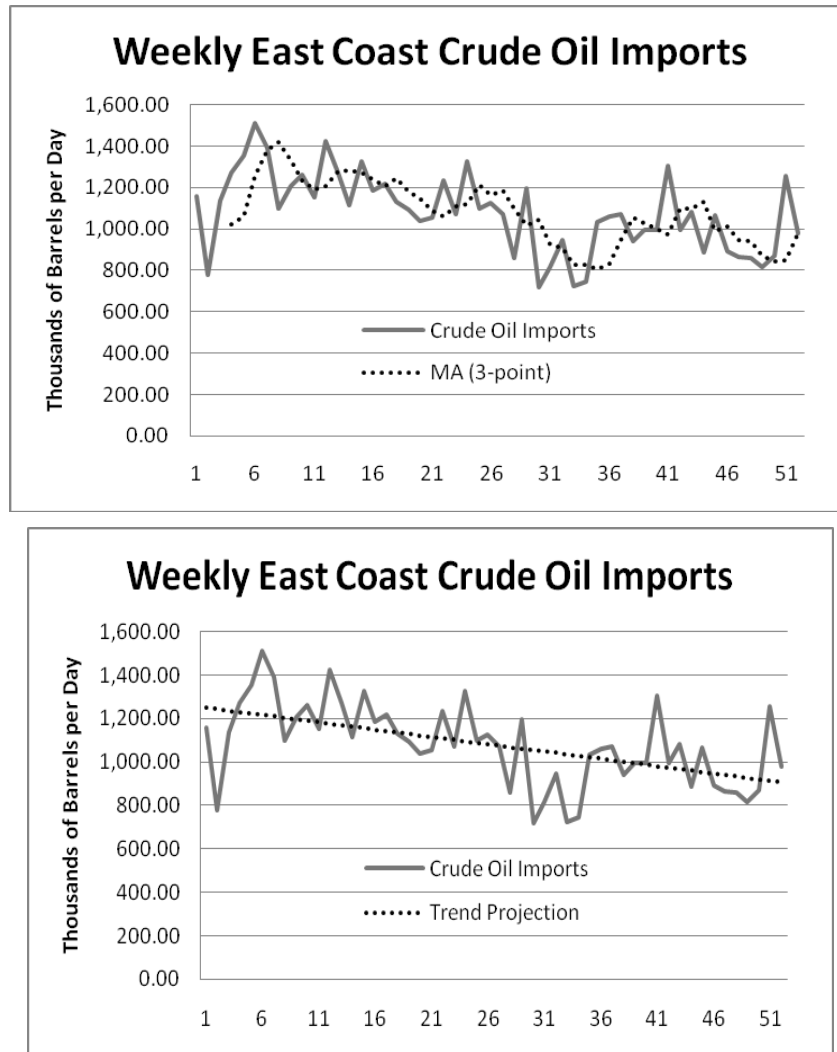
3 -Period Weighted Moving Average	
Forecast for Period 53	1,030
CFE	-194.80
MAD	124.42
MSE	25,404
MAPE	11.75%

Method 4 – Trend Projection (using all of the data)

Intercept	1257
Slope	-6.73
r^2	0.28
Forecast for Period 53	900.40
Forecast for Period 54	893.67
Forecast for Period 55	886.93
Forecast for Period 56	880.20
Forecast for Period 57	873.47
Forecast for Period 58	866.74
CFE	613.40
MAD	111.68
MSE	22,210
MAPE	10.85%

Moving Average and Weighted Moving Average provide very similar results. Trend Projection using Regression provide better results.

It is interesting to note, as seen in the following plots, that the MA and Trend models provide somewhat similar results by forecasting in different ways. The MA and WMA methods attempt to project the past forward while dampen random variation. The Trend Projection method attempts to isolate and project a linear rise or fall in the data series.

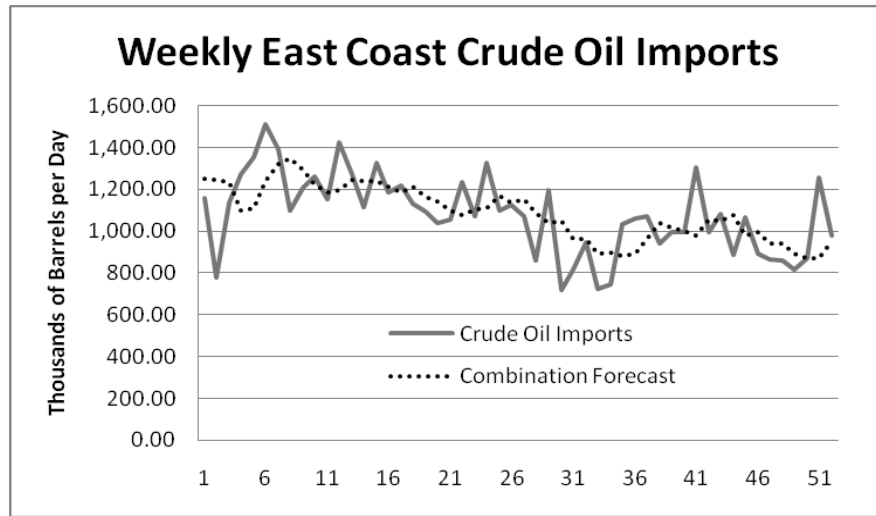


b. Since the performance of the Moving Average, Weighted Moving Average and Trend Projection methods are similar, one may decide to weigh these three methods equally to develop a combination forecast. The logic would be to improve the overall forecast by combining the benefits of each technique. An example Excel spreadsheet follows. Note that the calculation of CFE, MAD, MSE and MAPE are included.

Combination Forecast (MA,WMA, and Trend equally weighted)

Week (t)	Crude Oil Imports	Forecast	Error	Absolute Error	Squared Error	Absolute Percent Error
1	1,160.00	1,250.45	-90.45	90.45	8,180.66	7.80
2	779.00	1,243.72	-464.72	464.72	215,960.30	59.66
3	1,134.00	1,236.98	-102.98	102.98	10,605.62	9.08
4	1,275.00	1,096.63	178.37	178.37	31,816.43	13.99
5	1,355.00	1,123.36	231.64	231.64	53,656.04	17.10
6	1,513.00	1,245.39	267.61	267.61	71,617.77	17.69
7	1,394.00	1,328.42	65.58	65.58	4,300.88	4.70
8	1,097.00	1,347.33	-250.33	250.33	62,665.39	22.82
9	1,206.00	1,280.72	-74.72	74.72	5,583.08	6.20
10	1,264.00	1,217.30	46.70	46.70	2,181.05	3.69
11	1,153.00	1,189.54	-36.54	36.54	1,335.41	3.17
12	1,424.00	1,195.42	228.58	228.58	52,248.07	16.05
13	1,274.00	1,248.23	25.77	25.77	663.92	2.02
14	1,116.00	1,243.10	-127.10	127.10	16,154.53	11.39
15	1,328.00	1,227.78	100.22	100.22	10,044.29	7.55
16	1,183.00	1,212.33	-29.33	29.33	860.54	2.48
17	1,219.00	1,186.05	32.95	32.95	1,085.93	2.70
18	1,132.00	1,206.75	-74.75	74.75	5,587.13	6.60
19	1,094.00	1,160.23	-66.23	66.23	4,385.81	6.05
20	1,040.00	1,137.93	-97.93	97.93	9,589.49	9.42
21	1,053.00	1,096.09	-43.09	43.09	1,857.02	4.09
22	1,232.00	1,077.60	154.40	154.40	23,837.87	12.53
23	1,073.00	1,110.46	-37.46	37.46	1,403.32	3.49
24	1,329.00	1,109.88	219.12	219.12	48,011.96	16.49
25	1,096.00	1,174.44	-78.44	78.44	6,152.80	7.16
26	1,125.00	1,135.72	-10.72	10.72	114.88	0.95
27	1,073.00	1,145.42	-72.42	72.42	5,244.46	6.75
28	857.00	1,087.40	-230.40	230.40	53,082.76	26.88
29	1,197.00	1,027.50	169.50	169.50	28,731.10	14.16
30	718.00	1,051.79	-333.79	333.79	111,413.72	46.49
31	817.00	958.63	-141.63	141.63	20,059.60	17.34
32	946.00	951.24	-5.24	5.24	27.50	0.55
33	725.00	900.31	-175.31	175.31	30,733.87	24.18
34	748.00	892.18	-144.18	144.18	20,787.29	19.28
35	1,031.00	876.13	154.87	154.87	23,983.45	15.02
36	1,061.00	901.27	159.73	159.73	25,514.32	15.05
37	1,074.00	970.96	103.04	103.04	10,617.78	9.59
38	941.00	1,037.97	-96.97	96.97	9,403.00	10.30
39	994.00	1,012.29	-18.29	18.29	334.59	1.84
40	994.00	997.67	-3.67	3.67	13.47	0.37
41	1,307.00	978.54	328.46	328.46	107,887.72	25.13
42	997.00	1,063.99	-66.99	66.99	4,488.12	6.72
43	1,082.00	1,052.05	29.95	29.95	897.03	2.77
44	887.00	1,071.22	-184.22	184.22	33,935.81	20.77
45	1,067.00	973.81	93.19	93.19	8,685.09	8.73

46	890.00	992.34	-102.34	102.34	10,473.48	11.50
47	865.00	943.66	-78.66	78.66	6,187.84	9.09
48	858.00	935.94	-77.94	77.94	6,074.82	9.08
49	814.00	889.34	-75.34	75.34	5,676.37	9.26
50	871.00	869.59	1.41	1.41	2.00	0.16
51	1,255.00	870.51	384.49	384.49	147,833.01	30.64
52	980.00	964.88	15.12	15.12	228.72	1.54
		984.88	78.31	115.55	21,992.79	10.99



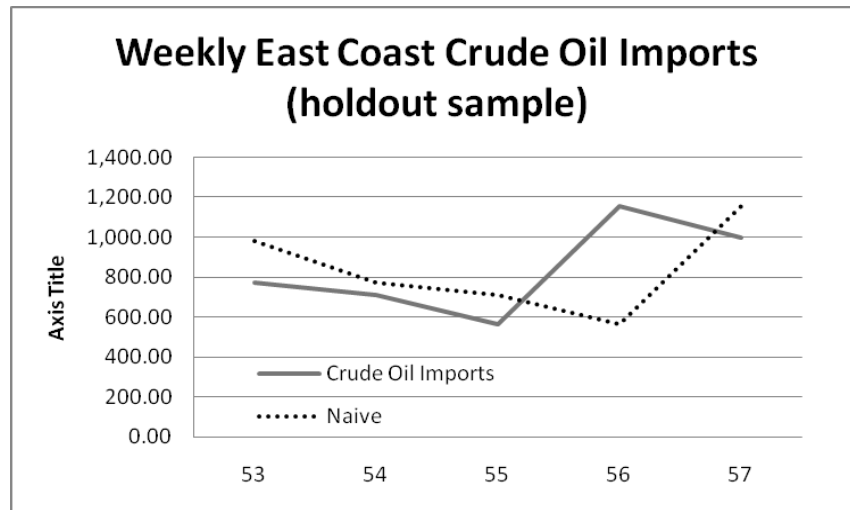
In terms of CFE, the performance of the combination forecast is best. For MAD, MSE and MAPE, the combination forecast is better than the performance of the MA and WMA forecasts and close to the Trend Projection method.

In-Class Exercise

The following spreadsheets and plots provide the forecasts and the performance of the Naive, MA, Trend Projection and Combination Forecasts as new data are added.

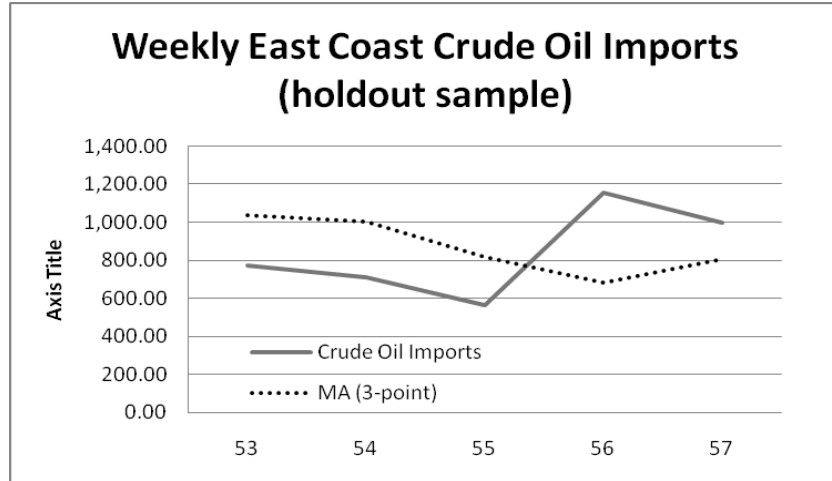
1-Period Moving Average (Naïve) Forecast

Week (t)	Crude Oil Imports	Forecast	Error	Absolute Error	Squared Error	Absolute Percent Error
53	771.00	980.00	-209.00	209.00	43,681.00	27.11
54	709.00	771.00	-62.00	62.00	3,844.00	8.74
55	562.00	709.00	-147.00	147.00	21,609.00	26.16
56	1,154.00	562.00	592.00	592.00	350,464.00	51.30
57	998.00	1,154.00	-156.00	156.00	24,336.00	15.63
			18.00	233.20	88,786.80	25.79



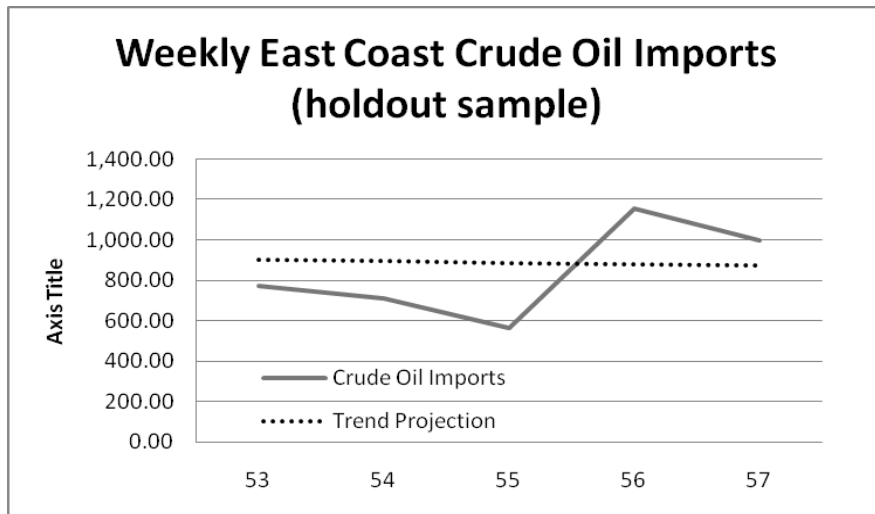
3-Period Moving Average Forecast

Week (t)	Crude Oil Imports	Forecast	Error	Absolute Error	Squared Error	Absolute Percent Error
53	771.00	1,035.33	-264.33	264.33	69,872.11	34.28
54	709.00	1,002.00	-293.00	293.00	85,849.00	41.33
55	562.00	820.00	-258.00	258.00	66,564.00	45.91
56	1,154.00	680.67	473.33	473.33	224,044.44	41.02
57	998.00	808.33	189.67	189.67	35,973.44	19.00
			-152.33	295.67	96,460.60	36.31



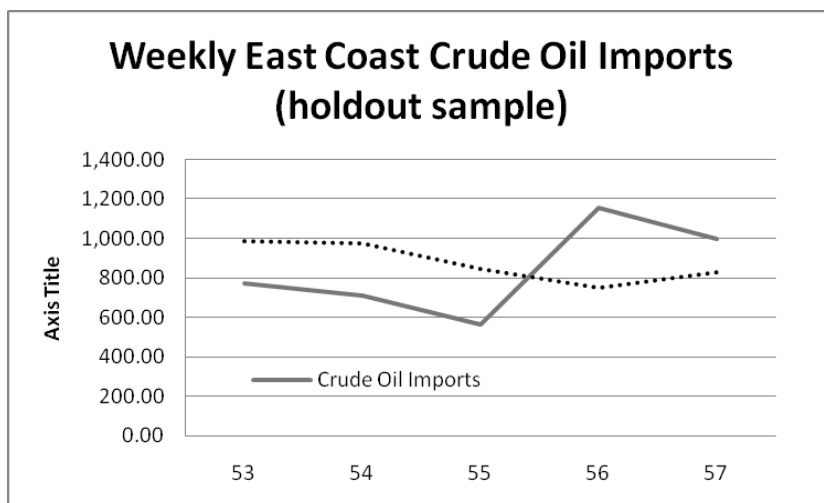
Trend Projection with Regression Forecast

Week (t)	Crude Oil Imports	Forecast	Error	Absolute Error	Squared Error	Absolute Percent Error
53	771.00	900.40	-129.40	129.40	16,743.89	16.78
54	709.00	893.67	-184.67	184.67	34,101.70	26.05
55	562.00	886.93	-324.93	324.93	105,582.60	57.82
56	1,154.00	880.20	273.80	273.80	74,964.77	23.73
57	998.00	873.47	124.53	124.53	15,507.39	12.48
		-240.67	207.47	49,380.07	27.37	



Combination Forecast (MA,WMA, and Trend equally weighted)

Week (t)	Crude Oil Imports	Forecast	Error	Absolute Error	Squared Error	Absolute Percent Error
53	771.00	988.51	-217.51	217.51	47,310.82	28.21
54	709.00	958.19	-249.19	249.19	62,095.07	35.15
55	562.00	838.61	-276.61	276.61	76,513.97	49.22
56	1,154.00	743.22	410.78	410.78	168,737.55	35.60
57	998.00	841.57	156.43	156.43	24,470.90	15.67
			-176.10	262.10	75,825.66	32.77



In terms of the overall best-performing methods given the holdout data:

CFE – Naïve Method (18.00)

MAD – Trend Projection (207.47)

MSE – Trend Projection (49,380.07)

MAPE – Naïve Method (25.79)

The intercept and slope parameters calculated with the Trend Projection with Regression method were not updated after each holdout data point was provided. Students may be interested in examining the effectiveness of recalibrating the regression equation each period.

Recalibrated regression equations are as follows:

$$\hat{y}_{53} = 1257.1787 - 6.7317x$$

$$\hat{y}_{54} = 1262.0617 - 7.0030x$$

$$\hat{y}_{55} = 1268.5390 - 7.3563x$$

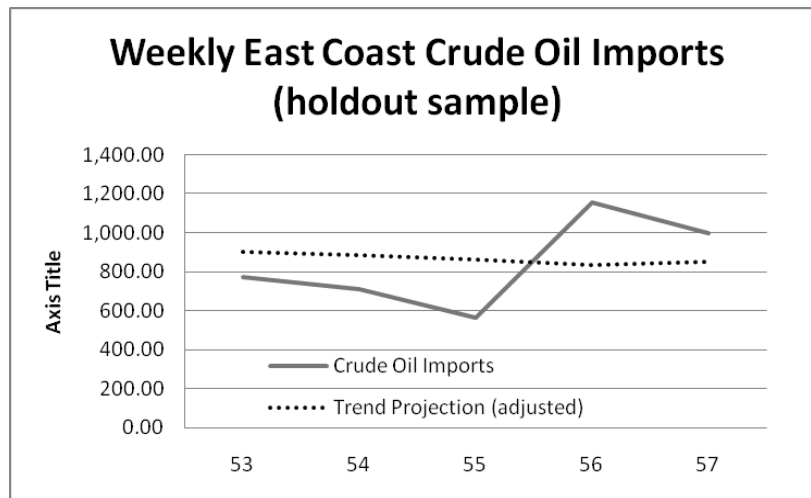
$$\hat{y}_{56} = 1279.5192 - 7.9445x$$

$$\hat{y}_{57} = 1268.1130 - 7.3442x$$

Parameter recalibration provides the following forecast performance for Trend Projection:

Trend Projection with Regression Forecast - updated each holdout period

Week (t)	Crude Oil Imports	Forecast	Error	Absolute Error	Squared Error	Absolute Percent Error
53	771.00	900.40	-129.40	129.40	16,743.89	16.78
54	709.00	883.90	-174.90	174.90	30,590.21	24.67
55	562.00	863.94	-301.94	301.94	91,168.61	53.73
56	1,154.00	834.63	319.37	319.37	101,999.58	27.68
57	998.00	849.49	148.51	148.51	22,053.98	14.88
			-138.36	214.82	52,511.25	27.55



Comparing Results of History File vs. Holdout File

The following table addresses the reason for doing a holdout sample. We want to see if the error measures found for the history file give an overly optimistic picture of how well the forecasting techniques will do on data that was not considered when the models were developed.

Forecasting Technique	CFE		MAD	
	History File	Holdout Sample	History File	Holdout Sample
Naive	-295.00	18.00	147.40	233.20
Moving Average	-183.67	-152.33	124.31	295.67
Trend Progression	613.40	-240.67	111.68	207.47
Combination	78.31	-176.10	115.55	262.10

These results show surprisingly that the techniques generally do better on the holdout sample than the history file with respect to CFE. Unfortunately, it is a different story with regard to MAD. MAD errors are roughly double those experienced with the history file. Developing models using demand data on which their performance is evaluated may indeed overstate the accuracy of the models in forecasting future demand, as opposed to explaining past demand.

ILLUSTRATIVE GRADED HOMEWORK ASSIGNMENT

Shown below is on way to make graded homework assignments, using Problem 7 as a case in point.

Name _____

Graded Homework #6: Time-series Forecasting

Due on Tuesday 11/27 on Blackboard at 1:45 pm and on paper in class.

See Problem 7 in Chapter 14 of your textbook. The problem lists six forecasting methods (*i* through *vi*). Using the OM Explorer's *Time Series Forecasting* solver, answer the below questions **only for methods *i*, *ii*, and *v*.**

1.	What is the forecast for the next period using method <i>i</i> ?	_____
2.	What is the forecast for the next period using method <i>ii</i> ?	_____
3	What is the forecast for the next period using method <i>iii</i> ?	_____
3.	What is the forecast for the next period using method <i>v</i> ?	_____
4	If MAD is the performance criterion chosen by the administration, which forecasting method should it choose?	_____
5.	If MSE is the performance criterion chosen by the administration, which forecasting method should it choose?	_____
6.	If bias is the performance criterion chosen by the administration, which forecasting method should it choose? <i>Hint: "Bias" is CFE or CFE / n.</i>	_____

- Submit your answers in Blackboard ASSIGNMENTS at “**Time-series Forecasting Submission**” by the required time above.
- In addition, submit your paper answer in class as follows:
 - a. This page with answers entered above.
 - b. Attach printouts of “*Details and Error Analysis*” page from *POM for Windows* for **each** of the three forecasting methods with your name clearly identified on each.

