CHAPTER 1
INTRODUCTION TO THE FIELD

Review and Discussion Questions

1. What is the difference between OM and OR/MS? Between OM and IE?

Operations Management (OM) is a synthesis of concepts and techniques that relate directly to production systems and enhance their management. Operations Management has a distinct management role that differentiates it from OR and IE. Operations Managers use the tools of OR in decision making and are concerned with many of the same issues as Industrial Engineers. Operations Research/Management Science (OR/MS) is a branch of applied mathematics, while Industrial Engineering (IE) is an engineering discipline.

2. How would you distinguish OM from management and organizational behavior as taught at your university?

Management and organizational behavior is concerned with the formulation of corporate strategic policy. Operations Management is concerned with the operations strategy, which specifies how the firm will employ its production capabilities to support its corporate strategy.

3. Take a look at the want ads in The Wall Street Journal and evaluate the opportunities for an OM major with several years of experience.

The following are some examples of jobs available to OM graduates with several years of experience from the Wall Street Journal, January 18, 2000.

FDX Supply Chain Services, a subsidiary of FDX Logistics and FDX Corporation, is a leading provider of supply chain management consulting, global transportation management services and integrated logistics solutions.

Director of Operations

This key management position is based at our Livonia, Michigan Regional Office and will oversee all aspects of operations. This includes implementing operational procedures, reviewing capital expenditure requests, developing/modifying company programs to ensure profitability and supporting sales/marketing efforts. Provides developmental assignments to support the succession planning strategy of the organization.

You are required to have a Bachelor's degree (Master's preferred), 15 years of integrated logistics/supply chain experience and 10 years of P&L leadership experience/responsibility. Strong knowledge of group dynamics, transportation, warehouse/supply chain systems, marketing and planning concepts is needed. Excellent customer service, communication, interpersonal, leadership and analytical skills are a must.

We offer competitive wages, excellent benefits and unlimited opportunities for growth. Send your resume with salary history to: **FDX Supply Chain Services, 38935 Ann Arbor Road, Suite 100, Livonia, MI 48150, Attn: HR-DO, Fax: (734) 462-7628, E-mail: rmerced@fdxsupplychain.com.**

Equal opportunity employer

www.fdxsupplychain.com

Reach the World

FDX Supply Chain Services

MANUFACTURING MANAGER

- excellent salary
- Just a little NW of Mpls
- relocation allowance available

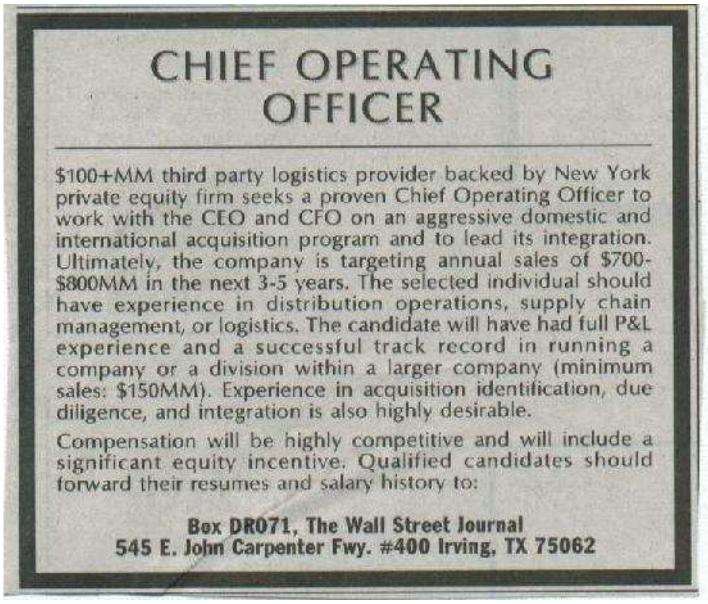
Komo Machine, Inc., of St. Cloud, MN. Is a rapidly growing Manufacturer of computerized machine tools for the metal-working, woodworking and automation industries. Komo currently has a unique opportunity for the right individual to improve manufacturing processes through total management of production departments and leadership of manufacturing per-sonnel. Qualified applicants will have a BSME or a related field degree and a minimum of 4 years of experience in the manufac-ture of CNC and automated machine tools/equipment. Equiva-lent work experience is acceptable. Experience in MRP, BOM, and ISO-9000 manufacturing systems and process skills used to develop automated equipment is necessary. Strong communica-tion and leadership skills in a team manufacturing environment is a must. Must have the ability to plan, direct, coordinate and control all manufacturing to achieve established goals. Must pro-vide guidance to ensure that scheduled products are completed a optimum costs, consistent with safety and quality requirements for on-time delivery to customers.

Please submit resume and salary expectations to:

Human Resources, KOMO Machine, Inc.
11 Industrial Blvd., Saint Cloud, MN 56379

NO PHONE CALLS PLEASE
EOE

Some additional advertisements.



4. What factors account for the resurgence of interest in OM today?

With the expanding objectives of productive systems combined with increased applications to services and increased efficiency of Japanese producers, there is increased interest in nuts and bolts issues.

5. Using Exhibit 1.2 as a model, describe the input-transformation-output relationships found in the following systems:

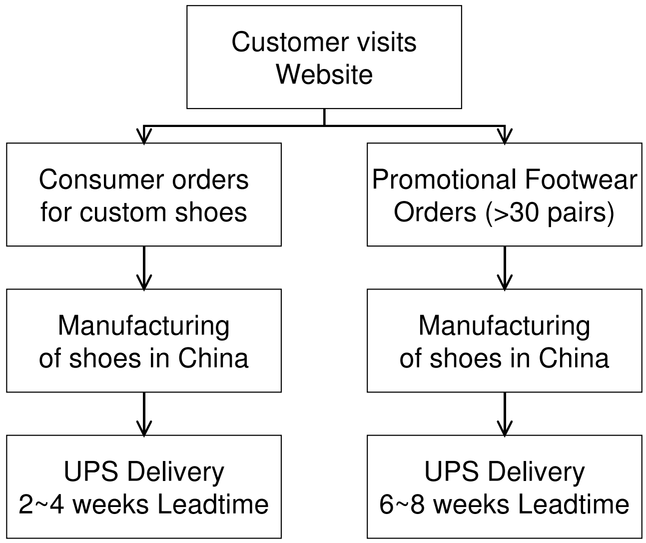
a. An airline
  Inputs: passengers
  Components: planes, crews, equipment, terminals
  Primary functions: transportation
  Output: satisfied, safe customers

b. A state penitentiary
  Inputs: criminals
  Components: legal system, physical plant (prison), guards and support staff
  Primary functions: segregation of prisoners from society, punishment, rehabilitation
  Output: reformed society members

c. A branch office of a bank
  Inputs: customers
  Components: tellers, bank officers, teller windows, systems
  Primary functions: deposit and withdrawal handling, loan initiation, storing money and valuables
  Output: satisfied customers, positive return on loan ratios

d. The home office of a major banking firm
  Inputs: paperwork from customers and other institutions
  Components: loan underwriters, clerks, computer systems
  Primary function: record-keeping, loan processing, coordinating cash flows
  Output: satisfied customers, sound investment portfolios

6. Sketch the production-delivery system used by CMAX.com Solemates, Inc. in providing the custom tennis shoes. Could this approach be applied to other consumer goods? Give examples.



This charts the flow of the CMAX.com Solemates, Inc.'s production system. The production process combines mass production capability with high customization. This is possible in part due to the use of flexible manufacturing. The needs and wants of the customer are considered at every step of the process.

This approach can be applied in a large number of industries. However, the approach seems most appropriate in recreational consumer goods and products requiring high customization. Many production companies have high volume and low volume lines. Many low volume production facilities could learn from the CMAX.com Solemates, Inc..

7. Suppose that Rolling Stone presented the following headlines relating to OM. What particular historical events or individuals would they be referring to?

OVER 5 BAZILLION SOLD TO DATE--Refers to McDonald's and their unique approach to quality and productivity that stands as a reference point for delivering high-volume standardized services.

BEANTOWN B-SCHOOL DISCOVERS YOU CAN'T HAVE IT ALL---Refers to Harvard professors William Abernathy, Kim Clark, Robert Hays, and Steven Wheelwright and the emphasis on a manufacturing strategy based on tradeoffs among performance measures.

INVENTORY—OH NO!—Taichi Ohno's successful implementation of the Just-In-Time philosophy at Toyota Motors in the early 1980s, dramatically decreased inventory levels.

BUSINESSES USE A BIG HAMMER TO FORCE CHANGE--Michael Hammer pushed companies to become lean by seeking innovations in processes by which they run their operations. This approach became know as business process reengineering (BPR).

FAST HENRY BECOMES MARVEL OF MOTOWN--This refers to Henry Ford as the first to develop a highly integrated, efficient production system.

EXECS FOLLOW GURU'S RECIPE FOR BIG Q STEW—Refers to quality gurus such as W. E. Deming, Joseph Juran, Armand Feigenbaum and Philip Crosby.

10 BILLION FAX MACHINES DUMPED IN THE OCEAN--Refers to the obsolescence of the fax machine with the widespread adoption of the World Wide Web (WWW) and the Internet in general for business communications.

"THE CHAIN GANG" MOVES TO TOP OF THE CHARTS--Supply chain management has emerged an important aspect of business.

CHAPTER 2
OPERATIONS STRATEGY AND COMPETITIVENESS

Review and Discussion Questions

1. Can a factory be fast, dependable, flexible, produce high-quality products, and still provide poor service from a customer's perspective?

Yes, if a customer's needs are not considered and does not influence strategy development, an organization could be delivering the wrong service or product. Even though the product or service is delivered fast, dependable, and flexible in design and features and is of high technical quality, overall service could be rated "poor" by a customer who demands a different mix of features and attributes. It is often best not to be fastest to the market, but to be the best firm in the market as judged by the ultimate customer.

2. Why should a service organization worry about being world class if it does not compete outside its own national border? What impact does the Internet have on this?

As the environment changes, firms can find themselves faced with competition from outside their industry or from outside their home country. Even if they do not, the principles of a world class firm can be applied to any and all manufacturing and service concerns. Benchmarking or rating your firm's performance to the best in your industry or class can provide future strategic directions for improvements.

The Internet is global by its very nature. Retail stores must now compete with Internet stores. Local auction houses will be in competition with Internet auction sites such as eBay. Virtually all organizations will be impacted in some form by the Internet. It is important that this impact be considered.

3. What are the major priorities associated with operations strategy? How has their relationship to each other changed over the years?

The four major imperatives are cost, quality, delivery, and flexibility. In the sixties, these four imperatives were viewed from a tradeoff's perspective. For example, this meant that improving quality would result in higher cost. However, more recent thought posits that these four imperatives can improve simultaneously, and in many industries may be necessary for success. The problem then becomes one of prioritizing and managing towards orderly improvement.

4. For each of the different priorities in question 3, describe the unique characteristics of the market niche with which it is most compatible.

Cost is most compatible with products that are commodities (i.e., highly standardized products with many alternative suppliers). Quality provides companies a means of (1) differentiating a product and winning orders or (2) competing in a market and qualifying for orders. Quality is now pervasive among all market niches in that customers now expect high quality. Speed and reliability of delivery are essential in those markets where there is a large degree of customization. In addition, reliable delivery may be a competitive advantage in some regions of the world where delivery is difficult due to geographical or political reasons. Flexibility is important where customers demand low volume but wide varieties of products.

5. A few years ago the dollar showed relative weakness with respect to foreign currencies, such as the yen, mark, and pound. This stimulated exports. Why would long-term reliance on a lower valued dollar be at best a short-term solution to the competitiveness problem?

This approach is dependent on economic policies of other nations. This is a fragile dependency. A long-term approach is to increase manufacturing and service industry productivity in order to regain competitive advantage. At a national level, solutions appear to lie in reversing attitudes and strategies identified in the MIT Commission Report. At a firm level, competitive weapons are consistent quality, high performance, dependable delivery, competitive pricing, and design flexibility.

6. In your opinion, do business schools have competitive priorities?

Their competitive priorities include:

Quality of professors and curriculum—consistent quality and high performance

Leader in development of new curriculum topics—design changes

Academic level of student attracted—consistent quality

Quantity and quality of research published—consistent quality

Quality of library resources—quality

What companies recruit at the school—after sales service

Success rate of graduates—consistent quality

Availability of financial aid—low price and after sales service

Cost of tuition—low price

7. Why does the "proper" operations strategy keep changing for companies that are world-class competitors?

The top three priorities have generally remained the same over time: make it good, make it fast, and deliver it on time. Others have changed. Part of this may be explained by realizing that world class organizations have achieved excellence in these three areas and are, therefore, focusing attention on some of the more minor areas to gain competitive advantage. The changes in the minor priorities may result from recognizing opportunities or from changes in customer desires or expectations.

8. What is meant by the expressions order winners and order qualifiers? What was the order winner(s) for your last purchase of a product or service?

Order winners are dimensions that differentiate the product or service or services of one firm from another. Order qualifiers are dimensions that are used to screen a product or service as a candidate for purchase. Obviously, answers will vary for the order winners from your last purchase.

9. What do we mean when we say productivity is a "relative" measure?

For productivity to be meaningful, it must be compared with something else. The comparisons can be either intracompany or intercompany as in the case of benchmarking. Intercompany comparisons of single factor productivity measures can be somewhat tenuous due to differences in accounting practices (especially when comparing with foreign competitors). Total factor productivity measures are somewhat more robust for comparison purposes.

10. What are the typical performance measures for quality, speed of delivery, and flexibility?

The typical performance measure for quality is percent defective or yield rate. Other quality indicators include environmental measures of toxic waste produced, scrap, rework, and waste. Scrap is categorized as engineered or nonengineered scrap.

Speed of delivery is measured by length and variability in product lead time.

Flexibility is measured by the number of products sold, and the time required to get a new product to market.

11. What should be the criteria for management to adopt a particular performance measure?

The choice of performance measure(s) must be rooted in a deep understanding of the firm's distinctive competencies, the market, the competition, and the firm's desired future competitive position. The choice of performance measures should be consistent with the desired future position of the firm. In addition, total factor productivity measures potentially provide a more compete picture of the firm's competitiveness.

Problems

Problem	Type of Problem			Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Total Productivity Measure	Multifactor Productivity Measure	Partial Productivity Measure				
1			Yes	Moderate			Yes
2		Yes	Yes	Moderate			
3	Yes		Yes	Moderate			
4			Yes	Easy			
5			Yes	Easy			
6			Yes	Easy			
7			Yes	Easy			

1. Labor Productivity – units/hour

Model	Output in Units	Input in Labor Hours	Productivity (Output/Input)
Deluxe Car	4,000	20,000	0.20
Limited Car	6,000	30,000	0.20

Labor Productivity – dollars

Model	Output in Dollars	Input in Dollars	Productivity (Output/Input)
Deluxe Car	4,000($8,000)= $32,000,000	20,000($12.00)= $240,000	133.33
Limited Car	6,000($9,500)= $57,000,000	30,000($14.00)= $420,000	135.71

The labor productivity measure is a conventional measure of productivity. However, as a partial measure, it may not provide all of the necessary information that is needed. For example, increases in productivity could result from decreases in quality, and/or increases in material cost.

2. Labor Productivity

Country	Output in Units	Input in Hours	Productivity (Output/Input)
U.S.	100,000	20,000	5.00
LDC	20,000	15,000	1.33

Capital Equipment Productivity

Country	Output in Units	Input in Hours	Productivity (Output/Input)
U.S.	100,000	60,000	1.67
LDC	20,000	5,000	4.00

Yes. You would expect the capital equipment productivity measure to be higher in the U.S. than in a LDC.

b. Multifactor – Labor and Capital Equipment

Country	Output in Units	Input in Hours	Productivity (Output/Input)
U.S.	100,000	20,000 + 60,000= 80,000	1.25
LDC	20,000	15,000 + 5,000= 20,000	1.00

Yes, labor and equipment can be substituted for each other. Therefore, this multifactor measure is a better indicator of productivity in this instance.

c. Raw Material Productivity

Country	Output in Units	Input in Dollars	Productivity (Output/Input)
U.S.	100,000	$20,000	5.00
LDC	20,000	FC $20,000/10= $2,000	10.00

The raw material productivity measures might be greater in the LDC due to a reduced cost paid for raw materials, which is typical of LDC's.

3. Total Productivity

Year	Output in Dollars	Input in Dollars	Productivity (Output/Input)
2002	$200,000	$30,000 + 35,000 + 5,000 + 50,000 + 2,000 = $122,000	1.64
2003	$220,000	$40,000 + 45,000 + 6,000 + 50,000 +3,000 = $144,000	1.53

Partial Measure – Labor

Year	Output in Dollars	Input in Dollars	Productivity (Output/Input)
2002	$200,000	$30,000	6.67
2003	$220,000	$40,000	5.50

Partial Measure – Raw Materials

Year	Output in Dollars	Input in Dollars	Productivity (Output/Input)
2002	$200,000	$35,000	5.71
2003	$220,000	$45,000	4.89

Partial Measure – Capital

Year	Output in Dollars	Input in Dollars	Productivity (Output/Input)
2002	$200,000	$50,000	4.00
2003	$220,000	$50,000	4.40

The overall productivity measure is declining, which indicates a possible problem. The partial measures can be used to indicate cause of the declining productivity. In this case, it is a combination of declines in both labor and raw material productivity, but an increase in the capital productivity. Further investigation should be undertaking to explain the drops in both labor and raw material productivity. An increase in the cost of both of these measures, without an accompanying increase in the selling price might explain these measures.

4.

Contract	Output in Units	Input in Hours	Productivity (Output/Input)
Navy	2300	25(2)40 = 2000	1.15
Army	5500	35(3)40 = 4200	1.31

The workers were most productive on the Army contract.

5.

Month	Output in Dollars	Input in Hours	Productivity (Output/Input)	Percentage Change
April	$45,000	1560	28.85	
May	$56,000	1820	30.77	(30.77-28.85)/28.85 = 6.67%

6.

Year	Output in Packages	Input in Drivers	Productivity (Output/Input)	Percentage Change
2004	103,000	84	1226.2	
2005	112,000	96	1166.7	(1166.7 -1226.2)/1226.2 = - 4.85%

7.

Part	Output in Hamburger Equivalents	Input in Hours	Productivity (Output/Input)
700 Hamburgers 900 Cheeseburgers (1.25) 500 Chicken Sandwiches (.80)	2225	200	11.125
700 Hamburgers 700 Cheeseburgers (1.25) 700 Chicken Sandwiches (.80)	2135	200	10.675

TECHNICAL NOTE 2
OPTIMIZING THE USE OF RESOURCES WITH LINEAR PROGRAMMING

Problems

Problem	Type of Problem			Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Excel	Graphical	Formu-lation				
1	Yes			Easy			
2	Yes			Easy			Yes
3	Yes		Yes	Moderate			
4		Yes	Yes	Moderate			Yes
5		Yes	Yes	Moderate			
6	Yes		Yes	Difficult			
7	Yes		Yes	Moderate			
8	Yes			Moderate	Yes		
9	Yes			Moderate	Yes		
10	Yes			Moderate	Yes		

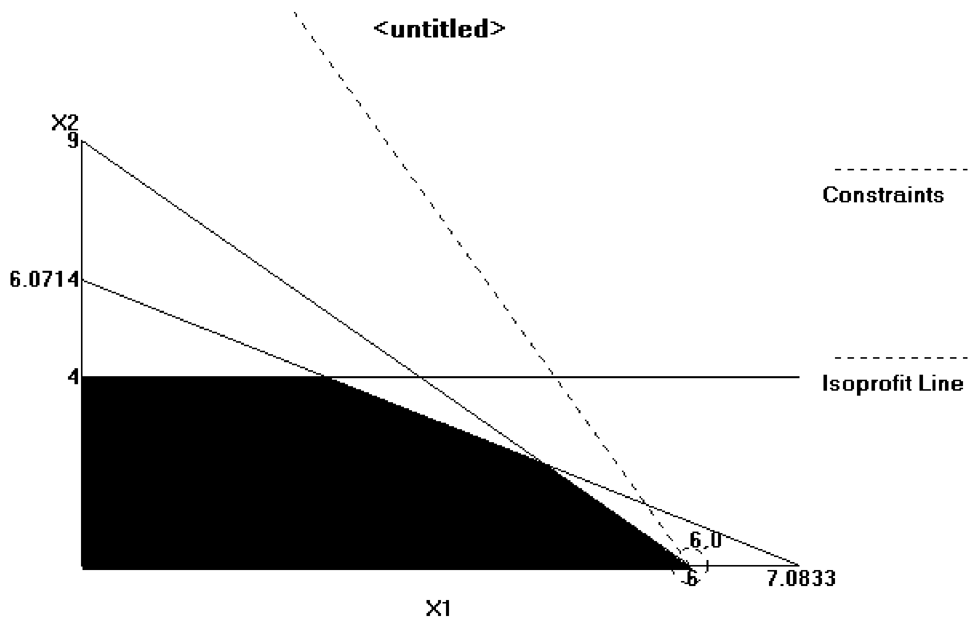
*Solution procedure modified.

1. Excel Solution

	X	Y	Total	
Decision	6	0		
Profit	$3	$1	$18	

			Resources	
	X	Y	Used	Capacity
A	12	14	72 <=	85
B	3	2	18 <=	18
C		1	0 <=	4

Graphical solution--the problem requested the Excel solution, but the following graphical solution is provided for classroom use if desired.

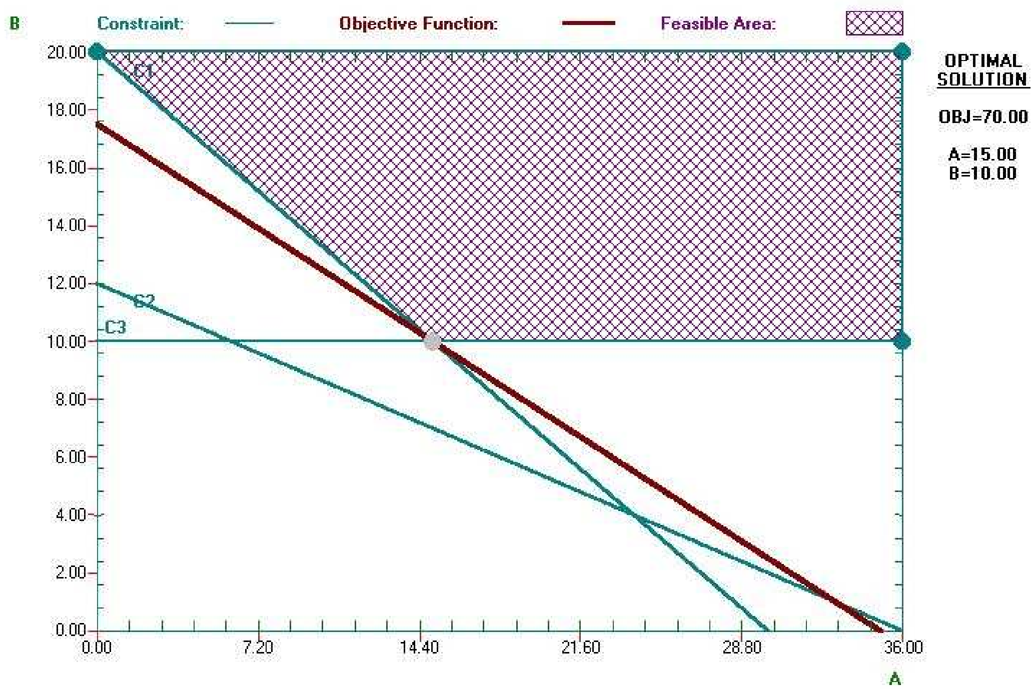


2.

	A	B	Total
Decision	15	10	
Profit	$2	$4	$70

			Resources	
	A	B	Used	Capacity
A	4	6	120 >=	120
B	2	6	90 >=	73
C		1	10 >=	10

Graphical solution--the problem requested the Excel solution, but the following graphical solution is provided for classroom use if desired.



3. a. Maximize $Z = 20X_1 + 6X_2 + 8X_3$

s.t.

$$8X_1 + 2X_2 + 3X_3 \leq 800$$

$$4X_1 + 3X_2 \leq 480$$

$$2X_1 + X_3 \leq 320$$

$$X_3 \leq 80$$

$$X_1, X_2, X_3 \geq 0$$

b. Excel solution

	X1	X2	X3	Total
Decision	45	100	80	
Profit	$20	$6	$8	$2,140

	X1	X2	X3	Resources Used		Capacity
Milling	8	2	3	800	<=	800
Lathes	4	3		480	<=	480
Grinders	2		1	170	<=	320
Sales			1	80	<=	80

c. Solution is $X_1 = 45$ $S_1 = 0$ $Z = \$2140$

$X_2 = 100$ $S_2 = 0$

$X_3 = 80$ $S_3 = 150$

$S_4 = 0$

d. $S_1 = 0$ implies milling machines at capacity

$S_2 = 0$ implies lathes at capacity

$S_3 = 150$ implies grinders not at capacity, with 150 hours available

$S_4 = 0$ implies that X_3 is not at maximum sales capacity

e. The shadow price for the milling machine department is $2.25 per hour. Since it only cost

$1.50 per hour to work overtime in this department, it is worthwhile to do so. The maximum overtime is 400. However, only 200 hours are available. Therefore, it is recommended that 200 hours of overtime in the milling machine department be used.

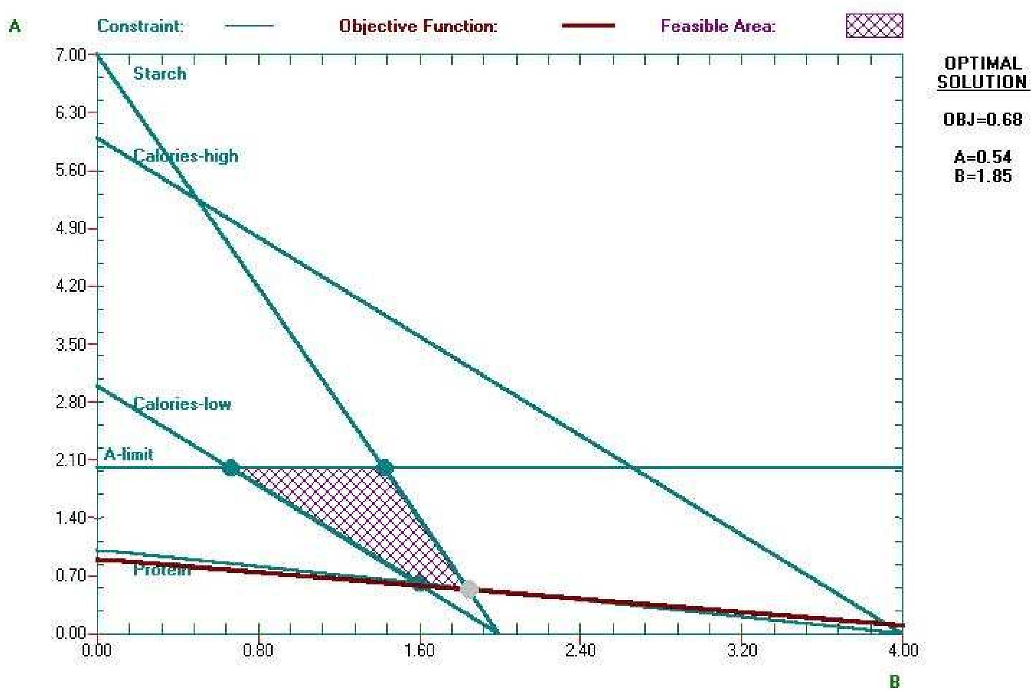
4. a.

Let A = pounds of food A

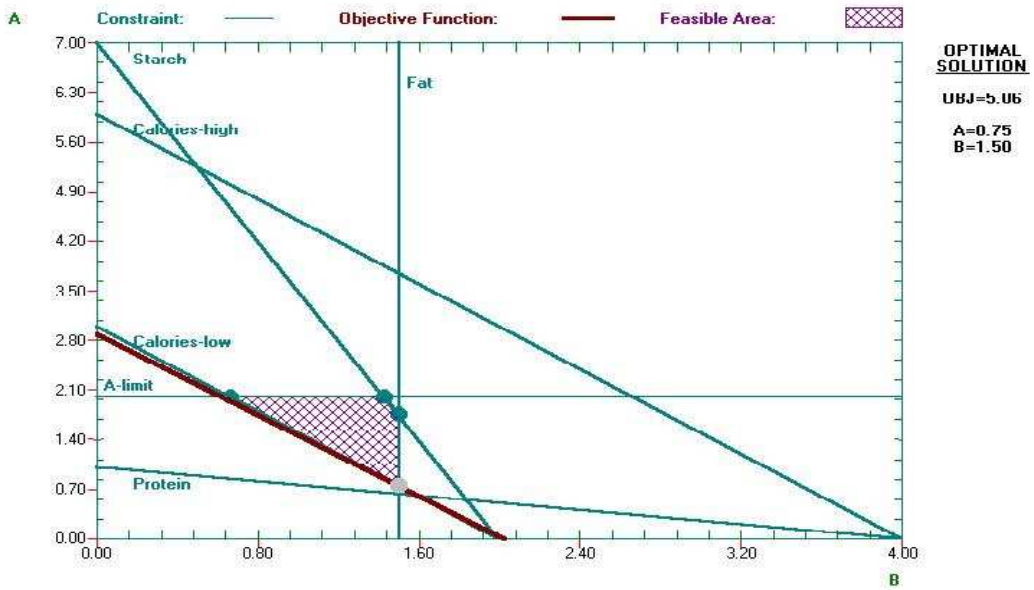
B = pounds of food B

Minimize : $z = .75A + .15B$

s.t.	$600A + 900B \leq 3{,}600$	Maximum calories
	$600A + 900B \geq 1{,}800$	Minimum calories
	$200A + 700B \leq 1{,}400$	Maximum starch
	$400A + 100B \geq 400$	Minimum protein
	$A \leq 2$	Maximum amount of A



5. Add constraint 100B < 150, and change objective function to z = 1.75A + 2.50B



6. a.

Let A = gallons of fuel A to mix

B = gallons of fuel B to mix

Minimize z = 1.20A + 0.90B

s.t.	A +	B $\geq$ 3,000		fuel demand
	A +	B $\leq$ 4,000		Maximum storage
	A	$\leq$ 2,000		Maximum fuel A available
		B $\leq$ 4,000		Maximum fuel B available
	10A -	5B $\geq$	0	Blend 80 octane minimum*
	A, B $\geq$ 0			

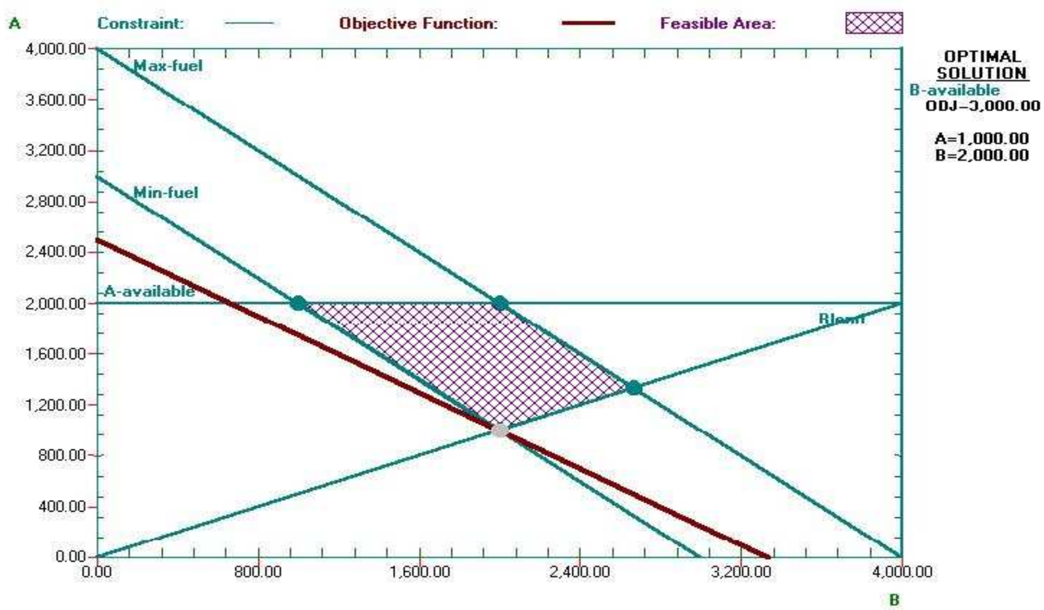
*Note, blend constraint can be stated as (90A + 75B)/(A + B) $\geq$ 80

b.

	A	B	Total		
Decision	1000	2000	3000		
Profit	$1	$1	$3,000		

			Resources		
	A	B	Used		Capacity
Min demand	1	1	3000	>=	3000
Max Storage	1	1	3000	<=	4000
Max Fuel A	1		1000	<=	2000
Max Fuel B		1	2000	<=	4000
Blend	10	-5	3.342E-07	>	0

Graphical solution--the problem requested the Excel solution, but the following graphical solution is provided for classroom use if desired.



7. Let: F = dollars spent on food

S = dollars spent on shelter

E = dollars spent on entertainment

Maximize Z = 2F + 3S + 5E

s.t.