NOTE: *You have to solve the problem three times – once for each method. Recall that you can put your name in the data set “title” field so it appears on the printouts.*

Source: This assignment was prepared by Dr. Daniel Steele, University of South Carolina, and illustrates one way to convert homework problems into graded homework assignments. The assessment components in myomlab also offers powerful options.

Chapter

15 Operations Planning and Scheduling

DISCUSSION QUESTIONS

1. Over the past several years, many corporations have experienced reductions in the workforce of sufficient size to receive attention in the media. Restructuring charges reflected in the annual reports to stockholders are often in the order of magnitude of \$100,000 per employee. If business is expected to recover within a year, the company would usually be better off to keep these employees on the payroll, perhaps shifting some of them to sales, or loan others for community volunteer work. It is difficult to estimate the monetary value of the following costs associated with layoffs:
 - ☐ Decreased morale and loyalty of employees not laid off
 - ☐ Employee stress, mortgage defaults, failed marriages, suicides
 - ☐ Customers may question the ability to perform, creating a chilling effect on sales
 - ☐ Suppliers may become suspicious of firm's financial strength, demand cash
 - ☐ Loss of experience, skill and knowledge inventories
 - ☐ Loss of goodwill in community, future cooperation in zoning
 - ☐ Loss of redevelopment incentives
 - ☐ Loss of reputation as an employer, future difficulty in hiring a qualified workforce
2. Responses will vary depending on which firms are used as examples. Some industries, such as the U.S. auto industry, have a long history and tradition of workforce furlough and recall to match production with demand. Generations of employees are accustomed to this cycle, and fairly smoothly transition between working in the plant during good times and finding other temporary careers when business is slow. Other industries, such as utilities, have a history of stable employment, but are now faced with competition, restructuring, and dealing with employees who hired on for life and now feel betrayed. Stable employment requires stable markets, management loyalty to the workforce, long product lifecycles, financial strength, skilled workforces, and competition that also needs stable workforces.
3. Several arguments support these policies. First, the revenue management policies maximize the revenues generated from fixed capacity. Maximizing profits helps the firm succeed and support its workforce. Second, it is the customers themselves who determine the price differentials. The more they gamble (with an increased probability of losing), the more likely they will get a free room.

Arguments against begin with many customers not knowing fully how the “Total Rewards” card program is being used. The ethics of being denied a room, saying that there is no capacity, when the real reason is that the customer is not a big gambler, is debatable. In addition, the process supports an activity that can be addictive to some people and goes beyond entertainment.

4. Priority systems affect operations performance and aid management in making operational decisions. They facilitate prioritizing of work in the organization, as all the work to be performed in the organization cannot be done at the same time. The choice of priority system also helps management to focus and consciously decide on the scheduling system that will emphasize the performance criteria it considers to be important. By providing guidance for the numerous routine decisions associated with determining the sequence in which jobs are to be processed, priority systems allow managers to spend more time with strategic issues.

PROBLEMS

1. Barberton Municipal Division of Road Maintenance

- a. The peak demand is 19,000 hours in quarter 3. As each employee can work 600 hours per quarter (500 on regular time and 100, or 0.20×500 , on overtime), the level workforce that relies just on overtime, allows no delay, and minimizes undertime is

$19,000/600 = 31.67$ or 32 employees.

Cost	Calculation	Amount
Regular wages	(\$6,000 per quarter)(32)(4 quarters)	\$768,000
Overtime wages	(3,000 hr in quarter 3)(\$18 per hr)	54,000
Hire costs	(\$3,000 per hire)(21 hires)	<u>63,000</u>
	TOTAL	\$885,000

The 32 workers can produce $(32)(500) = 16,000$ hours of regular time in any quarter. The 19,000-hour requirement in quarter 3 exceeds this amount by 3000 hours.

The total undertime hours can be calculated as:

Quarter 1	$32(500) - 6,000$	=	10,000 hours
Quarter 2	$32(500) - 12,000$	=	4,000
Quarter 4	$32(500) - 9,000$	=	<u>7,000</u>
			21,000 hours

- b. The chase strategy:

Quarter	Demand (hr)	Workforce	Hires	Layoffs
1	6,000	12	1	
2	12,000	24	12	
3	19,000	38	14	
4	9,000	<u>18</u>	<u>0</u>	<u>20</u>
TOTAL		92	27	20

Cost	Calculation	Amount
Regular wages	(\$6,000 per quarter)(92)	\$552,000
Hire costs	(\$3,000 per hire)(27 hires)	81,000
Layoff costs	(\$2,000 per layoff)(20 layoffs)	<u>40,000</u>
	TOTAL	\$673,000

c. Proposed plan

This plan uses a mixed strategy. Although it uses the chase strategy for the first two quarters, it hires on 7 extra workers in Quarter 3, using 3,500 hours of overtime in (the equivalent of 6.2 workers) to fill the gap. The savings in hiring and layoff costs exceeds the extra overtime costs.

Quarter	Demand (hr)	Workforce	Hires	Layoffs	Overtime (hr)
1	6,000	12	1		
2	12,000	24	12		
3	19,000	31	7		3,500
4	9,000	<u>18</u>	<u>0</u>	<u>13</u>	<u>0</u>
TOTAL		85	20	13	3,500

Cost	Calculation	Amount
Regular wages	(\$6,000 per quarter)(85)	\$510,400
Hire costs	(\$3,000 per hire)(20 hires)	60,000
Layoff costs	(\$2,000 per layoff)(13 layoff)	26,000
Overtime	(\$18 per hour)(3,500 hours)	<u>63,000</u>
	TOTAL	\$659,000

2. Bob Carlton's Golf Camp

a. The level strategy:

The peak demand is 6,400 hours in quarter 2. As each employee can work 600 hours per quarter (480 on regular time and 120 on overtime), the level workforce that covers requirements and minimizes undertime is $6,400/600 = 10.67$ or 11 employees.

Cost	Calculation	Amount
Regular wages	(\$7200 per quarter)(11)(8 quarters)	\$633,600
Overtime wages*	(1,120 hr in quarter 2)(\$20 per hr)	22,400
	(960 hr in quarter 6)(\$20 per hr)	19,200
Hire costs	(\$10,000 per hire)(3 hires)	<u>30,000</u>
	TOTAL	\$705,200

* The 11 workers can produce $(11)(480) = 5,280$ hours of regular time in any quarter. The 6,400-hour requirement in quarter 2 exceeds this amount by 1,120 hours. The 6,240-hour requirement in quarter 6 exceeds this amount by 960 hours.

The total undertime hours can be calculated as:

Quarter 1	$11(480) - 4,200$	1,080 hours
Quarter 3	$11(480) - 3,000$	2,280
Quarter 4	$11(480) - 4,800$	480
Quarter 5	$11(480) - 4,400$	880
Quarter 7	$11(480) - 3,600$	1,680
Quarter 8	$11(480) - 4,800$	<u>480</u>
		6,880 hours

b. The chase strategy:

Quarter	Demand (hr)	Workforce	Hires	Layoffs
1	4,200	9	1	
2	6,400	14	5	
3	3,000	7		7
4	4,800	10	3	
5	4,400	10		
6	6,240	13	3	
7	3,600	8		5
8	4,800	10	2	0
TOTAL		81	14	12

Cost	Calculation	Amount
Regular wages	(\$7,200 per quarter)(81)	\$583,200
Hire costs	(\$10,000 per hire)(14 hires)	140,000
Layoff costs	(\$4,000 per layoff)(12 layoffs)	48,000
TOTAL		\$771,200

c. Proposed plan:

This plan begins with just 9 workers for Quarter 1, as with the chase strategy. However, it increases temporarily the workforce to 11 employees in Quarters 2 and 6, making up the shortfall with overtime.

Quarter	Demand (hr)	Workforce	Hires	Layoffs	Overtime (hr)
1	4,200	9	1		
2	6,400	11	2		1,120
3	3,000	9		2	
4	4,800	9			480
5	4,400	9			80
6	6,240	11	2		960
7	3,600	9		2	
8	4,800	9	0	0	480
TOTAL		76	5	4	3,120

Cost	Calculation	Amount
Regular wages	(\$7,200 per quarter)(76)	\$547,200
Hire costs	(\$10,000 per hire)(5 hires)	50,000
Layoff costs	(\$4,000 per layoff)(4 layoffs)	16,000
Overtime	(\$20 per hour)(3,120 hours)	62,400
TOTAL		\$675,600

This plan is more like the level strategy, except that only 9 employees are on the workforce each quarter, with another 2 hired temporarily in Quarters 2 and 6. It also uses more overtime than with the level strategy.

3. Bob Carlton's Golf Camp with part-time instructors

- a. One of many plans that take advantage of flexibility provided by part-time instructors, this plan reduces hiring and layoffs of certified instructors, reduces overtime, and reduces total costs.

Qtr	Demand (hr)	Certified Workforce	Cert Hires	Cert Layoffs	PT Work Hours	PT Hires	PT Layoffs	Overtime (hr)
1	4,200	9	1					
2	6,400	10	1		720	3		880
3	3,000	8		2			3	
4	4,800	8			720	3		240
5	4,400	8			560			
6	6,240	10	2		720			720
7	3,600	8		2			3	
8	4,800	8			720	3		240
TOTAL		69	4	4	3,440	9	6	2,080

Cost	Calculation	Amount
Regular wages	(\$7,200 per quarter)(69)	\$496,800
Cert. hire costs	(\$10,000 per hire)(4 hires)	40,000
Cert. layoff costs	(\$4,000 per hire)(4 layoffs)	16,000
PT. hire costs	(\$2,000 per hire)(9 hires)	18,000
PT. labor costs	(\$12/hr) (3,440 hrs)	41,280
Overtime	(\$20 per hour)(2,080 hours)	<u>41,600</u>
	TOTAL	\$653,680

4. Donald Fertilizer Company

- a. For Parts (a) and (b), we need to find the level production rate that is high enough to avoid any backorders or backlogs. A good place to start is with the average quarterly demand level, or $340,000/4 = 85,000$ gallons per quarter. That pace may or may not be sufficient, but let's check it out. If we run short, then we must increase the output rate until we reach a level that does not result in a shortage for any of the four quarters. This particular production level is evaluated in the following table, showing that it just gets by with no extra anticipation inventory at the end of the Quarter 4.

Quarter	Production Rate (gallons) in Quarter	Demand (gallons) in Quarter	Anticipation Inventory (gallons) at Quarter's End
1	85,000	80,000	5,000
2	85,000	50,000	40,000
3	85,000	80,000	45,000
4	85,000	130,000	0

- b. The anticipation inventory is shown in the above table. The anticipation inventory for a quarter is the beginning inventory of the prior period (0 at the start of quarter 1), plus production, minus demand. For Quarter 1, it is 5,000 gallons (or $0 + 85,000 - 80,000$).
- c. In part (a), the average demand rate fortunately can also be our average production rate. That solution is not always sufficient, as demonstrated here for another demand pattern where the peak occurs early in the year. Shown below is what would happen if we used 85,000 as the level production rate with the new

demand forecasts. The column for anticipation inventory shows backorders in Quarters 2 and 3, which are not allowed.

Quarter	Production Rate (gallons) in Quarter	Demand (gallons) in Quarter	Anticipation Inventory (gallons) at Quarter's End
1	85,000	80,000	5,000
2	85,000	130,000	-40,000
3	85,000	50,000	-5,000
4	85,000	80,000	0

So we will have to set the production rate higher to meet demand, which has the peak in Quarter 2. Using trial-and-error with increasingly larger production rates (say 90,000, 100,000, and finally 105,000), we discover that the 105,000 level production rate will meet the demand for each quarter. The table below shows a large buildup of anticipation inventory at the end of the year, which will carry over into the next year. If next year's demand is about the same as this year's, we will be able to cut back on our level production rate next year. Probably a better solution is to consider a mixed strategy.

Quarter	Production Rate (gallons) in Quarter	Demand (gallons) in Quarter	Anticipation Inventory (gallons) at Quarter's End
1	105,000	80,000	25,000
2	105,000	130,000	0
3	105,000	50,000	55,000
4	105,000	80,000	80,000

5. Kerby Corporation

a. Level Strategy Production Plan – using Excel Spreadsheet

Level Strategy

Month	Demand	Number of Employees	Total Production	Beginning Inventory	Ending Inventory	Hires	Layoff s
-		140			-		
1	500	163	1,630	-	1,130	23	-
2	800	163	1,630	1,130	1,960	-	-
3	1,000	163	1,630	1,960	2,590	-	-
4	1,400	163	1,630	2,590	2,820	-	-
5	2,000	163	1,630	2,820	2,450	-	-
6	3,000	163	1,630	2,450	1,080	-	-
7	2,700	163	1,630	1,080	10	-	-
8	1,500	163	1,630	10	140	-	-
9	1,400	163	1,630	140	370	-	-
10	1,500	163	1,630	370	500	-	-
11	2,000	163	1,630	500	130	-	-
12	1,200	163	1,630	130	560	-	-
Sum		1,956			13,740	23	-

Level Strategy

Wages	\$2,000/month/employee	\$3,912,000
Hire costs	\$2,000/hire	\$46,000
Layoff costs	\$500/layoff	\$0
Inventory costs	\$32/unit/month	\$439,680
Total Cost		\$4,397,680

b. Chase Strategy Production Plan – using Excel Spreadsheet

Chase Strategy

Month	Demand	Number of Employees	Total Production	Beginning Inventory	Ending Inventory	Hires	Layoffs
-		140			-		
1	500	50	500	-	-	-	90
2	800	80	800	-	-	30	-
3	1,000	100	1,000	-	-	20	-
4	1,400	140	1,400	-	-	40	-
5	2,000	200	2,000	-	-	60	-
6	3,000	300	3,000	-	-	100	-
7	2,700	270	2,700	-	-	-	30
8	1,500	150	1,500	-	-	-	120
9	1,400	140	1,400	-	-	-	10
10	1,500	150	1,500	-	-	10	-
11	2,000	200	2,000	-	-	50	-
12	1,200	120	1,200	-	-	-	80
Sum		1,900			-	310	330

Chase Strategy

Wages	\$2,000/month/employee	\$3,800,000
Hire costs	\$2,000/hire	\$620,000
Layoff costs	\$500/layoff	\$165,000
Inventory costs	\$32/unit/month	\$0
Total Cost		\$4,585,000

c. Mixed Strategy Production Plan – using Excel Spreadsheet

Mixed Strategy

Month	Demand	Number of Employees	Total Production	Beginning Inventory	Ending Inventory	Hires	Layoffs
0		140			0		
1	500	163	1,630	0	1,130	23	0
2	800	163	1,630	1,130	1,960	0	0
3	1,000	163	1,630	1,960	2,590	0	0
4	1,400	163	1,630	2,590	2,820	0	0
5	2,000	163	1,630	2,820	2,450	0	0
6	3,000	163	1,630	2,450	1,080	0	0
7	2,700	163	1,630	1,080	10	0	0
8	1,500	150	1,500	10	10	0	13
9	1,400	140	1,400	10	10	0	10
10	1,500	150	1,500	10	10	10	0
11	2,000	200	2,000	10	10	50	0
12	1,200	120	1,200	10	10	0	80
Sum		1,901			12,090	83	103

Mixed Strategy

Wages	\$2,000/month/employee	\$3,802,000
Hire costs	\$2,000/hire	\$166,000
Layoff costs	\$500/layoff	\$51,500
Inventory costs	\$32/unit/month	\$386,880
Total Cost		\$4,406,380

d. Cost Comparisons – Total cost is minimized by the Level Strategy

	Level	Chase	Mixed
Wages	\$3,912,000	\$3,800,000	\$3,802,000
Hire costs	\$46,000	\$620,000	\$166,000
Layoff costs	\$0	\$165,000	\$51,500
Inventory costs	\$439,680	\$0	\$386,880
Total Cost	\$4,397,680	\$4,585,000	\$4,406,380

6. Tax Prep Advisers Inc.

a. Level strategy

The most overtime we can use is 25% of regular-time capacity (W), so we have $1.25W = 20$ employees (maximum need in any period)

$$W = 20/1.25 = 16 \text{ employees}$$

This staff size minimizes the resulting amount of undertime, although is it still considerable because anticipation inventory is not an option for this service provider. As there are already 10 employees, Tax Prep Advisers should hire 6 more. Plan 1 shows the resulting hires and overtime.

Plan 1: Level Strategy

Period	1	2	3	4	5	6	7	8	9	10	11	12	Total
Inputs													
Forecasted demand	5	8	10	13	18	20	20	14	12	8	2	1	131
Workforce level	16	16	16	16	16	16	16	16	16	16	16	16	192
Undertime	11	8	6	3				2	4	8	14	15	71
Overtime					2	4	4						10
Vacation time													0
Subcontracting time													0
Backorders													0
Derived													
Utilized time	5	8	10	13	16	16	16	14	12	8	2	1	121
Inventory	0	0	0	0	0	0	0	0	0	0	0	0	0
Hires	6	0	0	0	0	0	0	0	0	0	0	0	6
Layoffs	0	0	0	0	0	0	0	0	0	0	0	0	0
Calculated													
Utilized time cost	\$7,500	\$12,000	\$15,000	\$19,500	\$24,000	\$24,000	\$24,000	\$21,000	\$18,000	\$12,000	\$3,000	\$1,500	\$181,500
Undertime cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Overtime cost	\$0	\$0	\$0	\$0	\$4,500	\$9,000	\$9,000	\$0	\$0	\$0	\$0	\$0	\$22,500
Vacation time cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Inventory cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Backorders cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Hiring cost	\$15,000	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$15,000
Layoff cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Subcontracting cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total cost	\$22,500	12,000	15,000	19,500	28,500	33,000	33,000	21,000	18,000	12,000	3,000	1,500	\$219,000

b. Chase strategy

This strategy simply involves adjusting the workforce as needed to meet demand. Plan 2 shows the effect of changing the staff level with hires and layoffs.

	1	2	3	4	5	6	7	8	9	10	11	12	Total
Requirement	5	8	10	13	18	20	20	14	12	8	2	1	131
Staff level	5	8	10	13	18	20	20	14	12	8	2	1	131
Hires	—	3	2	3	5	2	—	—	—	—	—	—	15
Layoffs	5	—	—	—	—	—	—	6	2	4	6	1	24
Overtime	—	—	—	—	—	—	—	—	—	—	—	—	0

Output from OM Explorer confirms these calculations:

Period	1	2	3	4	5	6	7	8	9	10	11	12	Total
Inputs													
Forecasted demand	5	8	10	13	18	20	20	14	12	8	2	1	131
Workforce level	5	8	10	13	18	20	20	14	12	8	2	1	131
Uvertime													0
Overtime													0
Vacation time													0
Subcontracting time													0
Backorders													0
Derived													
Utilized time	5	8	10	13	18	20	20	14	12	8	2	1	131
Inventory	0	0	0	0	0	0	0	0	0	0	0	0	0
Hires	0	3	2	3	5	2	0	0	0	0	0	0	15
Layoffs	5	0	0	0	0	0	0	6	2	4	6	1	24
Calculated													
Utilized time cost	\$7,500	\$12,000	\$15,000	\$19,500	\$27,000	\$30,000	\$30,000	\$21,000	\$18,000	\$12,000	\$3,000	\$1,500	\$196,500
Uvertime cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Overtime cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Vacation time cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Inventory cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Backorders cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Hiring cost	\$0	\$7,500	\$5,000	\$7,500	\$12,500	\$5,000	\$0	\$0	\$0	\$0	\$0	\$0	\$37,500
Layoff cost	\$10,000	\$0	\$0	\$0	\$0	\$0	\$0	\$12,000	\$4,000	\$8,000	\$12,000	\$2,000	\$48,000
Subcontracting cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total cost	\$17,500	19,500	20,000	27,000	39,500	35,000	30,000	33,000	22,000	20,000	15,000	3,500	\$282,000

c. Mixed Strategy: The Level strategy had a lower cost (because undertime has no cost) than the chase strategy (because of the frequent hiring and layoff costs). In addition, anticipation inventory is not allowed. These observations suggest a strategy of chasing the increasing demand until the peak is reached (rather than hiring them all in period 1), and then keep the workforce level at that level for the rest of the year. The plan is shown below.

Period	1	2	3	4	5	6	7	8	9	10	11	12	Total
Inputs													
Forecasted demand	5	8	10	13	18	20	20	14	12	8	2	1	131
Workforce level	10	10	10	13	16	16	16	16	16	16	16	16	171
Uvertime	5	2						2	4	8	14	15	50
Overtime					2	4	4						10
Vacation time													0
Subcontracting time													0
Backorders													0
Derived													
Utilized time	5	8	10	13	16	16	16	14	12	8	2	1	121
Inventory	0	0	0	0	0	0	0	0	0	0	0	0	0
Hires	0	0	0	3	3	0	0	0	0	0	0	0	6
Layoffs	0	0	0	0	0	0	0	0	0	0	0	0	0
Calculated													
Utilized time cost	\$7,500	\$12,000	\$15,000	\$19,500	\$24,000	\$24,000	\$24,000	\$21,000	\$18,000	\$12,000	\$3,000	\$1,500	\$181,500
Uvertime cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Overtime cost	\$0	\$0	\$0	\$0	\$4,500	\$9,000	\$9,000	\$0	\$0	\$0	\$0	\$0	\$22,500
Vacation time cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Inventory cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Backorders cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Hiring cost	\$0	\$0	\$0	\$7,500	\$7,500	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$15,000
Layoff cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Subcontracting cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total cost	\$7,500	12,000	15,000	27,000	36,000	33,000	33,000	21,000	18,000	12,000	3,000	1,500	\$219,000

Plan 3 has the same cost as Plan 1. Management may find it better on qualitative basis, because it calls for less undertime (although still sizeable). Much depends on whether management can attract a workforce that seeks part-time jobs.

d. Cost comparisons for the staffing plans

Cost	Plan 1: Level Strategy		Plan 2: Chase Strategy		Plan 3: Mixed Strategy	
Utilized RT @ \$1500	121 wrk-mo.	= \$181,500	131 worker-mo.	= \$196,500	121 worker-mo.	= \$181,500
OT @ \$2,250	10 worker-mo.	= \$ 22,500	0 worker-mo.	= \$ 0	10 worker-mo.	= \$ 22,500
Hire @ \$2,500	6 workers	= \$ 15,000	15 workers	= \$ 37,500	6 workers	= \$ 15,000
Layoff @ \$2,000	0 workers	= \$ 0	24 workers	= \$ 48,000	0 workers	= \$ 0
	Total	\$219,000		\$282,000		\$219,000

7. Climate Control Inc.

- a. If overtime is authorized only in months in which regular time production and current inventory levels are not adequate to meet the current month's demand, not enough overtime capacity will be available. Overtime is first required in month 6. If management waits until this point to use overtime, shortages will occur.