$F + S + E \leq 1500$ Total Budget

$F + S \leq 1000$ Maximum on Food and Shelter

$S \leq 700$ Maximum on Shelter alone

$E \leq 300$ Maximum on Entertainment

	F	S	E	Total
Decision	300	700	300	
Profit	2	3	5	4,200

	X_1	X_2	X_3	Resources Used		Capacity
total budget	1	1	1	1300	<=	1500
$ on food and shelter	1	1		1000	<=	1000
$ on shelter		1		700	<=	700
$ on entertainment			1	300	<=	300

8. Produced 50 barrels of Expansion Draft and 50 barrels of Burning River. The total revenue will be $1400.

	Expansion Draft	Burning River	Total
Decision	50	50	
Sales	$20	$8	$1400

	X_1	X_2	Resources Used		Capacity
Corn	8	2	500	<=	500
Rice	0	6	300	<=	300
Hops	4	3	350	<=	400

9. Run zone for 6 hours and man for 4 hours at a cost of $384.

	Zone	Man	Total	
Decision	6	4		
Cost	$48	$24	$384	

	X_1	X_2	Processes Produced		Demand
BCP1	3	1	22	>=	20
BCP2	1	1	10	>=	10
BCP3	1	0	6	>=	6

10. She should plant 700 acres in corn and 100 acres in soybeans.

	Corn	Soybeans	Wheat	Total
Decision	700	100	0	800
Profit per acre	$2,000	$2,500	$3,000	$1,650,000

				Resources		
	Corn	Soybeans	Wheat	Used		Capacity
Labor (workers)	0.1	0.3	0.2	100	<=	100
Fertilizer (tons)	0.2	0.1	0.4	150	<=	150
Acres Planted	700	100	0	800	<=	900

CHAPTER 4
PRODUCT DESIGN PROCESS

Review and Discussion Questions

1. Describe the generic product development process described in this chapter. How does this process change for "technology push" products?

Products that are developed using the "technology push" would be more narrowly focused in phase 0 and phase 1 of Marketing. There focus would be narrower because you would only look at market segments that could benefit from the application of your technology. The rest of the generic process may be somewhat less complex as well since the technology of the product current exist in your manufacturing facilities

2. Discuss the product design philosophy behind industrial design and design for manufacture and assembly. Which one do you think is more important in a customer-focused product development?

Industrial design is concerned with designing a product from the end-user's point of view, such as aesthetics and user-friendliness of the product. Design for manufacturability, on the other hand, makes the product design less complicated and easier to manufacture. Very often it results in less parts, smaller size, increased reliability, and lower cost.

Both philosophies are equally important for a customer-focused product development. In order to attract customers, the product must be aesthetically pleasing and user-friendly (industrial design). However, to sustain customer interests, it should also have a lower cost and higher reliability (design for manufacturability).

3. Discuss design-based incrementalism, which is frequent product redesign throughout the product's life. What are the pros and cons of this idea?

Pro: enhanced function, higher quality, and lower cost through continuously advancing technology.

Con: time and money spent on frequent product and process redesigns, low priority given in servicing the existing and older products.

4. What factors must be traded off by product development before introducing a new product?

The factors that need careful attention for new products are product performance, development speed, product cost, and development program expense. Smith and Reinertsen identify six pairs of trade-offs in their book. These include all possible pairs among the four factors noted above.

5. How does the QFD approach help? What are some limitations of the QFD approach?

QFD helps to get the voice of the customer into the design process using interfunctional teams. The limitations of QFD relate to the culture of the organization. In the United States, we tend to be vertically oriented and try to promote breakthrough. This can work against interfunctional teamwork, which is needed for QFD success. If a breakthrough culture can be maintained with a continuous improvement mentality through interfunctional teams, this would lead to tremendous improvements in productivity.

Problems

Problem	Type of Problem				Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	NPV Problem	House of Quality	Assembly Chart	Flow Process Chart				
1	Yes				Moderate	Yes		
2	Yes				Moderate	Yes		
3					Easy			
4		Yes			Moderate			
5			Yes	Yes	Difficult			

1. Tuff Wheels Kiddy Dozer
 a. Base case

Project Schedule	Year 1				Year 2				Year 3				Year 4			
Kiddy Dozer	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Development	333	333	333													
Pilot Testing			100	100												
Ramp-up			200	200												
Marketing and Support				38	38	38	38	38	38	38	38	38	38	38	38	38
Production Volume					15	15	15	15	15	15	15	15	15	15	15	15
Unit Production Cost					100	100	100	100	100	100	100	100	100	100	100	100
Production Costs					1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500	1500
Sales Volume					15	15	15	15	15	15	15	15	15	15	15	15
Unit Price					170	170	170	170	170	170	170	170	170	170	170	170
Sales Revenue					2550	2550	2550	2550	2550	2550	2550	2550	2550	2550	2550	2550
Period Cash Flow	**-333**	**-333**	**-633**	**-338**	**1013**	**1013**	**1013**	**1013**	**1013**	**1013**	**1013**	**1013**	**1013**	**1013**	**1013**	**1013**
PV Year 1 r = 8	**-333**	**-327**	**-609**	**-318**	**935**	**917**	**899**	**881**	**864**	**847**	**831**	**814**	**798**	**783**	**767**	**752**
Project NPV	**8503**															

b. The results are shown below for both scenarios. If sales are only 50,000 then the project is still worthwhile since the NPV decrease to $6,759,000. If Tuff Wheels has under estimated the sales and it ends up being 70,000 per year then NPV will increase from $8,503,000 base case to $10,247,000 with the higher sales rate.

Sales Revised to 50,000 per Year

Project Schedule	Year 1				Year 2				Year 3				Year 4			
Kiddy Dozer	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Development	333	333	333													
Pilot Testing			100	100												
Ramp-up			200	200												
Marketing and Support				38	38	38	38	38	38	38	38	38	38	38	38	38
Production Volume					13	13	13	13	13	13	13	13	13	13	13	13
Unit Production Cost					100	100	100	100	100	100	100	100	100	100	100	100
Production Costs					1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250	1250
Sales Volume					13	13	13	13	13	13	13	13	13	13	13	13
Unit Price					170	170	170	170	170	170	170	170	170	170	170	170
Sales Revenue					2125	2125	2125	2125	2125	2125	2125	2125	2125	2125	2125	2125
Period Cash Flow	**-333**	**-333**	**-633**	**-338**	**838**	**838**	**838**	**838**	**838**	**838**	**838**	**838**	**838**	**838**	**838**	**838**
PV Year 1 r = 8	**-333**	**-327**	**-609**	**-318**	**774**	**759**	**744**	**729**	**715**	**701**	**687**	**674**	**660**	**647**	**635**	**622**
Project NPV	**6759**															

Sales Revised to 70,000 per Year

Project Schedule	Year 1				Year 2				Year 3				Year 4			
Kiddy Dozer	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Development	333	333	333													
Pilot Testing			100	100												
Ramp-up			200	200												
Marketing and Support				38	38	38	38	38	38	38	38	38	38	38	38	38
Production Volume					18	18	18	18	18	18	18	18	18	18	18	18
Unit Production Cost					100	100	100	100	100	100	100	100	100	100	100	100
Production Costs					1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750	1750
Sales Volume					18	18	18	18	18	18	18	18	18	18	18	18
Unit Price					170	170	170	170	170	170	170	170	170	170	170	170
Sales Revenue					2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975	2975
Period Cash Flow	**-333**	**-333**	**-633**	**-338**	**1188**	**1188**	**1188**	**1188**	**1188**	**1188**	**1188**	**1188**	**1188**	**1188**	**1188**	**1188**
PV Year 1 r = 8	**-333**	**-327**	**-609**	**-318**	**1097**	**1076**	**1054**	**1034**	**1014**	**994**	**974**	**955**	**936**	**918**	**900**	**882**
Project NPV	**10247**															

c. The impact of changing the interest rate is shown below. There is still a positive NPV but it shrinks the interest rate increases. This would be expected since a higher the interest rate reduces the present value of future cash flows.

Base Case	8%	$8,503,043
	9%	$8,283,241
	10%	$,8069,666
	11%	$7,862,116

2. Perot Corporation Patay2 Chip.

a. In the base case the Patay2 Chip Project has a very good NPV of $10,460,000, see below.

Project Schedule	Year 1		Year 2		Year 3		Year 4	
Patay2 Chip	1st half	2nd half	1st half	2nd half	1st half	2nd half	1st half	2nd half
Development Cost	5,000	5,000	5,000	5,000				
Pilot Testing Cost			2,500	2,500				
Debug Cost			1,500	1,500				
Ramp-up Cost				3,000				
Advance Marketing Cost				5,000				
Ongoing Marketing and Support					500	500	500	500
Production Volume					125	125	75	75
Unit Production Cost					655	655	545	545
Production Costs					81,875	81,875	40,875	40,875
Sales Volume					125	125	75	75
Unit Price					820	820	650	650
Sales Revenue					102,500	102,500	48,750	48,750
Period Cash Flow	**-5,000**	**-5,000**	**-9,000**	**-17,000**	**20,125**	**20,125**	**7,375**	**7,375**
PV Year 1 r = 12	**-5,000**	**-4,762**	**-8,163**	**-14,685**	**16,557**	**15,768**	**5,503**	**5,241**
Project NPV	**10,460**							

.

b. Additional 10 million for higher price is clearly worthwhile as it raises the NPV from $10.46 million to $16.654 million. See results below.

Project Schedule	Year 1		Year 2		Year 3		Year 4	
Patay2 Chip	1st half	2nd half	1st half	2nd half	1st half	2nd half	1st half	2nd half
Development Cost	7,500	7,500	7,500	7,500				
Pilot Testing Cost			2,500	2,500				
Debug Cost			1,500	1,500				
Ramp-up Cost				3,000				
Advance Marketing Cost				5,000				
Ongoing Marketing and Support					500	500	500	500
Production Volume					125	125	75	75
Unit Production Cost					655	655	545	545
Production Costs					81,875	81,875	40,875	40,875
Sales Volume					125	125	75	75
Unit Price					870	870	700	700
Sales Revenue					108,750	108,750	52,500	52,500
Period Cash Flow	**-7,500**	**-7,500**	**-11,500**	**-19,500**	**26,375**	**26,375**	**11,125**	**11,125**
PV Year 1 r = 12	**-7,500**	**-7,143**	**-10,431**	**-16,845**	**21,699**	**20,666**	**8,302**	**7,906**
Project NPV	**16,654**							

c. Reduced sales estimates have a significant impact on the NPV. It reduces the NPV all the way down to $10,000. The success of the Patay2 Chip is very dependent on the sales estimates. It would be wise for Perot to make sure that there is sufficient demand for Patay2 Chips.

Project Schedule	Year 1		Year 2		Year 3		Year 4	
Patay2 Chip	1st half	2nd half	1st half	2nd half	1st half	2nd half	1st half	2nd half
Development Cost	5,000	5,000	5,000	5,000				
Pilot Testing Cost			2,500	2,500				
Debug Cost			1,500	1,500				
Ramp-up Cost				3,000				
Advance Marketing Cost				5,000				
Ongoing Marketing and Support					500	500	500	500
Production Volume					100	100	50	50
Unit Production Cost					655	655	545	545
Production Costs					65,500	65,500	27,250	27,250
Sales Volume					100	100	50	50
Unit Price					820	820	650	650
Sales Revenue					82,000	82,000	32,500	32,500
Period Cash Flow	**-5,000**	**-5,000**	**-9,000**	**-17,000**	**16,000**	**16,000**	**4,750**	**4,750**
PV Year 1 r = 12	**-5,000**	**-4,762**	**-8,163**	**-14,685**	**13,163**	**12,536**	**3,545**	**3,376**
Project NPV	**10**							

3. Answers will vary based upon the product selected and the student. Issues that should be considered in the design and manufacture of a product include design process (traditional vs. concurrent engineering), customer needs and expectations, legal considerations (EPA, OSHA, etc.), service life, reliability, appearance, standardization, any industry standards that should be considered (e.g., television set and the type of signal received from stations), method of shipment, material cost and availability, stage of the product life cycle, design for manufacturability, design for assembly, packaging, environmental, unit cost, pricing, availability of purchased material, availability of capacity, availability of subcontractors, setup cost, manufacturing time, volume, and expected product life.

4. Answers may vary.

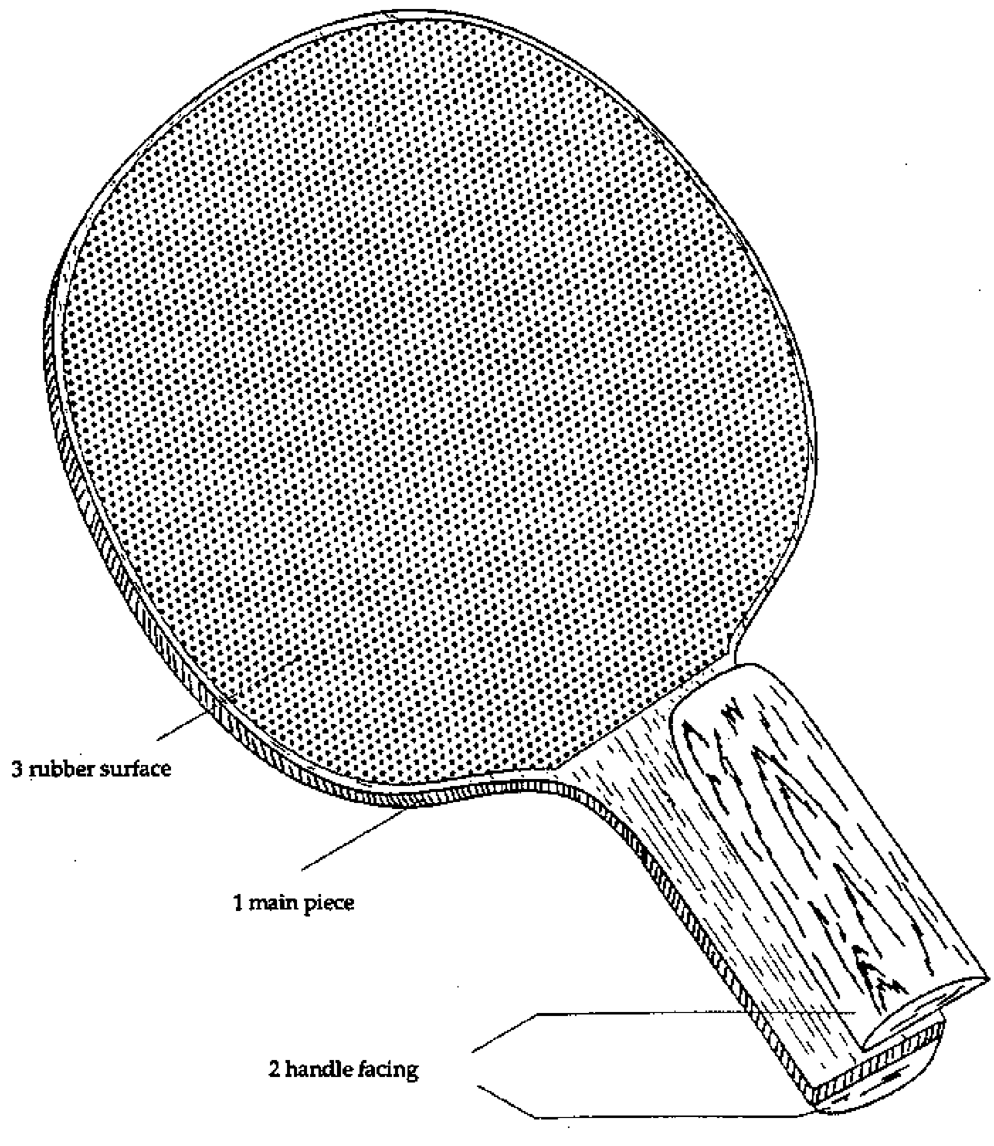
WHATs versus HOWs
Strong Relationship: ●
Medium Relationship: ○
Weak Relationship: △

WHATs versus HOWs	Physical Aspects	Course location	Ground maintenance	Landscaping	Pin placement	Course tuning	Tee placement	Service Facilities	Customer-trained attendants	Top quality food	Highly rated chefs	Attractive restaurant	Tournament Facilities	Calloway handicapping	Exciting door prizes	Perception Issues	Invitation only	Types of guests	Income level	Celebrity
Physical Aspects																				
Manicured grounds		○	●	●	●	●	○							△					●	●
Easy access		△	●	●	●	○	○							△					●	●
Challenging		△	●	●	●	○	●							△					●	●
Service Facilities																				
Restaurant Facilities																				
Good food		○	△	△					○	●	●	○					△		●	●
Good service		○	△	△					●	●	○	○					△		●	●
Good layout		○	△	△					○	△	△	●					△		●	●
Plush locker room									△	△	△	△					△		●	●
Helpful service attend									●	△	△	○					△		●	●
Tournament Facilities																				
Good tournament prize														○	●		●		●	●
Types of players		△	△	△	△	△	○							○	○		●		●	●
Fair handicapping sys		△	△	△	△	△	○							●	○		●		●	●
Perception Issues																				
Prestigious		●	○	○	△	○	○		○	○	○	○		△	○		●		●	●

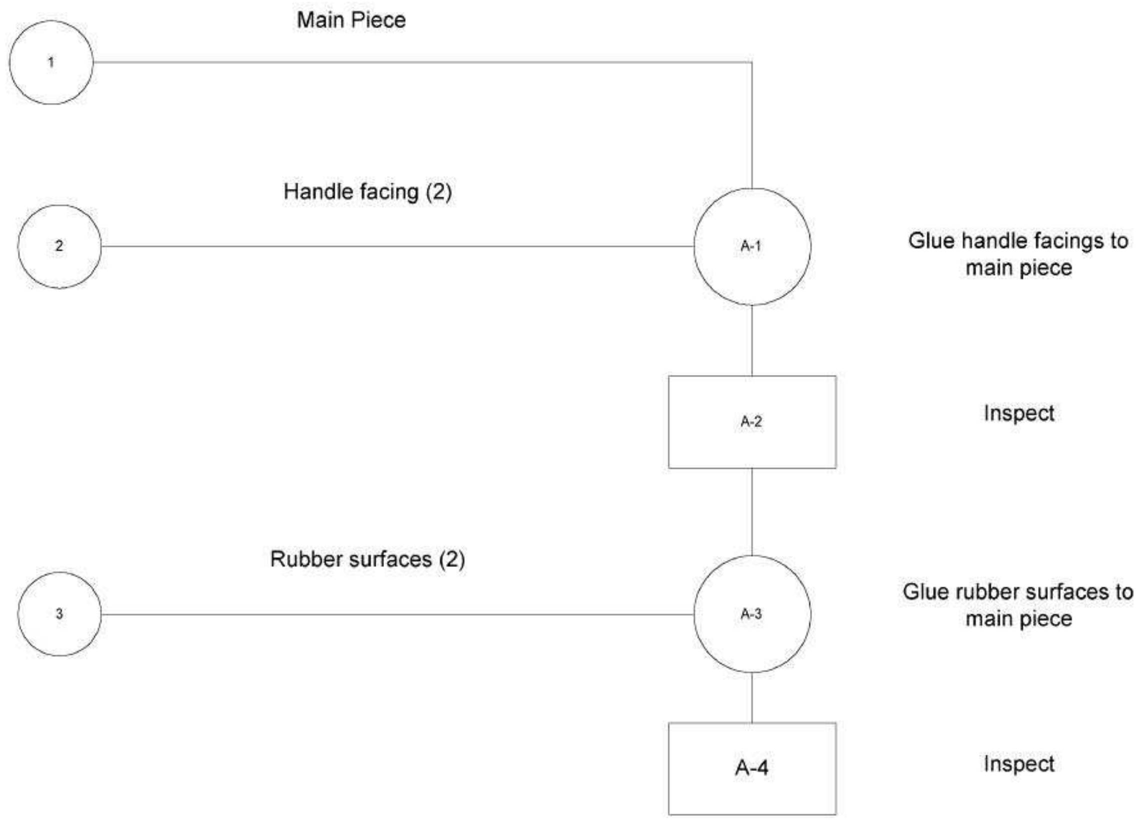
5. This can be a fairly extensive assignment depending upon the amount of research students do into paddle manufacturing. Without doing any library or field study on the production process, students should be able to come up with a solution approximating the one given below.

   a. obtain paddle for model
   b. equipment and materials
      equipment: bandsaw, hand saws, circular saw, sanding machine, lathe, glue press, handtruck
      materials: wood, plywood, rubber for paddle surface, glue, lacquer, plastic bags for wrapping, shipping boxes, and tape.

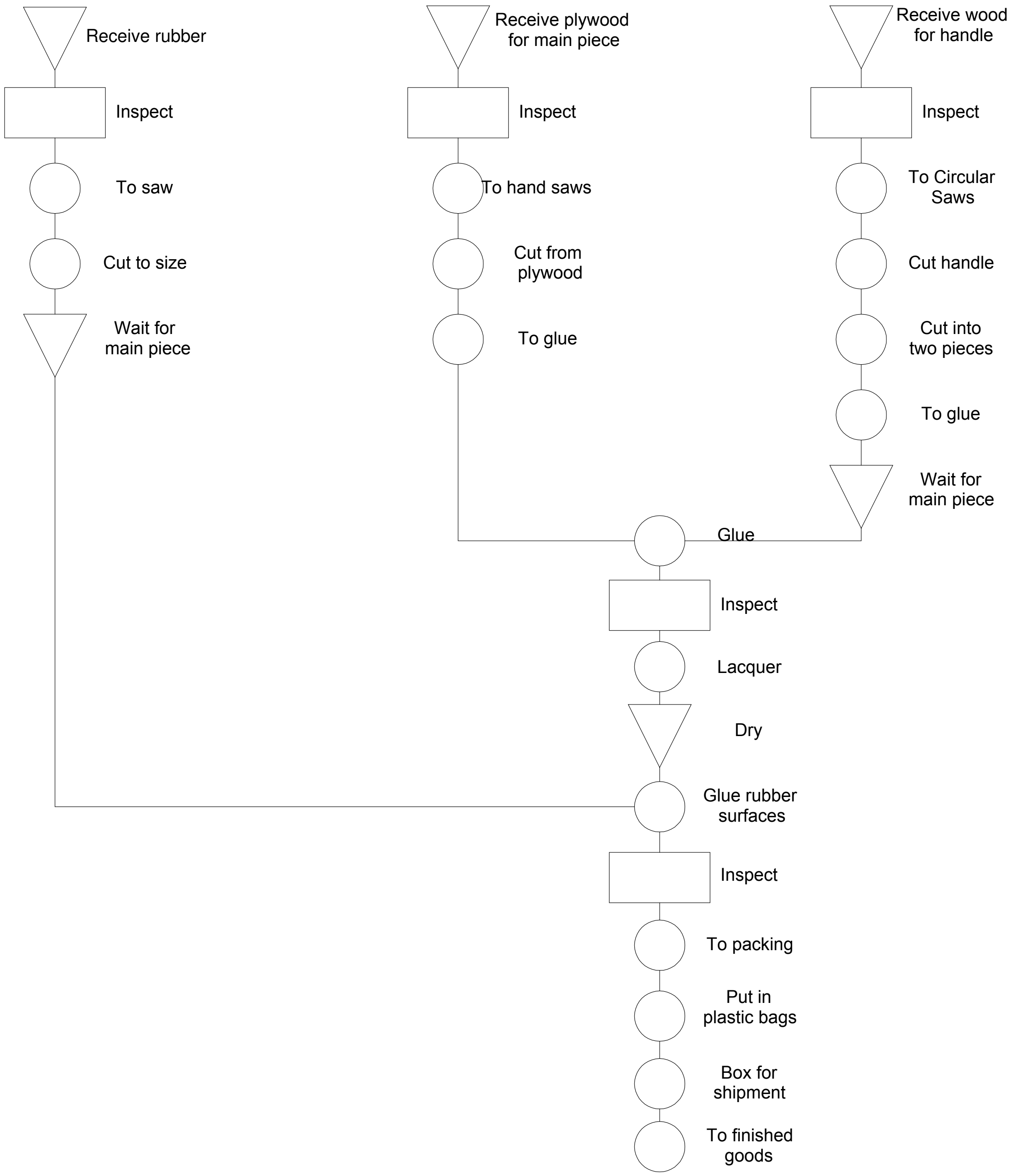
      (1) Assembly drawing



(2) Assembly chart



(3) Flow Process Chart



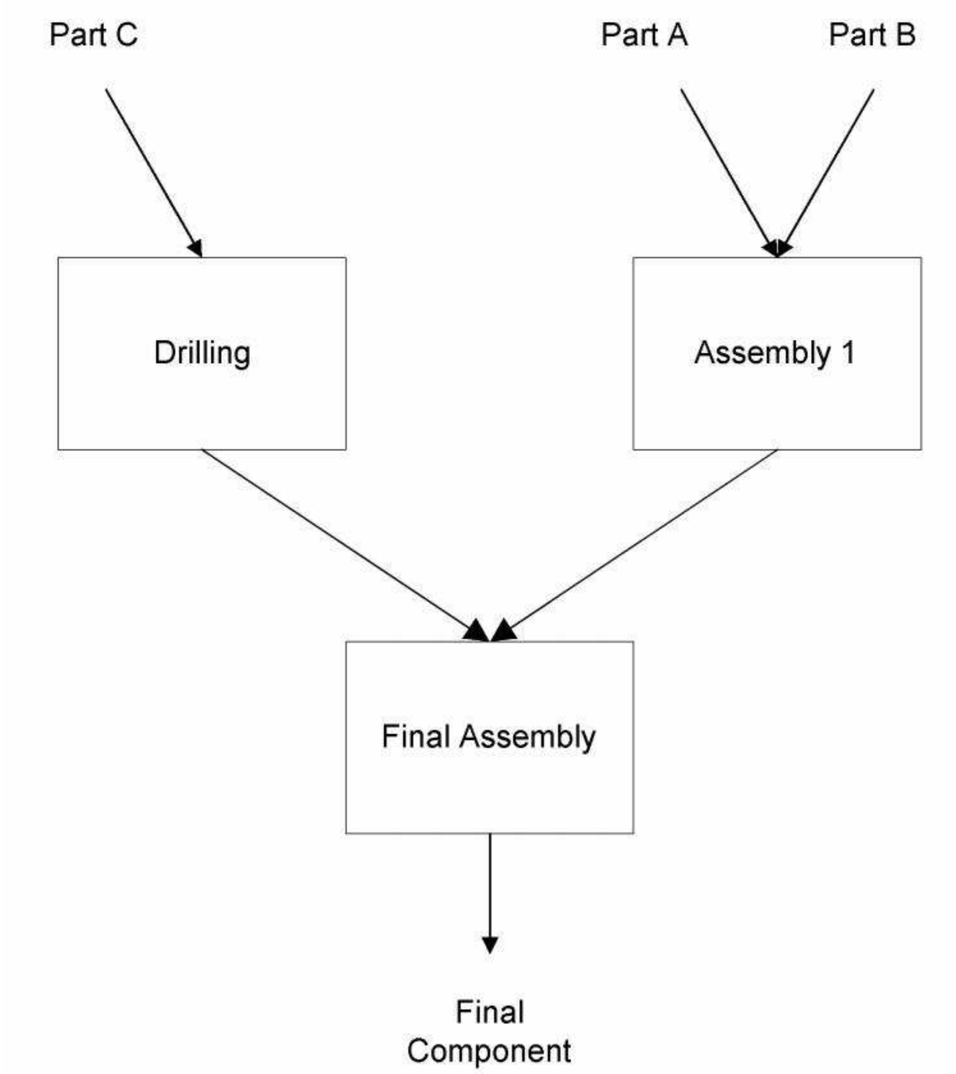
(4) Process route sheets

Part Name: Main Piece					
Operation number	Operation description	Dept.	Setup time	Pieces per hour	Tools
10	Cut to size	Saw	1.0	100	Band saw
20	Glue handle facing	Glue	0.5	50	Clamps
21	Lacquer	Glue	0.3	100	Paint brush
22	Glue rubber surface	Glue	0.1	100	Paint brush

Part Name: Handle Facing					
Operation number	Operation description	Dept.	Setup time	Pieces per hour	Tools
15	Cut to size	Saw	0.25	400	Circular saw
16	Cross cut diameter	Saw	0.25	100	Circular saw
20	Glue handle facing	Glue	0.5	50	Clamps

Part Name: Rubber Surface					
Operation number	Operation description	Dept.	Setup time	Pieces per hour	Tools
16	Cut to size in batches of 24	Saw	0.3	300	Band saw
22	Glue rubber surface	Glue	0.1	100	Paint brush

5. a. Process Flow Diagram.



Capacity of assembly line 1 = 140 units/hour X 8 hours/day X 5 days/week = 5,600 units/week.

Capacity of drill machines = 3 drill machines X 50 parts/hour X 8 hours/day X 5 days/week = 6,000 units/week.

Capacity of final assembly line = 160 units/hour X 8 hours/day X 5 days/week = 6,400 units/week.

The capacity of the entire process is 5,600 units per week, with assembly line 1 limiting the overall capacity.

b. Capacity of assembly line 1 = 140 units/hour X 16 hours/day X 5 days/week = 11,200 units/week.

Capacity of drill machines = 4 drilling machines X 50 parts/hour X 8 hours/day X 5 days/week = 8,000 units/week.

Capacity of final assembly line = 160 units/hour X 16 hours/day X 5 days/week = 12,800 units/week.

The capacity of the entire process is 8,000 units per week, with drilling machines limiting the overall capacity.

c. Capacity of assembly line 1 = 140 units/hour X 16 hours/day X 5 days/week = 11,200 units/week.

Capacity of drill machines = 5 drilling machines X 50 parts/hour X 8 hours/day X 5 days/week = 10,000 units/week.

Capacity of final assembly line = 160 units/hour X 12 hours/day X 5 days/week = 9,600 units/week.

The capacity of the entire process is 9,600 units per week, with final assembly machines limiting t he overall capacity.

d. Cost per unit when output = 8,000 units.

Item	Calculation	Cost
Cost of part A	$.40 X 8,000	$3,200
Cost of part B	$.35 X 8,000	2,800
Cost of part C	$.15 X 8,000	1,200
Electricity	$.01 X 8,000	80
Assembly 1 labor	$.30 X 8,000	2,400
Final assembly labor	$.30 X 8,000	2,400
Drilling labor	$.15 X 8,000	1,200
Overhead	$1,200 per week	1,200
Depreciation	$30 per week	30
Total		$14,510

Cost per unit = Total cost per week/Number of units produced per week

= $14,510/8,000

= $1.81

. Cost per unit when output = 9,600 units.

Item	Calculation	Cost
Cost of part A	$.40 X 9,600	$3,840
Cost of part B	$.35 X 9,600	3,360
Cost of part C	$.15 X 9,600	1,440
Electricity	$.01 X 9,600	96
Assembly 1 labor	$.30 X 9,600	2,880
Final assembly labor	$.30 X 9,600	2,880
Drilling labor	$.15 X 9,600	1,440
Overhead	$1,200 per week	1,200
Depreciation	$30 per week	30
Total		$17,166

Cost per unit = Total cost per week/Number of units produced per week

= $17,166/9,600

= $1.79

Let X = the number of units that each option will produce. When the company buys the units, the cost is $3.00 per unit (3X). When it manufactures the units, they incur a fixed cost of $120,000 (4 drilling machines at $30,000 a piece) and a per unit cost of $1.81. Therefore, 120,000 + 1.81X is the cost of this option. Set them equal to each other and solve for X to determine the breakeven point.

$3X = 120{,}000 + 1.81X$

$X = 100{,}840$ units.

Therefore, it is better to buy the units when you produce less than 100,840, and better to produce them when demand is greater than 100,840 units.

TECHNICAL NOTE 4
LEARNING CURVES

Review and Discussion Questions

1. If you kept any of your old exam grades from last semester, get them out and write down the grades. Use Exhibits TN4.5 and TN4.6, log-log graph paper, or a spreadsheet to find whether the exponential curve fits showing that you experienced learning over the semester (insofar as your exam performance is concerned). If not, can you give some reasons why not?

For example, if your scores were;

Exam 1 = 85

Exam 2 = 75

The learning percentage = 75 ÷ 85 = 88%

Since 88% lies between 85 and 90% on the learning curve exhibit (TN4.5), we must interpolate to find the improvement ratio for the third exam. It would be .8169

Therefore, exam 3 = .8169 x 85 = 69.4

Suppose, that the reverse was true, that is, the student's grade is improving.

Exam 1 = 75

Exam 2 = 85

Because improvement curves are usually associated with decreases in some variable over time, we convert this to a decrease in lost points, i.e., exam 1 = 25, exam 2 = 15. The learning percentage is 15/25 = .60.

The number of lost points for exam 3 = 25 x .4450 = 11.1

The grade for exam 3 = 100 – 11.1 = 88.9

Generally, learning curves are used for repetitive tasks. In other words, doing the same exact task over and over again. In this case, new material is covered from one exam to the next. This change in material might impact on the learning curve.

2. How might the following business specialists use learning curves: accountants, marketers, financial analysts, personnel managers, and computer programmers?

Accountants:	estimating costs
Marketers:	setting-selling prices
Financial analysts:	performing a breakeven analysis for purposes of investment decision making
Personnel managers:	estimating the number of workers required
Computer programmers:	estimating times to write programs

3. As a manager, which learning percentage would you prefer (other things being equal), 110 percent or 60 percent? Explain.

Students tend at first glance to erroneously associate higher learning percentages with faster learning. Relative to the 110 percent learning rate, strict interpretation of this would mean that every time output doubles, production time per unit increases by 10 percent. With a 60 percent learning rate, every time output doubles, production time per unit decreases by 40 percent. These statements can be verified by simple arithmetic.

4. What difference does it make if a customer wants a 10,000 unit order produced and delivered all at one time or in 2,500 unit batches?

Aside from the costs of resetup, undoubtedly some relearning is necessary each time one of the 2,500 unit orders is produced. This would result in additional time and more material and other resource usage. What might be better and cheaper (at least from a learning curve perspective) is to produce the entire 10,000 unit order and simply deliver 2,500 units at a time to the customer.