Month	Demand	Number of Employees	Regular Production Capacity	Beginning Inventory	Ending Inventory	Overtime Required	Overtime Available
-		9			24,000		
1	25,000	9	18,000	24,000	17,000	-	-
2	16,000	9	18,000	17,000	19,000	-	-
3	15,000	9	18,000	19,000	22,000	-	-
4	19,000	9	18,000	22,000	21,000	-	-
5	32,000	9	18,000	21,000	7,000	-	-
6	29,000	9	18,000	7,000	(400)	4,000	3,600
7	27,000	9	18,000	(400)	(5,800)	9,400	3,600
8	22,000	9	18,000	(5,800)	(6,200)	9,800	3,600
9	14,000	9	18,000	(6,200)	-	2,200	2,200
10	15,000	9	18,000	-	3,000	-	-
11	20,000	9	18,000	3,000	1,000	-	-
12	6,000	9	18,000	1,000	13,000	-	-
Sum		108			90,600	25,400	13,000

- b. The ability to backorder up to 5,000 suits from month to month instead of using overtime is also an inadequate strategy. In month 6, backorders of 4000 units must be backordered. Starting in month 7 and beyond, well over the 5,000 unit limit would have to be backordered each month to keep up with demand.

Month	Demand	Number of Employees	Regular Production Capacity	Beginning Inventory	Ending Inventory	Units of Backorders Required
-		9			24,000	
1	25,000	9	18,000	24,000	17,000	-
2	16,000	9	18,000	17,000	19,000	-
3	15,000	9	18,000	19,000	22,000	-
4	19,000	9	18,000	22,000	21,000	-
5	32,000	9	18,000	21,000	7,000	-
6	29,000	9	18,000	7,000	(4,000)	4,000
7	27,000	9	18,000	(4,000)	(13,000)	13,000
8	22,000	9	18,000	(13,000)	(17,000)	17,000
9	14,000	9	18,000	(17,000)	(13,000)	13,000
10	15,000	9	18,000	(13,000)	(10,000)	10,000
11	20,000	9	18,000	(10,000)	(12,000)	12,000

- c. The preemptive use of overtime in months 1-4 will adequately address the shortage issue as long as a small amount of overtime is authorized in month 8.

Month	Demand	Number of Employees	Regular Production Capacity	Beginning Inventory	Ending Inventory	Overtime Required	Overtime Used
-		9			24,000		
1	25,000	9	18,000	24,000	20,600	3,600	3,600
2	16,000	9	18,000	20,600	26,200	3,600	3,600
3	15,000	9	18,000	26,200	32,800	3,600	3,600
4	19,000	9	18,000	32,800	35,400	3,600	3,600
5	32,000	9	18,000	35,400	21,400	-	-
6	29,000	9	18,000	21,400	10,400	-	-
7	27,000	9	18,000	10,400	1,400	-	-
8	22,000	9	18,000	1,400	-	2,600	2,600
9	14,000	9	18,000	-	4,000	-	-
10	15,000	9	18,000	4,000	7,000	-	-
11	20,000	9	18,000	7,000	5,000	-	-
12	6,000	9	18,000	5,000	17,000	-	-
Sum		108			181,200	2,600	17,000

8. Gretchen's Kitchen

- a. Each hamburger requires 4 minutes, each pint of chili requires 3 minutes, each drink/shake requires 2 minutes, and each bag of French fries requires 2 minutes. Because the average customer buys 2.1 hamburgers, 0.2 pint of chili, 1 drink, and 1 bag of French fries, the average time required per customer is:

$$2.1(4) + 0.2(3) + 1.0(2) + 1.0(2) = 13 \text{ minutes}$$

The service requirements, given in hours, are:

Month	J	F	M	A	M	J	J	A	S	O	N	D	Total
Cust.	3,200	2,600	3,300	3,900	3,600	4,200	4,800	4,200	3,800	3,600	3,500	3,000	43,700
Hrs.*	693.3	563.3	715	845	780	910	1,040.0	910.0	823.3	780.0	758.3	650.0	9468.2

* In any month, the hours of requirements are the estimated number of customers times 13 minutes divided by 60 minutes.

- b. Three strategies

Level strategy with overtime and undertime:

The maximum requirement in any month is 1,040 hours. The maximum number of hours an employee can work is 96 hours: 80 on regular time and 16 on overtime. Consequently, to avoid lost demand we need $1,040/96 = 10.83$ or 11 employees. This gives us a monthly capacity of $11(80) = 880$ hours on regular time. With this workforce we would need the following overtime: 30 hours in June, 160 hours in July, and 30 hours in August, for a total of 220 hours.

Total cost = Regular-time wages + Overtime wages + Hire costs

$$= 11(\$400)(12 \text{ months}) + 220(\$7.50) + 1(\$250)$$

$$= \$54,700$$

Modified chase strategy with a base workforce of 10:

With 10 employees the regular-time capacity is 800 hours per month. Hiring and laying off to avoid overtime and undertime results in the following plan:

	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Requirements	693.3	563.3	715.0	845.0	780.0	910.0	1,040.0	910.0	823.3	780.0	758.3	650.0
Workforce	10	10	10	11	10	12	13	12	11	10	10	10
Capacity	800	800	800	880	800	960	1,040	960	880	800	800	800
Hires	-	-	-	1	-	2	1	-	-	-	-	-
Layoffs	-	-	-	-	1	-	-	1	1	1	-	-

$$\begin{aligned}
 \text{Total cost} &= \text{Wages} + \text{Hire costs} + \text{Layoff costs} \\
 &= (129 \text{ employee-months})(\$400) + 4(\$250) + 4(\$50) \\
 &= \$52,800
 \end{aligned}$$

Chase strategy:

With this plan, hiring and laying off is used to match the requirements without the need for overtime.

	Month											
	J	F	M	A	M	J	J	A	S	O	N	D
Requirements	693.3	563.3	715	845	780	910	1,040.0	910.0	823.3	780.0	758.3	650.0
Workforce	9	8	9	11	10	12	13	12	11	10	10	9
Capacity	720	640	720	880	800	960	1,040	960	880	800	800	720
Hires	—	—	1	2	—	2	1	—	—	—	—	—
Layoffs	1	1	—	—	1	—	—	1	1	1	—	1

$$\begin{aligned}
 \text{Total cost} &= \text{Wages} + \text{Hire costs} + \text{Layoff costs} \\
 &= (124 \text{ employee-months})(\$400) + 6(250) + 7(\$50) \\
 &= \$51,450
 \end{aligned}$$

The best plan is the chase strategy.

- c. If the cost of hiring were only \$50, the total costs of the plans would be:

Level strategy: \$54,500

Modified chase strategy with base workforce: \$52,000

Chase strategy: \$50,250

The strategy would not change in this case. The best is still a pure chase strategy. However, the manager should consider employee morale. Hiring and laying off employees may cause a reduction in productivity. Eventually, it may be difficult to find employees willing to work if they think they may be laid off after a few months.

9. King Kool Company

- a. Level strategy with overtime, undertime, and vacations:

The following plan calls for a level workforce of 142 employees, because when combined with 28 employee-month equivalents (or $0.20 \times 142 = 28.4$) of overtime in June avoids any backorders. The total cost is \$2,706,000. The plan's biggest advantage is a stable workforce. However, inventory is not allowed with the level strategy. The workforce must be increased, and yet undertime and overtime costs are high. Paid vacations amount to 65 employee-month periods (or 0.5×130) for the current employees, and are used during the slack season. If demand holds up in the following year, paid vacations would increase to 71 periods for all 142 employees.

	J	F	M	A	M	J	J	A	S	O	N	D	Total
Inputs													
Forecasted demand	70	90	100	100	130	170	170	150	110	60	20	40	1210
Workforce level	142	142	142	142	142	142	142	142	142	142	142	142	1704
Underline	47	37	32	32	12				32	82	118	91	483
Overtime						28	28	8					64
Vacation time	15	15	10	10							4	11	65
Subcontracting time													0
Backorders													0
Derived													
Utilized time	80	90	100	100	130	142	142	142	110	60	20	40	1,156
Inventory	0	0	0	0	0	0	0	0	0	0	0	0	0
Hires	12	0	0	0	0	0	0	0	0	0	0	0	12
Layoffs	0	0	0	0	0	0	0	0	0	0	0	0	0
Calculated													
Utilized time cost	\$120,000	\$135,000	\$150,000	\$150,000	\$195,000	\$213,000	\$213,000	\$213,000	\$165,000	\$90,000	\$30,000	\$60,000	\$0 \$1,734,000
Underline cost	\$70,500	\$55,500	\$48,000	\$48,000	\$18,000	\$0	\$0	\$0	\$48,000	\$123,000	\$177,000	\$136,500	\$0 \$724,500
Overtime cost	\$0	\$0	\$0	\$0	\$0	\$63,000	\$63,000	\$18,000	\$0	\$0	\$6,000	\$0	\$0 \$144,000
Vacation time cost	\$22,500	\$22,500	\$15,000	\$15,000	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$16,500	\$0 \$97,500
Inventory cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0 \$0
Backorders cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0 \$0
Hiring cost	\$6,000	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0 \$6,000
Layoff cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0 \$0
Subcontracting cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0 \$0
Total cost	\$219,000	213,000	213,000	213,000	213,000	276,000	276,000	231,000	213,000	213,000	213,000	213,000	0 \$2,706,000

b. Chase strategy with vacations:

The following plan costs less at \$2,285,000. However, the workforce fluctuates widely, which creates a considerable amount of hiring and layoffs. Students may not agree on how many periods to provide for paid vacations. Accounting students will argue that vacation time is accrued; that so long as an employee is on the workforce at the end of the previous year, he/she gets vacation the following year; i.e at least all 80 in January, if not all 130 current employees who've already earned it.

Here we provide overtime during November and December, and base the amount on the workforce size at the end of October, or $60 \times 0.5 = 30$. If it is based on the number employed in November, only 40 vacations periods are needed, which reduces the cost to \$2,265,000. One does wonder if this plan does justice to the workers who have been with the company for years.

	J	F	M	A	M	J	J	A	S	O	N	D	Total
Inputs													
Forecasted demand	70	90	100	100	130	170	170	150	110	60	20	40	1210
Workforce level	80	90	100	100	130	170	170	150	110	60	40	50	1250
Undertime													0
Overtime											20	10	30
Vacation time													0
Subcontracting time													0
Backorders													0
Derived													
Utilized time	80	90	100	100	130	170	170	150	110	60	20	40	1,220
Inventory	0	0	0	0	0	0	0	0	0	0	0	0	0
Hires	0	10	10	0	30	40	0	0	0	0	0	10	100
Layoffs	50	0	0	0	0	0	0	20	40	50	20	0	180
Calculated													
Utilized time cost	\$120,000	\$135,000	\$150,000	\$150,000	\$195,000	\$255,000	\$255,000	\$225,000	\$165,000	\$90,000	\$30,000	\$60,000	\$1,830,000
Undertime cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Overtime cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Vacation time cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$30,000	\$15,000	\$45,000
Inventory cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Backorders cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Hiring cost	\$0	\$5,000	\$5,000	\$0	\$15,000	\$20,000	\$0	\$0	\$0	\$0	\$0	\$5,000	\$50,000
Layoff cost	\$100,000	\$0	\$0	\$0	\$0	\$0	\$0	\$40,000	\$80,000	\$100,000	\$40,000	\$0	\$360,000
Subcontracting cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total cost	\$220,000	140,000	155,000	150,000	210,000	275,000	255,000	265,000	245,000	190,000	100,000	80,000	0
													\$2,285,000

c. Mixed strategy with inventory, overtime, backorders and vacations:

The cost of the following plan costs drops to \$2,239,000. The workforce is smaller and more stable, and only 50 vacation periods are needed (or 100×0.5). If 59 vacation periods are provided, given the 118-person workforce in September, the cost would not really change. The 9 extra vacation periods would be offset by a 9-period decrease in undertime (if it is provided in October-December). In balance, this plan seems to be the best of the three plans presented.

Inputs	J	F	M	A	M	J	J	A	S	O	N	D	Total
Forecasted demand	70	90	100	100	130	170	170	150	110	60	20	40	1210
Workforce level	118	118	118	118	118	118	118	118	118	100	100	100	1362
Under time										30	60	40	130
Overtime						23		15					38
Vacation time										10	20	20	50
Subcontracting time													0
Backorders								8					8
Derived													
Utilized time	118	118	118	118	118	118	118	118	118	60	20	40	1,182
Inventory	38	66	84	102	90	38	9	0	0	0	0	0	427
Hires	0	0	0	0	0	0	0	0	0	0	0	0	0
Layoffs	12	0	0	0	0	0	0	0	0	18	0	0	30
Calculated													
Utilized time cost	\$177,000	\$177,000	\$177,000	\$177,000	\$177,000	\$177,000	\$177,000	\$177,000	\$177,000	\$90,000	\$30,000	\$60,000	\$1,773,000
Under time cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$45,000	\$90,000	\$60,000	\$195,000
Overtime cost	\$0	\$0	\$0	\$0	\$0	\$51,750	\$33,750	\$0	\$0	\$0	\$0	\$0	\$85,500
Vacation time cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$15,000	\$30,000	\$30,000	\$75,000
Inventory cost	\$3,800	\$6,600	\$8,400	\$10,200	\$9,000	\$3,800	\$900	\$8,000	\$0	\$0	\$0	\$0	\$42,700
Backorders cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$8,000
Hiring cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Layoff cost	\$24,000	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$36,000	\$0	\$0	\$60,000
Subcontracting cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0
Total cost	\$204,800	183,600	185,400	187,200	186,000	180,800	229,650	218,750	177,000	186,000	150,000	150,000	\$2,239,200

10. Breakeven Analysis

The fixed cost for the regular time only is the sum of the hire and layoff costs, whereas the fixed cost of the overtime option is \$0. Setting the total cost of the regular time only option to the total cost of the overtime option, and solving for w , we get:

$$\begin{aligned} 5,000 + 500w &= 750w \\ 250w &= 5,000 \\ w &= 20 \end{aligned}$$

Thus the hire/layoff option using regular time only has a lower cost than overtime if the duration of the demand surge exceeds 20 weeks.

11. Michaels Distribution Center

Day	M	T	W	Th	F	S	Su
Requirements	6	3	5	3	7	2	3

M	T	W	Th	F	S	Su	Employee
6	3	5	3	7	2	3	1
5	2	4	2	6	2	3	2
4	1	3	1	5	2	3	3
3	1	3	0	4	1	2	4
2	0	2	0	3	1	2	5
1	0	2	0	2	0	1	6
0	0	1	0	1	0	1	7

The number of employees is 7. They are scheduled to take the boxed days off.

12. Cara Ryder's ski school needs 11 instructors.

a. Alternative 1. The heuristic does have a number of different solutions.

M	T	W	Th	F	S	Su	Instructor
7	5	4	5	6	9	8	1
6	5	4	5	5	8	7	2
5	4	4	5	5	7	6	3
5	4	4	4	4	6	5	4
4	4	4	4	3	5	4	5
3	3	4	4	3	4	3	6
3	3	3	3	2	3	3	7
2	2	2	2	2	3	3	8
2	2	2	1	1	2	2	9
1	1	1	1	1	2	1	10
1	1	0	0	0	1	0	11

- b. Instructors are scheduled to take the boxed days off in the solution shown in part (a).

	M	T	W	Th	F	S	Su
On-duty	7	5	4	5	6	9	8
Requirements	7	5	4	5	6	9	8
Slack	0	0	0	0	0	0	0

Alternative 2 (Optional)

	M	T	W	Th	F	S	Su	Instructor
7		5	4	5	6	9	8	1
6		5	4	5	5	8	7	2
5		4	4	5	5	7	6	3
5		4	4	4	4	6	5	4
4		3	4	4	4	5	4	5
4		3	3	3	3	4	4	6
3		3	3	3	2	3	3	7
2		2	2	2	2	3	3	8
2		2	2	1	1	2	2	9
1		1	1	1	1	2	1	10
1		1	0	0	0	1	1	11

Instructors are scheduled to take the boxed days off.

	M	T	W	Th	F	S	Su
On-duty	7	5	4	5	6	9	8
Requirements	7	5	4	5	6	9	8
Slack	0	0	0	0	0	0	0

13. The environmentally progressive mayor of Cambridge, Colorado.
- a. We used *Workforce Scheduler* Solver in OM Explorer to arrive at the minimum number of collectors. For each employee, the sentences on the right show his or her two off-days.

	M	T	W	Th	F	S	Su	
Base Requirements	12	7	8	8	5	3	6	
Employee 1	12	7	8	8	5	3	6	Employee gets F/S off.
Employee 2	11	6	7	7	5	2	5	Employee gets S/Su off.
Employee 3	10	5	6	6	4	2	5	Employee gets F/S off.
Employee 4	9	4	5	5	4	1	4	Employee gets S/Su off.
Employee 5	8	3	4	4	3	1	4	Employee gets F/S off.
Employee 6	7	2	3	3	3	0	3	Employee gets S/Su off.
Employee 7	6	1	2	2	2	0	3	Employee gets F/S off.
Employee 8	5	0	1	1	2	0	2	Employee gets T/W off.
Employee 9	4	0	1	0	1	0	1	Employee gets S/Su off.
Employee 10	3	0	0	0	0	0	1	Employee gets T/W off.
Employee 11	2	0	0	0	0	0	0	Employee gets S/Su off.
Employee 12	1	0	0	0	0	0	0	Employee gets S/Su off.

The minimum number of employees is 12. However, many schedules (particular assignments of on-duty periods) are possible.

- b. The work schedule for the analysis in part (a) is to assign employees the stipulated days off.

On-duty	12	10	10	10	7	4	7
Requirements	12	7	9	9	5	3	6
Slack	0	3	1	1	2	1	1

- c. We can use the heuristic method again to find whether we can get by with fewer employees. One solution follows.

	M	T	W	Th	F	S	Su	Employee
8	7	7	7	7	7	7	7	1
7	6	6	6	6	7	7		2
6	5	5	6	6	6	6		3
5	5	5	5	5	5	5		4
4	4	4	4	4	5	5		5
3	3	3	4	4	4	4		6
2	3	3	3	3	3	3		7
2	3	2	2	2	2	2		8
1	2	1	1	1	2	2		9
0	1	0	1	1	1	1		10
0	1	0	0	0	0	0		11

- i. Only 11 employees would be needed now. Total slack generated from this work schedule is:

	M	T	W	Th	F	S	Su
On-duty	9	7	9	8	8	7	7
Requirements	8	7	7	7	7	7	7
Slack	1	0	2	1	1	0	0

- ii. With preference to S-Su pairs.

	M	T	W	Th	F	S	Su	Employee
8	7	7	7	7	7	7	7	1
7	6	6	6	6	7	7		2
6	5	5	6	6	6	6		3
5	5	5	5	5	5	5		4
4	4	4	4	4	5	5		5
3	3	3	4	4	4	4		6
2	3	3	3	3	3	3		7
2	2	2	2	2	2	2	3	8
1	1	1	1	2	2	2		9
0	0	1	1	1	1	1		10

The number of employees needed is reduced to 10, and no slack is generated from this solution.

	M	T	W	Th	F	S	Su
On-duty	8	7	7	7	7	7	7
Requirements	8	7	7	7	7	7	7
Slack	0	0	0	0	0	0	0

- iii. Because each employee requires a truck, the number of trucks needed would be 8 to cover Monday, even though the actual number of employees available would be 9 in the solution (i). Assuming that extra employees are put to work doing some support activities, the smoothing of the workload will result in a reduction of 4 trucks over the requirements schedule in part (a).

14. Little 6, Inc.

As shown in the following table, the number of accountants required each day is a function of the number of each type of return to be prepared. For example, on Tuesday the demand for an accountant's time is $(14 \times 1.5 \text{ hrs}) + (10 \times 4.0 \text{ hrs}) = 61 \text{ hrs}$. Since each accountant can work no more than 10 hours per day, 7 accountants are needed.

	Time	M	T	W	Th	F	S	Su
Personal tax returns	1.5	24	14	18	18	10	28	16
Corporate tax returns	4.0	16	10	12	15	224	12	4
Total hours required		100	61	75	87	111	90	40
Accountants	10.0	10	7	8	9	12	9	4

- a. The following table provides definitions for the Linear Programming decision variables ("W" indicates a work day). Thus, accountants assigned to schedule X1 will work Monday – Friday

Decision Variable	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
X ₁	W	W	W	W	W		
X ₂		W	W	W	W	W	
X ₃			W	W	W	W	W
X ₄	W			W	W	W	W
X ₅	W	W			W	W	W
X ₆	W	W	W			W	W
X ₇	W	W	W	W			W
Demand	10	7	8	9	12	9	4

One optimal solution is provided in the following table

Decision Variable	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Number of Accountants Scheduled
X_1	W	W	W	W	W			4
X_2		W	W	W	W	W		3
X_3			W	W	W	W	W	0
X_4	W			W	W	W	W	2
X_5	W	W			W	W	W	3
X_6	W	W	W			W	W	1
X_7	W	W	W	W			W	0
Demand	10	7	8	9	12	9	4	59
Supply	10	11	8	9	12	9	6	65
Surplus		4					2	6

In this accountant-minimizing solution of 13 accountants, 4 accountants work Monday-Friday, 3 accountants work Tuesday – Saturday, 2 accountants work Thursday – Monday, 3 accountants work Friday – Tuesday, and 1 accountant works Saturday – Wednesday.