Problems

Problem	Type of Problem	Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Learning Curve				
1	Yes	Easy			
2	Yes	Easy			
3	Yes	Moderate			Yes
4	Yes	Easy			
5	Yes	Moderate			
6	Yes	Moderate			
7	Yes	Easy			Yes
8	Yes	Moderate			
9	Yes	Easy			
10	Yes	Easy			
11	Yes	Easy			Yes
12	Yes	Moderate			
13	Yes	Easy			
14	Yes	Moderate			
15	Yes	Moderate			
16	Yes	Moderate			

1. Ratio for 50th unit from Exhibit TN4.5 is .5518; standard time for 50th unit is .20.

Unit	Ratio (Exhibit TN4.5)	Time
100th	.4966	$\frac{.20}{.5518}$ (.4966) = .18 hours
200th	.4469	$\frac{.20}{.5518}$ (.4469) = .16 hours
400th	.4022	$\frac{.20}{.5518}$ (.4022) = .15 hours

2. a.

Unit	Ratio (Exhibit TN4.5)	Cost
1st ten	1.0000	$2,500.00
2nd ten	.7000	$2,500 x .7000 = $1,750.00
3rd ten	.5682	$2,500 x .5682 = $1,420.50
4th ten	.4900	$2,500 x .4900 = $1,225.00
5th ten	.4368	$2,500 x .4368 = $1,092.00

b. The price should be between the cost of the first twenty ($2,500 + $1,750 = $4,250), and the cost of the next twenty ($1,420.50 + $1,225.00 = $2,645.50)

3.

For labor the following learning was experienced:

Unit 1 to 2 = 1500/2000 = 75%, from units 2 to 4 = 1275/1500 = 85%

Based on this, we estimate an average labor learning rate of 80%

For cost the following learning was experienced:

Unit 1 to 2 = 37050/39000 = 95%, from units 2 to 4 = 31492.5/37050 = 85%

Based on this, we estimate an average cost of parts learning rate at 90%

Labor for 12 more units:

From Exhibit TN4.6	16 units	= 8.920
	-4 units	= 3.142
		5.778

Therefore, Labor for 12 more units = 2,000(5.778) = 11,556 hours

Cost for 12 more units:

From Exhibit TN4.6	16 units	= 12.040
	-4 units	= 3.556
		8.484

Therefore, Cost for 12 more units = 39,000(8.484) = $330,876

4. a. **Labor:**

LR = 3500/5000 = 70%

From Exhibit TN4.6	12 units	= 5.501
	-2 units	= 1.700
		3.801

Therefore, Labor cost for 10 more units = 5,000(3.801)(30) = $570,150

Material:

LR = 200000/250000 = 80%

From Exhibit TN4.6	12 units	= 7.227
	-2 units	= 1.800
		5.427

Therefore, Labor cost for 10 more units = 250,000(5.427) = $1,356,750

Total Cost is $570,150 + $1,356,750 = $1,926,900

b. The minimum cost would be as calculated in part a, $1,926,900. This would assume no forgetting. However, the worst case would be total forgetting, which would imply that there was no benefit to having produced units 1 and 2. This cost would be as follows.

Complete forgetting:

Labor: 4.931(5,000)(30)	= $ 739,650
Material: 6.315($250,000)	= $1,578,750
Total	= $2,318,400

Therefore, the range is from $1,926,900 to $2,318,400.

5.

a.

Units 1 to 2 = 640/970 = 65.98%
Units 2 to 4 = 380/640 = 59.37%
Units 4 to 8 = 207/380 = 54.47%

Average learning rate = 59.94% Round this to 60%

b. From Exhibit TN4.6	200 units	= 12.090
	-10 units	= 3.813
		8.277

Therefore, time for 190 more units = 970(8.277) = 8,029 hours

c. For 1,000th unit from Exhibit TN4.5:

.0062(970) = 6.0 hours

6.

a.

For units 1 to 2 = 10/12 = 83.33%
For units 2 to 4 = 6.5/10 = 65 %
For units 4 to 8 = 3.6/6.5 = 55.38%
For units 8 to 16 = 2.7/3.6 = 75%

The average learning rate is = 69.67 Round this to 70%.

b. From Exhibit TN4.6 120 units = 19.570

-20 units = 7.407

12.163

Therefore, cost for 100 more units = 12 million (12.163) = $145,956,000

c. From Exhibit TN4.5: Cost for 120^{th} unit is $12 million(.0851) = $1,021,200

7. LR = 1,800/2,000 = 90%

From Exhibit TN4.6 6 units = 5.101

-3 units = 2.746

2.355

Therefore, time for 3 more units = 2,000(2.355) = 4,710 hours

8. LR = 6.3/9.0 = 70%

The breakeven point where the AVERAGE labor hours on all cars serviced by the mechanic equals 3 hours. According to the following table, that doesn't occur until after car 25. Unless each mechanic is going to service over 25 cars, it's not a good deal. Since the dealer expects to perform the service on 300 vehicles (approximately 50 per mechanic), it appears that Honda's rate is fair.

Learning Rate	70%	
Unit	70%	Average
1	9.0	9.00
2	6.3	7.65
3	5.1	6.80
4	4.4	6.21
5	3.9	5.75
6	3.6	5.39
7	3.3	5.09
8	3.1	4.84
9	2.9	4.63
10	2.8	4.44
11	2.6	4.27
12	2.5	4.13
13	2.4	3.99
14	2.3	3.87
15	2.2	3.76
16	2.2	3.66
17	2.1	3.57
18	2.0	3.49
19	2.0	3.41
20	1.9	3.33
21	1.9	3.26
22	1.8	3.20
23	1.8	3.14
24	1.8	3.08
25	1.7	3.03
26	1.7	2.97
27	1.7	2.92
28	1.6	2.88
29	1.6	2.83
30	1.6	2.79

9. Labor LR = 3,200/4,000 = 80%

Material LR = 21,000/30,000 = 70%

a. For the 22nd unit:

Labor 4,000(.3697)($18 per hour)	= $26,618.40
Material $30,000(.2038)	= $ 6,114.00
Total	= $32,732.40

b. From Exhibit TN4.6

22 units	=	11.230
-2 units	=	1.800
		9.430

Labor time for 20 more units = 4,000(9.430) = 37,720 hours

Average time = 37,720/20 = 1,886 hours

c. From Exhibit TN4.6

22 units	=	7.819
-2 units	=	1.700
		6.119

Therefore, material cost for 20 more units = $30,000(6.119) = $183,570

Average material cost = $183,570/20 = $9,178.50

Average labor cost = 1,886($18) = $33,948.00

Average total cost = $9,178.50 + $33,948.00 = $43,126.50

10. a. LR = 80/100 = 80%

Therefore, for the 20th unit (from Exhibit TN4.5) = .3812(100) = 38.12 minutes.

Do not hire.

b. Two factors determine if an individual will meet the 30 minute requirement for the 20th unit: the time for the first unit and the learning rate. Using tables such as Exhibit TN4.5, the expected time for the 20th unit can be calculated. Compare this value to the required 30 minutes.

c. Concern is that the value of the learning rate is estimated from on two points.

11. a. LR = 40/50 = 80%

Time for the 3rd (from Exhibit TN4.5) is .7021(50) = 35.1 hours

b. Time for 1,000 units (from Exhibit TN4.6) is 158.7(50) = 7,935 hours

Average time per unit is 7,935/1,000 = 7.935 hours.

Since the average time per unit is less than 20 hours, take the contract.

12. LR = 85%

From Exhibit TN2.5, the factor for the 10th unit is .5828, and .5584 for the 12th.

We interpolate to find the factor for the 11th. Use (.5828+.5584)/2 = .5706 for the 11th.

Using the cost for the 10th unit of $2.5 million, estimate the cost for the 1st unit:

$2.5 million/.5828 = $4,289,636

The cost for

11th unit is $4,289,636(.5706) = $2,447,666

12th unit is $4,289,636(.5584) = $2,395,333

The price with a 10% profit should be

11th unit, $2,447,666/.90 = $2,719,629

12th unit, $2,395,333/.90 = $2,661,481

Total price for 11th and 12th unit is $5,381,110

13. LR = 47.5/50 = 95%

a. For the 10th unit (from Exhibit TN4.5) the expected time is 50(.8433) = 42.165 minutes

b. For the 100th unit (from Exhibit TN4.5) the expected time is 50(.7112) = 35.56 minutes

14.

a.

For units 1 to 2 = 29/39 = 74.35%
For units 2 to 4 = 19/29 = 65.55%
For units 4 to 8 = 13/19 = 68.42%

The average learning rate is = 69.44 Round this to 70%.

b. From Exhibit TN4.6	100 units	=	17.790
	-10 units	=	4.931
			12.859

Labor time for 90 more units = 39(12.859) = 501.5 minutes

c. From Exhibit TN4.5, the 1,000th unit will take 39(.0200) = .78 minutes

15. 85% learning. 1,000/hour implies 500 in 30 minutes or .5 hours. From TN4.5 we see that it takes .4930 hours after 20 batches are encoded.

16. 75% learning. From TN4.6 in 24 hours 100 batches of 20 are produced. From TN4.5, the production rate at 100 batches and 75% learning is .1479 hours/batch, which is 6.76 batches/hour or 135 sandwiches per hour.

CHAPTER 5
PROCESS ANALYSIS

Review and Discussion Questions

1. Compare McDonald's old and new processes for making hamburgers. How valid is McDonald's claim that the new process will produce fresher hamburgers for the customers? Comparing McDonald's new process to the processes used by Burger King and Wendy's, which process would appear to produce the freshest hamburgers?

   Exhibit 5.2 illustrates the various processes. McDonald's old process was a make-to-stock, where orders were pulled from finished goods. However, McDonald's new process will assemble-to-order. Therefore, McDonald's claim of a fresher hamburger should hold. Burger King's process is a combination of McDonald's old and new processes. The best Burger King can hope to do is match McDonald's with their orders that are assembled-to-order. The ones that are taken from finished goods will generally not be as fresh. Wendy's, on the other hand, should beat both McDonald's and Burger King on freshness, since they cook-to-order (Make-to-order)!

2. State in your own words what Little's Law means. Think of an example that you have observed where Little's Law applies.

   Little's Law shows the relationship between throughput rate, throughput time, and the amount of work-in-process inventory. Specifically, it is throughput time equals amount of work-in-process inventory divided by the throughput rate. Little's Law is useful for examining the performance of a process. Example 5.1, bread-making operation, illustrate an application of Little Law.

3. Explain how having more work-in-process inventory can improve the efficiency of a process? How can this ever be bad?

   More work-in-process inventory can be used to buffer multiple stage processes. Specifically, it can help with blocking or starving. Blocking is when the activities in the stage must stop because there is no place to deposit the item just completed. Starving is when the activities in a stage must stop because there is no work. Buffer inventories between operations can help relieve these problems, and improve the efficiency of the overall process. Increasing work-in-process inventory can be bad in that it involves more investment in inventory, as well as taking-up valuable floor space. Also, the JIT philosophy view work-in-process as being negative for a variety of reasons (more on JIT in a later chapter).

4. Recently some Operations Management experts have begun insisting that simple minimizing process velocity, which actually means minimizing the time that it takes to process something through the system, is the single most important measure for improving a process. Can you think of a situation when this might not be true?

   The problem with focusing exclusively on process velocity is that other dimensions might be ignored, such as quality or safety. There are many examples. One would be if drying time was reduced, this might impact the quality of the process. Another example would be whiskey, reducing the aging time would probably impact its quality.

Problems

Problem	Type of Problem	Difficulty	New Problem	Modified Problem	Check Figure in Appendix H
	Process Analysis				
1	Yes	Easy			Yes
2	Yes	Easy			
3	Yes	Moderate			Yes
4	Yes	Moderate			
5	Yes	Moderate			
6	Yes	Moderate			
7	Yes	Moderate	Yes		
8	Yes	Moderate	Yes		
9	Yes	Moderate			

1. Traditional method: 20 minutes setup plus 10 companies times 2 minutes per company.

   20 + (10*2) = 40 minutes.

   Alternative method: 1 minute setup plus 10 companies times 5 minutes per company.

   1 + (10*5) = 51 minutes.

   Therefore, the traditional method is best.

2. The longest process on this "assembly line" will govern the output. Therefore, the maximum output from this line will be:

   Output = available time/cycle time = (40 hours per week)*(60 minutes per hour)/1.5 minutes per student = 1,600 students per week.

   Therefore, this line cannot produce the 2,000 students per week.

3.

   a. The market can only be served at 3 gal/hr, while raw material is received at 4 gal/hr. Consequently, there is a 1gal/hr build-up of WIP in the bathtub. After 50 hours (50 gal bathtub/1 gal per hour build-up), the bathtub will overflow.

   b. The average amount being supplied is only 2.5 gal/hr, so that is the output rate. The market will be shy by .5 gal/hr, and a stock-out will occur within each 2 hour cycle.

4.

   a. One operator per project: 10 projects per day/8 hours per day = 1.25 projects/hour. The productivity of this option is also 1.25 projects/hour. For the two operator approach, the second operator will limit the system to a rate of 2 projects/hour (this assumes 30 minutes per project). The first operator would be idle for an average of 10 minutes each project. The productivity for the two operator approach is 2 projects per hour/2 hours of labor = 1 project/hour.

b. With the one operator, 1000 projects would take 1000 projects/1.25 project per hour = 800 hours or 100 days. With two operators, it would take 1000 projects/2 projects per hour = 500 hours or 62.5 days. The labor content for the first option is 800 hours. The second option requires 1000 hours of labor.

5.

Current plans are to make 100 units of component A, then 100 units of component B, then 100 units of component A, then 100 units of component B, etc, where the setup and run times for each component are given below.

Component	Setup / Changeover Time	Run Time/unit
A	5 minutes	0.2 minutes
B	10 minutes	0.1 minutes

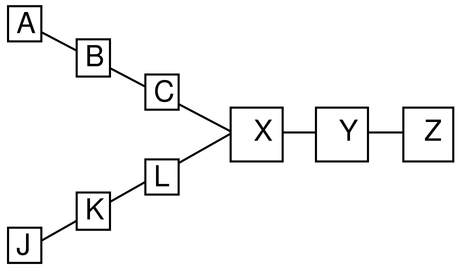
Assume the packaging of the two components is totally automated and only takes 2 seconds per unit of the final product. This packaging time is small enough that you can ignore it. What is the average hourly output, in terms of the number of units of packaged product (which includes 1 component A and 1 component B)?

5 + 10 + .2(100) + .1(100) = 15 + 30 = 45 minutes/100 units

45/100 = 60/X

X = 133.3 units/hr.

6.



Given the following amount of work in seconds required at each station:

A	38	J	32	X	22
B	34	K	30	Y	18
C	35	L	34	Z	20

a.

(8 X 60 X 60)/38 = 757

b.

Efficiency: 263/ (9 X 38) = 76.9%

c.

6 x 38 = 228 seconds

7.

a.

Take Order = 100 per hour * 12 hours = 1200
Pick Order = 80 per hour * 24 hours = 1920
Pack Order = 60 per hour * 24 hours = 1440

Maximum output is determined by order taking (1200) since the pick and pack operations can work up to 24 hours to clear out their order backlog.

b.

If we take the maximum of 1200 orders then:
Pick Order = 1200 orders/80 per hour = **15 hours**
Pack Order = 1200 orders/60 per hour = **20 hours**

c.

Orders can be taken at a rate of 100/hours and can be picked at the rate of 80/hour so they build at the rate of 20/hour. Orders are taken for 12 hours.

Maximum orders waiting for picking = 20/hour * 12 hours = **240**

d.

Orders can be picked at a rate of 80/hours and can be packed at the rate of 60/hour so they build at the rate of 20/hour. Orders are picked for 15 hours.

Maximum orders waiting for packing= 20/hour * 15 hours = **300**

e.

(b. revisited) If we take the maximum of 1200 orders then:
Pick Order = 1200 orders/80 per hour = **15 hours**
Pack Order = 1200 orders/120 per hour = 10 hours
However, Packing has to wait for the orders to be picked so it would be 15 hours

(c. revisited) This answer does not change.
Orders can be taken at a rate of 100/hours and can be picked at the rate of 80/hour so they build at the rate of 20/hour. Orders are taken for 12 hours.

Maximum orders waiting for picking = 20/hour * 12 hours = **240**

(d. revisited)
Orders can be picked at a rate of 80/hours and can be packed at the rate of 120/hour so they build at the rate of 0/hour. Orders are picked for 15 hours.

Maximum orders waiting for packing= 0/hour * 15 hours = **0**

8.

a.

The maximum capacity at National State would be (8 tellers * 60 minutes)/5 minutes per customer or 96 customers per hour.

b. We can not handle all the customers by 5:00 pm (see table below). The last customers are processed after National State closes their doors at 5:00 but they will be done at 5:05.

c. The maximum waiting time is 12.5 minutes (see table below) and it occurs from 4:40 – 4:45.

Time	Customers Arriving During Period (Cumulative)	Customers Departing During Period (Cumulative)	Customers at Teller or Waiting	Customers Waiting at end of Period	Expected Waiting Time*
4:00 - 4:05	2	2(2)	2	0	0
4:05 - 4:10	5(7)	5(7)	5	0	0
4:10 - 4:15	6(13)	6(13)	6	0	0
4:15 - 4:20	8(21)	8(21)	8	0	0
4:20 - 4:25	10(31)	8(29)	10	2	1.25
4:25 - 4:30	12(43)	8(37)	14	6	3.75
4:30 - 4:35	16(59)	8(45)	22	14	8.75
4:35 - 4:40	12(71)	8(53)	26	18	11.25
4:40 - 4:45	**10(81)**	**8(61)**	**28**	**20**	**12.50**
4:45 - 4:50	6(87)	8(69)	26	18	11.25
4:50 - 4:55	4(91)	8(77)	22	14	8.75
4:55 - 5:00	2(93)	8(85)	16	8	5.00
5:00 - 5:05	**0(93)**	**8(93)**	**8**	**0**	**0**

* Waiting time is customers waiting * .625 minutes. A customer should complete service every .625 minutes (5 minutes service/8 tellers)

9. The expected output is 3.5 professors per hour (the average of 1, 2, 3, 4, 5, and 6, the individual output rates). But, after simulating this process, the actual output would be less due to the starving that takes place in the system.

TECHNICAL NOTE 5
JOB DESIGN AND WORK MEASUREMENT

Review and Discussion Questions

1. Why might practicing managers and industrial engineers be skeptical about job enrichment and sociotechnical approaches to job design?

   Job enrichment by definition moves away from specialization, which, from a purely mechanical standpoint, is the most efficient way to work. Sociotechnical approaches include job enrichment as a design strategy and in addition emphasize worker and work group autonomy. Thus, managers and industrial engineers have legitimate concerns about the implications of these approaches on output, planning, and control.

2. Professors commonly complain to their families that book writing is hard work and that they should be excused from helping out with the housework so that they can rest. Which exhibit in this chapter should they never let their families see?

   Exhibit TN5.3, listing caloric requirements for various activities, indicates that writing requires only slightly more calories than sitting at rest. Thus, from a purely physical standpoint, professors cannot plead overwork on the job to avoid chores at home.

3. Is there an inconsistency when a company requires precise time standards and encourages job enlargement?

   This depends greatly on the job at hand. However, if the elements of the enriched job are well defined and standardized, there is no reason why objective standards cannot be set for enriched jobs.

   As an aside, it is worth emphasizing that work simplification notions are not incompatible with any of the behaviorally oriented approaches to job design. For example, just because a worker is given autonomy in performing a task doesn't mean that the methods by which that task is accomplished shouldn't be efficient.

4. Match the following techniques to their most appropriate application;

a. Worker-machine chart	a. Washing clothes at a Laundromat
b. Process chart	b. Tracing your steps in getting a parking permit
c. Work sampling	c. Faculty office hours kept

5. You have timed your friend, Lefty, assembling widgets. His time averaged 12 minutes for the two cycles you timed. He was working very hard, and you believe that none of the nine other operators doing the same job can beat his time. Are you ready to put this time forth as the standard for making an order of 5,000 widgets? If not, what else could you do?

   Exhibit TN5.10 can be used to evaluate the adequacy of the sample size (i.e., number of cycle times). The average time in hours for the first two cycles is .200. Since there are to be 5,000 widgets each requiring one cycle, then according to Exhibit TN5.10, the appropriate number of cycles to be studied is 8. Thus, six additional cycles should be timed. Also, it is important to know if being left-handed affects assembly time and whether Left's added effort should be accounted for through performance rating to assure that all workers will have a reasonable standard.

6. Comment on the following:

   a. "Work measurement is old hat. We have automated our office, and now we run every bill through our computer (after our 25 clerks have typed the data into our computer database)."

   While work measurement may be "old hat" in the face of computerization, the fact remains that there are 25 clerks doing manual work that is amenable to methods analysis and time study.

   b. "It's best that our workers don't know that they are being time studied. That way, they can't complain about us getting in the way when we set time standards."

   Not only does this violate good time study practice, it also leaves the company open to worker distrust and union reactions. Most large companies have specific policies on how standards are to be set and rarely would a union agree to the covert approach advocated in the above statement.

   c. "Once we get everybody on an incentive plan, then we will start our work measurement program."

   This is extremely poor practice. Wage incentives should never be instituted until jobs are measured and standardized.

   d. "Rhythm is fine for dancing, but it has no place on the shop floor."

   One of the principles of motion economy is "work should be arranged to provide a natural rhythm that can become automatic."

7. Organization wide financial incentive plans cover all the workers. Some units or individuals may have contributed more to corporate profits than others. Does this detract from the effectiveness of the incentive plan system? How would your incentive scheme for a small software development firm compare to an established auto manufacturing firm?

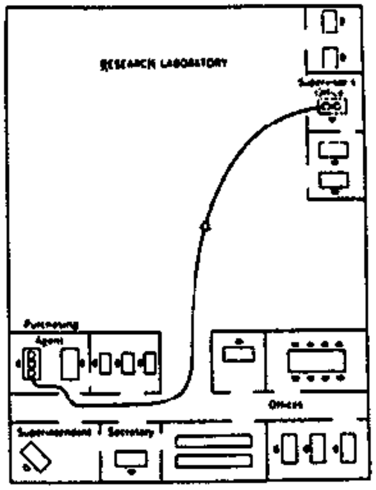
   Employee participation is an important dimension of incentive plans. The contribution of units or individuals to corporate profits will naturally be different due to the law of diminishing marginal returns. This means that effective plans will be designed to generate productivity improvements across the entire organization. A small software development firm could likely get by with one general plan covering all employees, while a large automobile manufacturing company would likely apply different plans to the various parts of the organization.

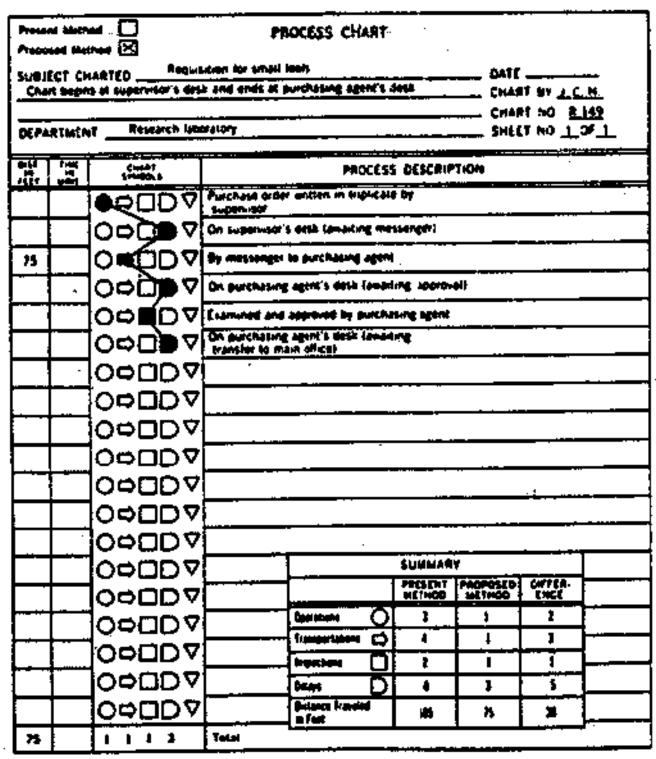
Problems

Problem	Type of Problem				Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Process Chart	Job Satis-faction	Work Sampling	Time Study				
1		Yes			Easy			
2	Yes				Moderate			
3				Yes	Moderate			Yes
4			Yes		Moderate			
5				Yes	Easy			
6				Yes	Easy			
7				Yes	Moderate			Yes
8				Yes	Moderate			
9			Yes		Moderate			

1. We have used this exercise to illustrate the fact that the degree of correspondence to the guidelines for job design is a pretty accurate predictor of the general level of subjective satisfaction people have with their jobs. For example, if a person's job averages one or less on the scale given, they probably found it to be an unsatisfactory job when he was doing it. Similarly, if a person ended up with a score of three or more, they probably found it to be a fairly satisfactory job. Of course, the factor of wages is not considered in this exercise, but this doesn't seem to alter the generally accurate matching of subjective job satisfaction with that implied by the numerical score.

2. Flow diagram and process chart of an office procedure—proposed method*





PROCESS CHART

Present Method ☐
Proposed Method ☒

SUBJECT CHARTED Requisition for small tools
Chart begins at supervisor's desk and ends at purchasing agent's desk

DATE
CHART BY J. C. H.
CHART NO R 149
SHEET NO 1 OF 1

DEPARTMENT Research laboratory

DIST. IN FEET	TIME IN MINS	CHART SYMBOLS	PROCESS DESCRIPTION
		●	Purchase order written in triplicate by supervisor
		D	On supervisor's desk (awaiting messenger)
75		⇨	By messenger to purchasing agent
		D	On purchasing agent's desk (awaiting approval)
		■	Examined and approved by purchasing agent
		D	On purchasing agent's desk (awaiting transfer to main office)
75		1 1 1 2	Total

SUMMARY

	PRESENT METHOD	PROPOSED METHOD	DIFFERENCE
Operations ○	3	1	2
Transportations ⇨	4	1	3
Inspections ☐	2	1	1
Delays D	8	3	5
Distance traveled in Feet	105	75	30

*Requisition is written in triplicate by supervisor and approved by purchasing agent. From Ralph M. Barnes, *Motion and Time Study* (New York: John Wiley & Sons, 1968).

3.

a. NT = (total time)(working time proportion)(performance index)/ (total number of pieces produced) = (45 minutes)(1)(.90)/30 = 1.35 minutes

b. ST = NT (1 + Allowance) = 1.35 (1 +.12) = 1.51 minutes

$$\text{or} \quad ST = \frac{NT}{(1-allowances)} = \frac{1.35}{(1-.12)} = 1.53 \text{ minutes}$$

c. Daily output at standard = 8 hours (60 minutes per hour)/1.51 minutes = 317.9 units Since this worker did not achieve standard output, no bonus would be paid. Pay would be 8 hours per day ($6 per hours) = $48

4. p = 95%, absolute error = 2.5%

From Exhibit TN5.11, n = 304. Average samples per day = 304 samples/60 days = 5.07

Using random number from Appendix B, the following observation times can be obtained for the first day:

Time	Assign Number
8:00 – 8:59	000 – 059
9:00 – 9:59	100 – 159
10:00 – 10:59	200 – 259
11:00 – 11:59	300 – 359

Random numbers from Appendix: 799, 077, 383, 683, 152, 331, 285, 045, 513, 456, 176, 524, 574, 151, 322

Answer will vary depending upon the random numbers selected.

Random number	Observation time
045	8:45
151	9:51
152	9:52
322	11:22
331	11:31

5. NT = (total time)(working time proportion)(performance index)/ (total number of pieces produced) = (480 minutes)(.91)(1.15)/1000 = .502 minutes

ST = NT (1 + Allowance) = .502 (1 +.10) = .552 minutes

$$\text{or} \quad ST = \frac{NT}{(1-allowances)} = \frac{.502}{(1-.10)} = .558 \text{ minutes}$$

6. NT = (total time)(working time proportion)(performance index)/ (total number of pieces produced) = (280 minutes)(1)(1.25)/5000 = .07 minutes

ST = NT (1 + Allowance) = .07 (1 +.10) = .077 minutes

or ST = $\frac{NT}{(1-allowances)} = \frac{.07}{(1-.10)}$ = .078 minutes

7.

a. NT = (total time)(working time proportion)(performance index)/ (total number of pieces produced) = (30 minutes)(1)(1.30)/42 = .9286 minutes

b. ST = NT (1 + Allowance) = .9286 (1 +.15) = 1.0679 minutes

or ST = $\frac{NT}{(1-allowances)} = \frac{.9286}{(1-.15)}$ = 1.0925 minutes

c. Daily output at standard = 8 hours (60 minutes per hour)/1.0679 minutes = 449.5 units If 500 units are produced, wages (day) would be 500/449.5 times $5 per hour times 8 hours per day = $44.49

8.

a. NT = (total time)(working time proportion)(performance index)/ (total number of pieces produced) = (90 minutes)(1)(1.30)/10 = 11.7 minutes

b. ST = NT (1 + Allowance) = 11.7 (1 +.15) = 13.455 minutes

or ST = $\frac{NT}{(1-allowances)} = \frac{11.7}{(1-.15)}$ = 13.765 minutes

c. Daily output at standard = 8 hours (60 minutes per hour)/13.455 minutes = 35.67447 units

If 50 units are produced, wages (day) would be 50/35.67447 times $12 per hour times 8 hours per day = $134.55

9. p = 30%, absolute error = 3%

From Exhibit TN5.11, n = 933. Average samples per day = 933 samples/60 days = 15.55

Using random number from Appendix B, the following observation times can be obtained for the first day:

Time	Assign Number
8:00 – 8:59	000 – 059
9:00 – 9:59	100 – 159
10:00 – 10:59	200 – 259
11:00 – 11:59	300 – 359
1:00 – 1:59	400 – 459
2:00 – 2:59	500 – 559
3:00 – 3:59	600 – 659
4:00 – 4:59	700 – 759

Random numbers from Appendix: 748, 420, 729, 958, 085, 596, 958, 345, 462, 337, 337, 348, 866, 733, 772, 784, 898, 186, 063, 260, 967, 130, 779, 553, 580, 276, 925, 679, 575, 766, 678, 750, 110, 798, 695, 976, 317, 283, 422, 831, 977, 431, 098, 958, 708, 938, 936, 388, 971, 859, 143,

Answer will vary depending, upon the random numbers selected.

Random number	Observation time
110	9:10
126	9:26
130	9:30
143	9:43
317	11:17
337	11:37
345	11:45
348	11:48
420	1:20
422	1:22
431	1:31
553	2:53
708	4:08
729	4:29
733	4:33
748	4:48
750	4:50

CHAPTER 6
MANUFACTURING PROCESS SELECTION AND DESIGN

Review and Discussion Questions

1. What does the product-process matrix tell us? Where would you place a Chinese restaurant on the matrix?

   Products and processes are closely interrelated and both go through life-cycle stages. The stage in the lifecycle of the product will determine the process. The advantages of cost and flexibility can be combined through the adoption of Flexible Manufacturing Systems technology. The Chinese restaurant case might be debatable since it involves both high volume and high variety.

2. It has been noted that during World War II Germany made a critical mistake by having its formidable Tiger tanks produced by locomotive manufacturers, while American car manufacturers produced the less formidable U.S. Sherman tank. Use the product-process matrix to explain that mistake and its likely result.

   The locomotive manufacturers likely used project technology and processes. This is low volume, high cost production. On the other hand, mass-producing automakers had the technology to make high volume at low per unit cost.

3. How does the production volume affect break-even analysis?

   A break-even analysis takes into account the production volume and the relevant cost of producing the volume by the available alternative processes. It calculates the relative profit or loss of the alternative processes, thus helping to decide which alternative to choose for a certain volume of production.

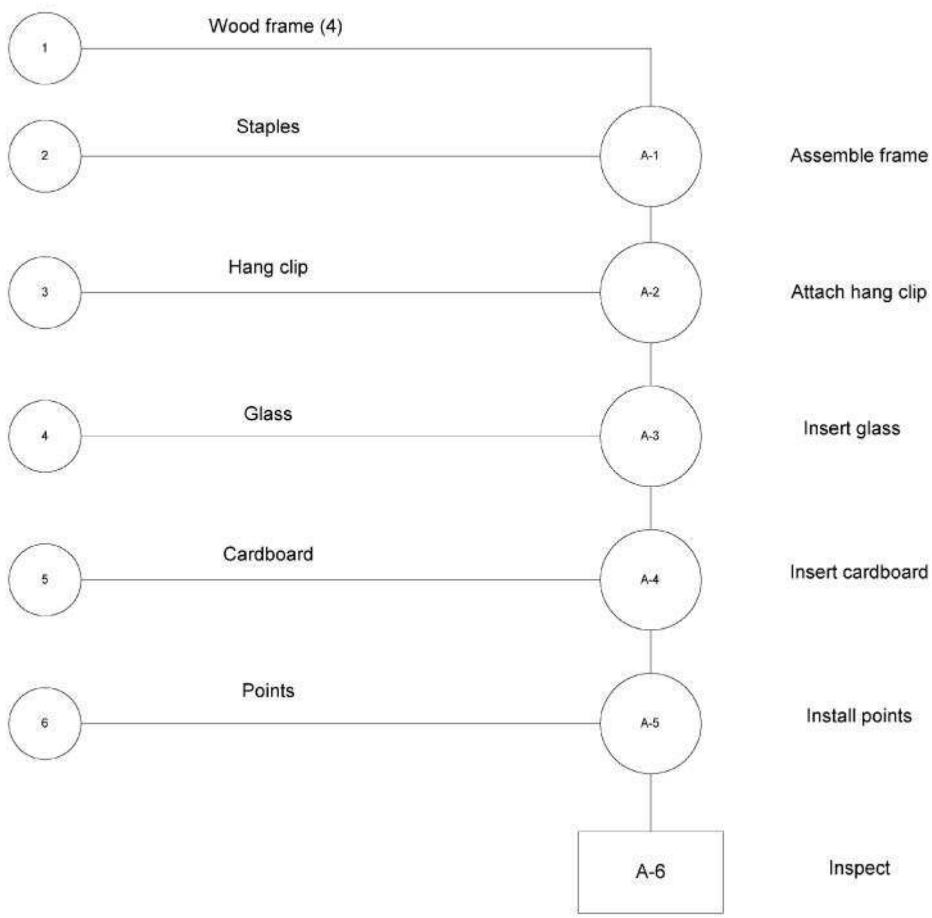
4. What is meant by a process? Describe its important features.