The POM for Windows *Linear Programming* formulation for part a:

	X1	X2	X3	X4	X5	X6	X7		RHS	Equation form
Minimize	1	1	1	1	1	1	1			Min $X_1 + X_2 + X_3 + X_4 + X_5 + X_6$
Monday	1	0	0	1	1	1	1	$\geq$	10	$X_1 + X_4 + X_5 + X_6 + X_7 \geq 10$
Tuesday	1	1	0	0	1	1	1	$\geq$	7	$X_1 + X_2 + X_5 + X_6 + X_7 \geq 7$
Wednesday	1	1	1	0	0	1	1	$\geq$	8	$X_1 + X_2 + X_3 + X_6 + X_7 \geq 8$
Thursday	1	1	1	1	0	0	1	$\geq$	9	$X_1 + X_2 + X_3 + X_4 + X_7 \geq 9$
Friday	1	1	1	1	1	0	0	$\geq$	12	$X_1 + X_2 + X_3 + X_4 + X_5 \geq 12$
Saturday	0	1	1	1	1	1	0	$\geq$	9	$X_2 + X_3 + X_4 + X_5 + X_6 \geq 9$
Sunday	0	0	1	1	1	1	1	$\geq$	4	$X_3 + X_4 + X_5 + X_6 + X_7 \geq 4$

The POM for Windows *Linear Programming* solution for part a:

	X1	X2	X3	X4	X5	X6	X7		RHS	Shadow Price
Minimize	1	1	1	1	1	1	1			
Monday	1	0	0	1	1	1	1	$\geq$	10	-.3333
Tuesday	1	1	0	0	1	1	1	$\geq$	7	0
Wednesday	1	1	1	0	0	1	1	$\geq$	8	-.3333
Thursday	1	1	1	1	0	0	1	$\geq$	9	0
Friday	1	1	1	1	1	0	0	$\geq$	12	-.3333
Saturday	0	1	1	1	1	1	0	$\geq$	9	-.3333
Sunday	0	0	1	1	1	1	1	$\geq$	4	0
Solution->	4	3	0	2	3	1	0		13	

POMS for Windows finds the same optimal solution with 13 accountants.

- b. Linear Programming decision variable definitions (“W” indicates a work day) and objective function coefficients.

Decision Variable	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Payrate
X ₁	W	W	W	W	W			\$1,200
X ₂		W	W	W	W	W		\$1,300
X ₃			W	W	W	W	W	\$1,450
X ₄	W			W	W	W	W	\$1,450
X ₅	W	W			W	W	W	\$1,450
X ₆	W	W	W			W	W	\$1,450
X ₇	W	W	W	W			W	\$1,350

The solution is provided in the following table

Decision Variable	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Number of Accountants Scheduled	Weekly Payroll Cost
X ₁	W	W	W	W	W			4	\$4,800
X ₂		W	W	W	W	W		3	\$3,900
X ₃			W	W	W	W	W	0	\$0
X ₄	W			W	W	W	W	2	\$2,900
X ₅	W	W			W	W	W	3	\$4,350
X ₆	W	W	W			W	W	1	\$1,450
X ₇	W	W	W	W			W	0	\$0
Demand	10	7	8	9	12	9	4	59	\$17,400
Supply	10	11	8	9	12	9	6	65	
Surplus		4					2	6	

In this payroll-minimizing solution, 4 accountants work Monday-Friday, 3 accountants work Tuesday – Saturday, 2 accountants work Thursday – Monday, 3 accountants work Friday – Tuesday, and 1 accountant works Saturday – Wednesday. The total payroll cost is \$17,400

The POM for Windows *Linear Programming* formulation and solution for part b:

	X1	X2	X3	X4	X5	X6	X7		RHS	Equation form
Minimize	1200	1300	1450	1450	1450	1450	1350			Min 1200X1 + 1300X2 + 1450X3 + 1450X4 + 1450X5 + 1450X6 + 1350X7
Monday	1	0	0	1	1	1	1	>=	10	X1 + X4 + X5 + X6 + X7 >= 10
Tuesday	1	1	0	0	1	1	1	>=	7	X1 + X2 + X5 + X6 + X7 >= 7
Wednesday	1	1	1	0	0	1	1	>=	8	X1 + X2 + X3 + X6 + X7 >= 8
Thursday	1	1	1	1	0	0	1	>=	9	X1 + X2 + X3 + X4 + X7 >= 9
Friday	1	1	1	1	1	0	0	>=	12	X1 + X2 + X3 + X4 + X5 >= 12
Saturday	0	1	1	1	1	1	0	>=	9	X2 + X3 + X4 + X5 + X6 >= 9
Sunday	0	0	1	1	1	1	1	>=	4	X3 + X4 + X5 + X6 + X7 >= 4

	X1	X2	X3	X4	X5	X6	X7		RHS	Shadow Price
Minimize	1200	1300	1450	1450	1450	1450	1350			
Monday	1	0	0	1	1	1	1	>=	10	-500
Tuesday	1	1	0	0	1	1	1	>=	7	0
Wednesday	1	1	1	0	0	1	1	>=	8	-350
Thursday	1	1	1	1	0	0	1	>=	9	0
Friday	1	1	1	1	1	0	0	>=	12	-350
Saturday	0	1	1	1	1	1	0	>=	9	-600
Sunday	0	0	1	1	1	1	1	>=	4	0
Solution->	4	3	0	2	3	1	0		17400	

POMS for Windows finds the same optimal solution with 13 accountants and a total payroll cost of \$17,400.

- c. Linear Programming decision variable definitions (“W” indicates a work day) and objective function coefficients. Variable X_8 has been included to represent the part-time employees available to work Friday – Sunday.

Decision Variable	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Payrate
X_1	W	W	W	W	W			\$1200
X_2		W	W	W	W	W		\$1300
X_3			W	W	W	W	W	\$1450
X_4	W			W	W	W	W	\$1450
X_5	W	W			W	W	W	\$1450
X_6	W	W	W			W	W	\$1450
X_7	W	W	W	W			W	\$1350
X_8					W	W	W	\$800

The solution is provided in the following table

Decision Variable	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Number of Accountants Scheduled	Weekly Payroll Cost
X_1	W	W	W	W	W			5	\$6,000
X_2		W	W	W	W	W		1	\$1,300
X_3			W	W	W	W	W	0	\$0
X_4	W			W	W	W	W	3	\$4,350
X_5	W	W			W	W	W	0	\$0
X_6	W	W	W			W	W	2	\$2,900
X_7	W	W	W	W			W	0	\$0
X_8					W	W	W	3	\$2,400
Demand	10	7	8	9	12	9	4	59	\$16,950
Supply	10	8	8	9	12	9	8	64	
Surplus		1					4	5	

In this payroll-minimizing solution, 5 accountants work Monday-Friday, 1 accountant work Tuesday – Saturday, 3 accountants work Thursday – Monday, 2 accountants work Saturday to Wednesday, and 3 temp accountant work Friday Sunday. The total payroll cost is \$16,950. a savings of \$450. over the optimal solution in part b.

The POM for Windows *Linear Programming* formulation and solution for part c:

	X1	X2	X3	X4	X5	X6	X7	X8	RHS	Equation form
Minimize	1200	1300	1450	1450	1450	1450	1350	800		Min 1200X1 + 1300X2 + 1450X3 + 1450X4 + 1450X5 + 1450X6 + 1350X7 + 800X8
Monday	1	0	0	1	1	1	1	0	>= 10	X1 + X4 + X5 + X6 + X7 >= 10
Tuesday	1	1	0	0	1	1	1	0	>= 7	X1 + X2 + X5 + X6 + X7 >= 7
Wednesday	1	1	1	0	0	1	1	0	>= 8	X1 + X2 + X3 + X6 + X7 >= 8
Thursday	1	1	1	1	0	0	1	0	>= 9	X1 + X2 + X3 + X4 + X7 >= 9
Friday	1	1	1	1	1	0	0	1	>= 12	X1 + X2 + X3 + X4 + X5 + X8 >= 12
Saturday	0	1	1	1	1	1	0	1	>= 9	X2 + X3 + X4 + X5 + X6 + X8 >= 9
Sunday	0	0	1	1	1	1	1	1	>= 4	X3 + X4 + X5 + X6 + X7 + X8 >= 4

	X1	X2	X3	X4	X5	X6	X7	X8		RHS	Shadow Price
Minimize	1200	1300	1450	1450	1450	1450	1350	800			
Monday	1	0	0	1	1	1	1	0	>=	10	-500
Tuesday	1	1	0	0	1	1	1	0	>=	7	0
Wednesday	1	1	1	0	0	1	1	0	>=	8	-350
Thursday	1	1	1	1	0	0	1	0	>=	9	-150
Friday	1	1	1	1	1	0	0	1	>=	12	-200
Saturday	0	1	1	1	1	1	0	1	>=	9	-600
Sunday	0	0	1	1	1	1	1	1	>=	4	0
Solution->	5	1	0	3	0	2	0	3		16950	

POMS for Windows finds the same optimal solution with a total payroll cost of \$16,950.

15. Return to Problem 11.

The following table provides definitions for the Linear Programming decision variables (“W” indicates a work day). Thus, loading dock workers assigned to schedule X1 will work Monday – Wednesday.

Decision Variable	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
X ₁	W	W	W				
X ₂		W	W	W	W		
X ₃			W	W	W	W	
X ₄				W	W	W	
X ₅					W	W	W
X ₆	W					W	W
X ₇	W	W				W	W
Demand	6	3	5	3	7	2	3

The solution is provided in the following table. 13 workers are required.

Decision Variable	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Number of Loaders Scheduled
X_1	W	W	W					5
X_2		W	W	W				0
X_3			W	W	W			5
X_4				W	W	W		0
X_5					W	W	W	2
X_6	W					W	W	0
X_7	W	W					W	1
Demand	6	3	5	3	7	2	3	29
Supply	6	6	10	5	7	2	3	39
Surplus		3	5	2				10

The POM for Windows *Linear Programming* model formulation and solution:

	X1	X2	X3	X4	X5	X6	X7		RHS	Equation form
Minimize	1	1	1	1	1	1	1			Min $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7$
Monday	1	0	0	0	0	1	1	$\geq$	6	$X_1 + X_6 + X_7 \geq 6$
Tuesday	1	1	0	0	0	0	1	$\geq$	3	$X_1 + X_2 + X_7 \geq 3$
Wednesday	1	1	1	0	0	0	0	$\geq$	5	$X_1 + X_2 + X_3 \geq 5$
Thursday	0	1	1	1	0	0	0	$\geq$	3	$X_2 + X_3 + X_4 \geq 3$
Friday	0	0	1	1	1	0	0	$\geq$	7	$X_3 + X_4 + X_5 \geq 7$
Saturday	0	0	0	1	1	1	0	$\geq$	2	$X_4 + X_5 + X_6 \geq 2$
Sunday	0	0	0	0	1	1	1	$\geq$	3	$X_5 + X_6 + X_7 \geq 3$

	X1	X2	X3	X4	X5	X6	X7		RHS	Shadow Price
Minimize	1	1	1	1	1	1	1			
Monday	1	0	0	0	0	1	1	$\geq$	6	-1
Tuesday	1	1	0	0	0	0	1	$\geq$	3	0
Wednesday	1	1	1	0	0	0	0	$\geq$	5	0
Thursday	0	1	1	1	0	0	0	$\geq$	3	0
Friday	0	0	1	1	1	0	0	$\geq$	7	-1
Saturday	0	0	0	1	1	1	0	$\geq$	2	0
Sunday	0	0	0	0	1	1	1	$\geq$	3	0
Solution->	5	0	5	0	2	0	1		13	

POMS for Windows finds the same optimal solution with 13 workers required.

16. Hickory Company
a. Schedules for two rules

FCFS rule:

Customer Sequence	Hr Since Order Arrived	Start Time (hr)		Machine Time (hr)		Finish Time (hr)	Due Date (hr)	Past Due (hr)	Flow Time (hr)
1	6	0	+	10	=	10	12	0	16
2	5	10	+	3	=	13	8	5	18
3	3	13	+	15	=	28	18	10	31
4	1	28	+	9	=	37	20	17	38
5	0	37	+	7	=	44	21	23	44

$$\text{Average flow time} = \frac{16 + 18 + 31 + 38 + 44}{5} = 29.4 \text{ hours}$$

$$\text{Average hours past due} = \frac{0 + 5 + 10 + 17 + 23}{5} = 11.0 \text{ hours}$$

EDD rule:

Customer Sequence	Hr Since Order Arrived	Start Time (hr)		Machine Time (hr)		Finish Time (hr)	Due Date (hr)	Hr Past Date	Flow Time (hr)
2	5	0	+	3	=	3	8	0	8
1	6	3	+	10	=	13	12	1	19
3	3	13	+	15	=	28	18	10	31
4	1	28	+	9	=	37	20	17	38
5	0	37	+	7	=	44	21	23	44

$$\text{Average flow time} = \frac{8 + 19 + 31 + 38 + 44}{5} = 28.0 \text{ hours}$$

$$\text{Average hours past due} = \frac{0 + 1 + 10 + 17 + 23}{5} = 10.2 \text{ hours}$$

The EDD rule is better than FCFS on both average flow time (28.0 vs. 29.4) and average hours past due (10.2 vs. 11.0). It gives the better schedule, although this is not always true.

17. Website designer
a. Schedules for two rules

FCFS rule:

Customer Sequence	Day Order Arrived	Start Time (days)		Processing Time (days)		Finish Time (days)	Due Date	Days Past Date	Flow Time (days)
A	180	190	+	20	=	210	216	0	30
B	182	210	+	12	=	222	240	0	40
C	184	222	+	28	=	250	256	0	66
D	187	250	+	24	=	274	248	26	87
E	188	274	+	32	=	306	290	16	118
Average								8.4	68.2

$$\text{Average flow time} = \frac{30 + 40 + 66 + 87 + 118}{5} = 68.2 \text{ days}$$

$$\text{Average days past due} = \frac{0 + 0 + 0 + 26 + 16}{5} = 8.4 \text{ days}$$

EDD RULE:

Customer Sequence	Day Order Arrived	Start Time (days)		Processing Time (days)		Finish Time (days)	Due Date	Days Past Date	Flow Time (days)
A	180	190	+	20	=	210	216	0	30
B	182	210	+	12	=	222	240	0	40
D	187	222	+	24	=	246	248	0	59
C	184	246	+	28	=	274	256	18	90
E	188	274	+	32	=	306	290	16	118
Average								6.8	67.4

$$\text{Average flow time} = \frac{30 + 40 + 59 + 90 + 118}{5} = 67.4 \text{ days}$$

$$\text{Average days past due} = \frac{0 + 0 + 0 + 18 + 16}{5} = 6.8 \text{ days}$$

- b. The EDD rule is better than FCFS on both average flow time (67.4 vs. 68.2) and average days past due (6.8 vs. 8.4). It gives the better schedule, although this is not always true.

18. Mowry Machine Shop
a. Schedules for two rules

FCFS rule:

Customer Sequence	Day Order Arrived	Start Time (days)		Processing Time (days)		Finish Time (days)	Due Date	Days Past Date	Flow Time (days)
A	12	23	+	10	=	33	45	0	21
B	13	33	+	8	=	41	36	5	28
C	15	41	+	4	=	45	42	3	30
	17	45	+	4	=	49	39	10	32
	22	49	+	3	=	52	53	0	30

$$\text{Average flow time} = \frac{21 + 28 + 30 + 32 + 30}{5} = 28.2 \text{ days}$$

$$\text{Average days past due} = \frac{0 + 5 + 3 + 10 + 0}{5} = 3.6 \text{ days}$$

EDD rule:

Customer Sequence	Day Order Arrived	Start Time (days)		Processing Time (days)		Finish Time (days)	Due Date	Days Past Date	Flow Time (days)
B	13	23	+	8	=	31	36	0	18
	17	31	+	4	=	35	39	0	18
C	15	35	+	4	=	39	42	0	24
A	12	39	+	10	=	49	45	4	37
	22	49	+	3	=	52	53	0	30

$$\text{Average flow time} = \frac{18 + 18 + 24 + 37 + 30}{5} = 25.4 \text{ days}$$

$$\text{Average days past due} = \frac{0 + 0 + 0 + 4 + 0}{5} = 0.8 \text{ days}$$

- b. The EDD rule is better than FCFS on both average flow time (25.4 vs. 28.2) and average days past due (0.8 vs. 3.6). It gives the better schedule, although this is not always true.

CASE: MEMORIAL HOSPITAL *

A. Synopsis

Memorial Hospital is a 265-bed regional hospital serving western North Carolina. The hospital is segmented into eight major care areas for the purpose of allocating nursing staff. Darlene Fry, Director of Nursing, is facing the annual problem of planning the nurse staffing levels for the upcoming year. Information pertaining to average patient census across the eight care areas as well as target patient-to-nurse ratios is presented. Students are also provided with sufficient cost data to help Darlene develop for next year a staffing plan that conforms to the mission and objectives of the hospital.

B. Purpose

The primary objective of the case is to have students develop a nurse staffing plan for Memorial Hospital next year. Parameters and data to allow students to use both demand and supply options to developing a feasible staffing plan are provided in the case. Available options that you should expect students to use and discuss in their plan include:

- ☐ Hiring and firing/layoff
- ☐ Overtime and undertime
- ☐ Use of temporary nurses (i.e., subcontracting)
- ☐ Use of vacations
- ☐ Cross training to be able to assign nurses across different care areas
- ☐ Offering new services such as HMOs for preventive medical care to keep skilled nurses employed

Students should be expected to address the trade-offs presented by the hospital's stated objectives, the costs of different options, and the projected demands for nursing services.

Students should also be able to begin to see the issues that are faced in the more detailed scheduling of personnel.

C. Analysis

Darlene faces several trade-offs to meet her three key objectives: maximizing customer service, minimizing costs, and minimizing workforce fluctuations. In general, maximizing customer service requires, on average, a larger nursing staff, which may possibly cause a direct trade-off with cost minimization. Minimizing workforce fluctuations requires some combination of overstaffing during slow months and using overtime or temp workers during heavy months.

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

Darlene can follow one of the three general staffing strategies—chase, modified level, or mixed.

- ❑ The chase strategy doesn't seem to be a desirable strategy based on both minimizing the workforce fluctuation and maximizing customer service objectives. In addition, the strategy has little advantage over a mixed strategy that can reduce the overstaffing/ understaffing and hiring/layoff costs.
- ❑ A modified level strategy means establishing a constant workforce level and then using a combination of temp workers and overtime during peak periods and undertime and vacations during slow periods. We call it “modified” because the use of temp workers is not level. This strategy would best meet the workforce fluctuation objective.
- ❑ A mixed strategy would use near level staffing with a minimal amount of hiring and/or layoffs during the peak and slow seasons. This strategy would require the trade-offs between the level workforce objective and the customer service and minimal cost objectives.

Students must first establish some guidelines for their analysis along with any simplifying assumptions. Some reasonable assumptions would be:

- ❑ The nurses in the seven care areas (ignoring surgery in this analysis) are interchangeable due to cross training. This level of aggregation may be too much of a simplification assumption for some students, who instead break them down into clusters of wards. For example, one way to disaggregate would be to have three subgroups. Subgroup 1 would consist of Intensive Care, Cardiac, Emergency, and Post Op; Subgroup 2 would have Maternity and Pediatric; and Subgroup 3 would be General. Transfers are allowed within the subgroups, but not between them. With this more disaggregate approach, students must make an assumption on how the current workforce of 110 nurses (excluding the 20 surgical nurses) is allocated to the three subgroups. Factors to consider if nurses are not aggregated into one workforce are: (1) similarity of skill requirements between wards, (2) differences in seasonal patient census patterns, and (3) translating nurse requirements into integers.
- ❑ The average daily patient census given in Table 15.4 indicates the patients needing care over the entire 24-hour period, seven days per week, and each week of the year. The daily data are assumed to be an average for the entire day; therefore differences between night and day shifts are accounted for in the data.
- ❑ Nurse requirements will be rounded up to the nearest full-time equivalent (FTE). A different approach is rounding to the nearest integer, either up or down. Students will differ as to how and when they convert to integer numbers. The rounding assumption, coupled by the level of aggregation of the workforce, can significantly affect their final determination of the number of FTE nurses required per month, and therefore total costs. A more detailed analysis can even allow partial FTEs and assign overtime to cover these requirements.

- ❑ Some assumption or decision must be made as to what constitutes a full week of regular time, so that nurse requirements can be expressed in terms of this number of hours. A common choice is a 40-hour week, because the case states current practice is four 10-hour days. Some hospitals are also moving to 12-hour days, which also could be considered. For our purposes here, we assume a nurse works 40 hours of regular time each week and can work another 20 hours on overtime each week (as long as not used excessively).
- ❑ Some allowance needs to be made for paid vacations. A plausible assumption is that vacation periods of four weeks (1/13 of a year) per full-time nurse can be assigned as needed across the year. The amount currently on the staff at the beginning of the planning horizon might be the ones entitled to a vacation, or perhaps the new ones hired are not entitled to vacations during their first year. A common tactic is to assign more vacation time for slow months and less vacation time for peak months, while not being so extreme in the assignments as to create excessive nurse dissatisfaction.
- ❑ Nurses can be given up to 10 hours per week of unpaid undertime, working only 30 hours per week. However, most students pass up this possible cost savings in favor of paying undertime, with each nurse working a minimum of 40 hours per week. This assumption is based on qualitative considerations, such as minimizing the amount of attrition from nurses seeking better jobs elsewhere.

Given these assumptions, some preliminary analysis can be done on the relative attractiveness of the reactive alternatives. Three comparisons are given following:

1. Hire/layoff versus temps
 $\$400 \text{ hire temp} = \$3/\text{hr premium}$
 $\$150 \text{ layoff}$
 $\$550 \text{ total}$
 $\$550 \div \$3/\text{hr} = 183 \text{ hours or } 4\text{--}5 \text{ weeks}$
 It is less expensive to hire a new nurse than to use a temporary nurse for over five weeks.
2. Overtime versus temps
 It is less expensive to use temporary nurses than to use an FTE nurse on overtime.

Temporary nurse	\$15/hour
Overtime	\$18/hour
3. Hire/layoff versus overtime
 $\$550 \div \$6/\text{hour premium} = 92 \text{ hours or } 2\text{--}3 \text{ weeks}$
 It is less expensive to hire a new nurse than to pay an FTE overtime for more than three weeks. (Maximum overtime for any one nurse is 20 hours per week.)

These three comparisons suggest that a low-cost solution would avoid excessive overtime, giving preference to temps, undertime, and vacation timing. Hiring and layoffs also appear attractive on a cost basis, except that the CEO lists aims to minimize fluctuations in workforce levels. Thus a near-level workforce, coupled with a liberal use of temps and judicious use of vacations, might lead to a good solution.

There are several ways to get the requirements row. Here are two approaches, illustrated for the Intensive Care (ICU) ward in the month of January:

1. Divide the average daily patient census per month in Table 15.5 by the patients per nurse required in Table 15.4, getting the number of nurses needed round the clock, 7 days per week. For ICU, it is $13/2 = 6.5$. Multiply this number by 168 hours per week ($7 \text{ days} \times 24 \text{ hours/day}$) and divide the product by the regular time capacity per week of one nurse. For the ICU ward, we get $(6.5 \times 168) / 40 = 27.3$ nurses. The equivalent of 27.3 nurses working 40 hours a week is required. Some students might inflate this number to account for lost vacation time, which is acceptable as long as they do not double count the vacations with their spreadsheets. The final number would be pooled with like numbers for the other wards in the workforce (or subgroup), and then rounded to an integer.
2. Another approach is to determine the total number of nurse hours needed each month, and then dividing by the regular time capacity made available over a month's time. The result should be comparable, depending on how many weeks (or days) are assumed in each month. For the ICU in January, the total demand in ICU nursing hours in January would be $(13/2) \times 24 \text{ hours/day} \times 31 \text{ days}$, or 4836 nurse hours. There are 4.43 weeks in January, so the typical nurse provides a month capacity of 177 hours. Dividing 4836 by this number gives 27.3 nurses required as before.

Using such logic, students will develop a projection of nurse requirements over the planning horizon, and then generate a number of feasible staffing plans using different strategies. One such plan is given in Appendix A. This plan holds that the nurse requirements in January for the whole workforce are 153 FTEs (with 40-hour weeks) and provides a level workforce throughout the year. The requirements show that Memorial Hospital has been understaffed, and proposes the workforce be increased to 148 full-time nurses. It uses no planned undertime and overtime, but depends instead on the temps and vacation schedules to handle the peaks and valleys of demand.

D. Recommendations

Obviously, the recommendations from the students will vary widely depending on the assumptions made and importance attributed to various qualitative factors. As the assumptions are relaxed, the staffing plan becomes more complex and difficult to develop.

E. Teaching Suggestions: As an Experiential Exercise

This case makes for an excellent team-based experiential exercise, spread over two days. It might take 45 minutes in the first day, and 30 minutes in the second day.

Day 1

Before the first day, have the class read over the case and ask each team to bring at least one laptop to class. When the session begins, get the teams to puzzle over the requirements and costs, with the goal to get them into using OM Explorer's *Sales and Operations Planning With Spreadsheets* Solver. They can talk about likely strategies

and perhaps try out several ones before the end of the class. In getting agreement on the requirements, make sure that they understand the need for 24-hour care (must provide for round-the-clock staffing). They must also decide how much to aggregate in dealing with the seven care areas (interchangeable or not), decide how to handle noninteger requirements (round or leave fractional), what to make a full-time week, how to handle paid vacations, whether to allow some unpaid undertime, and the like.

Day 2

For the second day, each team is to prepare a three-page report (maximum) describing their basic approach, strategy selected, spreadsheet (maybe sent by e-mail), and reasons why it is best (including qualitative factors). The instructor can make a transparency of the team results and lead the discussion of their results, seeing who (1) had low cost (open up their spreadsheet) and (2) had best for qualitative reasons (open up their spreadsheets). Maybe also bring out some basic analysis of:

- ☐ Hire/layoff versus temps
- ☐ Overtime versus temps
- ☐ Hire/layoff versus overtime

F. Teaching Suggestions: Out-of-Class Exercise

A more traditional approach is to assign it as an out-of-class exercise. Tell the students that they are to analyze the situation and can make some reasonable simplifying assumptions, but their assignment is to bring to class a staffing plan that they can share. They should be required to explain any assumptions made and to defend how their plan meets the three objectives of the hospital.

In class it is best to start with a general discussion of the alternative approaches that can be used to develop a staffing plan and how different approaches (level, chase, and mixed) may impact the hospital's objectives differently. Then have the students present their plans and explain their analysis and rationale. You may have to be prepared to show one of the plans provided to get the ball rolling.

After a few plans have been discussed, note that the differences are generally accounted for by the differing assumptions that were made or the differing priorities that were given the three objectives. Be sure that the students understand the impact assumptions such as the following have on staffing plans:

- ☐ Using FTE nurses versus partial nurses—overtime would be more appropriate when partial nurses are used.
- ☐ Interchangeability of nurses—the staffing plan would be more modularized by department without this assumption.
- ☐ Use of vacation periods as needed—loss of flexibility here would probably increase the requirements and costs.

The case can take as much time as you wish depending on the number of staffing plans you have students present. You should allow at least 30 to 45 minutes to discuss the issues and alternatives thoroughly.

APPENDIX A

Starting Workforce													110													Cost to Hire One Worker	\$400
Wages per Full-Time Nurse Equivalent per Period													\$2,080													Cost to Lay Off One Worker	\$150
Overtime Pay Percentage													150%														
Subcontracting Cost per Period													\$2,600														
☒ Employees Paid for Undertime																											
	← Fewer Periods												More Periods →														
Inputs	J	F	M	A	M	J	J	A	S	O	H	D	Total														
Forecasted demand	153	140	135	135	133	115	136	137	130	133	144	144	1635														
Workforce level	148	148	148	148	148	148	148	148	148	148	148	148	1776														
Vacation time	2	8	13	13	15	33	12	11	18	15	4	4	148														
Subcontracting time	7	0	0	0	0	0	0	0	0	0	0	0	7														
Derived																											
Utilized time	146	140	135	135	133	115	136	137	130	133	144	144	1,628														
Hires	38	0	0	0	0	0	0	0	0	0	0	0	38														
Layoffs	0	0	0	0	0	0	0	0	0	0	0	0	0														
Calculated																											
Utilized time cost	\$303,680	\$291,200	\$280,800	\$280,800	\$276,640	\$239,200	\$282,880	\$284,960	\$270,400	\$276,640	\$299,520	\$299,520	\$3,386,240														
Vacation time cost	\$4,160	\$16,640	\$27,040	\$27,040	\$31,200	\$68,640	\$24,960	\$22,880	\$37,440	\$31,200	\$8,320	\$8,320	\$307,840														
Hiring cost	\$15,200	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$15,200														
Layoff cost	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0														
Subcontracting cost	\$18,200	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$18,200														
Total cost	\$341,240	307,840	307,840	307,840	307,840	307,840	307,840	307,840	307,840	307,840	307,840	307,840	\$3,727,480														

ADDITIONAL CASE

CASE: FOOD KING *

A. Synopsis

The Food King case is set in the grocery supermarket industry where competition is severe and profit margins are a very small percentage of revenues. The principal in the case, Marty Moyer, has recently been promoted to the position of store manager at a large, flagship store in Columbia, South Carolina. Competitive positioning of the supermarket chain's service package has just been revised, and the store has recently adopted a 24-hour-a-day, 7-days-a-week open-door policy. The problem facing Marty is to develop a work schedule for the stocking/bagging employees that will satisfy competitive priorities and, at the same time, control costs.

B. Purpose

This case is designed to expose students to issues pertaining to scheduling workers in a service environment where demand typically exhibits large fluctuations over very short periods of time within a day or even within a shift.

Specific issues the case is meant to illustrate include:

- ☐ Adjusting capacity to meet demand, given workforce scheduling constraints concerning:
 - Organizational policies
 - Legal restrictions
 - Behavioral/psychological factors
 - Minimizing cost
- ☐ Seeing how the scheduling of workers impacts the ability of organizations to meet competitive priorities.
- ☐ Receiving enough information concerning demand, work policies, and costs to enable students to develop a work schedule.
- ☐ Rotating versus fixed work schedules within the context of meeting behavioral needs of the younger workers specifically.
- ☐ Appropriate measures for determining the effectiveness of the resulting schedule with respect to meeting the competitive priorities of Food King.

C. Analysis

The analysis should begin with a discussion of the target market and the accompanying shopper priorities. The issue here is translating customer requirements into organizational competitive priorities. Customer requirements given in the case were:

- ☐ Cleanliness

* This case was prepared by Dr. Brooke Saladin, Wake Forest University, as a basis for classroom discussion.

- ❑ Availability
- ❑ Timely service
- ❑ Reasonable prices

These requirements can be associated with the following competitive priorities:

1. *Quality*: Food King must maintain the quality of the service delivery package, which includes both high-performance design and service delivery process factors. Facilities that are easy to keep clean, don't look messy and cluttered, and are flexible with respect to changing displays and stocking locations should be designed. Stockers/baggers are the primary labor input in the housekeeping service process.
2. *Flexibility*: The many aspects of flexibility will impact virtually all of the customer requirements listed. The facilities must be designed to adapt to changing customer grocery item mixes. The store must keep the shelves stocked with what the customers want. Shelf space allocations, in-store displays, and the grocery item mix will be constantly changing.
3. *Fast and convenient delivery*: Perhaps on par with flexibility, the ability to provide fast, convenient service is important. The store recently established a 7-day, 24-hour open policy in response to customer and competitive requirements. Other aspects of fast delivery service include not having to wait at service counters (i.e., meat, deli, or bakery) or at the checkout counters.
4. *Low Cost*: The grocery store industry traditionally operates on very low profit margins. Customers may be willing to pay some premium for higher quality and faster service, but the issue is how much? This is one of the key trade-offs facing Food King. Stockers and baggers can be added to help meet each of the other competitive priorities, but then overall costs would rise.

Following a discussion of the trade-offs present in establishing the competitive priorities for Food King, students' attention should be directed to the development of a work schedule for stockers/baggers. This note contains one possible solution in Exhibits TN.1 through TN.7. Also attached is Appendix A, a student solution that contains two methods of approaching the schedule.

The solution in the teaching note is based on the following assumptions:

1. Full-time employees were assigned shifts of eight consecutive hours, each with two consecutive days off.
2. Part-time workers were scheduled in four-hour blocks of time.
3. The number of part-time hours worked could not exceed 50 percent of that of the full-time staff.
4. Standard full-time shifts began at 8 A.M., 4 P.M., and 12 A.M.
5. Maximize the use of full-time employees without creating a large amount of excess capacity.
6. Utilize part-time employees to avoid excess capacity and to lower labor costs.

The solution presented in the exhibits was developed using a modified version of the “minimize total slack capacity” approach outlined in Chapter 14, “Operations Planning and Scheduling.” The differences are that two consecutive four-hour blocks were used to identify the minimum requirement pairs. The work schedule for full-time employees is provided in Exhibit TN.1 with the procedure for the traditional shift schedules of 8:00 A.M., 4:00 P.M., and 12:00 A.M. given in Exhibits TN.2, TN.3, and TN.4. Twenty-two full-time stockers/baggers are utilized in this schedule. Eight will work from 8:00 A.M. to 4:00 P.M. with four having Sunday and Monday off and four having Wednesday and Thursday off. Six employees will work from 4:00 P.M. to 12:00 A.M. Two will have Wednesday and Thursday off, two will have Sunday and Monday off, and one will have Tuesday and Wednesday off.

Six employees will work the 12:00 A.M. to 8:00 A.M. shift with three having Saturday and Sunday off. Two employees will have Tuesday and Wednesday off and one will have Thursday and Friday off. The 21st and 22nd full-time employees were determined by creating a special 12:00 P.M. to 8:00 P.M. shift, as seen in Exhibit TN.5.

Exhibit TN.6 represents the remaining requirements after the 22 full-time employees had been scheduled. In order to cover these requirements, 12 part-time employees were scheduled. These workers represent 9.4 20-hour per week part-time employee equivalents. The part-time schedule is provided in Exhibit TN.7. The total costs of this schedule in labor cost dollars is:

$$\begin{aligned} 22 \text{ FT} \times 40 \text{ hrs/wk} \times \$5.25/\text{hr} &= \$4,620 \\ 9.4 \text{ PT} \times 20 \text{ hrs/wk} \times \$4.50/\text{hr} &= \underline{\quad 846 \quad} \\ &\$5,466 \end{aligned}$$

Of course there are many other combinations of part-time workers available. The configuration of part-time workers will change depending on the rules of thumb used to assign workers. However, if 22 full-time workers are employed, you need the equivalent of 9.4 part-time workers, each working 20 hours per week. General rules for the configuration in Exhibit TN.7 were to allocate 20 hours per worker when possible; do not allocate more than 8 hours in any one day, and try to spread like time slots across multiple days.

D. Recommendations

Once a schedule similar to the one provided in this note is developed, you can readily test its ability to cover expected demand and calculate the labor costs involved. There are no specified legal restrictions presented in this case. For example, most states have restrictions against high school students working after certain evening hours. In addition, there are organizational policies to consider with respect to limiting part-time employees to 50 percent of the hours of full-time employees and keeping part-time hours to 20 or fewer per employee. The solution presented has 22 full-time and 12 part-time employees scheduled, but some part-time employees work fewer than 20 hours per week. The effective full-time equivalent number of part-time employees is actually 9.4, well below the 50 percent target.

When students are convinced that the schedule meets demand, costs, and organizational guidelines, attention usually shifts toward the behavioral and psychological factors associated with the schedule. Therefore, additional recommendations will usually focus on the following issues:

- ❑ Should employees be rotated through the schedule in some manner to provide more fairness in days off and shifts?
- ❑ Are there other ways to assign individual employees to work schedules? Seniority? Performance ratings?
- ❑ Can employees swap days and shift times on a limited basis?
- ❑ What would be the impact of utilizing extended shift times, such as 10 hours?
- ❑ Having weekends off is usually a consideration brought up by the students. In the schedule provided, only three full-time employees have the whole weekend off, and they work the 12:00 A.M. to 8:00 A.M. shifts.

E. Teaching Suggestions

This is a pretty straightforward case that should be assigned as an overnight exercise. The primary focus, of course, is to challenge the student to adapt scheduling methodologies presented in the text in order to develop an acceptable schedule. The discussion should be sectioned into three stages. First, discuss the requirements being placed on the operating system, and make sure the students see how these customer requirements translate into competitive priorities. Second, go right into the development of a work schedule. Ask students to share their schedules and explain the assumptions and rules of thumb they used to arrive at their schedule. It is helpful if you can have at least two schedules presented so comparisons can be made and students can discuss the trade-offs made.

Finally, focus the students' attention on evaluating the schedule with respect to organizational policies and the behavioral implications of the schedule. It is easy to use an hour to discuss the case issues completely. I try to allocate 15 minutes to discuss the requirements and competitive priorities; 30 minutes to go over at least two different schedules; and 15 minutes to evaluate the schedules and discuss recommendations beyond the specific worker configuration. It is usually a good idea to have the solutions in this Teaching Note ready if students are reluctant to offer their solutions. However, make sure that they understand that this is not necessarily "the best" solution, just a feasible one. The best depends on the interpretation and prioritization of the trade-offs that are present.

EXHIBIT TN.1

Full-Time Work Schedule

Shift Time	Employee	M	T	W	Th	F	S	Su
8A–4P	1	off	X	X	X	X	X	Off
8A–4P	2	X	X	off	off	X	X	X
8A–4P	3	off	X	X	X	X	X	Off
8A–4P	4	X	X	off	off	X	X	X
8A–4P	5	off	X	X	X	X	X	Off
8A–4P	6	X	X	off	off	X	X	X
8A–4P	7	off	X	X	X	X	X	Off
8A–4P	8	X	X	off	off	X	X	X
4P–12A	9	X	X	off	off	X	X	X
4P–12A	10	off	X	X	X	X	X	Off
4P–12A	11	off	off	X	X	X	X	X
4P–12A	12	X	X	off	off	X	X	X
4P–12A	13	off	X	X	X	X	X	Off
4P–12A	14	X	off	off	X	X	X	X
12A–8A	15	X	X	X	X	X	off	Off
12A–8A	16	X	off	off	X	X	X	X
12A–8A	17	X	X	X	X	X	off	Off
12A–8A	18	X	off	off	X	X	X	X
12A–8A	19	X	X	X	off	off	X	X
12A–8A	20	X	X	X	X	X	off	Off
12P–8p	21	X	off	off	X	X	X	X
12P–8P	22	X	X	off	off	X	X	X

EXHIBIT TN.2

Full-Time 8:00 A.M.–4:00 P.M. Requirements

	M	T	W	TH	F	S	Su
8A–12P	6	8	5	5	8	15	4
12P–4P	6	8	5	5	10	15	6
8A–12P	6	7	4	4	7	14	4
12P–4P	6	7	4	4	9	14	6
8A–12P	5	6	4	4	6	13	3
12P–4P	5	6	4	4	8	13	5
8A–12P	5	5	3	3	5	12	3
12P–4P	5	5	3	3	7	12	5
8A–12P	4	4	3	3	4	11	2
12P–4P	4	4	3	3	6	11	4
8A–12P	4	3	2	2	3	10	2
12P–4P	4	3	2	2	5	10	4
8A–12P	3	2	2	2	2	9	1
12P–4P	3	2	2	2	4	9	3
8A–12P	3	1	1	1	1	8	1
12P–4P	3	1	1	1	3	8	3
8A–12P	2	0	1	1	0	7	0
12P–4P	2	0	1	1	2	7	2

Note: Bold pairs indicate chosen minimum requirements for each allocation. Pairs represent 8-hour shifts with consecutive days off.

EXHIBIT TN.3

Full-Time 4:00 P.M.–12:00 A.M. Requirements

	M	T	W	Th	F	S	Su
4P– 8P	5	6	5	5	15	15	6
8P– 12A	4	4	4	4	8	6	4
4P– 8P	4	5	5	5	14	14	5
8P– 12A	3	3	4	4	7	5	3
4P– 8P	4	4	4	4	13	13	5
8P– 12A	3	2	3	3	6	4	3
4P– 8P	4	4	3	3	12	12	4
8P– 12A	3	2	2	2	5	3	2
4P– 8P	3	3	3	3	11	11	3
8P– 12A	2	1	2	2	4	2	1
4P– 8P	3	2	2	2	10	10	3
8P– 12A	2	0	1	1	3	1	1
4P– 8P	2	2	2	1	9	9	2
8P– 12A	1	0	1	0	2	0	0

Note: Bold pairs indicate chosen minimum requirements for each allocation. Pairs represent 8-hour shifts with consecutive days off.

EXHIBIT TN.4

Full-Time 12:00 A.M.–8:00 A.M. Requirements

	M	T	W	Th	F	S	Su	
12A–4A	4	4	4	4	5	4	4	
4A–8A	8	4	4	8	5	4	4	
12A–4A	3	3	3	3	4	4	4	
4A–8A	7	3	3	7	4	4	4	
12A–4A	2	3	3	2	3	3	3	
4A–8A	6	3	3	6	3	3	3	
12A–4A	1	2	2	1	2	3	3	
4A–8A	5	2	2	5	2	3	3	
12A–4A	0	2	2	0	1	2	2	
4A–8A	4	2	2	4	1	2	2	
12A–4A	0	1	1	0	1	1	1	
4A–8A	3	1	1	4	1	1	1	
12A–4A	0	0	0	0	0	1	1	
4A–8A	2	0	0	3	0	1	1	

Note: Bold pairs indicate chosen minimum requirements for each allocation. Pairs represent 8-hour shifts with consecutive days off.

	EXHIBIT TN.5							Full-Time 12:00 A.M.–8:00 A.M. Requirements
	M	T	W	Th	F	S	Su	
12P– 4P*	2	0	1	1	2	7	2	
4P– 8P**	2	2	2	1	9	9	2	
12P– 4P	1	0	1	0	1	6	1	
4P– 8P	1	2	2	0	8	8	1	
12P– 4P	0	0	1	0	0	5	0	
4P– 8P	0	1	2	0	7	7	0	

* From Exhibit TN.2 last row of 12 P.M.–4 P.M.

** From Exhibit TN.3 last row of 4 P.M.–8 P.M.

EXHIBIT TN.6

Remaining Part-Time Employee Requirements

	M	T	W	Th	F	S	Su
8A–12P	2	0	1	1	0	7	0
12P–4P	0	0	1	0	0	5	0
4P–8P	0	1	2	0	7	7	0
8P–12A	1	0	1	0	2	0	0
12A–4A	0	0	0	0	0	1	1
4A–8A	2	0	0	3	0	1	1

Note: This matrix represents the requirements that remain after the full-time employees were scheduled. They are transcribed from the last row of requirements from Exhibits TN.2, TN.3, TN.4, and TN.5.

EXHIBIT TN.7

Part-Time Employee Work Schedule

	M	T	W	TH	F	S	SU
PT-1 (20 hr)	8A–12P		8A–12P	8A–12P		8A–4P	
PT-2 (20 hr)		4P–8p	4P–8P		4P–12A	4P–8P	
PT-3 (20 hr)	8p–12A		8P–12A		4P–12A	4P–8P	
PT-4 (20 hr)				4A–8A		12A–8A	12A–8A
PT-5 (20 hr)	4A–12P				4P–8P	8A–4P	
PT-6 (20 hr)	4A–8A			4A–8A	4P–8A	8A–4P	
PT-7 (20 hr)			12P–4P	4A–8A	4P–8P	12P–8P	
PT-8 (16 hrs)			4P–8P		4P–8P	8A–4P	
PT-9 (12 hrs)					4P–8P	8A–12P	
PT-10 (8 hrs)						4P–8P	
PT-11 (8 hrs)						8A–12P	
PT-12 (4 hrs)						4P–8P	
Total number of four-hour shifts	5	1	5	4	9	21	2

APPENDIX A Student Solutions

A. Food King—Scheduling

Two methods were used to determine the schedule. Both methods required the full-time employees to be given two consecutive days off. In addition, standard start times with 8-hour shifts were used whenever possible.