   A process means a set of tasks that transform input into useful outputs. The important features of process are (a) tasks, (b) flow (of material and information), and (c) storage (of material and information).

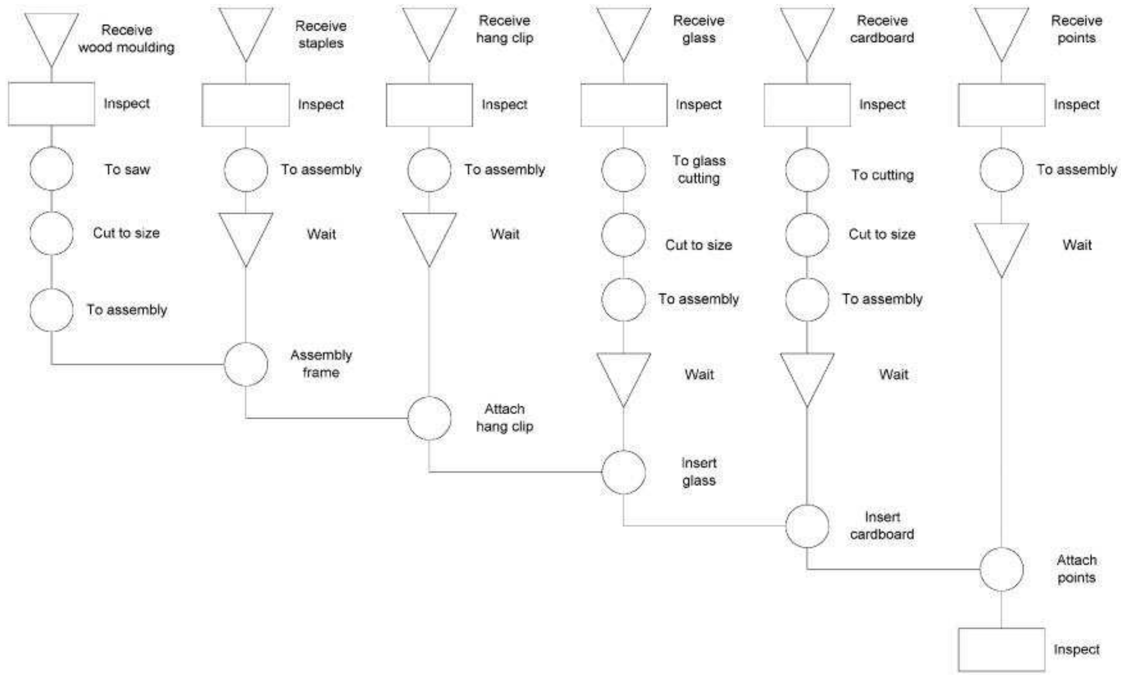
Problems

Problem	Type of Problem			Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Assembly Chart	Flow Process Chart	Break-even				
1	Yes	Yes		Moderate			
2	Yes	Yes		Difficult			
3		Yes		Moderate			Yes
4			Yes	Easy			
5			Yes	Easy			
6			Yes	Moderate			
7			Yes	Easy			Yes
8			Yes	Difficult			
9				Easy			
10				Easy			
11				Easy			
12				Easy			
13				Easy			

1.
   a. Assembly chart (answers may vary).



b. Flow process chart (answers may vary.)



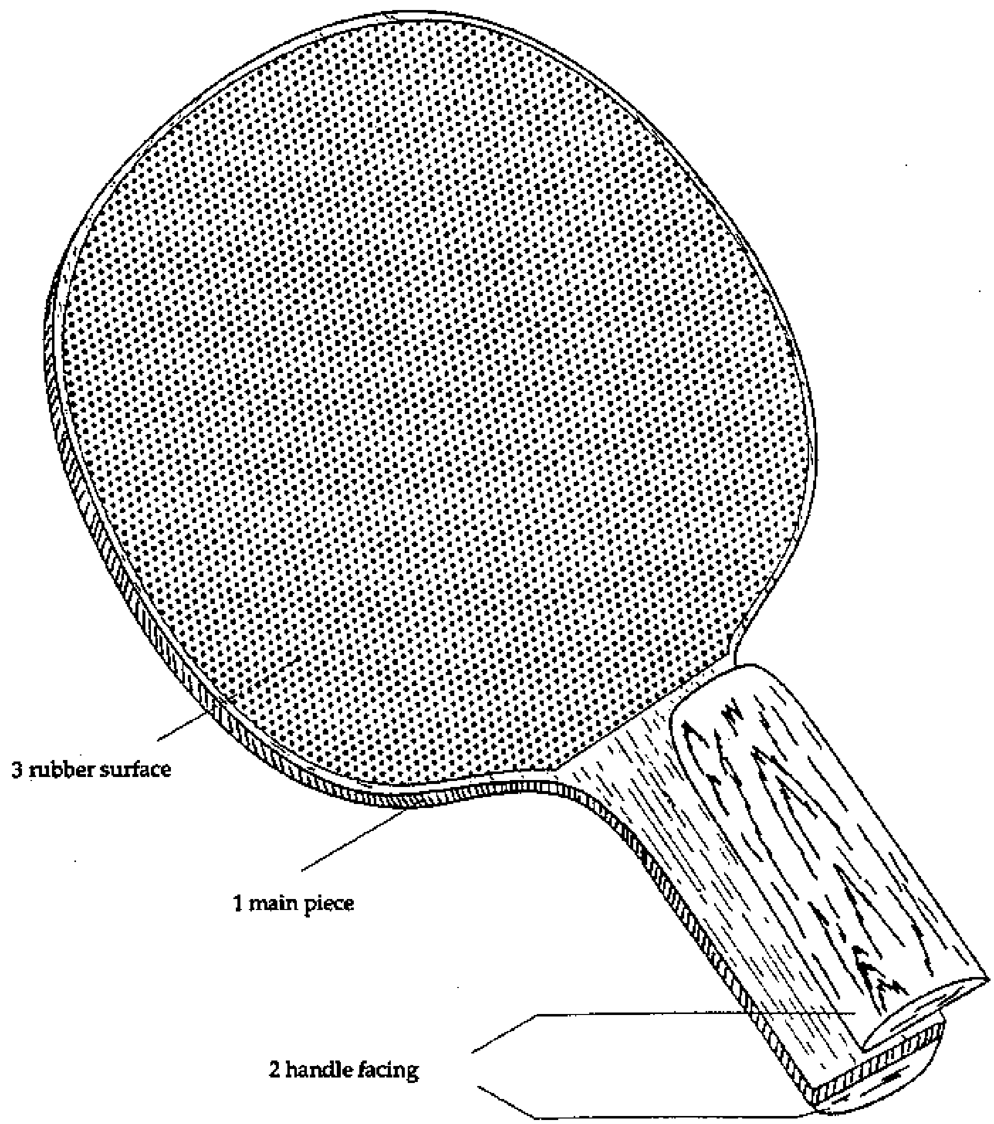
2. This can be a fairly extensive assignment depending upon the amount of research students do into paddle manufacturing. Without doing any library or field study on the production process, students should be able to come up with a solution approximating the one given below.

   a. obtain paddle for model
   b. equipment and materials

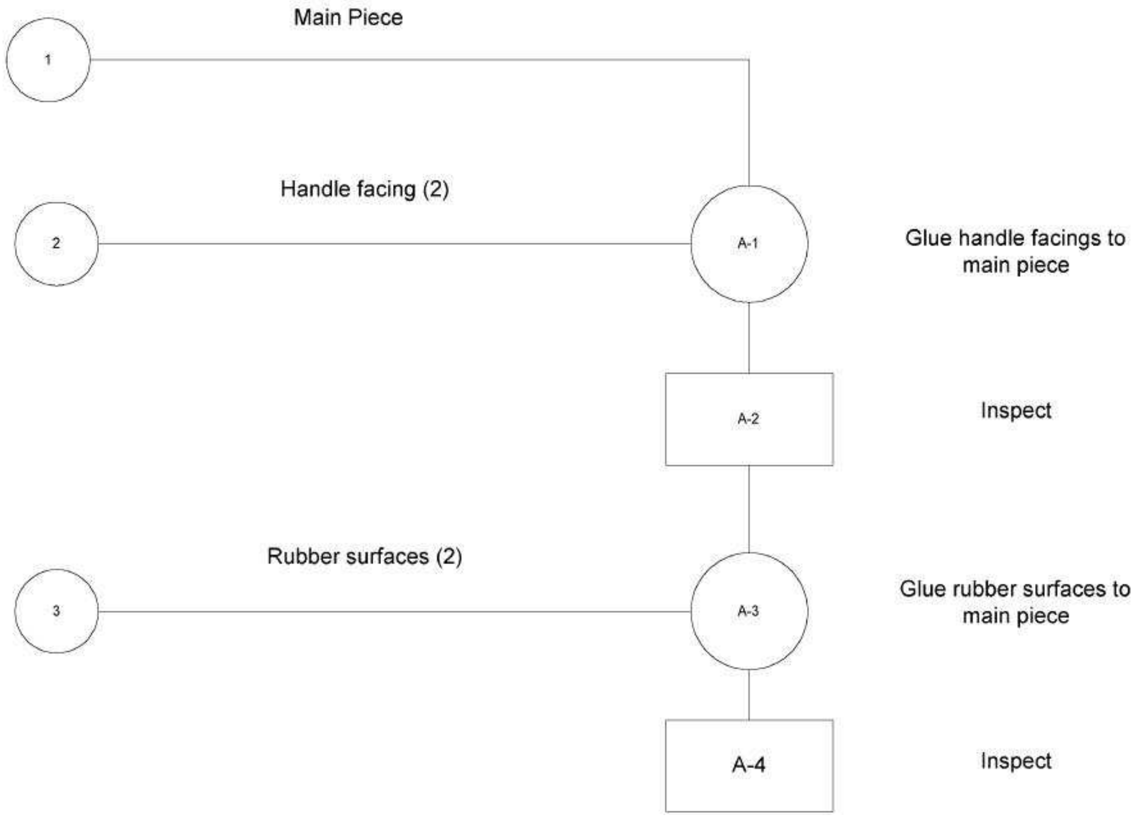
   equipment: bandsaw, hand saws, circular saw, sanding machine, lathe, glue press, handtruck

   materials: wood, plywood, rubber for paddle surface, glue, lacquer, plastic bags for wrapping, shipping boxes, and tape.

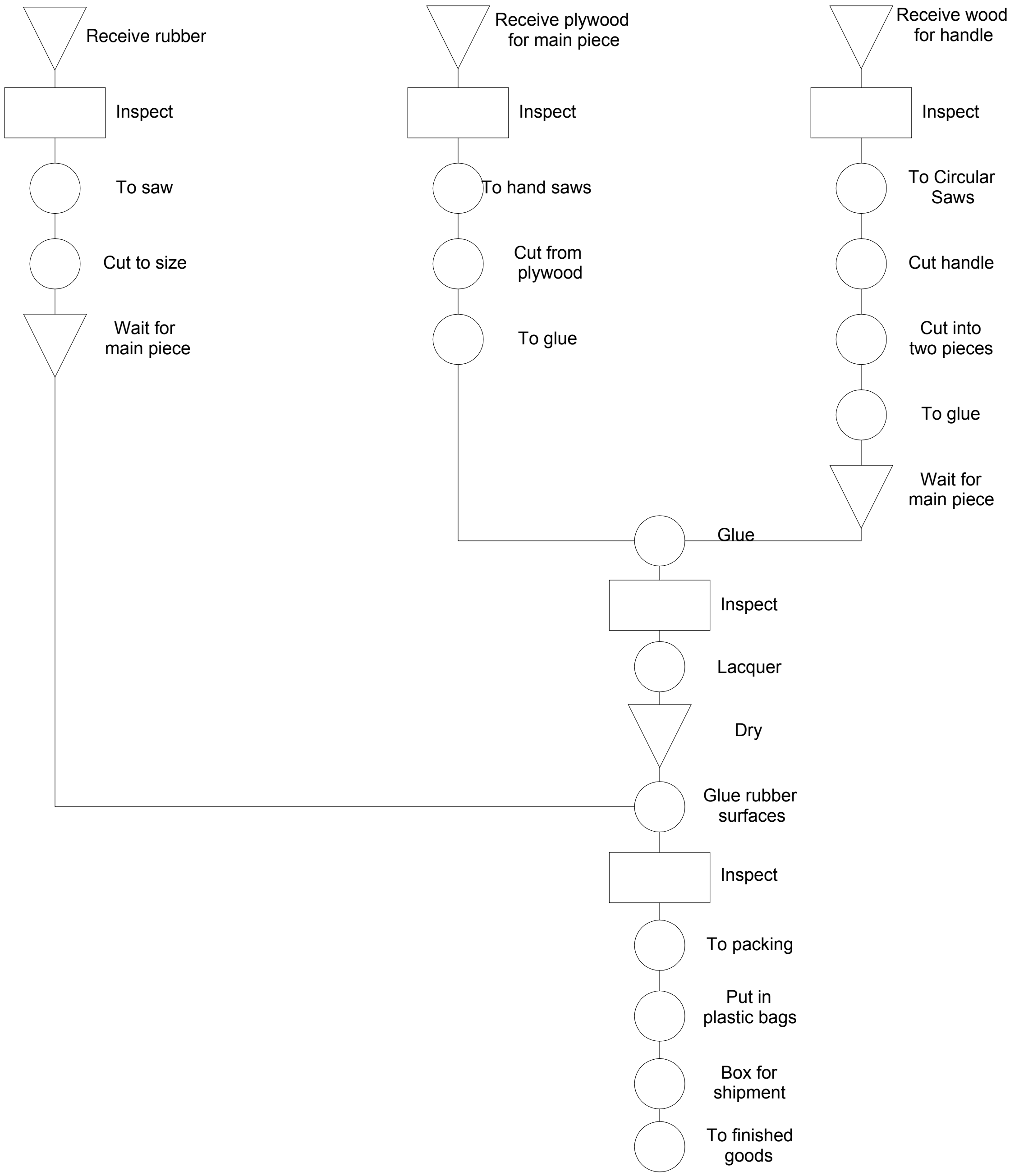
   (1) Assembly drawing



(2) Assembly chart



(3) Flow Process Chart



(4) Process route sheets

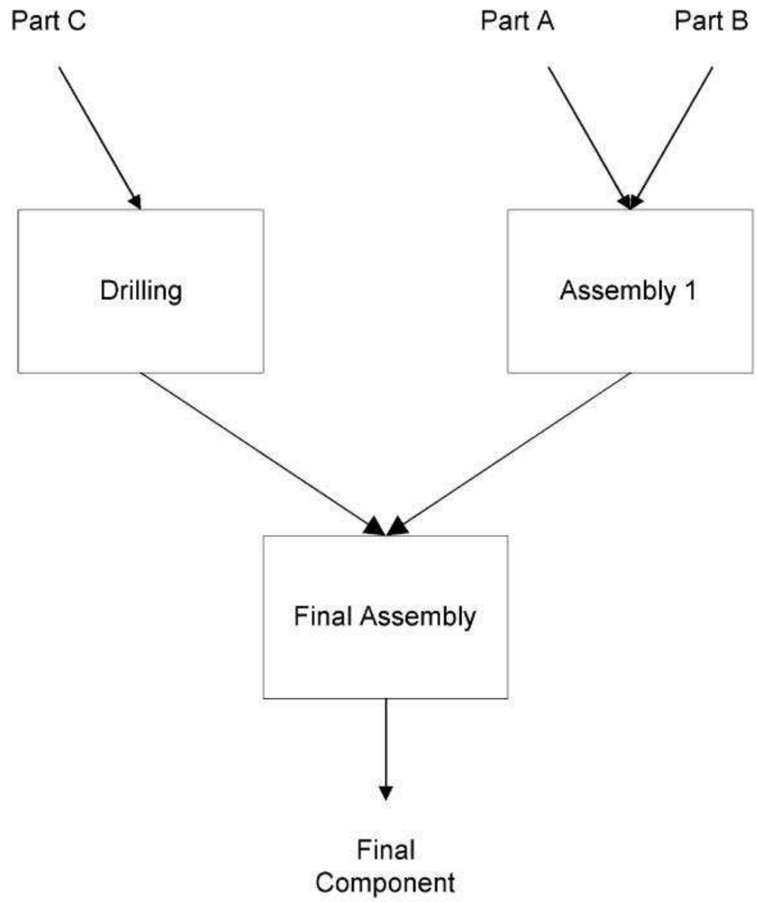
Part Name: Main Piece					
Operation number	Operation description	Dept.	Setup time	Pieces per hour	Tools
10	Cut to size	Saw	1.0	100	Band saw
20	Glue handle facing	Glue	0.5	50	Clamps
21	Lacquer	Glue	0.3	100	Paint brush
22	Glue rubber surface	Glue	0.1	100	Paint brush

Part Name: Handle Facing					
Operation number	Operation description	Dept.	Setup time	Pieces per hour	Tools
15	Cut to size	Saw	0.25	400	Circular saw
16	Cross cut diameter	Saw	0.25	100	Circular saw
20	Glue handle facing	Glue	0.5	50	Clamps

Part Name: Rubber Surface					
Operation number	Operation description	Dept.	Setup time	Pieces per hour	Tools
16	Cut to size in batches of 24	Saw	0.3	300	Band saw
22	Glue rubber surface	Glue	0.1	100	Paint brush

3. .

a. Process Flow Diagram



Capacity of assembly line 1 = 140 units/hour X 8 hours/day X 5 days/week
= 5,600 units/week.

Capacity of drill machines = 3 drill machines X 50 parts/hour X 8 hours/day X 5 days/week
= 6,000 units/week.

Capacity of final assembly line = 160 units/hour X 8 hours/day X 5 days/week
= 6,400 units/week.

The capacity of the entire process is 5,600 units per week, with assembly line 1 limiting the overall capacity.

b.

Capacity of assembly line 1 = 140 units/hour X 16 hours/day X 5 days/week = 11,200 units/week.

Capacity of drill machines = 4 drilling machines X 50 parts/hour X 8 hours/day X 5 days/week
= 8,000 units/week.

Capacity of final assembly line = 160 units/hour X 16 hours/day X 5 days/week
= 12,800 units/week.

The capacity of the entire process is 8,000 units per week, with drilling machines limiting the overall capacity.

c.

Capacity of assembly line 1 = 140 units/hour X 16 hours/day X 5 days/week
= 11,200 units/week.

Capacity of drill machines = 5 drilling machines X 50 parts/hour X 8 hours/day X 5 days/week
= 10,000 units/week.

Capacity of final assembly line = 160 units/hour X 12 hours/day X 5 days/week
= 9,600 units/week.

The capacity of the entire process is 9,600 units per week, with final assembly machines limiting the overall capacity.

d. Cost per unit when output = 8,000 units.

Item	Calculation	Cost
Cost of part A	$.40 X 8,000	$3,200
Cost of part B	$.35 X 8,000	2,800
Cost of part C	$.15 X 8,000	1,200
Electricity	$.01 X 8,000	80
Assembly 1 labor	$.30 X 8,000	2,400
Final assembly labor	$.30 X 8,000	2,400
Drilling labor	$.15 X 8,000	1,200
Overhead	$1,200 per week	1,200
Depreciation	$30 per week	30
Total		$14,510

Cost per unit = Total cost per week/Number of units produced per week
= $14,510/8,000
= $1.81

Cost per unit when output = 9,600 units.

Item	Calculation	Cost
Cost of part A	$.40 X 9,600	$3,840
Cost of part B	$.35 X 9,600	3,360
Cost of part C	$.15 X 9,600	1,440
Electricity	$.01 X 9,600	96
Assembly 1 labor	$.30 X 9,600	2,880
Final assembly labor	$.30 X 9,600	2,880
Drilling labor	$.15 X 9,600	1,440
Overhead	$1,200 per week	1,200
Depreciation	$30 per week	30
Total		$17,166

Cost per unit = Total cost per week/Number of units produced per week
= $17,166/9,600
= $1.79

Let X = the number of units that each option will produce.

When the company buys the units, the cost is $3.00 per unit (3X). When it manufactures the units, they incur a fixed cost of $120,000 (4 drilling machines at $30,000 a piece) and a per unit cost of $1.81. Therefore, 120,000 + 1.81X is the cost of this option. Set them equal to each other and solve for X to determine the breakeven point.

3X = 120,000 + 1.81X

X = 100,840 units.

Therefore, it is better to buy the units when you produce less than 100,840, and better to produce them when demand is greater than 100,840 units.

4. .

a. FC = (P - VC) * Break-even (where FC = fixed cost, P = price, and VC = variable cost)

$300,000 = ($23.00 - $8.00) * Break-even
Break-even = 20,000 books

b. Higher

c. Lower

5.

FC = (P - VC) * Break-even (where FC = fixed cost, P = price, and VC = variable cost)
$150,000 = ($90 - $70) * Break-even
Break-even = 7,500 units.

6.

a.

FC = (P - VC) * Break-even (where FC = fixed cost, P = price, and VC = variable cost).
$900 = ($5.50 - $4.50) * Break-even
Break-even = 900 units.

b.

FC + profit = (P - VC) * V
(where FC = fixed cost, P = price, and VC = variable cost, and V = Volume)
$900 + $500 = ($5.50 - $4.50) * V
V = 1400 units.

c.

Profit per unit = (P-VC)*V - FC)/V
$.25 = (($5.50 - $4.50)*V - $900)/V
.25V = V - 900
75V = 900
V = 1,200 units.

Profit per unit = ((P-VC)*V - FC)/V
$.50 = (($5.50 -$4.50)*V - $900)/V
.50V = V - $900
.50V = 900
V = 1,800 units.

Profit per unit = ((P-VC)*V - FC)/V
\$1.50 = ((\$5.50 -\$4.50)*V - \$900)/V
1.5V = V - 900
.50V = -900
V = -1,800 units. Not possible.

7. FC = (P - VC) * Break-even (where FC = fixed cost, P = price, and VC = variable cost).
\$2052 = (\$.36 - \$.144) * Break-even
Break-even = 9,500 miles.

8.

a. FC = (Pc - VCc) * Vc + (Pb -VCb) * Vb
where
FC = fixed cost
Pi = price for product i
VCi = variable cost for product i
Vi = volume for product i
where i is
c = chair
b = bar stool

V = Vc = Vb
\$20,000 = (\$50 - \$25) * V + (\$50 - \$20) * V
20,000 = 25V + 30 V
20,000 = 55V
V = 364 units of chairs and bar stools.
Break-even in dollars = \$50(364 + 364) = \$36,400.

b. FC = (Pc - VCc) * Vc + (Pb -VCb) * Vb
where
FC = fixed cost
Pi = price for product i
VCi = variable cost for product i
Vi = volume for product i
where i is
c = chair
b = bar stool

V = Vc = 4Vb
\$20,000 = (\$50 - \$25) * V + (\$50 - \$20) *4V
20,000 = 25V + 120 V
20,000 = 145V
V = 138 units of chairs and (4 * 138) = 552 bar stools.
Break-even in dollars = \$50(138 + 552) = \$34,500.

Issue	Job Shop	Flow Shop
Number of Changeovers	Many	Few
Labor content of product	High	Low
Flexibility	High	Low

9.

60/.75 = 80 units/hour

10.

Determine capacity analysis, look at moving from job shop to continuous flow production, price low and make up profits in volume, analyze production deadlines in order to determine labor needs (i.e. can the shop get by with a part time employee to meet the extra capacity).

11.

	Job Shop	Flow Shop
Engineering Emphasis	Product variety and improvements	Process improvements.
General Workforce Skill	Skilled workforce.	Lower skill levels.
Statistical Process Control	Less important.	More important.
Facility Layout	Process, functional.	Product, line, flow.
WIP Inventory Level	Depends on the product.	Lower.

12.
a. throughput time (time to covert raw material into product)

Throughput time decreases as you move from a job shop to flow shop environment.

b. capital/labor intensity

Capital intensity increases as you move to a flow shop (need for more machinery). Labor intensity (assuming you mean # of workers) would probably increase as well (depends on the level of automation). Ratio would increase in a flow shop because capital requirements are so much greater.

c. bottlenecks

Would probably decrease in a flow shop.

TECHNICAL NOTE 6
FACILITY LAYOUT

Review and Discussion Questions

1. What kind of layout is used in a physical fitness center?

   Process layout—similar equipment or functions are grouped together, such as rowing machines in one area, and weight machines in another. The exercise enthusiasts move through the fitness center, following an established sequence of operations.

2. What is the key difference between SLP and CRAFT?

   SLP is used to evaluate and include qualitative factors and does not require numerical flow of items between departments. CRAFT is a quantitative heuristic program that requires a quantitative measure of interdepartmental work or information flow.

3. What is the objective of assembly-line balancing? How would you deal with the situation where one worker, although trying hard, is 20 percent slower than the other 10 people on a line?

   The objective is to create an efficient balance between the tasks and workstations to minimize idle time. If the employee is deemed valuable, training may enhance his/her speed. It is also possible to place him/her in the "choice" job, i.e., that workstation which has most idle time to adjust for the slowness. Also, faster workers may assist the slowpoke if the balance and physical features of the line permit.

4. How do you determine the idle-time percentage from a given assembly-line balance?

   Idle-time percentage is given as "balance delay" in the chapter. It is simply one minus efficiency, where efficiency is equal to the sum of the task times divided by the number of workstations times the cycle time.

5. What information of particular importance do route sheets and process charts (discussed in Chapter 3) provide to the layout planner?

   Route sheets and process charts tell the layout planner the sequence of steps, the processing times, the equipment needed, and the delays and storage for the product to be made. Clearly, this information is critical to planning effective use of plant facilities.

6. What is the essential requirement for mixed-model lines to be practical?

   The need to develop a cycle mix that minimizes inventory build-up while keeping cycle time constant.

7. Why might it be difficult to develop a GT layout?

   a. Distinct parts families must exist. This requires developing and maintaining a computerized parts classification and coding system. This can be a major expense.

   b. Several of each type of machine must be available. This could be an expensive proposition, given the cost of purchasing and maintaining duplicate sets of machinery.

   c. Taking a machine out of a cluster should not rob a cluster of all of its capacity.

   d. There may be parts that cannot be associated with a family and specialized machinery that cannot be placed in a cell because of its general use.

   e. Training personnel to perform multiple types of tasks may be initially difficult. Union regulations and interpersonal problems within a group working in a cell must be resolved before the cell is implemented.

8. In what respects is facility layout a marketing problem in services? Give an example of a service system layout designed to maximize the amount of time the customer is in the system.

   The facility layout must be designed to meet customer expectations. Unlike fast food outlets, many finer restaurants will try to maximize the time that a customer is in system via requiring a waiting period before seating customers (even those with reservations). Many customers will patronize the cocktail lounge (thus enhancing profits).

9. Consider a department store. Which departments probably should not be located near each other? Would any departments benefit from close proximity?

   Ask the students to list the various types of departments in a department store. For example, typical departments include: women's clothing, men's clothing, children's clothing (both male and female), shoes, health and beauty aids, tools, camping supplies, home supplies, music, toys, etc. There are obvious noncomplimentary departments such as tools and health and beauty aids. An example of complimentary departments would be men's clothing and shoes.

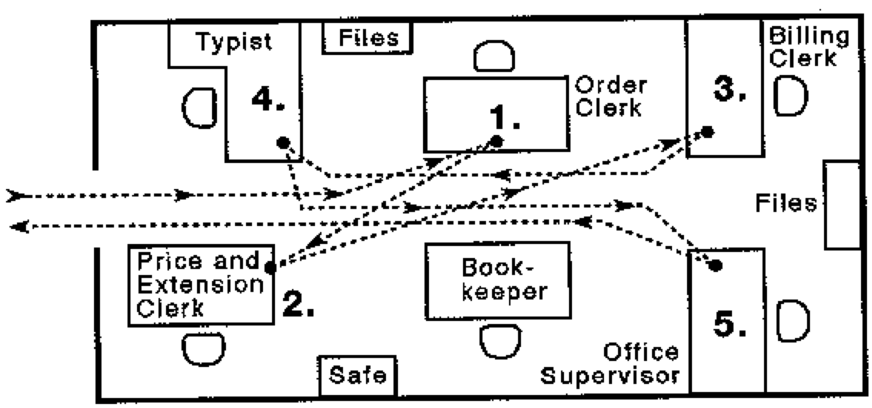
10. How would a flowchart help in planning the servicescape layout? What sorts of features would act as focal points or otherwise draw customers along certain paths through the service? In a supermarket, what departments should be located first along the customers' path? Which should be located last?

    The flowchart aids in monitoring the flow of customers through the service area. This would provide a means for providing a layout that minimizes the distance required for customers to reach the product. Focal points could include K-mart style blue lights and "end cap" displays. In a supermarket, the first things in the customer's path should be shopping carts and convenience items such as a delicatessen. It should be remembered that certain popular items such as milk and eggs are kept at the rear of a store to cause the customer to walk through the store and increase impulse purchases.

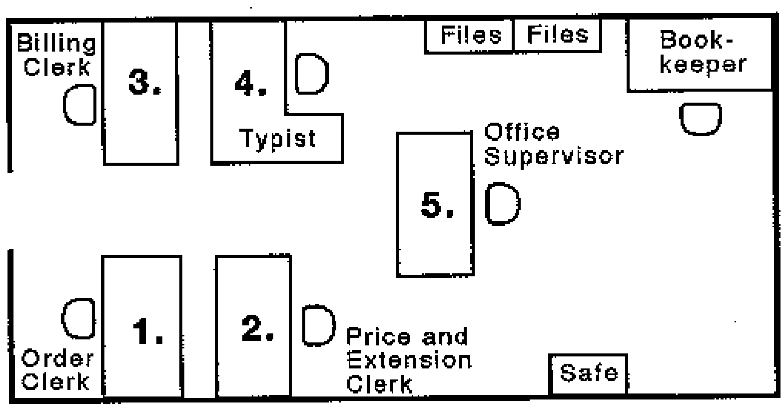
Problems

Problem	Type of Problem					Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Office Layout	Mixed-model Sequence	Assembly Line Balancing	SLP	Material Handling Cost Model				
1	Yes					Moderate			
2		Yes				Moderate			
3			Yes			Moderate			Yes
4			Yes			Moderate			
5			Yes			Difficult			
6					Yes	Moderate			
7			Yes			Difficult			
8				Yes		Difficult			
9			Yes			Difficult			Yes
10					Yes	Moderate			
11					Yes	Moderate			
12			Yes			Moderate			
13			Yes			Difficult			

1. Cyprus Citrus Cooperative has many alternatives. Below is the existing layout with the steps in the process numbered.



Students will identify many possible alternatives. Assuming that no jobs are combined, the following is a possibly:



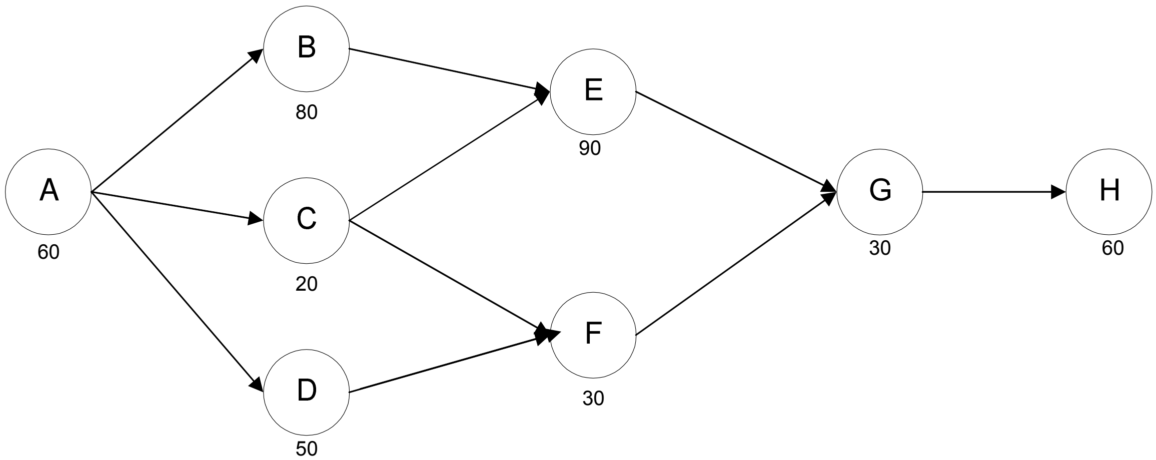
2. Mixed model balance.

Required output/day: 24B + 24D

Process times: 12 minutes per B, and 8 minutes per D.

Model sequence	B	B	D	D	D	B	B	B	B	D	D	D
Operation time	12	12	8	8	8	12	12	12	12	8	8	8
Minicycle time	24		24			24		24		24		

3. a.