- ❑ Method 1 results are provided as Attachment 1. For this method, workers were assigned in a way that emphasized three standard shifts: (Tue-Sat at 8 A.M., 4 P.M., and 12 A.M.). Other shifts were used as required to balance workers.
- ❑ Method 2 results are provided as Attachment 2. For this method, workers were assigned in a way that minimized slack, as defined in the text. Days off were selected one worker at a time, based on the minimum capacity (employee) requirements. The pair of 4-hour blocks selected was based on the maximum number of workers required for two consecutive blocks. These rules were modified as required to balance the number of workers.

Additional information concerning trade-offs and priorities:

- ❑ Excess full-time workers were not used with either method. With this restriction, the fraction of part-time employees slightly exceeded 50 percent for Method 1.
- ❑ Food King likely requires additional full-time workers because the part-time worker head count was based on 20-hour workweeks.
- ❑ Method 2 does a better job of minimizing part-time workers during peak stocking hours. For both methods, the use of part-time workers is maximized during peak bagging hours as much as possible.

Options to allow more fairness in the schedule:

- ❑ Food King should cycle individual worker schedules once a month or so. Workers should be allowed to swap 4-hour schedule blocks.
- ❑ A method should be developed to allow weekends off on a rotating basis.
- ❑ Extended shifts of up to 12 hours or four 10-hour days could be considered.

ATTACHMENT 1: FOOD KING Method 1

Stocking/bagging personnel required

	Mon	Tue	Wed	Thur	Fri	Sat	Sun	Total
8:00 A.M.	6	8	5	5	8	15	4	51
12:00 P.M.	6	8	5	5	10	15	6	55
4:00 P.M.	5	6	5	5	15	15	6	57
8:00 P.M.	4	4	4	4	8	6	4	34
12:00 A.M.	4	4	4	4	5	4	4	29
4:00 A.M.	8	4	4	8	5	4	4	37
	33	34	27	31	51	59	28	263

Full-time personnel

	Mon	Tue	Wed	Thur	Fri	Sat	Sun	Total	
8:00 A.M.	4	5	4	5	6	7	4	35	
12:00 P.M.	5	7	4	5	9	9	6	45	
4:00 P.M.	4	6	4	5	8	8	5	40	
8:00 P.M.	3	4	3	4	6	6	3	29	
12:00 A.M.	3	4	3	4	4	4	3	25	FT
4:00 A.M.	3	4	4	5	3	4	3	26	emps
	22	30	22	28	36	38	24	200	20

Part-time personnel

	Mon	Tue	Wed	Thur	Fri	Sat	Sun	Total	
8:00 A.M.	2	3	1	0	2	8	0	16	
12:00 P.M.	1	1	1	0	1	6	0	10	
4:00 P.M.	1	0	1	0	7	7	1	17	
8:00 P.M.	1	0	1	0	2	0	1	5	
12:00 A.M.	1	0	1	0	1	0	1	4	PT
4:00 A.M.	5	0	0	3	2	0	1	11	emps
	11	4	5	3	15	21	4	63	12.6

Hours\Days	Tu- Sa	We- Su	Th- Mo	Fr- Tu	Sa- We	Su- Th	
8:00 A.M.–4:00 P.M.	3		1	1			
12:00 P.M.–8:00 P.M.		1		3			
4:00 P.M.–12:00 A.M.	3		1				
8:00 P.M.–4:00 A.M.			1	1			Full-time
12:00 A.M.–8:00 A.M.	2					1	employees
4:00 A.M.–12:00 A.M.			1		1		20

ATTACHMENT 2: FOOD KING Method 2

Stocking/bagging personnel required

	Mon	Tue	Wed	Thur	Fri	Sat	Sun	Total
8:00 A.M.	6	8	5	5	8	15	4	51
12:00 P.M.	6	8	5	5	10	15	6	55
4:00 P.M.	5	6	5	5	15	15	6	57
8:00 P.M.	4	4	4	4	8	6	4	34
12:00 A.M.	4	4	4	4	5	4	4	29
4:00 A.M.	8	4	4	8	5	4	4	37
	33	34	27	31	51	59	28	263

Full-time personnel

Mon	Tue	Wed	Thur	Fri	Sat	Sun	Total	
8:00 A.M.	4	8	4	5	8	8	4	41
12:00 P.M.	5	8	4	5	9	10	5	46
4:00 P.M.	5	6	3	5	8	8	5	40
8:00 P.M.	4	4	2	4	6	6	4	30
12:00 A.M.	4	4	2	3	4	4	4	25
4:00 A.M.	4	4	3	4	5	4	4	28
	26	34	18	26	40	40	26	210
								FT emps 21

Part-time personnel

	Mon	Tue	Wed	Thur	Fri	Sat	Sun	Total
								1
8:00 A.M.	2	0	1	0	0	7	0	10
12:00 P.M.	1	0	1	0	1	5	1	9
4:00 P.M.	0	0	2	0	7	7	1	17
8:00 P.M.	0	0	2	0	2	0	0	4
12:00 A.M.	0	0	2	1	1	0	0	4
4:00 A.M.	4	0	1	4	0	0	0	9
	7	0	9	5	11	19	2	53
								10.6

Hours/Days	Mo- Fr	Tu- Sa	We- Su	Th- Mo	Fr- Tu	Sa- We	Su- Th	
8:00 A.M.–4:00 P.M.		2			1			
12:00 P.M.–8:00 P.M.		2		1	3			
4:00 P.M.–12:00 A.M.		1		1				
8:00 P.M.–4:00 A.M.		1		1	2			
								Full-time employees
12:00 A.M.–8:00 A.M.							1	21
4:00 A.M.–12:00 A.M.		2		1	2			

Chapter

16 Resource Planning

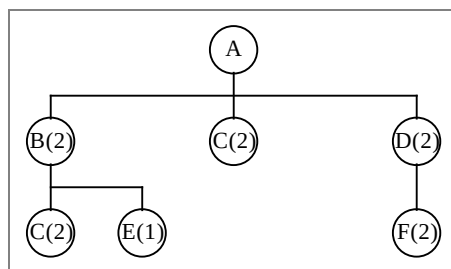
DISCUSSION QUESTIONS

1. The purpose of this exercise is to get the students to think about the usefulness of ERP for each of their major areas of interest. Because groups consist of different functional area representatives, the discussion is intended to emphasize the cross-functional needs that are satisfied with an information system such as ERP. Some responses to this exercise include:
 - ❑ Marketing—information about the availability of finished products that can be promised for delivery; finished goods inventory performance (service levels, stockouts).
 - ❑ Finance—short-term financing needs for production plans, developed from the order releases and projected inventory levels.
 - ❑ Accounting—billing invoices for products shipped to customers; payments to suppliers of raw materials and purchased components, developed from the schedule of orders actually received.
 - ❑ Operations—the schedule of order releases to support the master schedule; estimates of capacity requirements at critical work centers.
2. Some responses from each functional area could include:
 - ❑ Marketing: The available-to-promise quantities because they determine when orders can be promised to customers, the history of orders accepted for each product by time period because this information can be useful in projecting future demand patterns.
 - ❑ Finance: The projected MPS quantities and inventory levels because they will indicate cash needs.
 - ❑ Operations: The MPS start quantities because they indicate when production of products must begin to meet customer promises and because they provide the basis for estimating capacity needs at critical workstations.
3. A master flight schedule specifies the arrival and departure times for all the flights an airline must produce to meet customer demands. Here, the lead time is the time between departure and arrival, which is similar to the lead time in producing a quantity of a product. The passenger size of the aircraft is analogous to a production quantity, and the available-to-promise quantity in manufacturing bears similarity to the seats available on a given flight. In general, the flight schedule can be used to estimate the needs for resources such as pilots, flight attendants, airport slots, and aircraft.

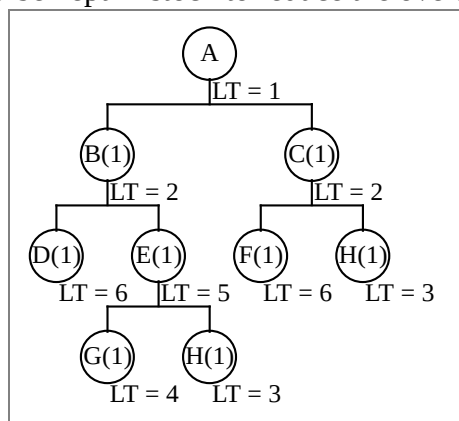
4. The principles of MRP can be used for UPS by identifying bills of resources for resources such as employees, trucks, planes, and equipment. Forecasts of delivery requirements and the BORs can be used to estimate resource needs and project the loads on critical sorting operations.

PROBLEMS

1. Bill of materials, Figure 16.27
 - a. Item I has only one parent (E). However, item E has two parents (B and C).
 - b. Item A has 10 unique components (B, C, D, E, F, G, H, I, J, and K).
 - c. Item A has five purchased items (I, F, G, H, and K). These are the items without components.
 - d. Item A has five intermediate items (B, C, D, E, and J). These items have both parents and components.
 - e. The longest path is I–E–C–A at 11 weeks.
2. Item A. The bill of materials for item A is shown following.

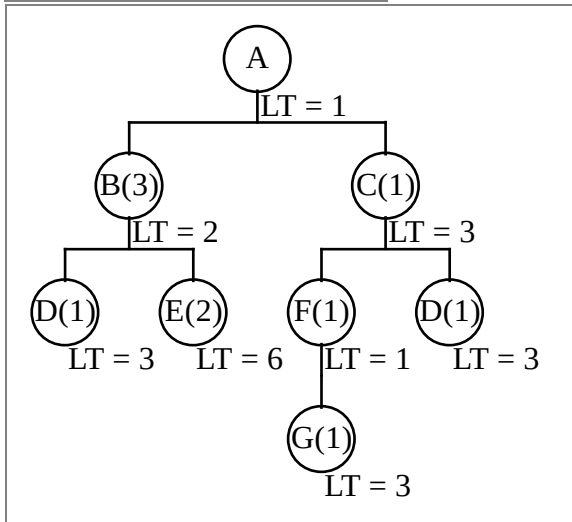


3. Lead time is determined by the longest path, C–B–A, at 13 weeks.
4. The bill of materials for item A with lead times is shown following.
 - a. Lead time is determined by the longest path
G–E–B–A = 12 weeks.
 - b. If purchased items D, F, G, and H are already in inventory, the lead time is reduced to: A–B–E = 8 weeks.
 - c. Item G is the purchased item with the longest lead time in the longest path. This purchased item could be kept in stock to reduce the overall lead time.



5. Refer to Figure 16.22 and Solved Problem 1.

FIGURE 15.19



Material requirement to produce 5 units of end-item A:

$$(5A \times 3B \text{ per } A) = 15B - 2B \text{ on hand} = 13B$$

$$(5A \times 1C \text{ per } A) = 5C$$

Material requirement to produce 13B:

$$(13B \times 1D \text{ per } B) = \mathbf{13D}$$

$$(13B \times 2E \text{ per } B) = \mathbf{26E}$$

Material requirement to produce 5C:

$$(5C \times 1D \text{ per } C) = \mathbf{5D}$$

$$(5C \times 1F \text{ per } C) = 5F - 1F \text{ on hand} = 4F$$

Material requirement to produce 4F:

$$(4F \times 1G \text{ per } F) = \mathbf{4G} - 3G \text{ on hand} = \mathbf{1G}$$

Purchased material requirements net of on-hand inventory: $13 + 5 = 18D$, $26E$, and $1G$.

6. MPS record in Figure 16.29 The following table is from the Master Production Scheduling Solver in OM Explorer. The ATP row is not required for this problem.

Solver Master Production Scheduling																
Enter data in yellow shaded areas.																
Lot Size	60															
Lead Time	1															
Quantity on Hand	35	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Forecast		20	18	28	28	23	30	33	38							
Customer Orders (Booked)		15	17	9	14	9		7								
Projected On-Hand Inventory		15	57	29	1	38	8	35	57							
MPS Quantity			60			60		60	60							
MPS start		60			60		60	60								
Available-to-Promise Inv (ATP)		20	20			51		53	60							
☐ Override Formulas		☒ Restore Formulas														

7. MPS record in Figure 16.30

Lot Size: 100	January					February		
Quantity on Hand: 75	1	2	3	4	5	6	7	8
Forecast	65	65	65	45	50	50	50	50
Customer orders (booked)	40	10	85	0	35	70	0	0
Projected on-hand inventory	10	45	60	15	65	95	45	95
MPS quantity		100	100		100	100		100
MPS start	100	100		100	100		100	

8. An end-item

Lot Size: 100	Week									
Quantity on Hand: 80	1	2	3	4	5	6	7	8	9	10
Forecast	30	20	35	50	25	25	0	40	0	50
Customer orders (booked)	22	30	15	9	0	0	5	3	7	0
Projected on-hand inventory	50	20	85	35	10	85	80	40	33	83
MPS quantity			100			100				100
MPS start	100			100				100		

9. Ball Bearings

Prospective MPS

a.

Solver Master Production Scheduling																
Enter data in yellow shaded areas.																
Lot Size	500															
Lead Time	1															
Quantity on Hand	400	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Forecast	550 300 400 450 300 350 200 300 450 400															
Customer Orders (Booked)	300 350 250 250 200 150 100 100 100 100															
Projected On-Hand Inventory	350 100 150 350 300 50 150															
MPS Quantity	500 500 500 500 500 500 500															
MPS start	500 500 500 500 500 500															
Available-to-Promise Inv (ATP)	250 250 250 150 300 400 400															
☐ Override Formulas		☒ Restore Formulas														

The first order for 500 (in week 4) should be accepted. Through week 4, on hand (400) plus three MPS quantities of 500 each = 1900. Of those, (300 + 350 + 250 + 250) = 1150 have been sold, leaving 750 available (250 after this commitment).

- b. The second order for 400 (in week 5) should be accepted. Through week 5, the 250 remaining after the first order plus one more MPS quantity of 500 = 750. Of those, 200 have been sold in the 5th week and 150 in the 6th week. Therefore, (250 + 500 – 200 – 150) = 400 are still available. There will be zero units remaining for sale even after accepting this order.

The third order for 300 units (in week 1) should *not* be accepted. At that time, of the 400 on hand, plus 500 MPS quantity to arrive in the first week, a total of 300 plus 350 has been sold. Note that because no MPS is scheduled for the 2nd week, the 350 ordered for the 2nd week must come from those on hand or those arriving in the 1st week. In total [(400 + 500) – (300 + 350)] = 250 remaining, which will not cover the order for 300. Although a partial order of 250 could be fulfilled, these 250 units are required to satisfy orders 1 and 2.

The fourth order for 300 units (in week 7) should be accepted. After accepting the second order (part ii), zero units remain. In the 7th week 500 units arrive. Of those, demands of 100 in each of weeks 7 and 8 have been promised, leaving (500 – 200) = 300. This order of 300 units would reduce the quantity available to promise to zero units.

10. Tabard Industries

a. The prospective MPS

	Week							
Quantity on Hand: 150	1	2	3	4	5	6	7	8
Forecast	120	120	120	100	100	100	80	80
Customer orders (booked)	100	80	60	40	10	10	0	0
Projected on-hand inventory	30	110	190	90	190	90	10	130
MPS quantity		200	200		200			200
MPS start	200	200		200			200	

b. The revised MPS given changes in forecasted demand

	Week							
Quantity on Hand: 150	1	2	3	4	5	6	7	8
Forecast	120	120	120	150	150	150	100	100
Customer orders (booked)	100	80	60	40	10	10	0	0
Projected on-hand inventory	30	110	190	40	90	-60	-160	-60
MPS quantity		200	200		200			200
MPS start	200	200		200			200	

The projected on-hand inventory row indicates a negative balance in week 6. However, this will become problematic only if the new customer orders meet these forecasts. If the new forecasts are accurate, the MPS quantities will need to be revised.

c. The revised MPS given a newly accepted customer order

	Week							
Quantity on Hand: 150	1	2	3	4	5	6	7	8
Forecast	120	120	120	100	100	100	80	80
Customer orders (booked)	100	280	60	40	10	10	0	0
Projected on-hand inventory	30	-50	30	-70	30	-70	-150	-30
MPS quantity		200	200		200			200
MPS start	200	200		200			200	

The projected on-hand inventory row indicates a negative balance in week 2. Since this change represents actual demand, this situation requires that the MPS quantity be revised or demand must be shifted to future weeks.

11. Completed MPS Record

ITEM: 2" Pneumatic Control Valve
LEAD TIME: 1 week

ORDER POLICY: 75 units
QUANTITY ON HAND: 10 units

	Week							
	1	2	3	4	5	6	7	8
Forecast requirements	40	40	40	40	30	30	50	50
Customer orders (booked)	60	45	30	35	10	5	5	0
Projected on-hand inventory	25	55	15	50	20	65	15	40
MPS quantity	75	75		75		75		75
MPS start	75		75		75		75	
Available-to-promise (ATP) inventory	25			30		65		75

Decisions on the arriving orders:

- ☐ Order 1 for 15 units in week 2 should be accepted because there are 25 units ATP from week 1. After this order is accepted 10 units remain in ATP from Week 1.
- ☐ Order 2 for 30 units in week 5 should be accepted because there are 30 units ATP from week 4. After this order is accepted 10 units still remain in ATP from week 1 and zero units from week 4.
- ☐ Order 3 for 25 units in week 3 should NOT be accepted because there are only 10 units remaining in ATP from week 1 and this is not adequate to fill the order completely. After this order is rejected 10 units continue to remain in ATP from week 1.
- ☐ Order 4 for 75 units in week 7 should be accepted because there will be 65 units in ATP from week 6, which, along with the 10 units that continue to remain in ATP from week 1, will be adequate to fill the order completely.

12. a. Completed MPS Record

ITEM: Electric Hand Drill
LEAD TIME: 1 week

ORDER POLICY: 60 units
QUANTITY ON HAND: 30 units

	Week					
	1	2	3	4	5	6
Forecast requirements	15	40	10	20	50	30
Customer orders (booked)	20	25	10	20		
Projected on-hand inventory	10	30	20		10	40
MPS quantity		60			60	60
MPS start	60			60	60	
Available-to-promise (ATP) inventory	10	5			60	60

- b. The shipping date would be week 2 because we will have 10 units from week 1 and 5 units from week 2 available-to-promise inventory to fill this order.

13. Completed MPS record

ITEM: Product C

LEAD TIME: 2 weeks

ORDER POLICY: 40 units

QUANTITY ON HAND: 10 units

	Week											
	1	2	3	4	5	6	7	8	9	10	11	12
Forecast requirements	15	15	15	15	20	20	20	20	15	15	15	15
Customer orders (booked)	25	12	8	10	2	3	0	0	0	0	0	0
Projected on-hand inventory	25	10	35	20	0	20	0	20	5	30	15	0
MPS quantity	40		40			40		40		40		
MPS start	40			40		40		40				
Available-to-promise (ATP) inventory	13		20			37		40		40		

14. Inventory record.

The tables following were generated with the Single-Item MRP solver from OM Explorer.