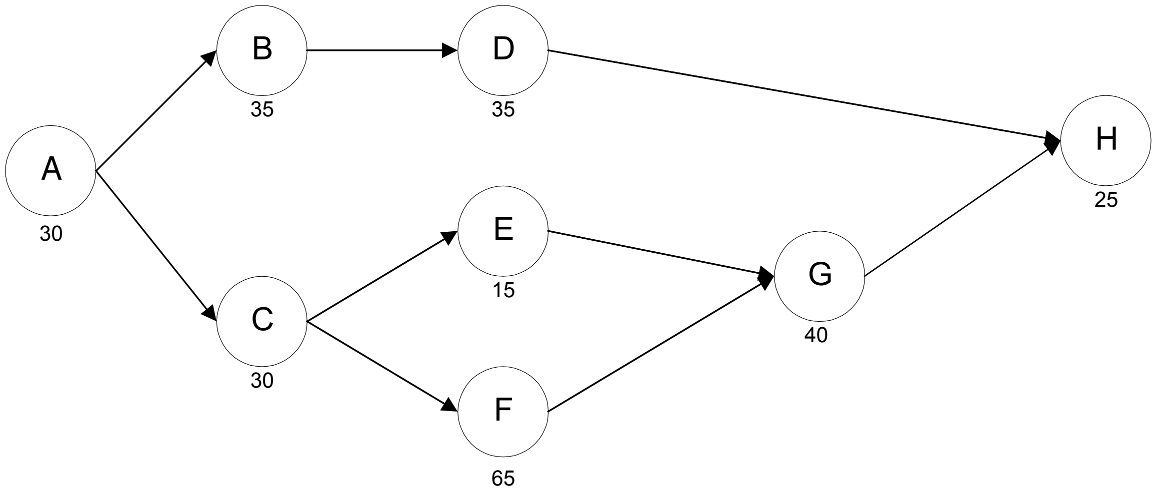
b. C = production time per day/required output per day = (8 hour/day)(3600 seconds/hour)/240 units per day = 120 seconds per unit

c.

Work station	Task	Task time	Idle time
I	A D	60 50	10
II	B C	80 20	20
III	E F	90 30	0
IV	G H	30 60	30

d. Efficiency = $\frac{T}{N_a C} = \frac{420}{4(120)}$ = .875 or 87.5%

4 a.



b. C = production time per day/required output per day = (450 minutes/day)/360units per day = 1.25 minutes per unit or 75 seconds per unit

c.

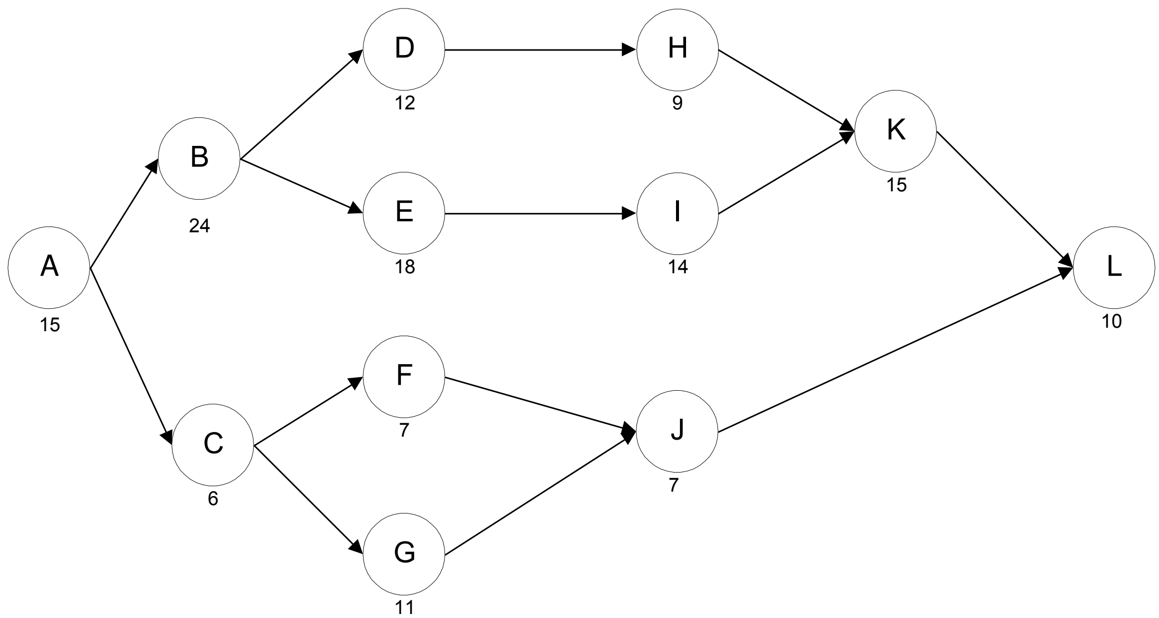
Work station	Task	Task time	Idle time
I	A	30	
	C	30	
	E	15	0
II	F	65	10
III	B	35	
	G	40	0
IV	D	35	
	H	25	15

d. Efficiency = $\frac{T}{N_a C} = \frac{275}{4(75)}$ = .917 or 91.7%

5. a. C = production time per day/required output per day

= (7.5 hour per day) (3600 seconds per hour)/1000units per day = 27 seconds per unit

b.

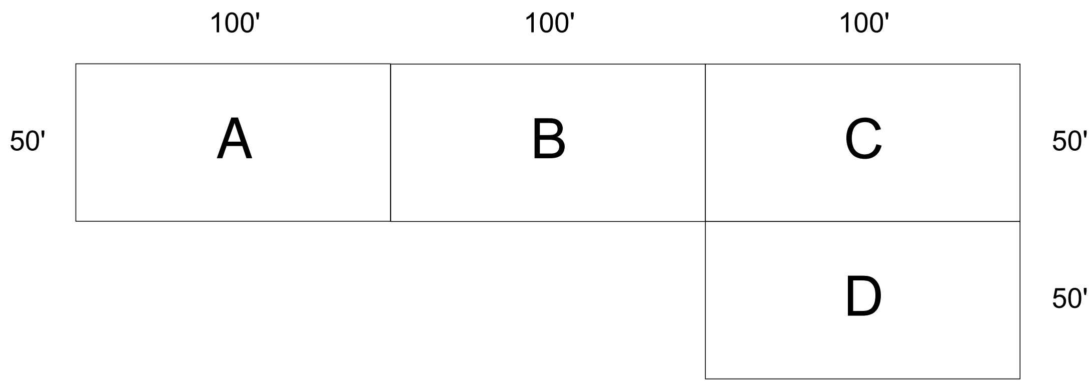


Work station	Task	Task time	Idle time
I	A	15	
	C	6	6
II	B	24	3
III	E	18	
	F	7	2
IV	I	14	
	D	12	1
V	G	11	
	H	9	
	J	7	0
VI	K	15	
	L	10	2

c. Efficiency = $\frac{T}{N_a C} = \frac{148}{6(27)}$ = .914 or 91.4%

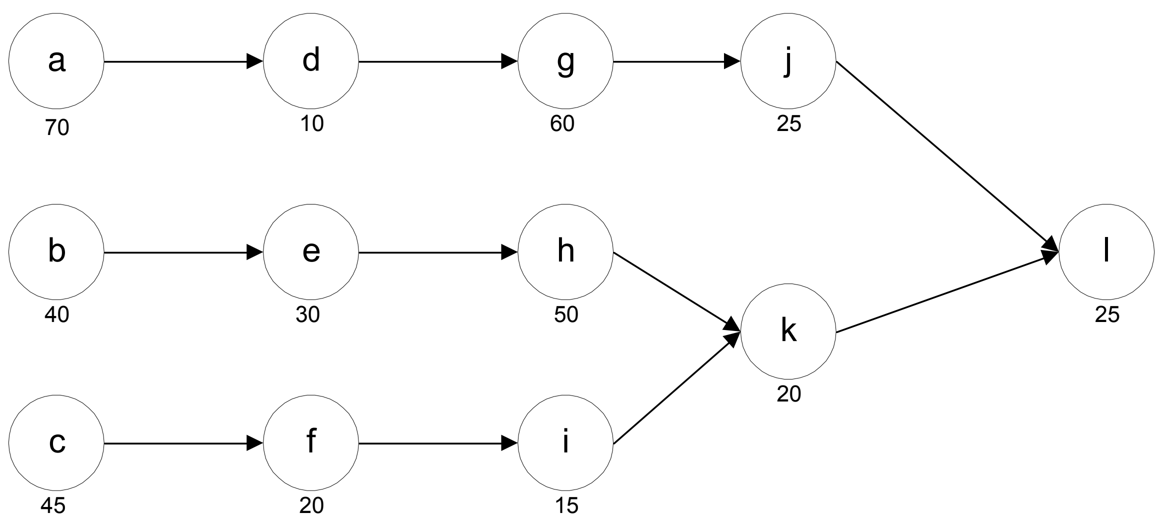
d. Reduce cycle time to 25 ((7.5*3600)/1100 = 24.54 seconds), which requires rebalancing the line or work overtime: (100 units) 27 seconds per unit = 2700 seconds or 45 minutes of overtime.

6.



From/to	Distances - rectilinear	Flow	Cost = distance X flow X $2
A to B	100’	10	$2,000
A to C	200’	25	10,000
A to D	250’	55	27,500
B to C	100’	10	2,000
B to D	150’	5	1,500
C to D	50’	15	1,500
Total			$44,500

7. a.



b. C = production time per day/required output per day = (7.5 hour per day) (3600 seconds per hour)/300 units per day = 90 seconds per unit

c. $N_i = \frac{T}{C} = \frac{410}{90}$ = 4.56 $\rightarrow$ 5 work stations

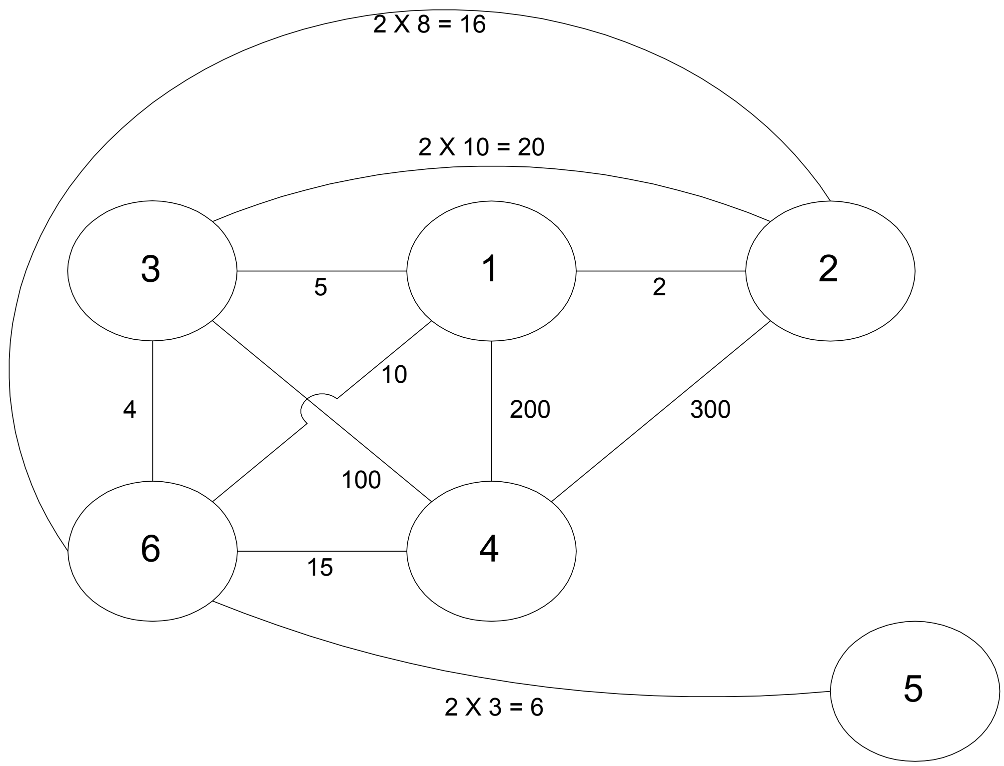
d.

Work station	Task	Task time	Idle time
I	a	70	
	d	10	10
II	g	60	
	j	25	5
III	c	45	
	b	40	5
IV	e	30	
	h	50	10
V	f	20	
	I	15	
	k	20	
	l	25	10

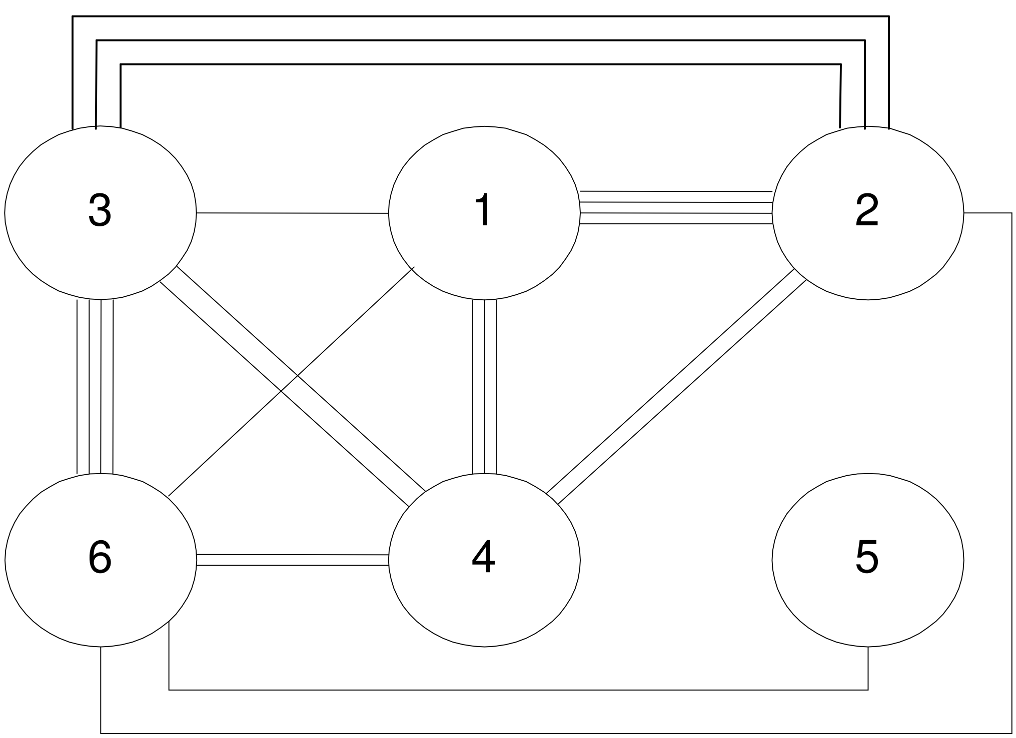
e. Efficiency = $\frac{T}{N_a C} = \frac{410}{5(90)}$ = .911 or 91.1%

f. Reduce cycle time to 81 seconds per unit. This produces (7.5 hours)(3600 seconds per hour)/81 seconds per units = 333.3 units. Another option is to work 45 minutes overtime (7.5 x 10% = .75 hour or 45 minutes). There are many other options possible that are combinations of these two options.

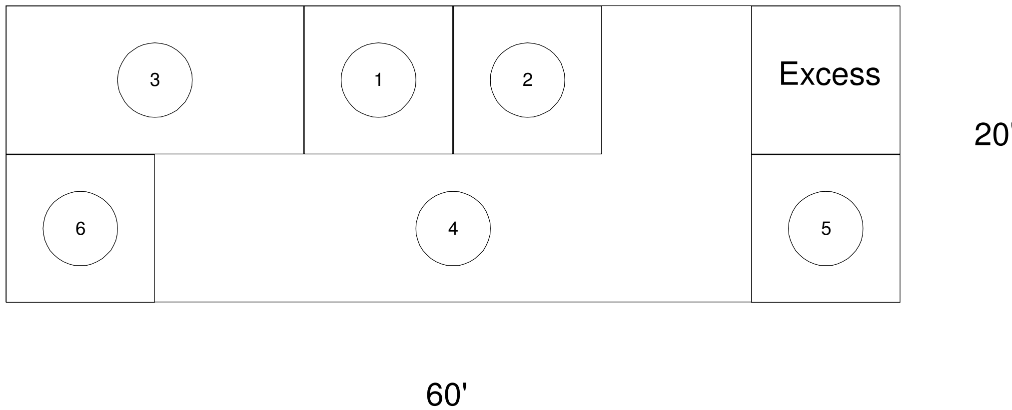
8. a.



b.



c.

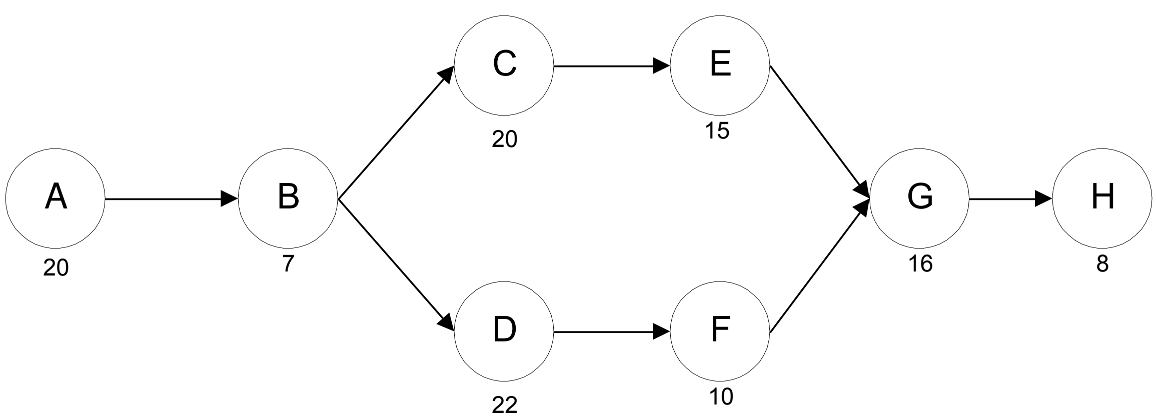


d. Unlikely. The nurses' station is not centrally located, and while patients may not go to the lab (department 5) very often, the nurses do. Thus, they will do a great deal of walking. It would be interesting to have the nursing staff develop closeness ratings and contrast them with that of administrators and M.D.s.

9. a. C = production time per day/required output per day = (7 hour per day) (3600 seconds per hour)/750 units per day = 33.6 seconds per unit

b. $N_i = \frac{T}{C} = \frac{118}{33.6}$ = 3.51 $\rightarrow$ 4 work stations

c.



d.

Work station	Task	Task time	Idle time
I	A	20	
	B	7	6.6
II	D	22	
	F	10	1.6
III	C	20	13.6
IV	E	15	
	G	16	2.6
V	H	8	25.6

e. Efficiency = $\dfrac{T}{N_a C} = \dfrac{118}{5(33.6)}$ = .702 or 70.2%

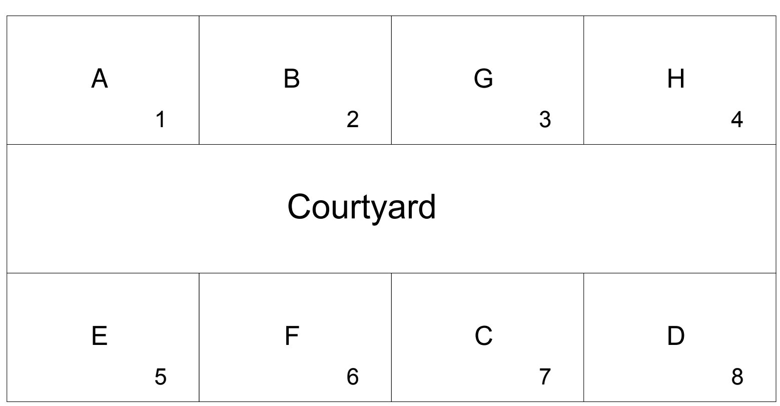
f. Reduce cycle time to 32. New production level is (7 hours/day)(3600 seconds per hour)/32 seconds per unit) = 787.5 units per day. Therefore, they are 800 – 787.5 = 12.5 units short. Work (12.5 units)(32 seconds per unit) = 400 seconds or 6.67 minutes overtime.

g. 1000 – 787.5 = 212.5 units short, work (212.5 units)(32 seconds per unit) = 6800 seconds or 113.3 minutes or 1.89 hours of overtime. May want to consider rebalancing the line.

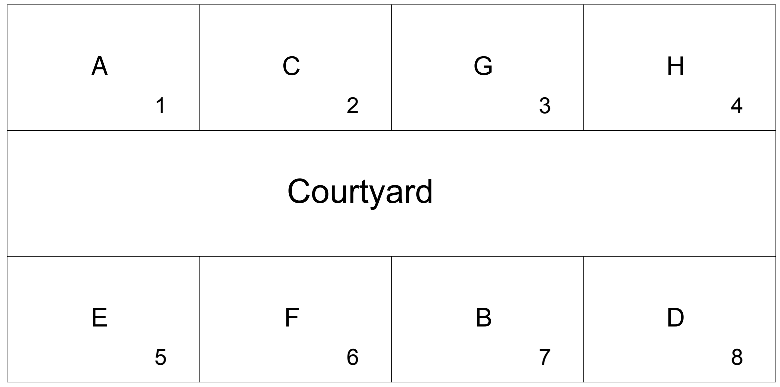
10. a. There are 8! = 40,320 assignments possible if no constraints are applied.

b. There are only two layout that satisfy all of the constraints.

Layout I



Layout II



The following table contains the total materials handling costs for the two alternative layouts.

Path	Flow	Distance		Cost	
		Layout 1	Layout II	Layout I	Layout II
A-B	2	10	25	20	50
A-C	0	25	10	0	0
A-D	0	34	34	0	0
A-E	5	15	15	75	75
A-F	0	18	18	0	0
A-G	0	20	20	0	0
A-H	0	30	30	0	0
B-C	0	18	18	0	0
B-D	0	25	10	0	0
B-E	0	18	20	0	0
B-F	3	15	10	45	30
B-G	0	10	15	0	0
B-H	2	20	18	40	36
C-D	0	10	25	0	0
C-E	0	20	18	0	0
C-F	0	10	15	0	0
C-G	0	15	10	0	0
C-H	3	18	20	54	60
D-E	4	30	30	120	120
D-F	0	20	20	0	0
D-G	0	18	18	0	0
D-H	0	15	15	0	0
E-F	1	10	10	10	10
E-G	0	25	25	0	0
E-H	0	34	34	0	0
F-G	1	18	18	18	18
F-H	0	25	25	0	0
G-H	4	10	10	40	40
Total				422	439

Based upon total material handling cost, layout I is optimal.

11. a.

1	2	3	4
8	7	6	5

b.

Adjacency	Flow	Distance	Flow * Distance
1-2	35	10	350
1-5	1	40	40
2-3	30	10	300
2-7	4	10	40
3-4	45	10	450
3-5	5	20	100
4-5	30	10	300
4-7	3	30	90
5-6	30	10	300
6-7	20	10	200
7-8	15	10	150
		Total	2320

12. a. Cycle time = Production time per day/required output per day

7.5 (60)(60)/900 units = 30 seconds

b. Efficiency = sum of task time/(actual number of workstations x cycle time)

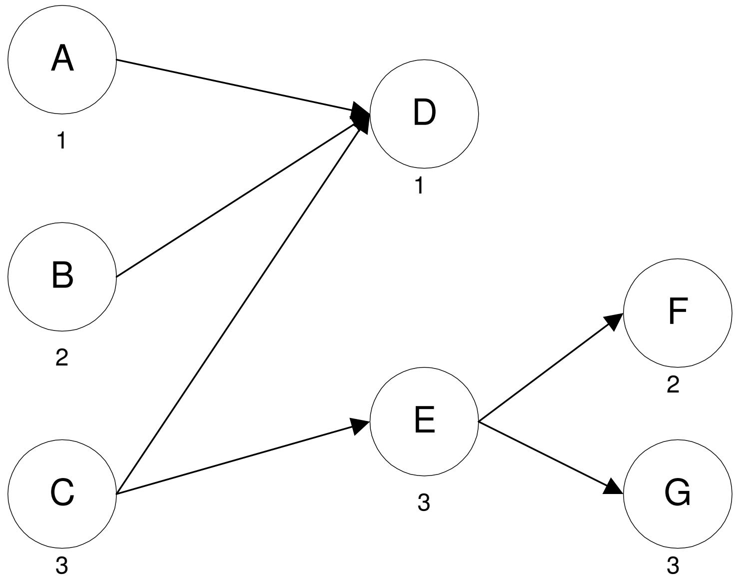
120 sec/ (4(30)) = 1 This is 100 percent efficient

c. To make 900 units per shift, station 3 will need to be duplicated.

Efficiency formula = 135 / (5(30)) = .9 This assume that each of the other

Operators still take 30 seconds to complete. The system becomes less efficient due to the idle time at the parallel workstations.

13. a.



b. C = production time per day/required output per day = 60 minutes per hour)/15 units per hour = 4 minutes per unit.

c.

Work station	Task	Task time	Idle time
I	A	1	
	C	3	0
II	E	3	1
III	B	2	
	F	2	0
IV	D	1	
	G	3	0

d. Efficiency = $\frac{T}{N_a C} = \frac{15}{4(4)}$ = .9375 or 93.75%

CHAPTER 7
SERVICE PROCESS SELECTION AND DESIGN

Review and Discussion Questions

1. Who is the "customer" in a jail? A cemetery? A summer camp for children?

   From the standpoint of society as a whole, the customer is the outside community. However, when we say in a jail, then we are talking about the prisoners. The customer in a cemetery is generally the family or friends of the "loved one." For a summer camp for children, the ostensible customers are the children. However, special efforts are usually made to serve the best food and provide the best amenities on parents' visit day.

2. How have price and variety competition changed McDonald's basic formula for success?

   McDonald's originally emphasized quick delivery of a limited menu. In response to competition, McDonald's has continuously expanded its menu. Some evidence suggests that service, including quick delivery, has suffered as a result.

3. Could a service firm use production line approach or self-serve design and still keep a high customer focus (personal attention)? Explain and support your answer with examples.

   Yes, this is possible. In many instances, the customer actually desires more technology and feels that the service will not have as high a quality without it. For example, dental care with its mechanized X-ray techniques requires far less customer time and less exposure to radiation. The self-service design can also support customer needs, for example the ATM provides customer access to funds at a variety of locations and 24 hours a day.

4. Why should a manager of a bank home office be evaluated differently than a manager of a bank branch?

   Since a bank home office typifies low contact quasimanufacturing, while a bank branch typifies medium contact mixed service, the problems faced by management differ considerably.

5. Identify the high-contact and low-contact operations of the following services:

   a. A dental office.

   Dental office high contact includes waiting rooms, receptionists, dentist(s), hygienist(s), x-ray, etc., while labs would be low contact.

   b. An airline.

   Airline high contact includes reservations desk, loading concourse, plane with crew and attendants, etc. Low contact includes maintenance, baggage handling, tower operations, etc.

c. An accounting office.

In an accounting office, high contact includes reception and CPAs, while low contact includes records, computer, library, etc.

d. An automobile agency

Automobile agency high contact includes showroom and offices. Low contact includes maintenance, preparation, records-files, etc.

6. Are there any service businesses that won't be affected by knowledge outsourcing?

Service businesses that require face-to-face contact are least likely to be affected by knowledge outsourcing. However, as technology improves even medical diagnosis and treatment might take place at home where the patient would hook their selves up to the right monitoring system the could be fed directly to a doctor anywhere in the world.

7. Relative to the behavioral science discussion, what practical advice do you have for a hotel manager to enhance the ending of a guest's stay in the hotel?

How about putting a couple of Starbuck's coffee coupons in the envelope along with the bill that is slipped under the door in the early morning of check-out day? For guests staying several days, arrange to have the manager say a personal good bye.

8. List some occupations or sporting events where the ending is a dominant element in evaluating success.

Attorney's closing argument at trial; the professor's final lecture in the course; the comedian saving his best joke for last, the magician saving best trick for last; the "dismount" in all gymnastic exercises; the entry into the water in diving competitions.

9. Behavioral scientists suggest that we remember events as snap shots, not movies. How would you apply this to designing a service?

What this means is that not all parts of the service are of equal impact in one's memory, and therefore place your resources on those areas that give you the most bang for the "memory buck." That is, think about which snap shots you want to clearly "frame" in the customer's memory-- these might be thought of as the sweet spots of the service. You might even want to create them. For example, a Lexus dealership in Los Angeles hands out a long stemmed rose when a customer comes to the service counter to pay for car servicing. While the general car servicing process involves mainly inconvenience, the "movie" experience was dominated by a positive snap shot of receiving a rose. Another example: At Splash Mountain at Disneyland, photographers regularly take pictures of people coming to the end of their ride. These become the keepsakes long after the details of the day are forgotten.

10. Some suggest that customer expectation is the key to service success. Give an example from your own experience to support or refute this assertion.

Most responses will probably support rather than refute this assertion.

11. Where would you place a drive-in church, a campus food vending machine, and a bar's automatic mixed drink machine on the service-system design matrix?

    Referring to the exhibit, the most logical placement would appear to be on-site technology.

12. Can a manufacturer have a service guarantee in addition to a product guarantee?

    Certainly, with some makes of automobiles, a rental car is guaranteed if the product fails. Many products are sold with warranties promising free and prompt service

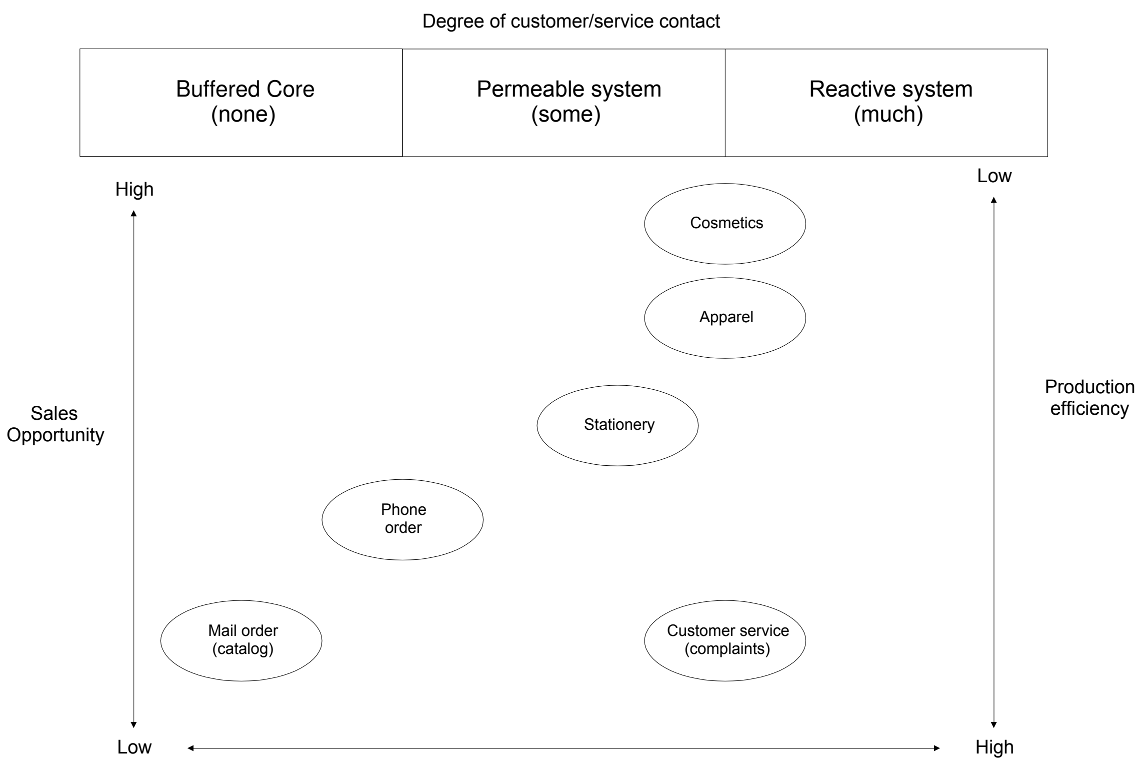
13. Suppose you were the manager of a restaurant and you were told honestly that a couple eating dinner had just seen a mouse. What would you say to them? How would you recover from this service crisis?

    The only thing you can do is to try to overcompensate for the event. Make dinner free. Promise to contract with an exterminator. Offer them another free dinner after a "cooling off" period. The Tylenol response is a good model to following in this situation.

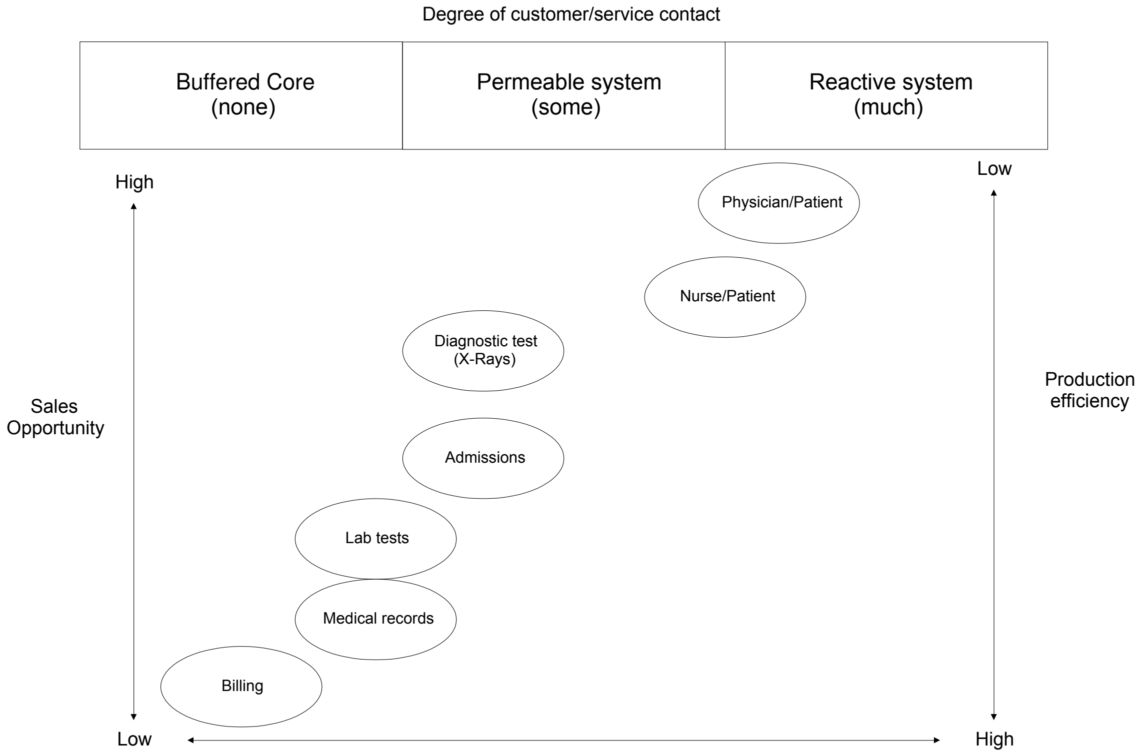
Problems

Problem	Type of Problem			Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Service-system design matrix	3-T's of service	System Design				
1	Yes			Easy			
2	Yes			Easy			
3		Yes		Moderate			
4			Yes	Difficult			
5			Yes	Easy			

1.