- a. Fixed order quantity = 110

Inputs

Solver - Single-Item MRP

Periods	8							
Item	M405-X				Period (P) for POQ			Lot Size (FOQ) 110
Description	Table Top Assembly							Lead Time 2
FOQ Rule								Safety Stock 0
	1	2	3	4	5	6	7	8
Gross Requirements	90		85		80		45	90
Scheduled Receipts	110							
Projected On-Hand Inventory	40	60	60	85	85	5	5	70
Planned Receipts			110				110	110
Planned Order Releases	110				110	110		

b. L4L

Inputs**Solver - Single-Item MRP**

Periods	8							
Item	M405-X		Period (P) for POQ			Lot Size (FOQ)		
Description	Table Top Assembly					Lead Time		
L4L Rule						Safety Stock		
			1	2	3	4	5	6
Gross Requirements		90			85		80	45
Scheduled Receipts		110						
Projected On-Hand Inventory	40	60	60					
Planned Receipts				25		80		45
Planned Order Releases		25		80		45	90	

c. POQ, $P = 2$ **Inputs****Solver - Single-Item MRP**

Periods	8							
Item	M405-X		Period (P) for POQ			2 Lot Size (FOQ)		
Description	Table Top Assembly					Lead Time		
POQ Rule						Safety Stock		
			1	2	3	4	5	6
Gross Requirements		90			85		80	45
Scheduled Receipts		110						
Projected On-Hand Inventory	40	60	60					90
Planned Receipts				25		80		135
Planned Order Releases		25		80		135		

15. Completed inventory records

a. FOQ of 150 units

Item:	Rotor assembly				Lot Size: Lead Time:		150 units 2 weeks	
Week	1	2	3	4	5	6	7	8
Gross requirements	65	15	45	40	80	80	80	80
Scheduled receipts	150							
Projected on hand	20	105	90	45	5	75	145	65
Planned receipts					150	150		150
Planned order releases			150	150		150		

b. L4L

Item:	Rotor assembly				Lot Size: Lead Time:		L4L 2 weeks	
Week	1	2	3	4	5	6	7	8
Gross requirements	65	15	45	40	80	80	80	80
Scheduled receipts	150							
Projected on hand	20	105	90	45	5	0	0	0
Planned receipts					75	80	80	80
Planned order releases			75	80	80	80		

c. POQ with $P = 2$

Item:	Rotor assembly				Lot Size: Lead Time:		POQ, $P = 2$ 2 weeks	
Week	1	2	3	4	5	6	7	8
Gross requirements	65	15	45	40	80	80	80	80
Scheduled receipts	150							
Projected on hand	20	105	90	45	5	80	0	80
Planned receipts					155		160	
Planned order releases			155		160			

16. Completed inventory records

a. FOQ of 50 units

Item:	Drive shaft				Lot Size: Lead Time:		50 units 3 weeks	
Week	1	2	3	4	5	6	7	8
Gross requirements	35	25	15	20	40	40	50	50
Scheduled receipts	80							
Projected on hand	10	55	30	15	45	5	15	15
Planned receipts				50		50	50	50
Planned order releases	50		50	50	50			

b. L4L

Item:	Drive shaft				Lot Size: Lead Time:		L4L 3 weeks	
Week	1	2	3	4	5	6	7	8
Gross requirements	35	25	15	20	40	40	50	50
Scheduled receipts	80							
Projected on hand	10	55	30	15	0	0	0	0
Planned receipts				5	40	40	50	50
Planned order releases	5	40	40	50	50			

c. POQ with $P = 4$

Item:	Drive shaft				Lot Size: Lead Time:		POQ, $P = 4$ 3 weeks	
Week	1	2	3	4	5	6	7	8
Gross requirements	35	25	15	20	40	40	50	50
Scheduled receipts	80							
Projected on hand	10	55	30	15	130	90	50	0
Planned receipts				135				50
Planned order releases	135				50			

17. Rear wheel assembly

a. Completed inventory record with an FOQ of 200 units

Item: MQ-09							Lot Size: FOQ of 200 units				
Description: Rear wheel subassembly							Lead Time: 1 week				
							Week				
		1	2	3	4	5	6	7	8	9	10
Gross requirements		25	105	110	90		45	110	60		
Scheduled receipts											
Projected on-hand inventory	50	25	120	10	120	120	75	165	105	105	105
Planned receipts			200		200			200			
Planned order releases		200		200			200				

b. Completed inventory record with an FOQ of 100 units

Item: MQ-09							Lot Size: FOQ of 100 units										
Description: Rear wheel subassembly							Lead Time: 1 week										
							Week										
								1	2	3	4	5	6	7	8	9	10
Gross requirements								25	105	110	90		45	110	60		
Scheduled receipts																	
Projected on-hand inventory							50	25	20	10	20	20	75	65	5	5	5
Planned receipts									100	100	100		100	100			
Planned order releases								100	100	100		100	100				

c. Completed inventory record with L4L

Item: MQ-09								Lot Size: L4L											
Description: Rear wheel subassembly								Lead Time: 1 week											
								Week											
									1	2	3	4	5	6	7	8	9	10	
Gross requirements									25	105	110	90		45	110	60			
Scheduled receipts																			
Projected on-hand inventory								50	25	0	0	0	0	0	0	0	0	0	0
Planned receipts										80	110	90		45	110	60			
Planned order releases									80	110	90		45	110	60				

18. Motor subassembly

a. Completed inventory record with L4L

Item: MQ-09							Lot Size: L4L											
Description: Motor subassembly							Lead Time: 2 week											
							Week											
								1	2	3	4	5	6	7	8	9	10	
Gross requirements									80	50	35	20	55	15	30	25	10	
Scheduled receipts								60										
Projected on-hand inventory							20	80	0	0	0	0	0	0	0	0	0	0
Planned receipts										50	35	20	55	15	30	25	10	
Planned order releases								50	35	20	55	15	30	25	10			

b. Completed inventory record with POQ ($P=2$ weeks)

Item: MQ-09								Lot Size: POQ P=2 weeks			
Description: Motor subassembly								Lead Time: 2 week			
								Week			
		1	2	3	4	5	6	7	8	9	10
Gross requirements			80	50	35	20	55	15	30	25	10
Scheduled receipts		60									
Projected on-hand inventory	20	80	0	35	0	55	0	30	0	10	0
Planned receipts				85		75		45		35	
Planned order releases		85		75		45		35			

c. Completed inventory record with POQ ($P=4$ weeks)

Item: MQ-09	Lot Size: POQ P=4 weeks										
Description: Motor subassembly	Lead Time: 2 week										
	Week										
		1	2	3	4	5	6	7	8	9	10
Gross requirements			80	50	35	20	55	15	30	25	10
Scheduled receipts		60									
Projected on-hand inventory	20	80	0	110	75	55	0	65	35	10	0
Planned receipts				160				80			
Planned order releases		160				80					

- d. The total cost of each lot sizing rule is calculated as follows:

Holding cost = total number of units held for 1 week over the time horizon * weekly holding cost

Ordering cost = the number of orders placed over the time horizon * order release cost

These calculations are provided in the following table for the three lot sizing rules used:

Lot size rule	Total Inventory units held	Number of Orders placed	Holding cost	Ordering cost	Total cost
L4L	80	8	\$80	\$400	\$480
POQ (P=2)	210	4	\$210	\$200	\$410
POQ (P=4)	430	2	\$430	\$100	\$530

POQ (P=2) provides the lowest holding+ordering cost

19. MRP for Figure 16.38

- a. This solution was developed using the *Material Requirements Planning* module in OM Solver.

Inputs

Solver - Material Requirements Planning

Enter data in yellow shaded areas.

Master Production Schedule

		1	2	3	4	5	6	7	8	9	10
Item A MPS Start	Descr:			100			200				
Item B MPS Start	Descr:										

☒ Use second finished item

Material Requirements Planning

Item C	Descr:										
L4L Rule											
	Usage Quantity for Item: A	1	B								
		1	2	3	4	5	6	7	8	9	10
Gross Requirements				100			200				
Scheduled Receipts											
Projected On-Hand Inventory	50	50	50	0	0	0	0	0	0	0	0
Planned Receipts			50				200				
Planned Order Releases		50			200						

Item D	Descr:	Period (P) for POQ		Lot Size (FOQ)		200	
FOQ Rule	▼			Lead Time		1	
Usage Quantity for Item:		A	2	B	C		
		1	2	3	4	5	6
Gross Requirements				200			400
Scheduled Receipts				200			
Projected On-Hand Inventory	200	200	200	200	200	200	0
Planned Receipts							200
Planned Order Releases						200	

Item E	Descr:	Period (P) for POQ		3		Lot Size (FOQ)	
POQ Rule	▼					Lead Time	
Usage Quantity for Item:		A	4	B	C	D	
		1	2	3	4	5	6
Gross Requirements				400			800
Scheduled Receipts				200			
Projected On-Hand Inventory		0	0	0	0	0	0
Planned Receipts				200			800
Planned Order Releases			200			800	

b. In week 1, an order for 50 units of item C should be released.

20. MRP for Figure 16.39

- a. This solution was developed using the *Material Requirements Planning* module in OM Solver.

For item C, an inventory shortage will occur in week 2. This item has no Projected On-Hand Inventory and the next Scheduled Receipt will not arrive until week 3. Items D and E can cover all Gross Requirements from current On-Hand Inventory, Scheduled Receipts and Planned Order Releases.

Solver - Material Requirements Planning

Enter data in yellow shaded areas.

Master Production Schedule

		1	2	3	4	5	6	7	8	9	10
Item A MPS Start	Descr:		85		200				50		
Item B MPS Start	Descr:			65	50	50			75		

■ Use second finished item

Material Requirements Planning

Item C	Descr:	Period (P) for POQ						Lot Size (FOQ)			
L4L Rule								Lead Time			
								Safety Stock			
Usage Quantity for Item: A		2	B		1						
		1	2	3	4	5	6	7	8	9	10
Gross Requirements			170	65	450	50			175		
Scheduled Receipts				200							
Projected On-Hand Inventory			0	-170	0	0	0	0	0	0	0
Planned Receipts				35	450	50			175		
Planned Order Releases			35	450	50		175				

Item D	Descr:	Period (P) for POQ					Lot Size (FOQ)		200		
FOQ Rule							Lead Time		1		
							Safety Stock				
Usage Quantity for Item: A		1	B	2	C						
		1	2	3	4	5	6	7	8	9	10
Gross Requirements			85	130	300	100			200		
Scheduled Receipts											
Projected On-Hand Inventory		0	115	185	85	185	185	185	185	185	185
Planned Receipts			200	200	200	200			200		
Planned Order Releases		200	200	200	200			200			

Item E	Descr:		Period (P) for POQ					2	Lot Size (FOQ)		
POQ Rule									Lead Time		
									Safety Stock		
Usage Quantity for Item: A 4 B C D											
		1	2	3	4	5	6	7	8	9	10
Gross Requirements			340		800				200		
Scheduled Receipts											
Projected On-Hand Inventory	200	200	0	0	0	0	0	0	0	0	0
Planned Receipts			140		800				200		
Planned Order Releases		140		800				200			

- b. This solution was developed using the *Material Requirements Planning* module in OM Solver.

The inventory shortage for item C may not be alleviated by placing a larger order in week 1. The best solution may be to expedite the Scheduled Receipt currently scheduled to arrive in week 3 to week 2.

Inputs

Solver - Material Requirements Planning

Enter data in yellow shaded areas.

Master Production Schedule

		1	2	3	4	5	6	7	8	9	10
Item A MPS Start	Descr:		85		200				50		
Item B MPS Start	Descr:			65	50	50			75		

☐ Use second finished item

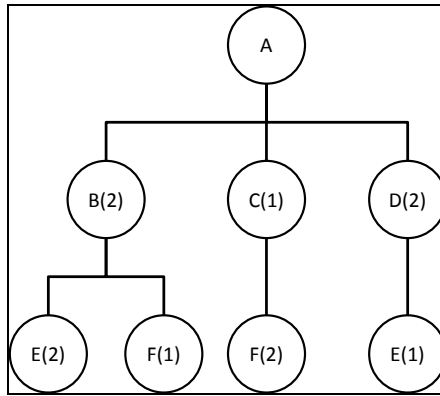
Material Requirements Planning

Item C	Descr:	Period (P) for POQ						Lot Size (FOQ)			
L4L Rule								Lead Time		2	
								Safety Stock			
Usage Quantity for Item: A		2	B		1						
		1	2	3	4	5	6	7	8	9	10
Gross Requirements			170	65	450	50			175		
Scheduled Receipts			200								
Projected On-Hand Inventory			0	30	0	0	0	0	0	0	0
Planned Receipts				35	450	50			175		
Planned Order Releases			35	450	50			175			

Item D	Descr:	Period (P) for POQ						Lot Size (FOQ)		200	
FOQ Rule								Lead Time	1		
								Safety Stock			
Usage Quantity for Item: A		1	B	2	C						
		1	2	3	4	5	6	7	8	9	10
Gross Requirements			85	130	300	100			200		
Scheduled Receipts											
Projected On-Hand Inventory		0	115	185	85	185	185	185	185	185	185
Planned Receipts			200	200	200	200			200		
Planned Order Releases		200	200	200	200			200			

Item E	Descr:	Period (P) for POQ					2	Lot Size (FOQ)						
POQ Rule												Lead Time		
													Safety Stock	
Usage Quantity for Item: A 4 B C D														
		1	2	3	4	5	6	7	8	9	10			
Gross Requirements			340		800				200					
Scheduled Receipts														
Projected On-Hand Inventory 200		200	0	0	0	0	0	0	0	0	0			
Planned Receipts			140		800				200					
Planned Order Releases		140		800				200						

21. MRP for Figure 16.40



Item:	B							
Description:								
Week	1	2	3	4	5	6	7	8
Gross requirements		100			130			160
Scheduled receipts		50						
Projected on hand	50	50	0	0	0	0	0	0
Planned receipts					130			160
Planned order releases			130			160		

Item:	C							
Description:								
Week	1	2	3	4	5	6	7	8
Gross requirements	20	70	20	20	85	20	20	100
Scheduled receipts								
Projected on hand	50	30	40	20	0	40	20	0
Planned receipts		80			125			100
Planned order releases	80			125			100	

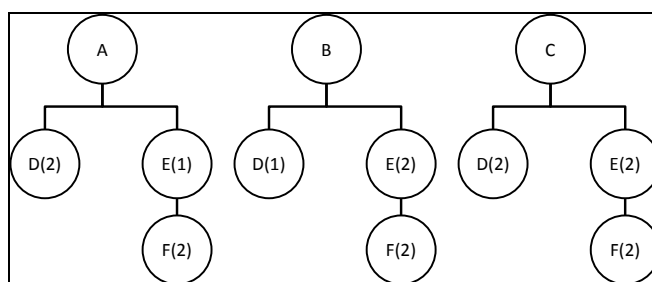
Item:	D							
Description:								
Week	1	2	3	4	5	6	7	8
Gross requirements		100			130			160
Scheduled receipts								
Projected on hand	120	120	20	20	20	140	140	230
Planned receipts					250			250
Planned order releases			250			250		

Item:	E							
Description:								
Week	1	2	3	4	5	6	7	8
Gross requirements			510			570		
Scheduled receipts								
Projected on hand	70	70	70	160	160	160	190	190
Planned receipts			600			600		
Planned order releases	600			600				

Item:	F							
Description:								
	Lot Size:				L4L			
	Lead Time:				1 week			
Week	1	2	3	4	5	6	7	8
Gross requirements	160		130	250		160	200	
Scheduled receipts								
Projected on hand	250	90	90	0	0	0	0	0
Planned receipts			40	250		160	200	
Planned order releases		40	250		160	200		

Action notices signal the need to place orders for 80 Cs and 600 Es. Please note that action notices were not asked for in the problem.

22. MRP for products A, B, and C in Figure 16.41



Item:	D							
Description:								
	Lot Size:				FOQ = 150			
	Lead Time:				3 weeks			
Week	1	2	3	4	5	6	7	8
Gross requirements			160	120	125	110		
Scheduled receipts			150					
Projected on hand	150	150	150	140	20	45	85	85
Planned receipts					150	150		
Planned order releases		150	150					

Item:	E							
Description:								
	Lot Size:				L4L			
	Lead Time:				1 week			
Week	1	2	3	4	5	6	7	8
Gross requirements			80	120	250	55		
Scheduled receipts		120						
Projected on hand	0	0	120	40	0	0	0	0
Planned receipts				80	250	55		
Planned order releases			80	250	55			

Item:	F							
Description:								
	Lot Size:				POQ, P = 2			
	Lead Time:				2 weeks			
	Safety Stock:				30 units			
Week	1	2	3	4	5	6	7	8
Gross requirements			160	500	110			
Scheduled receipts								
Projected on hand	100	100	100	530	30	30	30	30
Planned receipts			590		110			
Planned order releases	590		110					

Action notices: Delay the scheduled receipt of 120 units of E and order 590 units of F. Please note that action notices were not asked for in the problem.

23. MRP for Figure 16.42

- a. This solution was developed using the *Material Requirements Planning* module in OM Solver.

Solver - Material Requirements Planning

Enter data in yellow shaded areas.

Master Production Schedule

		1	2	3	4	5	6	7	8	9	10
Item A MPS Start	Descr:		125		95		150		130		
Item B MPS Start	Descr:			80			70				

☒ Use second finished item
Material Requirements Planning

Item C	Descr:	Period (P) for POQ								Lot Size (FOQ)	3
L4L Rule										Lead Time	
										Safety Stock	
Usage Quantity for Item: A		2		B							
		1	2	3	4	5	6	7	8	9	10
Gross Requirements			250		190		300		260		
Scheduled Receipts			200								
Projected On-Hand Inventory	85	85	35	35	0	0	0	0	0	0	0
Planned Receipts				155		300		260			
Planned Order Releases		155		300		260					

Item D	Descr:	Period (P) for POQ								Lot Size (FOQ)	2
POQ Rule										Lead Time	
										Safety Stock	
Usage Quantity for Item: A		2	B	1	C	1					
		1	2	3	4	5	6	7	8	9	10
Gross Requirements		155	250	380	190	260	370		260		
Scheduled Receipts											
Projected On-Hand Inventory	625	470	220	450	260	0	260	260	0	0	0
Planned Receipts				610			630				
Planned Order Releases		610			630						

Item E	Descr:	Period (P) for POQ								Lot Size (FOQ)	800
FOQ Rule										Lead Time	1
										Safety Stock	
Usage Quantity for Item: A		2	B	2	C		D	1			
		1	2	3	4	5	6	7	8	9	10
Gross Requirements		610	250	160	820		440		260		
Scheduled Receipts		800									
Projected On-Hand Inventory	350	540	290	130	110	110	470	470	210	210	210
Planned Receipts					800		800				
Planned Order Releases				800		800					

- b. In week 1, an order for 155 units of item C should be released and an order for 610 units of item D should be released
- c. This solution was developed using the *Material Requirements Planning* module in OM Solver. This software shows the cascading changes required by adding a new MPS of 200 units of product A in week 5.

For item C, a new Gross Requirement of 400 units in week 5 is accommodated by a Planned Receipt of 400 units and a new Planned Order Release of 400 units in week 2. Item C has a short enough lead time to respond to this proposed alteration in the MRP.

Solver - Material Requirements Planning

Enter data in yellow shaded areas.

Master Production Schedule

		1	2	3	4	5	6	7	8	9	10
Item A MPS Start	Descr:		125		95	200	150		130		
Item B MPS Start	Descr:			80			70				

☒ Use second finished item

Material Requirements Planning

Item C	Descr:		Period (P) for POQ		Lot Size (FOQ)		Lead Time		Safety Stock		3
L4L Rule	v										
Usage Quantity for Item: A 2 B											
		1	2	3	4	5	6	7	8	9	10
Gross Requirements			250		190	400	300		260		
Scheduled Receipts			200								
Projected On-Hand Inventory	85	85	35	35	0	0	0	0	0	0	0
Planned Receipts					155	400	300		260		
Planned Order Releases		155	400	300		260					

As items D and E have multiple parents, the required changes are substantially more complex. These changes are reflected in the records below. It should be noted that planner intervention will be required for both of these items.

For item D, the Projected On-Hand Inventory becomes negative (-180) in week 2. There is not enough inventory to accommodate the new Planned Order Release of 400 units in week 2 for part A. Further, without expediting, item D's two-week leadtime is too long for a new order to satisfy the resulting Gross Requirements.

For item E the situation is even more severe. The Gross Requirements in week one increases from 610 to 1410 units. This new demand for 800 additional units in week 1 produces an inventory shortage of 260 units.

Item D	Descr:	Period (P) for POQ					3	Lot Size (FOQ)			
POQ Rule								Lead Time			2
								Safety Stock			
Usage Quantity for Item: A 2 B 1 C 1											
		1	2	3	4	5	6	7	8	9	10
Gross Requirements		155	650	380	190	660	370		260		
Scheduled Receipts											
Projected On-Hand Inventory	625	470	-180	850	660	0	260	260	0	0	0
Planned Receipts				1410			630				
Planned Order Releases		1410			630						

Item E	Descr:	Period (P) for POQ						Lot Size (FOQ)	800			
FOQ Rule								Lead Time	1			
								Safety Stock				
Usage Quantity for Item:		A	2	B	2	C		D	1			
			1	2	3	4	5	6	7	8	9	10
Gross Requirements			1410	250	160	820	400	440		260		
Scheduled Receipts			800									
Projected On-Hand Inventory		350	-260	290	130	110	510	70	70	610	610	610
Planned Receipts				800		800	800			800		
Planned Order Releases			800		800	800			800			

24. MRP for Figure 16.43

- This solution was developed using the *Material Requirements Planning* module in OM Solver.

Inputs

Solver - Material Requirements Planning

Enter data in yellow shaded areas.

Master Production Schedule

	1	2	3	4	5	6	7	8	9	10
Item A MPS Start		120		120	120			120		
Item B MPS Start										

☒ Use second finished item

Material Requirements Planning

Item C	Descr:	Period (P) for POQ										Lot Size (FOQ)	3
L4L Rule												Lead Time	0
Usage Quantity for Item: A		2	B									Safety Stock	
		1	2	3	4	5	6	7	8	9	10		
Gross Requirements			240		240	240			240				
Scheduled Receipts			150										
Projected On-Hand Inventory		125	125	35	35	0	0	0	0	0	0	0	
Planned Receipts					205	240			240				
Planned Order Releases			205	240			240						

Item D	Descr:	Period (P) for POQ								Lot Size (FOQ)	700
FOQ Rule										Lead Time	3
										Safety Stock	0
Usage Quantity for Item: A		3	B		C						
		1	2	3	4	5	6	7	8	9	10
Gross Requirements			360		360	360			360		
Scheduled Receipts			450								
Projected On-Hand Inventory		0	0	90	90	430	70	70	70	410	410
Planned Receipts					700				700		
Planned Order Releases			700			700					

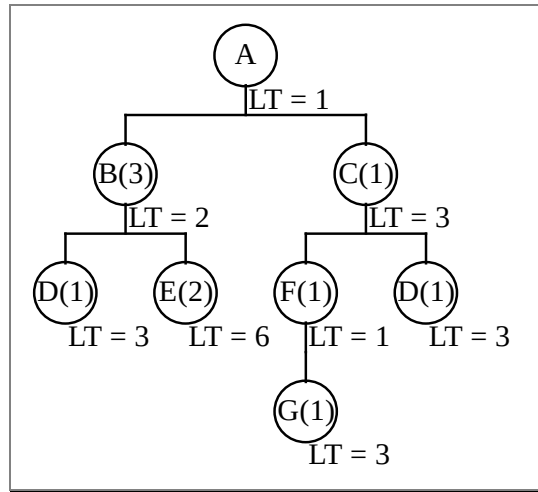
Item E	Descr:	Period (P) for POQ						Lot Size (FOQ)		700	
FOQ Rule								Lead Time	4		
								Safety Stock	0		
Usage Quantity for Item: A		2	B		C	1	D				
		1	2	3	4	5	6	7	8	9	10
Gross Requirements		205	480		240	480			240		
Scheduled Receipts		700									
Projected On-Hand Inventory		235	730	250	250	10	230	230	230	690	690
Planned Receipts						700			700		
Planned Order Releases		700			700						

Item F	Descr:	Period (P) for POQ						Lot Size (FOQ)		2	
L4L Rule								Lead Time		50	
Usage Quantity for Item: A		B	C		D		E	1			
		1	2	3	4	5	6	7	8	9	10
Gross Requirements		700			700						
Scheduled Receipts											
Projected On-Hand Inventory		750	50	50	50	50	50	50	50	50	50
Planned Receipts					700						
Planned Order Releases			700								

Item G	Descr:	Period (P) for POQ						Lot Size (FOQ)		1	
L4L Rule								Lead Time		0	
								Safety Stock			
Usage Quantity for Item: A		B	C	D	E	2	F				
		1	2	3	4	5	6	7	8	9	10
Gross Requirements		1400			1400						
Scheduled Receipts		1400									
Projected On-Hand Inventory		0	0	0	0	0	0	0	0	0	0
Planned Receipts					1400						
Planned Order Releases				1400							

- b. In week 1, an order for 205 units of item C, an order for 700 units of item D, and an order for 700 units of item E should be released.