2.


Degree of customer/service contact
Buffered Core
(none)
Permeable system
(some)
Reactive system
(much)
High
Low
Sales
Opportunity
Production
efficiency
Low
High
Physician/Patient
Nurse/Patient
Diagnostic test
(X-Rays)
Admissions
Lab tests
Medical records
Billing

3. Here is a form that the students could use.

Task:			
Treatment			
Tangible Features: (environment, layout, and appearance)			
Rating:	(1) poor	(3) average	(5) excellent

The following is what a completed form might look like.

Task:	Buy a shirt	Checkout	
Treatment	No salesperson available 1	Professional, efficient, but not extremely friendly 3	
Tangible Features: (environment, layout, and appearance)	Layout was efficient, appearance was excellent 5	Layout was logical, time in line was average 3	
Rating:	(1) poor	(3) average	(5) excellent

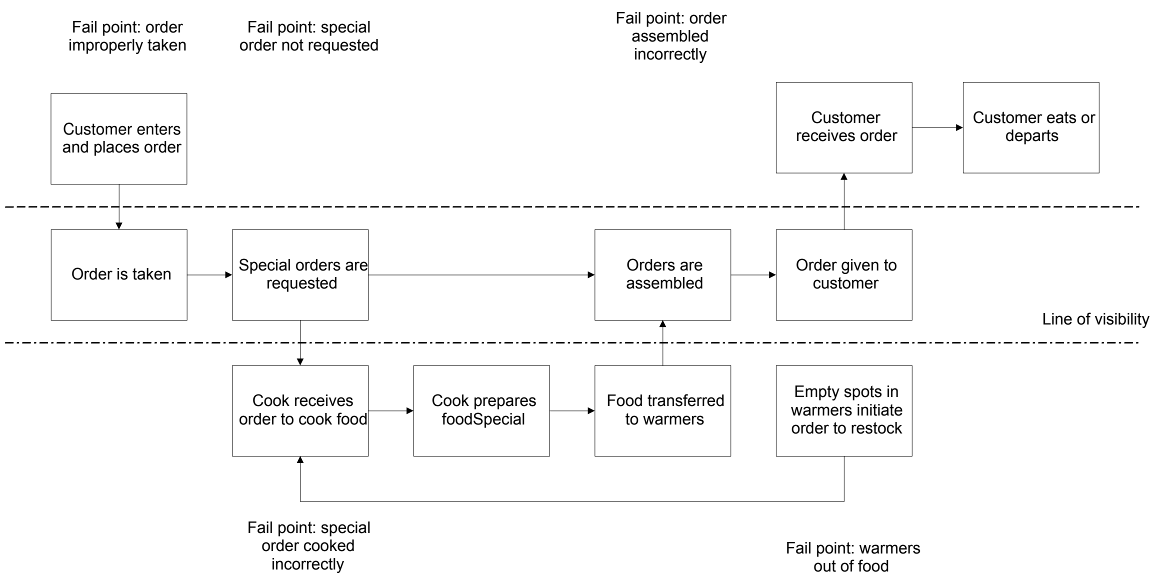
4.

a. The important aspects of the service package are rapid delivery of a uniform, high-quality mix of prepared foods in an environment of obvious cleanliness, order, and cheerful courtesy.

b. Most of the skills needed by employees are easily obtained through training. Probably one of the most important aspects is the employee's attitude. They should be willing to provide efficient service with cheerful courtesy.

c. Customer demand can be altered through promotions, such as discount for off-peak period. Also, extra services could be offered during off-peak periods to encourage customers. These could include having an employee walk through the facility offering free refills on drinks

d. An example of a service blueprint for McDonald's.



e. The customer/provider interface could be changed to include more technology by having the customer place the order himself on a display screen (this would also be more self-service). Many fast food restaurants have the customers get their on drinks.

f. One measure currently used is the average time to receive your order. Many times this is visible to the customer on the cash register. Other measures could include cleanliness of grounds, interior, restrooms, and counter; friendliness of employees, and sales.

5. What are the differences between high and low customer contact service (CCS) businesses, in general, for the dimensions listed below? {Example - Facility Layout: in a high CCS, the facility would be designed to enhance the feelings and comfort of the customer while in a low CCS, the facility would be designed for efficient processing.}

	Low CCS Businesses	**High CCS Businesses**
Worker Skill	Low	High
Capacity Utilization	High	Low
Level of Automation	High	Low

TECHNICAL NOTE 7
WAITING LINE MANAGEMENT

Review and Discussion Questions

1. Cultural factors affect waiting lines. For example, fast checkout lines (e.g., 10 items of less) are uncommon in Japan. Why do you think this is so?

   A manager of a major store chain told one of the authors that it "didn't make sense to give preferential treatment to people who buy less from you.

2. How many waiting lines did you encounter during your last airline flight?

   Possibilities include: baggage check-in, ticket counter, security check, check-in at gate, at boarding, and baggage pickup.

3. Distinguish between a channel and a phase.

   A channel is the initial service point of a queuing system. A phase refers to the number of stages that the service points provide. It is possible to have single to multiple service channels and single to multiple service phases.

4. What it the major cost trade-off that must be made in managing waiting line situations?

   The classic trade-off is between the cost of waiting for service versus the cost of providing additional service capacity, e.g., the cost of idle WIP versus the cost of adding more workers and machines to process the inventory.

5. Which assumptions are necessary to employ the formulas given for Model 1?

   Poisson arrival rates, exponential service rates, which imply a purely random process, but with a known mean (and hence known variance). Also assumed is that the process has reached a point of stochastic equilibrium. In other words, steady state conditions prevail.

6. In what way might the first-come, first served rule be unfair to the customer waiting for service in a bank or hospital?

   In a bank, FCFS may be perceived to be unfair by customers who have large accounts, but who must wait while the less "important" customers obtain service.

   In a hospital, especially in an emergency room, FCFS is probably the exception rather than the rule. FCFS would be unfair when a patient with a minor problem is treated before another experiencing severe pain.

7. Define, in a practical sense, what is meant by an exponential service time.

   An exponential service time means that most of the time, the service requirements are of short time duration, but there are occasional long ones. Exponential distribution also means that the probability that a service will be completed in the next instant of time is not dependent on the time at which it entered the system. We can see that a barber, for example, does not fit an exponential distribution in either case. The barber has an average time for cutting hair, and a person who has been sitting in the chair getting a haircut for the past 15 minutes has a higher probability of being completed in the next minute than a person who just walked in and sat down.

8. Would you expect the exponential distribution to be a good approximation of service times for

   a. Buying an airline ticket at the airport?

      Yes. Although certain customers will require special routings and payment methods, most ticketing is pretty straightforward and entails a short service time.

   b. Riding a merry-go-round at a carnival?

      No. The Merry-go-round has a fixed cycle time and hence constant services rate.

   c. Checking out of a hotel?

      No. Probably a better approximation would be a normal distribution since fast and slow checkouts are likely to be fairly equally balanced.

   d. Completing a midterm exam in your OM class?

      No. From our experience, students require the entire class period (and then some) to finish the typical mid-term. Thus, the service rate is close to constant.

9. Would you expect the Poisson distribution to be a good approximation of

   a. Runners crossing the finish line in the Boston Marathon?

      Yes. The arrival pattern typically shows a few runners arriving "early" and the majority arriving in a bunch and the remainder spread out along the tail of the distribution.

   b. Arrival times of the student in your OM class?

      No. Arrivals are not random since there is a schedule to be met.

   c. Arrival times of the bus to you stop at school?

      No. Again, arrivals are not random since the bus follows a set schedule.

Problems

Problem	Type of Problem					Difficulty	New Problem	Modified Problem	Check figure in Appendix A
	Model 1	Model 2	Model 3	Model 4	Waiting Time Aprox.				
1	Yes					Easy			
2	Yes		Yes			Moderate			
3	Yes					Easy			
4			Yes			Moderate			
5		Yes				Moderate			Yes
6	Yes		Yes			Moderate			
7		Yes				Moderate			
8	Yes	Yes				Moderate			
9				Yes		Difficult			Yes
10	Yes		Yes			Moderate			Yes
11	Yes					Moderate			
12				Yes		Difficult			
13	Yes					Easy			
14			Yes			Moderate			
15	Yes		Yes			Moderate			
16	Yes	Yes				Moderate			
17	Yes					Moderate			Yes
18	Yes					Moderate			
19	Yes					Moderate			
20	Yes		Yes			Moderate			
21	Yes					Difficult			
22		Yes				Moderate			
23					Yes	Moderate			
24					Yes	Moderate			

1. Use model 1.
   $\lambda = 4$/hour $\mu = 6$/hour

   a. $1-\rho = 1-\frac{\lambda}{\mu} = 1-\frac{4}{6} = .3333$ or 33.33%

   b. $L_q = \frac{\lambda^2}{\mu(\mu-\lambda)} = \frac{4^2}{6(6-4)}$ =1.33, $W_q = \frac{L_q}{\lambda} = \frac{1.33}{4}$ = 1/3 hour or 20 minutes

   c. $L_q = \frac{\lambda^2}{\mu(\mu-\lambda)} = \frac{4^2}{6(6-4)}$ = 1.33 students

   d. At least one other student waiting in line is the same as at least two in the system. This probability is 1-(P_0+P_1).

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

   $$P_0 = \left(1-\frac{4}{6}\right)\left(\frac{4}{6}\right)^0 = .3333$$

   $$P_1 = \left(1-\frac{4}{6}\right)\left(\frac{4}{6}\right)^1 = .2222$$

   Probability of at least one in line is 1-(.3333 + .2222) = .4444

2. Use model 1.
   a. $\lambda = 4$/hour $\mu = 10$/hour

   $$L_q = \frac{\lambda^2}{\mu(\mu-\lambda)} = \frac{4^2}{10(10-4)} = .267 \text{ students}$$

   Waiting cost = number in line times goodwill loss per hour times number of hours per day.
   =.267(10)8 = $21.33 per day
   Total cost = waiting cost + additional service cost
   =$21.33 + $99.50 = $120.83 per day

   b. Use model 3.
   M=2, $\rho = \frac{\lambda}{\mu} = \frac{4}{6}$ =.667

   Interpolating from Exhibit TN7.11, L_q = .0837

   Therefore, waiting cost = number in line times goodwill loss per hour times of hour per day
   = .0837(10)8 = $6.70 per day
   Total cost = waiting cost + additional service cost
   = $6.70 + $75.00 = $81.70 per day

   Consequently, it is better to hire another clerk.

3. Use model 1.
   $\lambda =$ 10/hour $\mu =$ 15/hour
   a. 1- ρ = $1-\frac{10}{15}$ = .3333 or 33.33%
   b. P(both clerks busy) = P(one clerk busy) * P(one clerk busy)
      = $\rho^2 = \left(\frac{10}{15}\right)^2$ = .4444 or 44.44
   c. P(both clerks idle) = P(one clerk idle) * P(one clerk idle)
      = (.3333)(.3333) = .1111 or 11.11%
   d. $L_q = \frac{\lambda^2}{\mu(\mu-\lambda)} = \frac{10^2}{15(15-10)}$ = 1.33 customers
   e. $L_s = \frac{\lambda}{\mu-\lambda} = \frac{10}{15-10} = 2$
      $W_s = \frac{L_s}{\lambda} = \frac{2}{10} = .2$ or 12 minutes

4. Use model 3
   $\lambda =$ 20/hour $\mu =$ 15/hour
   a. S =2 , and $\rho = \frac{\lambda}{\mu} = \frac{20}{15} = 1.3333$, from Exhibit TN7.11, L_q = 1.122
      $P_w = L_q\left(\frac{S}{\rho}-1\right) =$ 1.122(2/1.333 - 1) = 56%
      (55% from DSS for POM, 56% contains rounding error)
   b. 1.1 customers, see a for calculation.
   c. $L_s = L_q + \lambda/\mu$ =1.122 + 20/15 = 2.455
      $W_s = \frac{L_s}{\lambda} = \frac{2.455}{20} = .12$ hours or 7.2 minutes
   d. Yes, fewer customers in line and shorter time in system.

5. Use model 2.
   $\lambda =$ 60/50 per minute $\mu =$ 60/45 per minute
   minutes.

   $L_q = \frac{\lambda^2}{2\mu(\mu-\lambda)} = \frac{(60/50)^2}{2(60/45)(60/45-60/50)} =$ 4.05 cars
   $L_s = L_q + \lambda/\mu$ = 4.05 + (60/50)/(60/45) = 4.95 cars
   $W_q = \frac{L_q}{\lambda} = \frac{4.05}{(60/50)} = 3.375$
   $W_s = \frac{L_s}{\lambda} = \frac{4.95}{(60/50)}$ = 4.125 minutes

6. Use Model 1.

$\lambda =$ 100 per hour $\mu = 120$ per hour

a. $L_s = \dfrac{\lambda}{\mu - \lambda} = \dfrac{100}{120 - 100} = 5$

$W_s = \dfrac{L_s}{\lambda} = \dfrac{5}{100}$ = .05 hours or 3 minutes

b. Now, $\mu = 180$ per hour

$L_s = \dfrac{\lambda}{\mu - \lambda} = \dfrac{100}{180 - 100} = 1.25$

$W_s = \dfrac{L_s}{\lambda} = \dfrac{1.25}{100}$ = .0125 hours or .75 minutes or 45 seconds

c. Using model 3, $\lambda =$ 100 per hour $\mu = 120$ per hour

S =2 , and $\rho = \dfrac{\lambda}{\mu} = \dfrac{100}{120} = .8333$, from Exhibit TN7.11, L_q = .1756

$L_s = L_q + \dfrac{\lambda}{\mu} = .1756 + \dfrac{100}{120} = 1.01$

$W_s = \dfrac{L_s}{\lambda} = \dfrac{1.01}{100}$ = .0101 hours or .605 minutes or 36.3 seconds

7. Use model 2.

$\lambda =$ 10 per hour $\mu = 12$ per hour

a. $L_q = \dfrac{\lambda^2}{2\mu(\mu - \lambda)} = \dfrac{10^2}{2(12)(12 - 10)}$ = 2.083 people

b. $L_s = L_q + \lambda/\mu$ = 2.083 + 10/12 = 2.917 people

c. $W_q = \dfrac{L_q}{\lambda} = \dfrac{2.083}{10} = .2083$ hours.

d. $W_s = \dfrac{L_s}{\lambda} = \dfrac{2.917}{10}$ = .2917 hours

e. It will cause it to increase, at $\lambda =$ 12 per hour, $L_q = \dfrac{\lambda^2}{2\mu(\mu - \lambda)} = \dfrac{12^2}{2(12)(12 - 12)} \to \infty$

8. Use model 1

$\lambda =$ 3 per minute $\mu = 4$ per minute

a. $L_s = \dfrac{\lambda}{\mu - \lambda} = \dfrac{3}{4 - 3}$ = 3 customers

b. $W_s = \dfrac{L_s}{\lambda} = \dfrac{3}{3}$ = 1 minute

c. $\rho = \dfrac{\lambda}{\mu} = \dfrac{3}{4}$ = .75 or 75%

d. Probability of 3 or more is equal to 1 – probability of 0, 1, 2

$P_0 = \left(1 - \dfrac{3}{4}\right)\left(\dfrac{3}{4}\right)^0$ = .2500, $P_1 = \left(1 - \dfrac{3}{4}\right)\left(\dfrac{3}{4}\right)^1$ = .1875, $P_2 = \left(1 - \dfrac{3}{4}\right)\left(\dfrac{3}{4}\right)^2$ = .1406

Total of $P_0 + P_1 + P_2$ = (.2500 + .1875 + .1406) = .5781

Therefore, the probability of three or more is 1 - .5781 = .4219

e. If a automatic vendor is installed, use model 2.
(a. revisited)

$$L_q = \frac{\lambda^2}{2\mu(\mu-\lambda)} = \frac{3^2}{2(4)(4-3)}$$ =1.125 customers

$$L_s = L_q + \lambda/\mu$$ = 1.125 + ¾ =1.875

(b. revisited)

$$W_q = \frac{L_q}{\lambda} = \frac{1.125}{3} = .375 \text{ minutes}$$

$$W_s = \frac{L_s}{\lambda} = \frac{1.875}{3} = .625 \text{ minutes}$$

By converting to constant service time, the number in line is reduce from 3 to 1.875 people (a reduction of 1.125, and time in system is reduced from 1 minute to .625 minutes (a reduction of .375 minutes or 22.5 seconds).

9. Use model 4.
N = 4, population of 4 engineers,
S = 1, one technical specialist,
T = 1, average time to help engineer,
U = 7, time between requests for help

a. $X = \frac{T}{T+U} = \frac{1}{1+7}$ = .125, look up value of F in Exhibit TN7.12
F = .945, therefore, L = N(1-F) = 4(1-.945) = .22 engineers waiting

b. $W = \frac{L(T+U)}{N-L} = \frac{.22(1+7)}{4-.22}$ = .466 hours or 28 minutes

c. From Exhibit S6.12 at X=.125, and S=1, D = .362. In other words, 36.2% of the time an engineer will have to wait for the specialist.

10. Use model 1. $\lambda =$ 20 per hour $\mu = 30$ per hour

a. $L_s = \frac{\lambda}{\mu-\lambda} = \frac{20}{30-20}$ = 2 people in the system

b. $W_s = \frac{L_s}{\lambda} = \frac{2}{20}$ = .10 hours or 6 minutes

c. Probability of 3 or more is equal to 1 – probability of 0, 1, 2

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

$$P_0 = \left(1-\frac{20}{30}\right)\left(\frac{20}{30}\right)^0 = .3333$$

$$P_1 = \left(1-\frac{20}{30}\right)\left(\frac{20}{30}\right)^1 = .2222$$

$$P_2 = \left(1-\frac{20}{30}\right)\left(\frac{20}{30}\right)^2 = .1481$$

Total of $P_0 + P_1 + P_2$ = (.3333 + .2222 + .1481) = .7036
Therefore, the probability of three or more is 1 - .7036 = .2964

d. $\rho = \frac{\lambda}{\mu} = \frac{20}{30}$ = .67 or 67%

e. Use model 3.

$\rho = \frac{\lambda}{\mu} = \frac{20}{30}$ =.6667

From Exhibit TN7.11, L_q = .0093

$L_s = L_q + \lambda/\mu$ = .0093 + 20/30 = .676

$W_s = \frac{L_s}{\lambda} = \frac{.676}{20}$ = .0338 hours or 2.03 minutes

11. Use model 1

$\lambda =$ 5 per hour $\mu = 6$ per hour

a. $L_s = \frac{\lambda}{\mu - \lambda} = \frac{5}{6-5}$ = 5 people in the system

$W_s = \frac{L_s}{\lambda} = \frac{5}{5}$ = 1 hours

b. $L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{5^2}{6(6-5)}$ = 4.17 people on average

a. It would be busy $\rho = \frac{\lambda}{\mu} = \frac{5}{6}$ =.833 or 83.3% of the time, for a 12 hour day .833(12) = 10 hours

b. $P_0 = \left(1 - \frac{\lambda}{\mu}\right)\left(\frac{\lambda}{\mu}\right)^0 = \left(1 - \frac{5}{6}\right)\left(\frac{5}{6}\right)^0$ = .167 or 16.7%

c. $W_s =$ .75 and λ = 5 per hour,

$W_s = \frac{L_s}{\lambda} \Rightarrow .75 = \frac{L_s}{5} \Rightarrow L_s = 3.75$

$L_s = \frac{\lambda}{\mu - \lambda} \Rightarrow 3.75 = \frac{5}{\mu - 5} \Rightarrow \mu = 6.33$, therefore, the service rate must be at least 6.33 customers per hour

12. Use model 4.

N = 4, population of 4 pieces of equipment,
S = 1, one repairperson,
T = .0833, average time for repair,
U = .5, time between requests for repair (hours)

a. $X = \frac{T}{T+U} = \frac{.0833}{.0833 + .5}$ = .1428, look up value of F in Exhibit TN7.12

F = .928, therefore, L = N(1-F) = 4(1-.928) = .288 machines waiting

b. J=NF(1-X) = 4(.928)(1-.1428) = 3.18 machines operating

c. H = FNX =.928(4).1428 = .53 machines being serviced

d. n =L + H = .287 + .53 = .817 machines in the system

Cost of downtime is .817 times $20 per hour	= $16.34 per hour
Cost of one serviceperson	= $ 6.00 per hour
Total cost per hour	= $22.34

With 2 repairpersons, S =2,

$X = \frac{T}{T+U} = \frac{.0833}{.0833+.5}$ = .1428, look up value of F in Exhibit TN7.12

F = .995, therefore, L = N(1-F) = 4(1-.995) = .020 machines waiting

H = FNX =.995(4).1428 = .568 machines being serviced

n = L + H = .020 + .568 = .588

Cost of downtime is .588 times $20 per hour	= $11.76 per hour
Cost of two serviceperson	= $12.00 per hour
Total cost per hour	= $23.76

No, added cost of $1.42 per hour would be added for second repairperson

13. Use model 1.

$\lambda =$ 2 per hour $\mu = 3$ per hour

a. $L_q = \frac{\lambda^2}{\mu(\mu-\lambda)} = \frac{2^2}{3(3-2)}$ = 1.333 customers waiting

b. $W_q = \frac{L_q}{\lambda} = \frac{1.333}{2}$ = .667 hours or 40 minutes

c. $L_s = \frac{\lambda}{\mu-\lambda} = \frac{2}{3-2} = 2, \quad W_s = \frac{L_s}{\lambda} = \frac{2}{2}$ = 1 hour

d. $\rho = \frac{\lambda}{\mu} = \frac{2}{3}$ = .67 or 67% of the time

14. Use model 3.

$\lambda =$ 2 per hour $\mu = 3$ per hour

a. $\rho = \frac{\lambda}{\mu} = \frac{2}{3}$, from Exhibit TN7.11, L_q = .0837

b. $W_q = L_q / \lambda$ = .0837/2 = .0418 hours or 2.51 minutes

c. $L_s = L_q + \lambda/\mu = .0837 + 2/3 = .7504, \quad W_s = L_s / \lambda = .7504/2$ = .3751 hours or 22.51 minutes

15. Use model 1.

$\lambda =$ 6 per hour $\mu = 10$ per hour

a. $L_s = \frac{\lambda}{\mu-\lambda} = \frac{6}{10-6}$ = 1.5 people

$W_s = \frac{L_s}{\lambda} = \frac{1.5}{6}$ = .25 hours or 15 minutes

b. $\rho = \frac{\lambda}{\mu} = \frac{6}{10}$ = .60 or 60%

c. Probability of more then 3 people is equal to 1 – probability of 0, 1, 2

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

$$P_0 = \left(1 - \frac{6}{10}\right)\left(\frac{6}{10}\right)^0 = .4000$$

$$P_1 = \left(1 - \frac{6}{10}\right)\left(\frac{6}{10}\right)^1 = .2400$$

$$P_2 = \left(1 - \frac{6}{10}\right)\left(\frac{6}{10}\right)^2 = .1440$$

Total of $P_0 + P_1 + P_2$ = (.4000 + .2400 + .1440) = .7840
Therefore, the probability of three or more is 1 - .7840 = .2160

d. Use model 3.

$\rho = \frac{\lambda}{\mu} = \frac{6}{10}$ = .60, from Exhibit TN7.11, L_q = .0593

$$L_s = L_q + \lambda/\mu = .0593 + 6/10 = .6593$$

$W_s = L_s/\lambda$ = .6593/6 = .1099 hours or 6.6 minutes

16. Use model 1.

$\lambda =$ 60/55 per minute $\mu =$ 60/50 per minute

a. $L_s = \frac{\lambda}{\mu - \lambda} = \frac{60/55}{60/50 - 60/55}$ = 10.00 people

$W_s = \frac{L_s}{\lambda} = \frac{10.00}{(60/55)}$ = 9.167 minutes

b. $L_s = \frac{\lambda}{\mu - \lambda} = \frac{60/55}{60/50 - 60/55}$ = 10.00 people

c. Probability of 3 or more is equal to 1 – probability of 0, 1, 2

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

$$P_0 = \left(1 - \frac{60/55}{60/50}\right)\left(\frac{60/55}{60/50}\right)^0 = .0909$$

$$P_1 = \left(1 - \frac{60/55}{60/50}\right)\left(\frac{60/55}{60/50}\right)^1 = .0826$$

$$P_2 = \left(1 - \frac{60/55}{60/50}\right)\left(\frac{60/55}{60/50}\right)^2 = .0751$$

Total of $P_0 + P_1 + P_2$ = (.0909 + .0826 + .0751) = .2487
Therefore, the probability of three or more is 1 - .2487 = .7513

d. $\rho = \frac{\lambda}{\mu} = \frac{60/55}{60/50}$ = .9091 or 90.91%

e. Use model 2.

$$L_q = \frac{\lambda^2}{2\mu(\mu - \lambda)} = \frac{(60/55)^2}{2(60/50)(60/50 - 60/55)} = 4.545$$

$L_s = L_q + \lambda/\mu$ = 4.545 + (60/55)/(60/50) = 5.455 minutes

$W_s = L_s/\lambda$ = 5.455/(60/55) = 5.0 minutes

17. Use model 1.

$\lambda =$ 25 per hour $\quad \mu = 30$ per hour

a. $\rho = \frac{\lambda}{\mu} = \frac{25}{30}$ = .833 or 83.3%

b. $L_s = \frac{\lambda}{\mu - \lambda} = \frac{25}{30 - 25}$ = 5.00 document in the system

c. $W_s = \frac{L_s}{\lambda} = \frac{5.00}{25}$ = .20 hours or 12 minutes

d. Probability of 4 or more is equal to 1 – probability of 0, 1, 2, 3

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

$$P_0 = \left(1 - \frac{25}{30}\right)\left(\frac{25}{30}\right)^0 = .1667$$

$$P_1 = \left(1 - \frac{25}{30}\right)\left(\frac{25}{30}\right)^1 = .1389$$

$$P_2 = \left(1 - \frac{25}{30}\right)\left(\frac{25}{30}\right)^2 = .1157$$

$$P_3 = \left(1 - \frac{25}{30}\right)\left(\frac{25}{30}\right)^3 = .0965$$

Total of $P_0 + P_1 + P_2 + P_3$ = (.1667 + .1389 + .1157 + .0965) = .5178

Therefore, the probability of three or more is 1 - .5178 = .4822 or 48.22%

e. $L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{30^2}{30(30 - 30)} \rightarrow \infty$

18. Use model 1.

$\lambda =$ 4 per hour $\quad \mu = 6$ per hour

a. $\rho = \frac{\lambda}{\mu} = \frac{4}{6}$ = .667 or 66.7%

b. $L_s = \frac{\lambda}{\mu - \lambda} = \frac{4}{4 - 2}$ = 2.00 students in the system

c. $W_s = \frac{L_s}{\lambda} = \frac{2.00}{4}$ = .50 hours or 30 minutes

d. Probability of 4 or more is equal to 1 – probability of 0, 1, 2, 3

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

$$P_0 = \left(1-\frac{4}{6}\right)\left(\frac{4}{6}\right)^0 = .3333$$

$$P_1 = \left(1-\frac{4}{6}\right)\left(\frac{4}{6}\right)^1 = .2222$$

$$P_2 = \left(1-\frac{4}{6}\right)\left(\frac{4}{6}\right)^2 = .1481$$

$$P_3 = \left(1-\frac{4}{6}\right)\left(\frac{4}{6}\right)^3 = .0988$$

Total of $P_0 + P_1 + P_2 + P_3$ = (.3333 + .2222 + .1481 + .0988) = .8024
Therefore, the probability of three or more is 1 - .8024 = .1976 or 19.76%

e. $L_q = \frac{\lambda^2}{\mu(\mu-\lambda)} = \frac{6^2}{6(6-6)} \to \infty$

19. Use model 1.
$\lambda =$ 10 per minute $\mu = 12$ per minute

a. $L_q = \frac{\lambda^2}{\mu(\mu-\lambda)} = \frac{10^2}{12(12-10)}$ = 4.17 people

b. $L_s = \frac{\lambda}{\mu-\lambda} = \frac{10}{12-10}$ = 5, $W_s = \frac{L_s}{\lambda} = \frac{5}{10}$ = .5 minute or 30 seconds

c. $\rho = \frac{\lambda}{\mu} = \frac{10}{12}$ = .833 or 83.3%

d. Probability of 3 or more is equal to 1 – probability of 0, 1, 2

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

$$P_0 = \left(1-\frac{10}{12}\right)\left(\frac{10}{12}\right)^0 = .1667$$

$$P_1 = \left(1-\frac{10}{12}\right)\left(\frac{10}{12}\right)^1 = .1389$$

$$P_2 = \left(1-\frac{10}{12}\right)\left(\frac{10}{12}\right)^2 = .1157$$

Total of $P_0 + P_1 + P_2 + P_3$ = (.1667 + .1389 + .1157) = .4213
Therefore, the probability of three or more is 1 - .4213 = .5787 or 57.87%

20. Use model 3.

$\lambda =$ 10 per minute $\mu =$ 12 per minute

a. $\rho = \frac{\lambda}{\mu} = \frac{10}{12}$ = .8333, from Exhibit TN7.11, L_q = .175 cars

b. $L_s = L_q + \lambda/\mu$ = .175 + .8333 = 1.008

c. $W_s = \frac{L_s}{\lambda} = \frac{1.008}{10}$ = .101 minutes or 6.06 seconds

Use model 1, and cut λ in half.

d. $L_q = \frac{\lambda^2}{\mu(\mu - \lambda)} = \frac{5^2}{12(12-5)}$ = .298

Since there are two lines, the total number in line is 2 times .298, which is .596 cars

d. $L_s = \frac{\lambda}{\mu - \lambda} = \frac{5}{12-5}$ = .7143

$W_s = \frac{L_s}{\lambda} = \frac{.7143}{5}$ = .143 minutes or 8.58 seconds

21. Use model 1.

$\lambda =$ 2 per hour

With one repair person: $\mu = 2$

$$L_s = \frac{\lambda}{\mu - \lambda} = \frac{2}{2-2} \to \infty$$

With two repair people: $\mu = 3$

$$L_s = \frac{\lambda}{\mu - \lambda} = \frac{2}{3-2} = 2 \text{ cars}$$

With three repair people: $\mu = 4$

$$L_s = \frac{\lambda}{\mu - \lambda} = \frac{2}{4-2} = 1 \text{ car}$$

Number of repair personnel	Service rate per hour (μ)	$\overline{n}_s$	Cost of waiting per hour[1]	Cost of service per hour[2]	Total cost per hour
1	2	∞	$ ∞	$ 20	$ ∞
2	3	2	80	40	120
3	4	1	40	60	100

Note: 1 = cost of waiting is number in system times downtime cost of $40 per hour.
2 = cost of service is number of repair personnel times wage rate ($20 per hour).
Should use three repair persons.

22. Use model 2.

$\lambda =$ 750 per hour $\mu =$ 900 per hour

a. $W_s = L_s/\lambda$ = 2.92/750 = .003889 hours or .2333 minutes or 14 seconds

b. $L_q = \frac{\lambda^2}{2\mu(\mu - \lambda)} = \frac{750^2}{2(900)(900-750)}$ = 2.083 cars

$L_s = L_q + \lambda/\mu$ = 2.083 + 750/900 = 2.92 cars

23. You are planning a bank. You plan for 6 tellers. Tellers take 15 minutes per customer with a standard deviation of 7 minutes. Customers arrive 1 every three minutes according to an exponential distribution. Every customer that arrives eventually gets serviced. (Use the approximation model spreadsheet "Waiting Line Approximations.xls" for this solution.)

$\overline{X}_a = 3$, $S_a = 3$, $\overline{X}_s = 15$, $S_s = 7$, $S = 6$

$$C_a = \frac{S_a}{\overline{X}_a} = \frac{3}{3} = 1, \quad C_s = \frac{S_s}{\overline{X}_s} = \frac{7}{15} = .4667,$$

$$\lambda = \frac{1}{\overline{X}_a} = \frac{1}{3} = .3333, \quad \mu = \frac{1}{\overline{X}_s} = \frac{1}{15} = .06667, \quad \rho = \frac{\lambda}{S\mu} = \frac{.3333}{6(.06667)} = .8332$$

a. On average how many customers would be waiting in line?

$$L_q = \frac{\rho^{\sqrt{2(S+1)}}}{1-\rho} X \frac{C_a^2 + C_s^2}{2} = \frac{.8332^{\sqrt{2(6+1)}}}{1-.8332} X \frac{1^2 + .4667^2}{2} = 1.8468$$

b. On average how long would a customer spend in the bank?

$$L_s = L_q + S_\rho = 1.848 + (6)(.8332) = 6.8468$$

$$W_s = \frac{L_s}{\lambda} = \frac{6.8468}{.3333} = 20.5404$$

c. If a customer arrived, saw the line and decided not to get in line that customer has ________________________________.
Answer: Balked

d. A customer who enters the line but decides to leave the line before getting service is said to have ________________________________.
Answer: Reneged

24. You are planning the new layout for the local branch of the Sixth Ninth Bank. You are considering separate cashier windows for the three different classes of service. Each class of service would be separate with its own cashiers and customers. Oddly enough each class of service, while different, has exactly the same demand and service times. People for one class of service arrive every 4 minutes and arrival times are exponentially distributed. It takes 7 minutes to service each customer and the standard deviation of the service times is 3 minutes. You assign two cashiers to each type of service. (Use the approximation model spreadsheet "Waiting Line Approximation.xls".)

$\overline{X}_a = 4$, $S_a = 4$, $\overline{X}_s = 7$, $S_s = 3$, S = 2

$$C_a = \frac{S_a}{\overline{X}_a} = \frac{4}{4} = 1, \quad C_s = \frac{S_s}{\overline{X}_s} = \frac{3}{7} = .4285,$$

$$\lambda = \frac{1}{\overline{X}_a} = \frac{1}{4} = .2500, \quad \mu = \frac{1}{\overline{X}_s} = \frac{1}{7} = .1429, \quad \rho = \frac{\lambda}{S\mu} = \frac{.2500}{2(.1429)} = .8750$$

a. On average, how long will each line be at each of the cashier windows?

$$L_q = \frac{\rho^{\sqrt{2(S+1)}}}{1-\rho} X \frac{C_a^2 + C_s^2}{2} = \frac{.8750^{\sqrt{2(2+1)}}}{1-.8750} X \frac{1^2 + .4285^2}{2} = 3.4138$$

b. On average how long will a customer spend in the bank (assume they enter, go directly to one line and leave as soon as service is complete).

$$L_s = L_q + S_\rho = 3.4138 + (2)(.8750) = 5.1638$$

$$W_s = \frac{L_s}{\lambda} = \frac{5.1638}{.2500} = 20.6553$$

You decide to consolidate all the cashiers so they can handle all types of customers without increasing the service times.

c. What will happen to the amount of time each cashier spends idle? (increase, decrease, stay the same, depends on _____)

Answer: Stay the same

d. What will happen to the average amount of time a customer spends in the bank? (increase, decrease, stay the same, depends on _____)

Answer: Decrease

CHAPTER 8
QUALITY MANAGEMENT: FOCUS ON SIX SIGMA

Review and Discussion Questions

1. Is the goal of Six Sigma quality realistic for services such as Blockbuster Video Stores?

A goal of Six Sigma can also be used for services. The one area where Six Sigma maybe difficult is that many aspects of service quality are based upon customer perception--for example--the courtesy of the clerk. In spite of all efforts, someone may perceive that the clerk was not courteous. But in spite of this problem, every effort should be made to attain Six Sigma in both manufacturing and service settings.

2. "If line employees are required to work on quality improvement activities, their productivity will suffer." Discuss.

The Japanese have demonstrated that high quality and the high productivity needed to offer low prices are not mutually exclusive. Products made correctly the first time do not have to be reworked or scrapped, which translates into lower costs for materials and workers. If one includes the time required for rework, time expended for the production of each product would be lower if quality control becomes a line responsibility.

3. "You don't inspect quality into a product; you have to build it in." Discuss the implications of this statement.

The typical U.S. factory invests 20 to 25 percent of its operating budget in finding and fixing mistakes. One fourth of all workers fix things that are not done right. These are appraisal and internal failure cost. On the other hand, if quality standards are enforced as the item is being built, appraisal, internal and external failure costs will decrease while prevention costs will increase. The rule of thumb is that for every dollar spent in prevention, ten dollars are saved in failure and appraisal costs.

4. "Before you build quality in, you must think it in." How do the implications of this statement differ from those of Question 3?

The "thinking quality in" philosophy requires a longer-term perspective than the "building quality in" philosophy. "Building quality in" includes short-term techniques, such as tuning the production equipment to assure consistent quality. "Thinking quality in" includes longer-term techniques such as designing the product to be robust enough to achieve high quality despite fluctuations on the production line, training workers to be capable of "thinking in quality," and developing a working environment in which "thinking in quality" is nurtured.

5. Business writer Tom Peters has suggested that in making process changes, we should "Try it, test it, and get on with it." How does this square with the DMAIC/Continuous Improvement philosophy?

"Try it, test it, and get on with it" is closely related to Analyze and Improve stage of DMAIC (define, measure, analyze, improve, control). Missing from Peter's suggestion is the planning portion of the DMAIC cycle. The plan involves determining the appropriate improvement that is tested on a small scale during the analyze and improve activities, and implemented on a wider scale during the improve stage of the DMAIC.

6. Shingo told a story of a poka-yoke he developed to make sure that operators avoided the mistake of putting less than the required four springs in a push button device. The existing method involved assemblers taking individual springs from a box containing several hundred, and then placing two of them behind an ON button and two more behind an OFF button. What was the poka-yoke Shingo created?

One common poka-yoke is part kitting. By kitting individual boxes of four springs, operators could make sure no springs remain in the box after the assembly operations.

7. The typical computerized word processing package is loaded with poka-yokes. List three. Are there any others you wish the packages had?

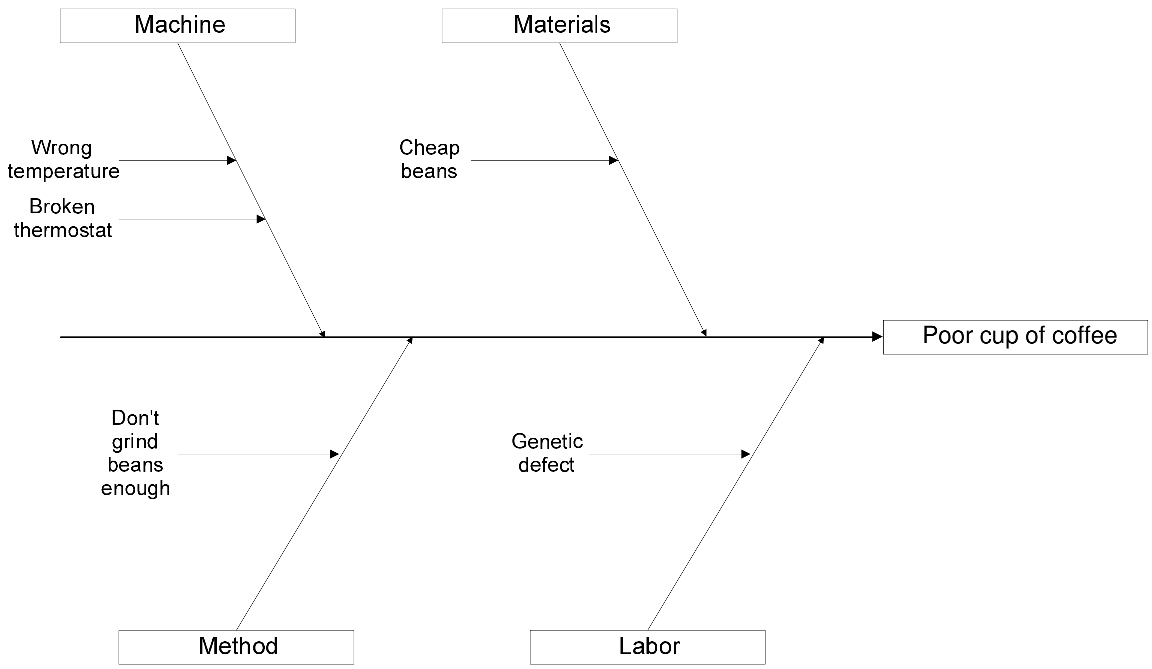
   (i) When exiting the word processor, a prompt asks whether or not you want to save the document. (ii) Many word processors will make backup files at various points in time. (iii) Many word processors will automatically correct certain words when they are misspelled, such as “the.” Word processors have made tremendous strides in this area. Although it would be nice if the word processor checked the form of a word like “to,” too,” and “two.”

Problems

Problem	Type of Problem					Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Fishbone	Benchmarking and CI	Six Sigma	Source of Defects	SERV QUAL e-SQ				
1			Yes			Moderate			
2	Yes					Moderate			
3		Yes				Difficult			
4				Yes		Moderate			
5					Yes	Moderate			
6					Yes	Moderate			
7		Yes				Moderate			
8		Yes				Moderate			

1. Not so good. He has 23 defectives, a DPMO of 15,333 and a sigma of around 2.4.
   DPMO = [23/1 defect opportunity/unit x 1500] x 1,000,000 = 15,333

2.



This fishbone diagram examines four elements of a process: materials, machine, method, and labor. In this example, Professor Chase has isolated the root cause of why he can't make a good cup of coffee—it's a genetic defect: his mother was never able to make a good cup of coffee. His solution is to change the labor force or skip coffee (retraining is hopeless).

3. Student-specific answer. Student should compare his or her performance to best performers in the class and similar classes. They should identify the critical success factors of these top students. A cause-and-effect diagram could be drawn to link the poor course performance to the root causes. They could then develop an improvement plan and test the plan in this single class and based on the performance improvement, they could apply the improved study processes to all classes.

4. Answers will vary. See Exhibit 8.10 for an example of the sources of defects table. One example might look like the following:
Michele and Wayne assembled a wardrobe with the following mistakes occurring.

They initially did not read the directions. (Omitted processing)

They assemble the wardrobe face-up and then had to turn it over to attach the backing. (Errors setting up)

As each component was attached the screws were tightened; however, the last piece would not fit into place. (Processing errors)

Components were continually moved to make room as the wardrobe took shape. (Errors setting up workpieces)

While the doors open and closed effortlessly, the right-hand door was slightly lower than the left-hand one.(Adjustment errors)

Several shelves that had been installed had to be taken out to allow other pieces to be assembled. (Processing wrong workpiece)

Several screws were left over when the wardrobe was finally assembled. (Missing or wrong parts)

The Philips head screw diver that they were using was slightly too large for the screw heads. (Tools improperly prepared).

5. Answers will vary from student-to-student, and from bank-to-bank. The five SERVQUAL dimensions follow:
Table 2: SERVQUAL IMPORTANCE WEIGHTS

Listed below are five features pertaining to banks and the services they offer. We would like to know how much each of these features is important to the customer. Please allocate 100 points among the five features according to how important it is to you. Make sure the points add up to 100.

1. The appearance of the banks physical facilities, equipment, personnel, and communication materials. _______________ points

2. The banks ability to perform the promised service dependably and accurately. _______________ points

3. The bank's willingness to help customers and provide prompt service. _______________ points

4. The knowledge and courtesy of the bank's employees and their ability to convey trust and confidence. _______________ points

5. The caring, individual attention the bank provides its employees. _______________ points

Total: 100 points

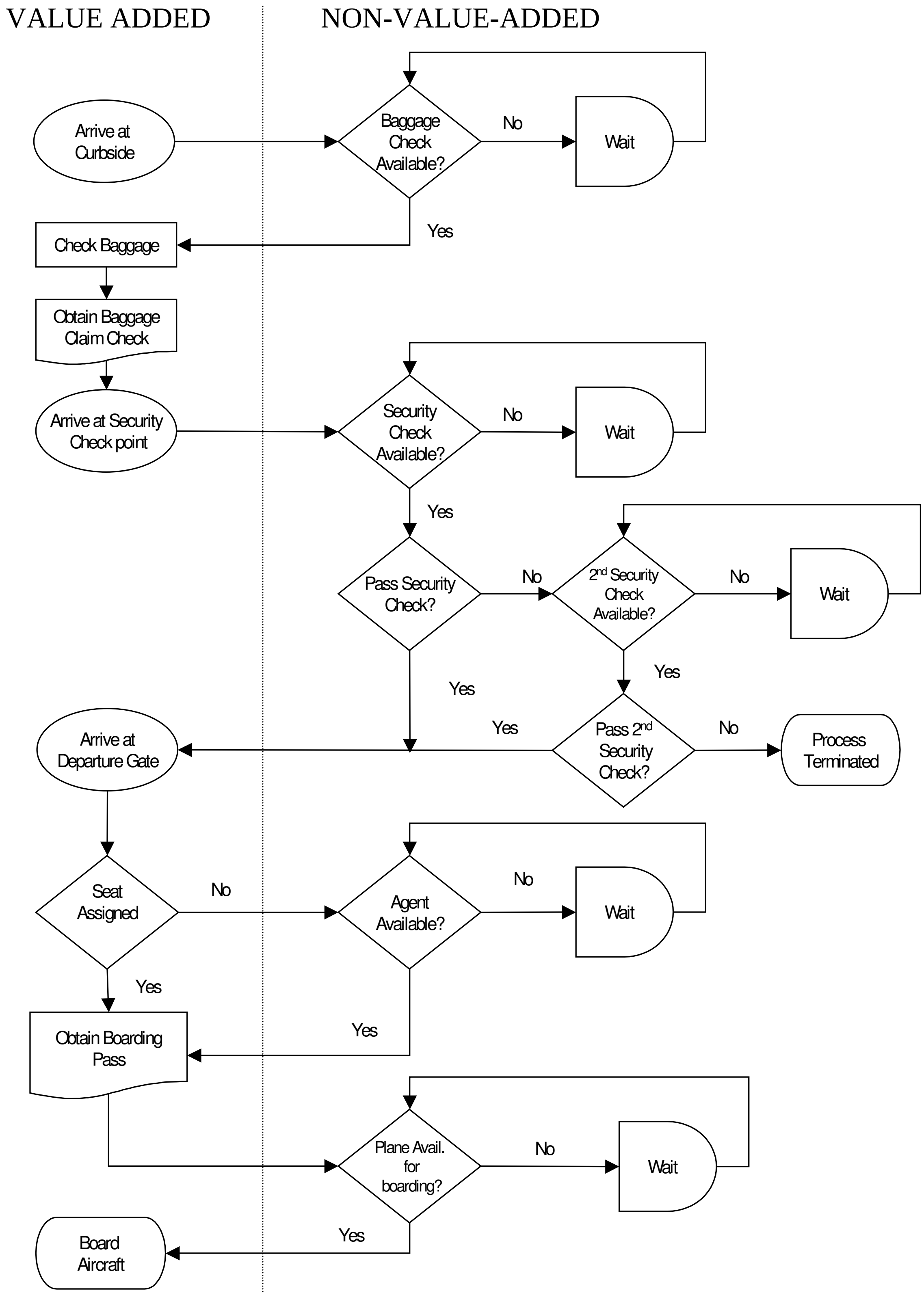
6. Answers will vary from student to student and from bank to bank.
    1. Reliability - Does the bank' site accurately delivery your account's information?
    2. Responsiveness - How quick does the site respond to your requests?
    3. Access - Speed of the web site.
    4. Flexibility - How well does the site adapt to different requests?
    5. Ease of Navigation - Ability to get around site and find wanted information.
    6. Efficiency - Ease of use.
    7. Assurance/Trust - Accuracy of account information.
    8. Security privacy - Does the site use encryption?
    9. Price knowledge - Not directly applicable to a bank's web site.
    10. Site Aesthetics - Is the site attractive.
    11. Customization/personalization - Can you set your own home page with the bank's site.

7.

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
Airport Operator	Facility		Ticket	Passengers
Airline	Plane & Personnel		Boarding Pass	
Sky Caps	Baggage		Checked Baggage	
Security Screeners	Passenger		Transportation	

Process Steps:
Arrive Curbside → Check Baggage (sky cap or ticket counter) → Security screening →check in at departure gate → board aircraft

8.


VALUE ADDED
NON-VALUE-ADDED
Arrive at Curbside
Baggage Check Available?
No
Wait
Yes
Check Baggage
Obtain Baggage Claim Check
Arrive at Security Check point
Security Check Available?
No
Wait
Yes
Pass Security Check?
No
2nd Security Check Available?
No
Wait
Yes
Yes
Yes
Arrive at Departure Gate
Pass 2nd Security Check?
No
Process Terminated
Seat Assigned
No
Agent Available?
No
Wait
Yes
Obtain Boarding Pass
Yes
Plane Avail. for boarding?
No
Wait
Yes
Board Aircraft

TECHNICAL NOTE 8
PROCESS CAPABILITY AND STATISTICAL QUALITY CONTROL

Review and Discussion Questions

1. The capability index allows for some drifting of the process mean. Discuss what this means in terms of product quality output.

When C_{pk} is larger then 1.33 or 1.5, this means that the mean of the process can drift (up to a limit) while still producing within specifications. This is what is implied by the phrase "a capable process."

2. Discuss the purposes and differences between the P-charts and X-bar and R charts.

P-charts are used to monitor the process for attribute data. These are typically binomial "go, no-go" data. An example of a P-chart is percent of pieces nonconforming. X-bar charts are used for charting population values for continuous measurement. X-bar charts operate effectively with smaller sample sizes than P-charts, but it is more involved to analyze the sample for an X-bar chart since a measurement must be taken. A rule of thumb for the sample size of a P-chart is to have at least one defective in each sample. This can require a relatively large sample size in some cases. If the process is slow, an X-bar chart will generally be a better choice since it functions with smaller sample sizes. An example of an X-bar chart is average time to complete a mile run for one person. R charts are used to compute process ranges for variable data, and are generally used in concert with X-bar charts.

3. In an agreement between a supplier and a customer, the supplier must ensure that all parts are within tolerance before shipment to the customer. What would be the effect on the cost of quality to the customer?

Before the agreement was made, the customer probably inspected each part to protect against off-spec supplies. This agreement (ideally) eliminates the need for this inspection. Appraisal costs, such as materials and supplies inspection and reliability testing, will be reduced since the agreement would ensure that the supplies are totally within tolerance. This allows the customer to focus attention on quality improvement within his or her own processes, requiring an increase in prevention cost. Scrap and rework costs will initially drop because of the improvement in the quality of the part supply. Once prevention programs are in force, scrap, repair, rework, and downtime costs will drop even further because of improvements in the internal process. External failure costs will drop because of improvement in the product and the process.

4. In the situation described in Question 3, what would be the effect on the cost of quality to the supplier?

If operating under the traditional definition for the quality control function, appraisal costs will increase since all parts, not just a sample, must be inspected before shipment. Coupled with costs associated with internal and external failure, an increase in the appraisal cost could drive up the price of the parts so that they are no longer competitive.

5. Discuss the trade-off between achieving a zero AQL (acceptable quality level) and a positive AQL (e.g., an AQL of 2 percent).

The tradeoff involves a cost/precision tradeoff. This is analogous to the service level/cost tradeoff. From a classical economic point of view, if the cost of defects is very high, an AQL of zero is economical. If defect costs are nominal, the cost of achieving near perfect quality can be prohibitive. This assumes that conformance is asymptotic to the cost axis.

Problems

Problem	Type of Problem					Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Cost of Inspection	P-chart	X-bar and R charts	Acceptance Sampling	C_{pk}				
1	Yes					Easy			Yes
2					Yes	Moderate			
3		Yes				Moderate			
4	Yes					Easy			
5	Yes					Easy			
6			Yes			Moderate			Yes
7				Yes		Easy			
8		Yes				Moderate			
9				Yes		Easy			Yes
10		Yes				Moderate			
11		Yes				Moderate			
12			Yes			Moderate			Yes
13					Yes	Moderate			
14					Yes	Moderate			

1. Defective average = .04, inspection rate = 50 per hour, cost of inspector = $9 per hour, and repair cost is $10 each.

   a.

	Calculation	Cost per hour
No inspection	.04 * (50) * $10	$20
Inspection		9

   Therefore, it is cheaper to inspect in this case.

   b. Cost per unit for inspection = $9/50 = $.18

   c. Benefit form the current inspection process is

   Hourly: cost of no inspection – cost of inspection ($20 - $9 = $11)

   Per unit: average cost of quality – cost of inspection ((.04)$10 - $.18 = $.22)

2.

a. $C_{pk} = \min\left\{\frac{UTL - \overline{X}}{3\sigma}, \frac{\overline{X} - LTL}{3\sigma}\right\} = \min\left\{\frac{1.01 - 1.002}{3(.003)}, \frac{1.002 - .99}{3(.003)}\right\} = \min\{.889, 1.333\}$
$= .889$

b. The process is capable of producing the desired quality, but at present it is not capable due to the process center. The process center should be adjusted.

3.

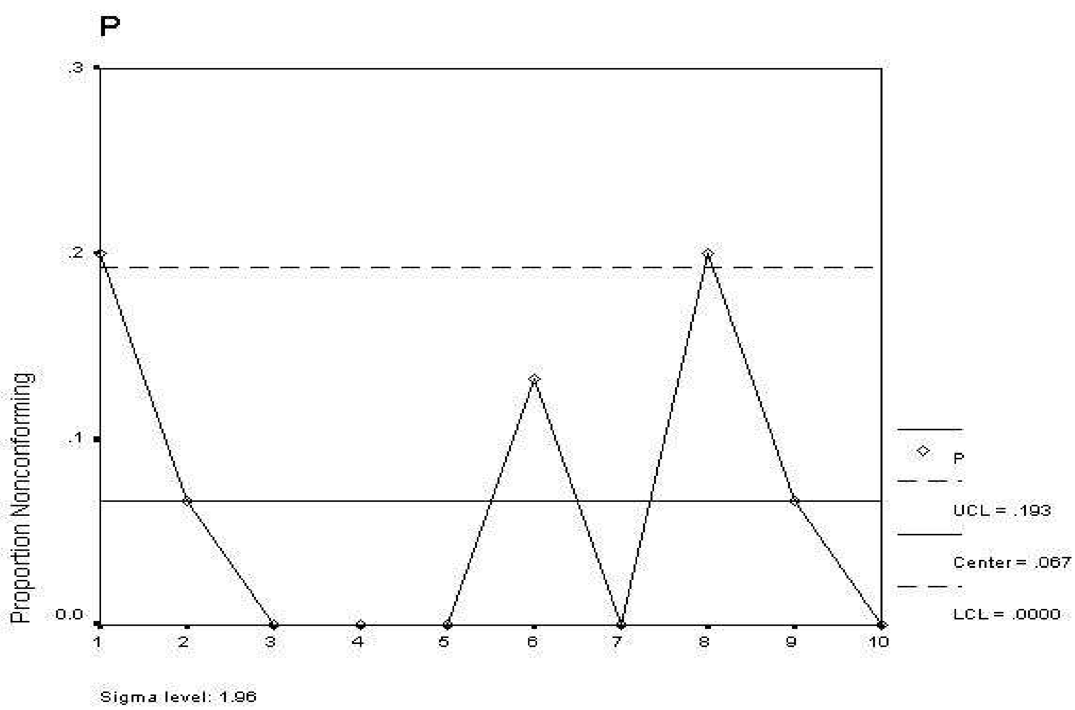
a. Ten defectives were found in 10 samples of size 15.

$$\overline{P} = \frac{10}{10(15)} = .067$$

$$S_p = \sqrt{\frac{\overline{P}(1 - \overline{P})}{n}} = \sqrt{\frac{.067(1 - .067)}{15}} = .0645$$

UCL = $\overline{P} + 1.96 S_p$ = .067 + 1.96(.0645) = .194

LCL = $\overline{P} - 1.96 S_p$ = .067 - 1.96(.0645) = -.060 $\rightarrow$ zero



b. Stop the process and look for the special cause, it is out of statistical control.

4. Defective average = .02, inspection rate = 20 per hour, cost of inspector = $8 per hour, and replacement cost is $25 each.

a.

	Calculation	Cost per hour
No inspection	.02(20)$25	$10
Inspection		8

Therefore, it is cheaper to inspect in this case.

b. Cost per unit for inspection = $8/20 = $.40

Benefit form the current inspection process per unit is: average cost of quality – cost of inspection ((.02)$25 - $.40 = $.10)

5. Defective average = .03, inspection rate = 30 per hour, cost of inspector = $8 per hour, and correction cost is $10 each.

	Calculation	Cost per hour	Cost per unit
No inspection	.03(30)$10	$9	$.300
Inspection		8	.267

Therefore, it is cheaper to inspect in this case.

6.

Sample	1	2	3	4	mean	range
1	1010	991	985	986	993.00	25
2	995	996	1009	994	998.50	15
3	990	1003	1015	1008	1004.00	25
4	1015	1020	1009	998	1010.50	22
5	1013	1019	1005	993	1007.50	26
6	994	1001	994	1005	998.50	11
7	989	992	982	1020	995.75	38
8	1001	986	996	996	994.75	15
9	1006	989	1005	1007	1001.75	18
10	992	1007	1006	979	996.00	28
11	996	1006	997	989	997.00	17
12	1019	996	991	1011	1004.25	28
13	981	991	989	1003	991.00	22
14	999	993	988	984	991.00	15
15	1013	1002	1005	992	1003.00	21

$\overline{\overline{X}} = 999.1, \ \overline{R} = 21.733$

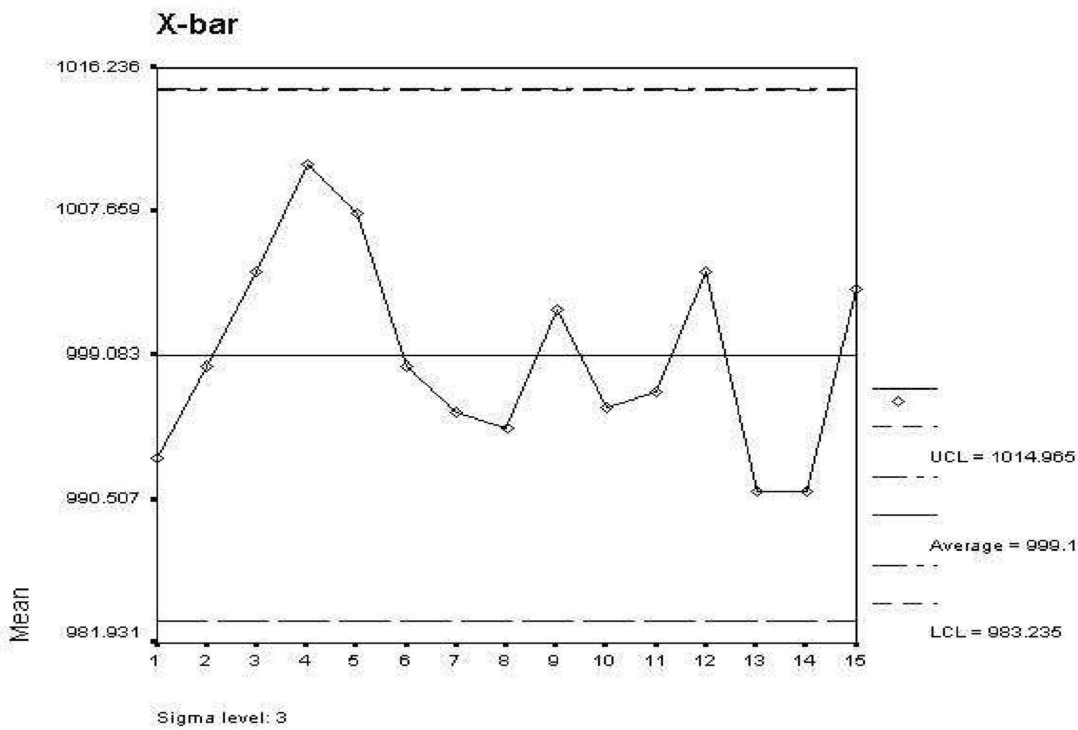
Control limits for X-bar chart:

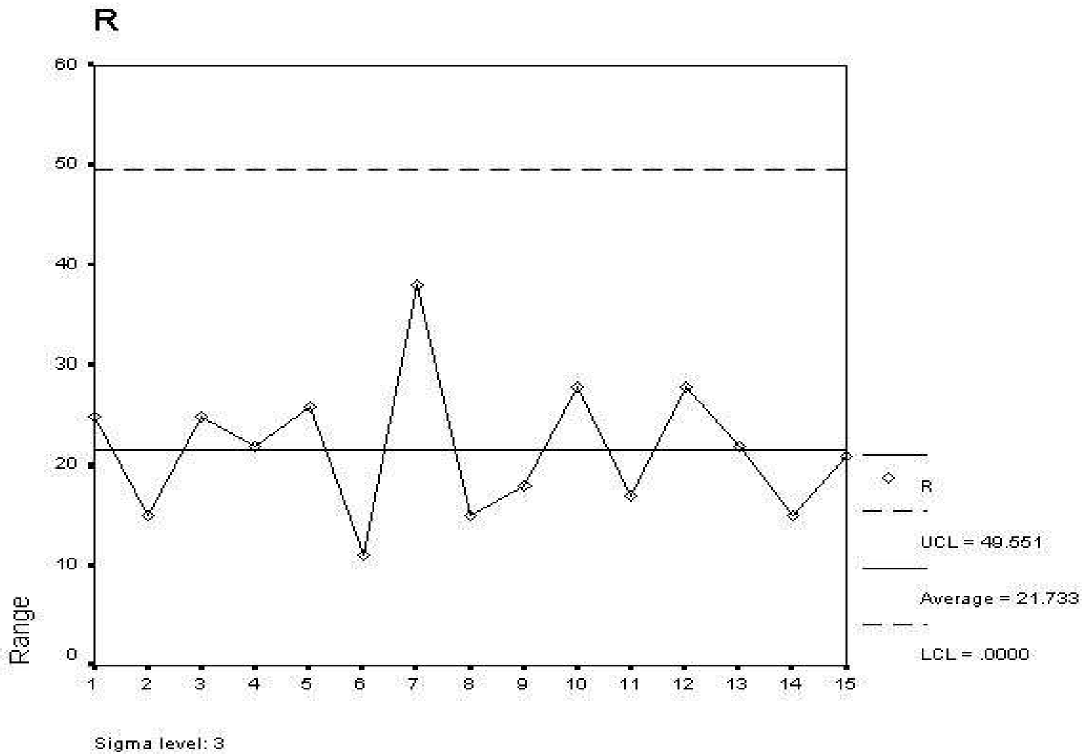
UCL, LCL = $\overline{\overline{X}} \pm A_2 \overline{R}$, = 999.1 $\pm$ .73(21.733) = 1014.965, 983.235

Control limits for R chart:

UCL = $D_4 \overline{R}$ = 2.28(21.7333) = 49.551

LCL = $D_3 \overline{R}$ = 0(21.7333) = 0.00





The process is in statistical control.

7.

a. AQL = .03, LTPD = .10

LTPD/AQL = .10/.03 = 3.333

From Exhibit TN8.10, c = 5.

Also from this Exhibit, n (AQL) = 2.613

$$n = \frac{2.613}{AQL} = \frac{2.613}{.03}$$ = 87.1, round up to 88

b. Allow up to 5 defective components

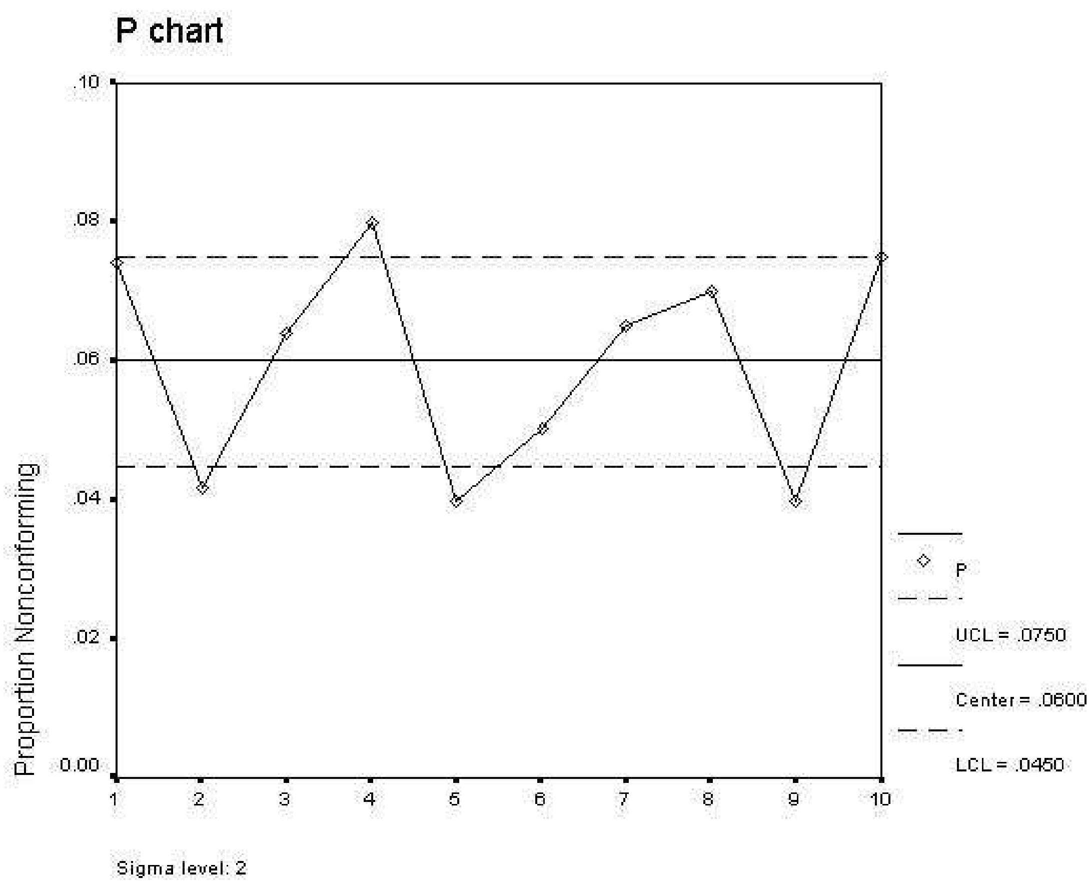
8.

a. $\overline{P} = \dfrac{600}{10(1000)} = .06$

$$S_p = \sqrt{\frac{\overline{P}(1-\overline{P})}{n}} = \sqrt{\frac{.06(1-.06)}{1000}} = .0075$$

UCL = $\overline{P} + 2S_p$ = .06 + 2(.0075) = .075

LCL = $\overline{P} - 2S_p$ = .06 - 2(.0075) = .045



b. The chart indicates that the process is out of control. The administrator should investigate the quality of the patient meals.