25. MRP for Figure 16.22



	Item					
Data Category	B	C	D	E	F	G
Lot-size rule	L4L	L4L	POQ (P = 2)	L4L	L4L	FOQ = 100
Lead time	2 weeks	3 weeks	3 weeks	6 weeks	1 week	3 weeks
Safety stock	30	10	0	0	0	0
Scheduled receipts	150	50	None	400	40	None
	(wk 2)	(wk 2)		(wk 6)	(wk 3)	
On-hand inventory	30	20	60	400	0	0

Item: A

Lot Size: 50

Final Asm. Lead Time: 1 wk

Quantity On Hand: 5

	Week									
	1	2	3	4	5	6	7	8	9	10
MPS Start		50				50		50	50	

Item: B
Description:

Lot Size:
Lead Time:
Safety Stock:

L4L
2 weeks
30 units

Week	1	2	3	4	5	6	7	8	9	10
Gross requirements		150				150		150	150	
Scheduled receipts		150								
Projected on hand	30	30	30	30	30	30	30	30	30	30
Planned receipts						150		150	150	
Planned order releases				150		150	150			

Item: C
Description:

Lot Size:
Lead Time:
Safety Stock:

L4L
3 weeks
10 units

Week	1	2	3	4	5	6	7	8	9	10
Gross requirements		50				50		50	50	
Scheduled receipts		50								
Projected on hand	20	20	20	20	20	10	10	10	10	10
Planned receipts						40		50	50	
Planned order releases			40		50	50				

Item:	D									
Description:										
	Lot Size: Lead Time: Safety Stock:									
	POQ = 2 3 weeks 0 units									
Week	1	2	3	4	5	6	7	8	9	10
Gross requirements			40	150	50	200	150			
Scheduled receipts										
Projected on hand	60	60	60	20	50	0	150	0	0	0
Planned receipts				180		350				
Planned order releases	180		350							

Item:	E									
Description:										
	Lot Size: Lead Time: Safety Stock:									
	L4L 6 weeks 0 units									
Week	1	2	3	4	5	6	7	8	9	10
Gross requirements				300		300	300			
Scheduled receipts						400				
Projected on hand	400	400	400	400	100	100	200	0	0	0
Planned receipts							100			
Planned order releases	100									

Item:	F									
Description:										
	Lot Size: Lead Time: Safety Stock:									
	L4L 1 week 0 units									
Week	1	2	3	4	5	6	7	8	9	10
Gross requirements			40		50	50				
Scheduled receipts			40							
Projected on hand	0	0	0	0	0	0	0	0	0	0
Planned receipts					50	50				
Planned order releases				50	50					

Item:	G									
Description:										
	Lot Size: Lead Time: Safety Stock:									
	FOQ = 100 3 weeks 0 units									
Week	1	2	3	4	5	6	7	8	9	10
Gross requirements				50	50					
Scheduled receipts										
Projected on hand	0	0	0	50	0	0	0	0	0	0
Planned receipts				100						
Planned order releases	100									

Action notices are to issue orders for 180 Ds, 100 Es, and 100 Gs. Please note that action notices were not asked for in the problem.

26. Master Production Schedule for end item

a. MPS

Lot Size: 100 LT = 2 weeks	Week									
Quantity on Hand: 60	1	2	3	4	5	6	7	8	9	10
Forecast	30	30	30	30	30	30	25	25	25	25
Customer orders (booked)	22	30	15	11	0	0	9	0	0	0
Projected on-hand inventory	30	0	70	40	10	80	55	30	5	80
MPS quantity			100			100				100
MPS start	100			100				100		
ATP	8		74			91				100

b. Order Acceptance

Accept order 1 for 40 units in period 3, which leaves 34 units in ATP for period 3.

Reject order 2 for 60 units in period 4, since we only have 8 available in period 1 and 34 available in period 3.

Accept order 3 for 70 units in period 6, which leaves 21 units in ATP for period 6.

Accept order 4 for 40 units in period 3, which leaves 2 units in ATP for period 1 and 0 units in ATP for period 3

Reject order 5 for 20 units in period 5, since we only have 2 units available in ATP for period 1. (Could offer delivery in week 6, but assume here that declined.)

Reject order 6 for 115 units in period 9, since we only have 2 units available in period 1 and 21 units available in period 6.

27. Master Production Schedule for end item

a. MPS

Lot Size: 75 LT = 2 weeks	Week									
Quantity on Hand: 100	1	2	3	4	5	6	7	8	9	10
Forecast	30	30	30	30	20	20	30	30	30	30
Customer orders (booked)	15	38	7	5	0	3	10	0	0	0
Projected on-hand inventory	70	32	2	47	27	7	52	22	67	37
MPS quantity				75			75		75	
MPS Start		75			75		75			
ATP	40			67			65		75	

b. Order Acceptance

Accept order 1, which leaves 20 units in ATP for period 1.

Accept order 2, which leaves 12 units in ATP for period 1 and 0 units for period 4.

Reject order 3, because we only have 12 units available in ATP. (Could offer delivery in week 9, or perhaps a split order, Here we assume that declined.)

Accept order 4, which leaves 2 units in ATP for period 1 and 0 units in ATP for period 7.

Reject order 5, which leaves 2 units in ATP for period 1, and 75 units in ATP for period 9.

28. Material Requirements Plan for Product A

This solution was developed using the *Material Requirements Planning* module in OM Solver.

Inputs

Solver - Material Requirements Planning

Enter data in yellow shaded areas.

Master Production Schedule

		1	2	3	4	5	6	7	8	9	10
Item A MPS Start	Descr:	100	100	100	100			100	100	100	100
Item B MPS Start	Descr:										

☐ Use second finished item

Material Requirements Planning

Item C	Descr:	Period (P) for POQ					Lot Size (FOQ)				
L4L Rule							Lead Time				
							Safety Stock				
Usage Quantity for Item: A		1	B								
		1	2	3	4	5	6	7	8	9	10
Gross Requirements		100	100	100	100			100	100	100	100
Scheduled Receipts											
Projected On-Hand Inventory		225	125	25	0	0	0	0	0	0	0
Planned Receipts				75	100			100	100	100	100
Planned Order Releases			75	100			100	100	100	100	

Item D	Descr:	Period (P) for POQ					Lot Size (FOQ)					2
L4L Rule	▼						Lead Time					
Usage Quantity for Item: A		1	B	C		1						
		1	2	3	4	5	6	7	8	9	10	
Gross Requirements		100	175	200	100		100	200	200	200	100	
Scheduled Receipts			100									
Projected On-Hand Inventory		350	250	175	0	0	0	0	0	0	0	
Planned Receipts				25	100		100	200	200	200	100	
Planned Order Releases			25	100		100	200	200	100			

Item E	Descr:	Period (P) for POQ						Lot Size (FOQ)			300
FOQ Rule								Lead Time			2
								Safety Stock			
Usage Quantity for Item: A		1	B	C	D	1					
		1	2	3	4	5	6	7	8	9	10
Gross Requirements		125	200	100	200	200	200	300	200	100	100
Scheduled Receipts			300								
Projected On-Hand Inventory		100	-25	75	275	75	175	275	275	75	275
Planned Receipts				300		300	300	300		300	
Planned Order Releases			300		300	300		300			

In week 1, an order for 25 units of item D and an order for 300 units of item E should be released.

Additionally, the negative Projected On-Hand Inventory level of item E must be addressed. Given this item's lead time, the manager will need to expedite the Scheduled Receipt currently expected in week 2.

29. Material Requirements Plan for Product A

This solution was developed using the *Material Requirements Planning* module in OM Solver.

Inputs

Solver - Material Requirements Planning

Enter data in yellow shaded areas.

Master Production Schedule

	1	2	3	4	5	6	7	8	9	10
Item A MPS Start Descr:	50	50	50			150		150		
Item B MPS Start Descr:										

☒ Use second finished item

Material Requirements Planning

Item C	Descr:	Period (P) for POQ					2	Lot Size (FOQ)				
POQ Rule								Lead Time				1
							Safety Stock					
Usage Quantity for Item: A		1	B									
		1	2	3	4	5	6	7	8	9	10	
Gross Requirements		50	50	50			150		150			
Scheduled Receipts												
Projected On-Hand Inventory		100	50	0	0	0	0	0	0	0	0	
Planned Receipts				50			150		150			
Planned Order Releases			50			150		150				

Item D	Descr:	Period (P) for POQ						Lot Size (FOQ)				
L4L Rule								Lead Time				1
							Safety Stock					
Usage Quantity for Item: A		1	B		C							
		1	2	3	4	5	6	7	8	9	10	
Gross Requirements		50	50	50			150		150			
Scheduled Receipts			100									
Projected On-Hand Inventory		-50	0	0	0	0	0	0	0	0	0	
Planned Receipts				50			150		150			
Planned Order Releases			50			150		150				

Item E	Descr:	Period (P) for POQ						Lot Size (FOQ)				300
FOQ Rule								Lead Time				2
							Safety Stock					
Usage Quantity for Item: A		1	B		C		D					
		1	2	3	4	5	6	7	8	9	10	
Gross Requirements		50	50	50			150		150			
Scheduled Receipts												
Projected On-Hand Inventory		110	60	10	260	260	260	110	110	260	260	
Planned Receipts					300				300			
Planned Order Releases			300				300					

Item F	Descr:	Period (P) for POQ					Lot Size (FOQ)		400											
FOQ Rule							Lead Time		4											
							Safety Stock													
Usage Quantity for Item: A							B		C		1		D		1		E		1	
		1	2	3	4	5	6	7	8	9	10									
Gross Requirements		300	100			300	300	300												
Scheduled Receipts		400																		
Projected On-Hand Inventory		40	140	40	40	40	140	240	340	340	340	340								
Planned Receipts						400	400	400												
Planned Order Releases		400	400	400																

In week 1, an order for 300 units of item E and an order for 400 units of item F should be released.

Additionally, the negative Projected On-Hand Inventory level of item D must be addressed. Given this item's lead time, the manager will need to expedite the Scheduled Receipt currently expected in week 2.

CASE: FLASHY FLASHERS, INC. *

A. Synopsis

Flashy Flashers, Inc. is a company that produces a line of automotive electrical components and serves about 95 auto parts suppliers and car dealers regionally. Recently the company installed an MRP system. After one year's use, Kathryn Marley, the Vice President of Operations and Supply Chain Management, is looking for ways to improve the resource planning process.

B. Purpose

This case provides the data to develop the MRP records for two products of Flashy Flashers, Inc. In addition to reinforcing the skills of developing dependent demand production plans, the case affords the opportunity to discuss possible implementation problems when using MRP. The case also brings out the value of action notices, capacity requirements planning, and the link between MRP and the MPS.

C. Analysis

A summary of the planned order release schedule is contained in Exhibit TN.1. The MRP records for each of the component items are contained in Exhibit TN.2. Exhibit TN.3 lists situations that the planner needs to act on this week in releasing new orders or adjusting scheduled receipt due dates.

D. Recommendations

Recommendations to management include the following:

1. Manage the MPS process more effectively:
 - The feast-or-famine capacity situation on the shop floor might be created in part at the MPS level by not checking that resources are available before the MPS is authorized.
 - The ATP feature of MPS may not be used effectively, given the comment about last-minute changes in the MPS that respond to requests by favorite customers. Customers appreciate reliability in meeting promises, even more than responding to expedited deliveries (unless on an exception basis). Giving them a promise date and then delivering on it is valued. Wanting to accommodate special requests is one thing, but being able to do so is another.
 - Freezing the short-term portion of the MPS should build in more stability in the material requirements plan.
2. Create a more formal system for generating action notices, so that planners can concentrate on the things that need their attention. It can be a simple list, such as given in TN.3. These actions should not be automatically done by the MRP

* The original version of this case was prepared by Dr. Soumen Ghosh, Georgia Institute of Technology, as a basis for classroom discussion.

system, because the planner needs to check if they are feasible, such as components and capacity are available.

3. Consider a priority planning system that updates priorities, based on valid due dates of scheduled receipts. This step will require updating scheduled receipt due dates as needs change.
4. Consider a capacity requirement planning system to project workloads into the future, particularly for bottleneck operations. Consider ways to incorporate the principles of TOC (see Chapter 7, “Constraint Management”) into the MRP process, including lot sizing rules and how to respond to action notices.
5. While taking steps to level capacity requirements, the “overrides” by the shop supervisor should be minimized and coordinated with the planners. His informal system can undermine the effectiveness of the MRP system. MRP logic “believes” that the due dates and quantities of scheduled receipts are going to happen. At the same time, MRP flexibly takes into account the unexpected by generating a new material requirements plan each week. The unanticipated consequences of such overrides are demonstrated by the MRP records of items SL123A and SL134P.
6. Train all employees who provide information to the MRP system in addition to those who must update the system. Only selected employees received training in the past. Everyone should be aware of the need for accurate and timely data. Also train those who will be primary users of the MRP information.

E. Teaching Suggestions

Initially the instructor should get agreement on the planned order release form (Exhibit TN.1). Be sure to rationalize any differences in the student forms because they will spur the discussion of the mechanics of producing MRP reports. The results lay the foundation for the conclusion that something definitely is wrong. Also compare notes on Exhibit TM.3. Although the mechanics of identifying action notices are not emphasized in the textbook, discussing them can enhance student insights on MRP capabilities.

After the mechanics are understood, the instructor should raise the question, “What can be done to improve this resource planning process?” The six points described in Section D are a starting point. Students may also point to other possibilities, including:

- ☐ Accepting orders on short notice, even if on-time delivery is unlikely
- ☐ Poor estimates for lead times
- ☐ Bad priority planning system
- ☐ Lack of capacity
- ☐ Bad input data
- ☐ Ineffective follow-up with suppliers
- ☐ Blaming everyone else

EXHIBIT TN.1

Completed Planned Order Release Form

Item Description and Part Number	Week					
	1	2	3	4	5	6
Side Lens (SL111P)	350					
Side Lens Rubber Gasket (SL113P)		100		100	100	
Side Frame Subassembly (SL112A)		80	110			
Side Frame (SL121F)	110					
Side Bulb Subassembly (SL122A)	110					
Flasher Bulb Subassembly (SL123A)	200					
Side Cable Grommet and Receptacle (SL131F)						
Flasher Cable Grommet and Receptacle (SL133F)						
Side Bulb (SL132P)						
Flasher Bulb (SL134P)	100					
Head Frame Subassembly (HL211A)	120	90	75			
Head Lens (HL212P)		350				
Head Lamp Module (HL222P)						
Head Frame (HL223F)	165					
Back Rubber Gasket (C310P)	180	180				
Screws (C206P)	2500					

EXHIBIT TN.2

Completed MRP Records

Item: SL111P								Lot Size:		350 units		
Description: Side Lens								Lead Time:		2 weeks		
								Safety Stock:		0 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements			140		80	145						
Scheduled receipts												
Projected on hand:	15	15	15	225	145	0	0	0	0	0	0	0
Planned receipts			350									
Planned order releases	350											

Item: SL112A								Lot Size:		L4L		
Description: Side Frame Subassembly								Lead Time:		3 weeks		
								Safety Stock:		0 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements			100		80	110						
Scheduled receipts		80										
Projected on hand:	20	20	100	0	0	0	0	0	0	0	0	0
Planned receipts					80	110						
Planned order releases		80	110									

Item: SL113P								Lot Size:		100 units		
Description: Side Lens Rubber Gasket								Lead Time:		1 week		
								Safety Stock:		20 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements			100		80	110						
Scheduled receipts												
Projected on hand:	20	20	20	20	20	40	30	30	30	30	30	30
Planned receipts			100		100	100						
Planned order releases		100		100	100							

Item: SL121F								Lot Size:		L4L		
Description: Side Frame								Lead Time:		2 weeks		
								Safety Stock:		0 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements		80	110									
Scheduled receipts		80										
Projected on hand:	0	0	0	0	0	0	0	0	0	0	0	0
Planned receipts			110									
Planned order releases	110											

Item: SL122A								Lot Size:		L4L		
Description: Side Bulb Subassembly								Lead Time:		2 weeks		
								Safety Stock:		0 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements		80	110									
Scheduled receipts		80										
Projected on hand:	0	0	0	0	0	0	0	0	0	0	0	0
Planned receipts			110									
Planned order releases	110											

EXHIBIT TN.2 Cont)

Completed MRP Records

Item: SL123A								Lot Size:		200 units		
Description: Flasher Bulb Subassembly								Lead Time:		2 weeks		
								Safety Stock:		0 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements		80	110									
Scheduled receipts												
Projected on hand:	0	0	-80	10	10	10	10	10	10	10	10	10
Planned receipts			200									
Planned order releases	200											

Item: SL131F								Lot Size:		POQ (P = 2)		
Description: Side Cable Grommet & Receptacle								Lead Time:		2 weeks		
								Safety Stock:		0 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements	110											
Scheduled receipts	110											
Projected on hand:	0	0	0	0	0	0	0	0	0	0	0	0
Planned receipts												
Planned order releases												

Item: SL132P								Lot Size:		100 units		
Description: Side Bulb								Lead Time:		1 week		
								Safety Stock:		25 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements	110											
Scheduled receipts	100											
Projected on hand:	35	25	25	25	25	25	25	25	25	25	25	25
Planned receipts												
Planned order releases												

Item: SL133F								Lot Size:		250 units		
Description: Flasher Cable Grommet & Receptacle								Lead Time:		2 weeks		
								Safety Stock:		0 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements	200											
Scheduled receipts												
Projected on hand:	240	40	40	40	40	40	40	40	40	40	40	40
Planned receipts												
Planned order releases												

EXHIBIT TN.2 Cont)

Completed MRP Records

Item: SL134P								Lot Size:		100 units		
Description: Flasher Bulb								Lead Time:		1 week		
								Safety Stock:		25 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements	200											
Scheduled receipts												
Projected on hand: 100	-100	0	0	0	0	0	0	0	0	0	0	0
Planned receipts		100										
Planned order releases	100											

Item: HL211A								Lot Size:		L4L		
Description: Head Frame Subassembly								Lead Time:		3 weeks		
								Safety Stock:		0 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements				120	90	75						
Scheduled receipts												
Projected on hand: 0	0	0	0	0	0	0	0	0	0	0	0	0
Planned receipts				120	90	75						
Planned order releases	120	90	75									

Item: HL212P								Lot Size:		350 units		
Description: Head Lens								Lead Time:		2 weeks		
								Safety Stock:		15 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements				120	90	75						
Scheduled receipts												
Projected on hand: 15	15	15	15	245	155	80	80	80	80	80	80	80
Planned receipts				350								
Planned order releases		350										

Item: HL222P								Lot Size:		POQ (P = 4)		
Description: Head Lamp Module								Lead Time:		3 weeks		
								Safety Stock:		10 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements	120	90	75									
Scheduled receipts	285											
Projected on hand: 10	175	85	10	10	10	10	10	10	10	10	10	10
Planned receipts												
Planned order releases												

EXHIBIT TN.2 (Cont.)

Completed MRP Records

Item: HL223F								Lot Size:		POQ (P = 4)		
Description: Head Frame								Lead Time:		1 week		
								Safety Stock:		0 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements	120	90	75									
Scheduled receipts	120											
Projected on hand:	0	0	75	0	0	0	0	0	0	0	0	0
Planned receipts		165										
Planned order releases	165											

Item: C310P								Lot Size:		180 units		
Description: Back Rubber Gasket								Lead Time:		1 week		
								Safety Stock:		20 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements	120	170	185									
Scheduled receipts	180											
Projected on hand:	40	100	110	105	105	105	105	105	105	105	105	105
Planned receipts		180	180									
Planned order releases	180	180										

Item: C206P								Lot Size:		2500 units		
Description: Screws								Lead Time:		1 week		
								Safety Stock:		30 units		
Date	1	2	3	4	5	6	7	8	9	10	11	12
Gross requirements	240	180	350	480	520	520						
Scheduled receipts												
Projected on hand:	270	30	2350	2000	1520	1000	480	480	480	480	480	480
Planned receipts		2500										
Planned order releases	2500											

EXHIBIT TN.3

Actions for Planners to Consider This Week

Release New Orders	
The following planned order releases are “mature for release,” because they are in the action bucket (period 1). We assume that there is a new explosion each week, so planned order releases in period 2 and later need no action. The planner needs to review for component and capacity availability for each mature POR before inputting an inventory transaction. That transaction issues a scheduled receipt to the shop or supplier with the desired quantity and due date..	
Side Lens (SL111P)	350 units (due date = week 3)
Side Frame (SL121F)	110 units (due date = week 3)
Side Bulb Subassembly (SL122A)	110 units (due date = week 3)
Flasher Bulb Subassembly (SL123A) ¹	200 units (due date = week 2)
Flasher Bulb (SL134P) ²	100 units (due date = week 1)
Head Frame Subassembly (HL211A)	120 units (due date = week 4)
Head Frame (HL223F)	165 units (due date = week 2)
Back Rubber Gasket (C3 I 0P)	180 units (due date = week 2)
Screws (C206P)	2,500 units (due date = week 2)
Realign Due Dates of Scheduled Receipts	
The following scheduled receipt is no longer valid. The planner needs to asses the feasibility of expediting or delaying schedule receipts that have become misaligned. If changes are not possible, the plans for their parents must be adjusted as needed. If changes are not possible all the way up the BOM to the MPS, then a call to the customer is needed. Knowing a shipment will be late is better than reacting to it later on.	
Side Bulb Subassembly (SL112A)	Postpone schedule receipt’s due date from week 2 to week 3. Otherwise this job may be occupying a bottleneck workstation at the expense of an order that really does need to be done in week 2.

¹ Upon further investigation, Marley found that the quantity called for in a SL123A scheduled receipt already finished was arbitrarily reduced in the shop, to help ease an overload. The unfortunate consequence is that now there is no current on-hand inventory for item SL123A, and a new rush order must be released with less than the 2-week offset for the lead time. Such situations often can be accommodated, as long as they are the exception rather than the rule.

² SL134P must be ordered as a rush job from the supplier, because of the unanticipated problems created by the shop’s override on a prior order for SL123A. Item SL133F is also a component of SL123A, but fortunately its current on-hand inventory is sufficient because of the remnants created by its FOQ rule. Remnants in this case absorbed the negative effects of a short shipment of SL123A.