9.

a. AQL = .15, LTPD = .40

LTPD/AQL = .40/.15 = 2.667

From Exhibit TN8.10, c = 8.

Also from this Exhibit, n(AQL) = 4.695

$$n = \frac{4.695}{AQL} = \frac{4.695}{.15} = 31.3, \text{ round up to } 32$$

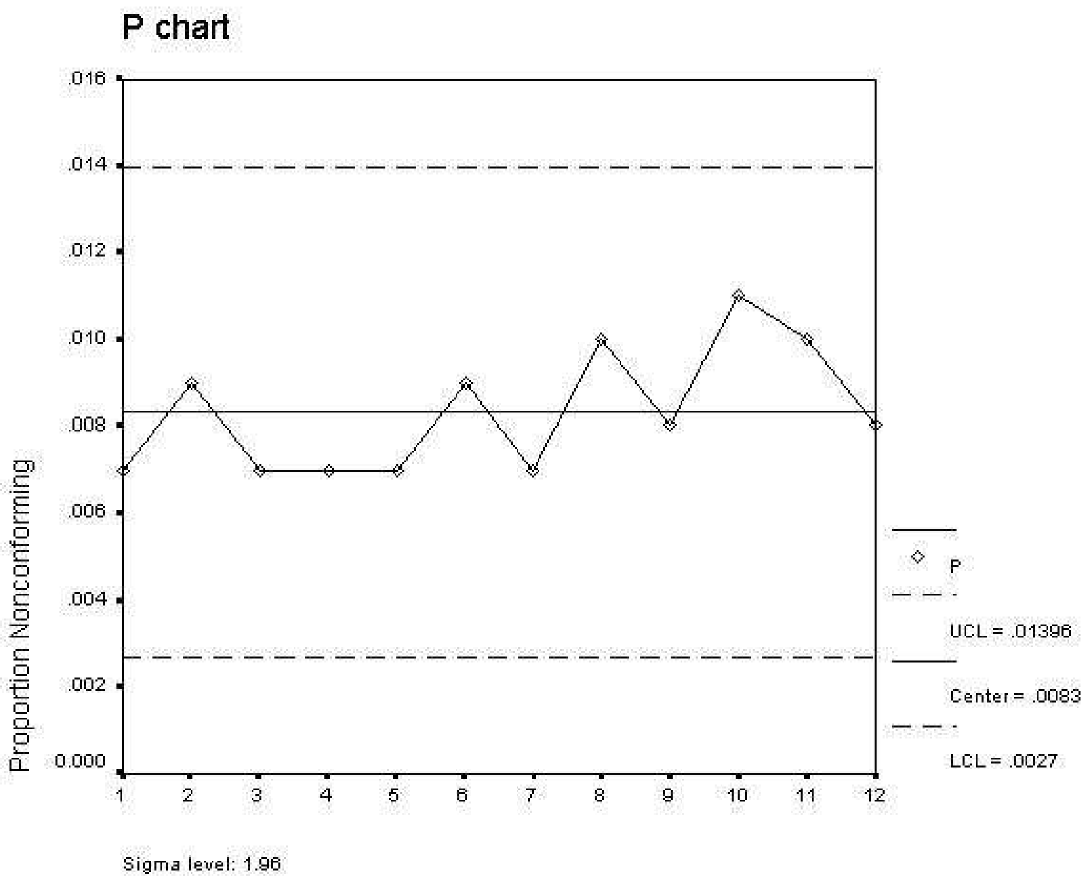
b. Randomly sample 32 LSI, reject the lot if more than 8 defective

10. $\overline{P} = \dfrac{100}{12(1000)} = .008333$

$$S_p = \sqrt{\frac{\overline{P}(1-\overline{P})}{n}} = \sqrt{\frac{.008333(1-.008333)}{1000}} = .00287$$

UCL = $\overline{P} + 1.96\,S_p$ = .008333 + 1.96(.00287) = .01396

LCL = $\overline{P} - 1.96\,S_p$ = .008333 - 1.96(.00287) = .0027



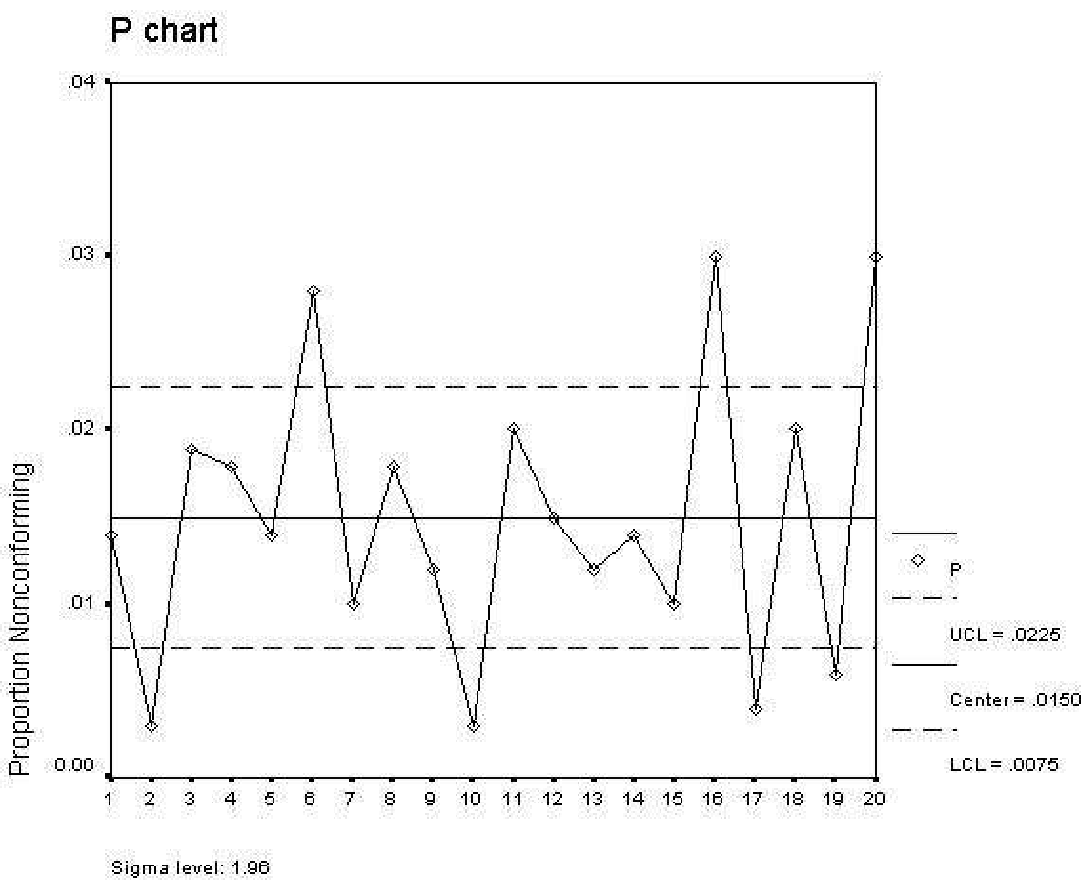
The process is in control. Therefore, it can be stated that the crime rate has not increased. However, there appears to be a gradual increase in the crime rate.

11. $\overline{P} = \dfrac{300}{20(1000)} = .015$

$$S_p = \sqrt{\frac{\overline{P}(1-\overline{P})}{n}} = \sqrt{\frac{.015(1-.015)}{1000}} = .00384$$

UCL = $\overline{P} + 1.96\,S_p$ = .015 + 1.96(.00384) = .0225

LCL = $\overline{P} - 1.96\,S_p$ = .015 - 1.96(.00384) = .0075



Process is out of statistical control. Specifically, three areas outside of UCL warrant further investigation, and four areas below LCL warrant investigation.

12.

Sample number	1	2	3	4	5	Mean	Range
1	.486	.499	.493	.511	.481	.494	.030
2	.499	.506	.516	.494	.529	.509	.035
3	.496	.500	.515	.488	.521	.504	.033
4	.495	.506	.483	.487	.489	.492	.023
5	.472	.502	.526	.469	.481	.490	.057
6	.473	.495	.507	.493	.506	.495	.034
7	.495	.512	.490	.471	.504	.494	.041
8	.525	.501	.498	.474	.485	.497	.051
9	.497	.501	.517	.506	.516	.507	.020
10	.495	.505	.516	.511	.497	.505	.021
11	.495	.482	.468	.492	.492	.486	.027
12	.483	.459	.526	.506	.522	.499	.067
13	.521	.512	.493	.525	.510	.512	.032
14	.487	.521	.507	.501	.500	.503	.034
15	.493	.516	.499	.511	.513	.506	.023
16	.473	.506	.479	.480	.523	.492	.050
17	.477	.485	.513	.484	.496	.491	.036
18	.515	.493	.493	.485	.475	.492	.040
19	.511	.536	.486	.497	.491	.504	.050
20	.509	.490	.470	.504	.512	.497	.042

$\overline{\overline{X}}$ = .499, $\overline{R}$ = .037

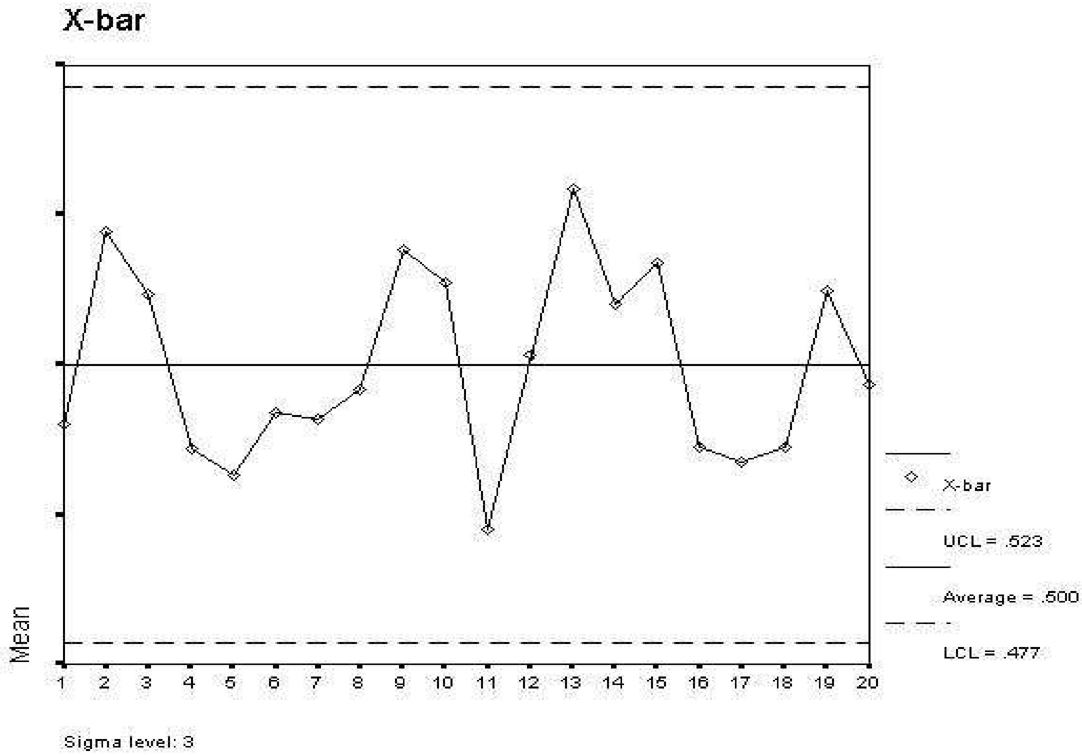
Control limits for X-bar chart:

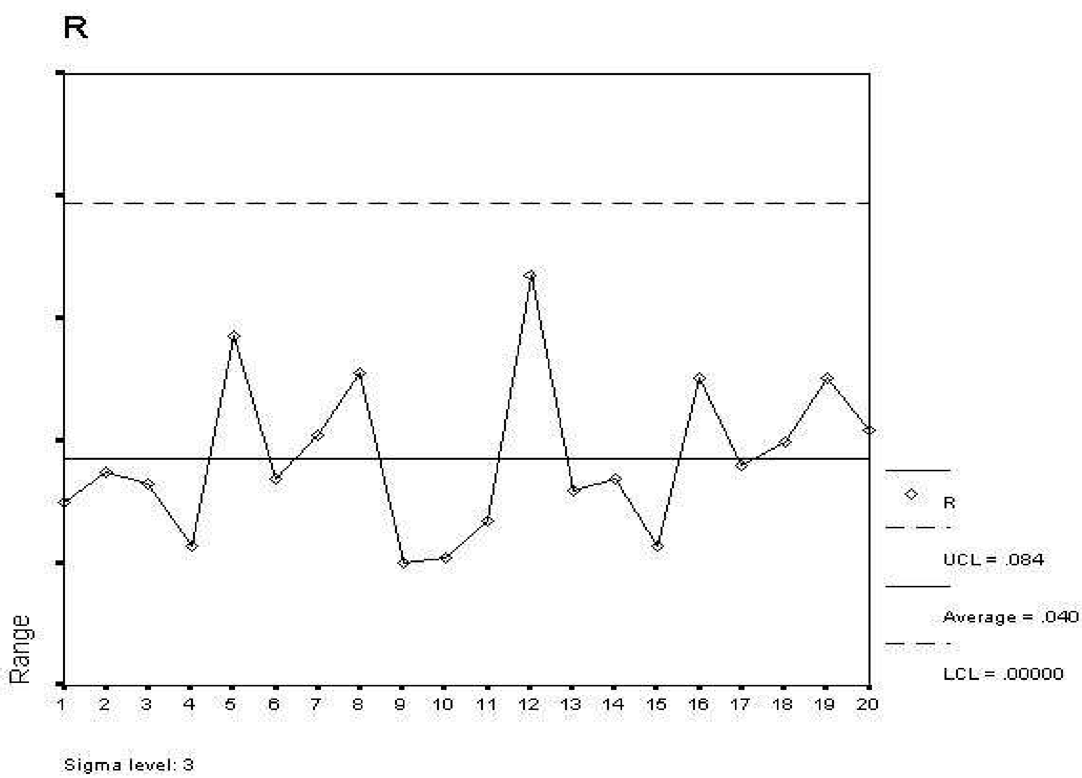
UCL, LCL = $\overline{\overline{X}} \pm A_2 \overline{R}$, = ..499 ± .58(.037) = .520, .478

Control limits for R chart:

UCL = $D_4 \overline{R}$ = 2.11(.037) = .078

LCL = $D_3 \overline{R}$ = 0(.037) = 0.00





Process is in statistical control.

13.

a.

$$C_{pk} = \min\left\{\frac{UTL-\overline{X}}{3\sigma}, \frac{\overline{X}-LTL}{3\sigma}\right\} = \min\left\{\frac{4.003-4.001}{3(.002)}, \frac{4.001-3.997}{3(.002)}\right\} = \min\{.333, .667\}$$
$$= .333$$

b. No, the machine is not capable of producing the part at the desired quality level.

14.

a. $$C_{pk} = \min\left\{\frac{UTL-\overline{X}}{3\sigma}, \frac{\overline{X}-LTL}{3\sigma}\right\} = \min\left\{\frac{110-100}{3(4)}, \frac{100-90}{3(4)}\right\} = \min\{.8333, .8333\}$$
$$= .8333$$

b. $$C_{pk} = \min\left\{\frac{UTL-\overline{X}}{3\sigma}, \frac{\overline{X}-LTL}{3\sigma}\right\} = \min\left\{\frac{110-92}{3(4)}, \frac{92-90}{3(4)}\right\} = \min\{1.5000, .1667\}$$
$$= .1667$$

c. Many defects will be produced. Assuming a normal distribution, the left tail is z = (92 - 90)/4 = .50, which corresponds to a probability of .1915. The right tail is z = (110-92)/4 = 4.5, which approximately corresponds to a probability of .5000. Therefore, .6915 (.1915 + .5000) are inside the specifications, while 1- .6915 = .3085 or approximately 31% are outside the specification limits.

CHAPTER 9
OPERATIONS CONSULTING AND REENGINEERING

Review and Discussion Questions

1. Check out the web sites of the consulting companies listed in the chapter outlines. Which ones impressed you most as a potential client and as a potential employee?

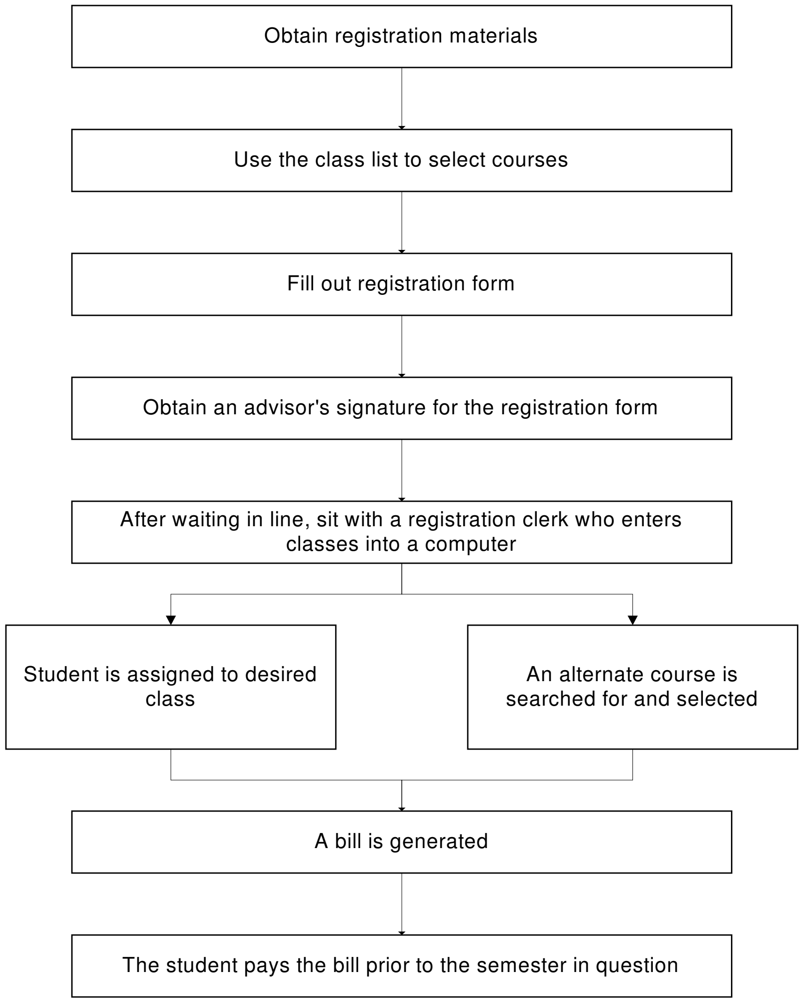
   Remember that web sites can change at any time. However, a good web site should be technically sound and contain the appropriate information. Technical aspects include the appearance including the choice of colors and fonts, the ability to find material on the site (organization), ability to find the site (is it linked in the various search engine or on professional organization's web sites?), ability to load easily, as well as the overall user friendliness of the site. Content should include what the company does, what they could do for your, their experience in the area, and their professional training of employees (e.g., degrees held, certifications, etc.).

2. What does it take to be a good consultant? Is this a career for you?

   Good consultants generally need good communications skills, good analytical skills plus expertise and experience in the area they wish to consult in. Additionally, in considering a career as a consultant, the student should considered whether they would like to be a consultant.

3. Think about the registration process at your university. Develop a flow chart to understand it. How would you radically redesign this process?

   A typical registration process might be:



   One means of reengineering this process is to implement a telephone or Internet registration system. This could eliminate several steps in the process.

4. Have you driven any car lately? Try not to think of the insurance claims settlement process while you drive! How would you reengineer your insurance company's claims process?

   For a simple auto claim not involving injury, the process involves contacting an agent, an adjustor is assigned, the injured party obtains three estimates, the estimates are sent to the adjustor, the job is assigned to a body shop, and the work is eventually performed. Depending upon the situation, the check is either sent to the body shop or the injured part.

   Any of the steps could be combined, reassigned or eliminated. For example, the adjustor could take the vehicle to a preferred body shop and pay the bill immediately.

5. Identify the typical processes in manufacturing firms. Discuss how the new product development process interacts with the traditional functions in the firm.

   Traditional processes in a firm are broadly categorized into three areas: planning, organizing, and controlling operations. Planning includes the aggregate planning process, strategic planning, product planning, etc. Organizing includes the processes of process selection, organizing the work force, layout, etc. Control processes include quality control, costs controls, inventory controls, etc.

   New product development is changing radically with concurrent engineering. This has forced an integrative, cross-functional approach to product design. The logical extension of this process is to operate cross-functionally while becoming closer to the customer.

6. In discussing characteristics of efficient plants, Goodson, developer of "Rapid Plant Assessments", suggests that numerous forklifts are a sign of poor space utilization. What do you think is behind this observation?

   Forklifts require wide aisles and are expensive to operate. They also increase pollution, and encourage unnecessary movement of materials. "In the best plants, if materials need to be moved a short distance, employees use hand-propelled roll carts; if the materials are too heavy to move by hand, garden tractors pull the carts in linked trains." Eugene Goodson, "Read a Plant Fast," *Harvard Business Review*, May 2002, p. 109.

Problems

Problem	Type of Problem		Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Consulting	Reengineering				
1	Yes		Moderate			
2	Yes		Moderate			
3		Yes	Moderate			
4		Yes	Moderate			
5	Yes		Moderate			
6	Yes		Moderate			

1. Answers will vary. But the proposal should include the following:

   a. Situation faced by client.

   b. Desired client outcomes

   c. Planning premises (including possible complications).

   d. Specific problem statement.

   e. Initial hypotheses.

   f. Work plan, including approach to be followed, client involvement, and data needs from client.

   g. Scope of project, identifying specific phases and deliverables.

   h. Identification of project team members and support capabilities.

   i. Fee structure and payment schedule.

   j. Specification of the precise features of a service guarantee (if used).

2. Answers will vary based upon the group. A good solution should follow the hint to develop a good prospectus. Specifically, check to see if the prospectus contains a reasonable target market and do the skills of the team match the target market's needs.

3. The typical procurement process involves drafting a request for proposal (RFP, possibly involving attorneys), mailing the RFPs to suppliers, receiving bids, evaluating bids, drafting contracts, drafting purchase orders (PO), sending copies of POs to the supplier and accounting, receiving the supplies and a bill, transmitting the bill to accounting, and paying the bill (from accounting.

The Bose Corporation has adopted an interesting restructuring of purchasing. The concept is termed JIT II. At Bose, suppliers are given authority to write purchase orders thereby eliminating the purchasing department.

Additionally many organizations are using corporate procurement cards (a type of credit card for the company) for small valued purchases to eliminate many of the steps in the procurement process.

Since this process is multi-functional, reengineering is a good approach. It appears that all of the steps can either be combined or eliminated. Losing control of the process is typically cited as a reason for not eliminating some of these steps. Students should be asked to identify organizational and technological enablers that will facilitate the reengineering process.

4. There is a potential for continuous improvement. However, the large number of defects demonstrates the need for reengineering. The Chapter outlines a set of steps for improving this process. These steps include: stating a case for action, evaluating enablers, studying the current process, creating a new process design and implementing the reengineered process.

5. We suggest having teams simply report in class on what they have observed in their plant tour. Goodson notes that he has had teams look at cinema complexes, car dealers, and microbreweries, as well as large and small manufacturing operations. Benefits come even from taking tours during non-business hours. Goodson points out that 30-minute tours of three fire truck manufacturing plants being considered for auction bidding by Oshkosh Truck provided enough information about how costs could be cut that they became high bidders and won. (The surveys indicated that a few million dollars a year could be saved, for example, by eliminating materials handling bottlenecks, consolidating plants, reducing inventories, and running the shop paint shop on one shift instead of three.)

6. Refer to discussion in Question 5.

CHAPTER 10
SUPPLY CHAIN STRATEGY

Review and Discussion Questions

1. What recent changes have caused supply chain management to gain importance?

   Changes include:

   a. Competitive pressures from foreign firms.

   b. Elevation of product quality to a very high level of importance.

   c. International marketing and international purchasing.

   d. Trends towards choosing sole-source suppliers and long term relationships.

   e. Product varieties and ranges are rapidly changing, and speed of delivery to market is essential.

   f. Product life cycles have shortened necessitating knowledge and control of inventories in the various pipelines.

   g. Adoption of JIT production has changed supplier relationships and has also increased the focus on reducing inventories.

   h. Trends in the legal system hold manufacturers liable for product failures, even though causes of failure may lie outside of the production system itself.

   i. Use of EDI in purchasing.

   j. The growth of supplier development.

2. With so much productive capacity and room for expansion in the United States, why would a company based in the United States choose to purchase items from foreign firm? Discuss the pros and cons.

   The use of foreign firms can provide a U.S. firm more alternatives in selecting a supplier. The pros are more choices, potentially reduced costs in the areas of materials, transportation, production, and distribution, and potentially moving closer to a foreign market. The cons are the distance is generally increased, communications problems are increased due to distance, culture, and technology. There may be problems with customs, government regulations, political stability, etc.

3. Describe the differences between functional and innovative products.

   Functional products are staples that people buy in a wide range of retail outlets. Typically, they do not change much over time, have low profit margins, stable predictable demand and long life cycles. Innovative products, on the other hand, give customers additional reasons to buy. Fashionable clothes and personal computers are examples of innovative products. Innovative products have short life cycles, high profit margins, and volatile demand.

4. What are characteristics of efficient, responsive, risk-hedging and agile supply chains? Can a supply chain be both efficient and responsive? Risk-hedging and Agile? Why or Why not?

   Efficient supply chains are designed to minimize cost that requires high utilization, minimizing inventory, and selecting vendors based primarily on cost and quality, and designing products that are produced at minimum cost. Market-responsive supply chains are designed to minimize lead time to respond to unpredictable demand, thus minimizing stockout costs and obsolete inventory costs. Risk sharing supply chains are those that share resources so that risks in the supply chain can be shared. Agile are those supply chains that are flexible while still sharing risks of shortages across the supply chain. Generally, these supply chains carry excess capacity and higher buffer stocks. Vendor in responsive supply chains would be selected for speed, flexibility, and quality. It is possible to be both efficient and responsive, and both Risk-hedging and Agile, but Exhibit 10.4 helps illustrate why supply chains are generally not both.

5. As a supplier, which factors would you consider about a buyer (your potential customer) to be important in setting up a long-term relationship?

   The financial stability and credit worthiness of the company is of primary importance. The reputation of the company visavis their supplier is also very important. For example, is this a company that is fair with its suppliers and honors its payables in a timely fashion? Is the technological match between supplier and customer sufficient? Will delivery schedules and quantities be stable, facilitating smooth operations?

6. For the value density example in Exhibit 10.9, what would the effect be if a competing firm offers you a similar service for 10 percent less than Federal Express's rates?

Weight (lbs.)	United Parcel Service: 8-day Ground Service	Competitor 2-Day Air Service	Cost Savings with UPS	Break-Even Product Value	Break-Even Product Value (per pound)
1	$3.30	$16.43	$13.13	$2,661.46	$2,661.46
2	$3.60	$18.45	$14.85	$3,011.25	$1,505.63
3	$3.85	$20.25	$16.40	$3,325.56	$1,108.52
4	$4.10	$22.05	$17.95	$3,639.86	$909.97
5	$4.30	$24.08	$19.78	$4,009.93	$801.99
6	$4.50	$25.88	$21.38	$4,334.38	$722.40
7	$4.65	$27.68	$23.03	$4,668.96	$666.99
8	$4.75	$29.48	$24.73	$5,013.68	$626.71
9	$4.85	$31.28	$26.43	$5,358.40	$595.38
10	$5.00	$33.08	$28.08	$5,692.99	$569.30

7. What are the advantages of using the postponement strategy?

   Process postponement delays the process step that differentiate the product to as late in the supply chain as possible. The advantages of this approach are that lower levels of inventory, and fewer models are needed to match customer requirements. This results in higher levels of customer satisfaction at a lower cost.

8. Describe how outsourcing works. Why would a firm want to outsource?

   Outsourcing is the act of moving some of a firm's internal activities and decision responsibilities to outside providers. The terms of the agreement are established in a contract. Outsourcing goes beyond the more common purchasing and consulting contracts because not only are the activities transferred, but also resources that make the activities occur are transferred. Reasons for outsourcing are listed in Exhibit 10.6. Some of the major categories from this Exhibit include organizational, improvement, financial, revenue, cost, and employee driven reasons.

9. What is so different about Li & Fung's approach to working with their customers? Would this approach work with functional products like toothpaste and basketballs?

   There is greater opportunity with innovative products, such as clothing, in that each season the production mix and production schedule is different. However, dispersing the manufacturing to different countries depending upon the costs and skill will work for staple products.

10. What are the basic building blocks of an effective mass customization program? What kind of company wide cooperation is required for a successful mass customization program?

    The three organizational design principles for mass customization are 1) A product should be designed so it consists of independent modules that can be assembled into different forms of the product easily and inexpensively, 2) Manufacturing and service processes should be designed so that they consists of independent modules that can be moved or rearranged easily to support different distribution network designs, 3) The supply network--the positioning of inventory and the location, number, and structure of service, manufacturing, and distribution facilities--should be designed to provide two capabilities. First, it must be able to supply the basic product to the facilities performing the customization in a cost-effective manner. Second, it must have the flexibility and the responsiveness to take individual customer's orders and deliver the finished, customized good quickly.

Problems

Problem	Type of Problem		Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Supply Chain Performance	Value Density				
1		Yes	Moderate			Yes
2	Yes		Easy			
3	Yes		Easy			
4	Yes		Moderate			

1. Shipping cost - U.S. Postal Service - Peoria, IL to Memphis, TN.

Weight (lbs.)	Cost (overnight)	Cost (3 day)	Cost Savings	Break-even	Break-even value per pound
2	$15.00	$2.87	$12.13	$8,854.90	$4,427.45
3	17.25	3.34	13.91	10,154.30	3,384.77
4	19.40	3.78	15.62	11,402.60	2,850.65
5	21.55	4.10	17.45	12,738.50	2,547.70
6	25.40	4.39	21.01	15,337.30	2,556.22
7	26.45	4.67	21.78	15,899.40	2,271.34
8	27.60	4.91	22.69	16,563.70	2,070.46
9	28.65	5.16	23.49	17,147.70	1,905.30

2. Days of raw material on-hand
= (production material on hand in dollars/cost of revenue)*365 days per year.
= (234/14,137) *365 = 6.04 days.
The amount of raw materials at the end of the year will depend on the timing of payment, physical units on had may be higher than this.

3. Inventory turnover = cost of goods sold/average aggregate inventory value
= (4,000 hamburgers * $1 per pound * 1/4 pound per hamburger * 52 week per year)/(350 pounds * $1 per pound)
= 148.5 turns/year

Day of supply = (average aggregate inventory value/cost of goods sold)*365
= ((350 pounds * $1 per pound)/(4,000 hamburgers * $1 per pound * 1/4 pound per hamburger * 52 week per year))*365
= 2.46 days

4.

a. Inventory turnover = costs of good sold/average aggregate inventory value.

Quarter	1	2	3	4	Total
Cost of goods sold	280	295	340	350	1265
Raw material	50	40	55	60	
WIP	100	105	120	150	
Distribution Center Inventory	40	42	43	51	
Aggregate Inventory	190	187	218	261	

Average aggregate inventory value = (190 + 187 + 218 + 261)/4 = 214
Inventory turnover = 1265/214 = 5.91

b. Focus on reducing WIP.

c. Average raw material inventory value = (50 + 40 + 55 + 60)/4 = 51.25
Day of supply = (average aggregate raw material inventory value/cost of goods sold)*52
= (51.25/500)*52 = 5.33

CHAPTER 11
STRATEGIC CAPACITY MANAGEMENT

Review and Discussion Questions

1. What capacity problems were encountered when a new drug was introduced to the market??

   The first two problems are the high capital cost of capacity and the opportunity cost of restricting investments in other facilities. These problems are exacerbated by uncertainty over patent infringement, competitor's response and that there is only a 45% probability of launching the product. If the product is launched it is possible to lose sales because there is not sufficient capacity to meet customer demand. The estimates of demand varied by 600% and if actual sales are at the high end or the low end of the estimates the project will be a financial disaster unless the correct capacity decision is made.

2. List some practical limits to economies of scale; that is, when should a plant stop growing?

   The obvious answer is that a plant should stop growing when its long-run average cost curve hits the inflection point. However, since this determination is often difficult to make (in the short run), other factors such as coordination problems, excess capacity, capacity imbalance, and market shifts indicate a need to consider setting capacity limits.

3. What are some capacity balance problems faced by the following organizations or facilities?

   a. An airline terminal.

   Waiting areas, distances from boarding gates, ground crew requirements, landing strips.

   b. A university computing center.

   Input/output time vs. computer processing time; CPU capacity vs. peripheral storage capacity; high speed, high capacity computer vs. multiple low speed, low capacity computers; computer center consultant's skill vs. customer requirements.

   c. A clothing manufacturer.

   Many manufacturers now use highly decentralized shops to make clothes. This means that capacity of multiple sites must be accounted for in planning production.

4. What are some major capacity considerations in a hospital? How do they differ from those of a factory?

   Some capacity considerations are size and composition of nursing staff (RNs vs. LPNs), balance between operating room and intensive care units, emergency rooms, etc., and, of course, how many beds are to be available. One of the differences in capacity considerations between a hospital and a factory is that a hospital can add capacity rather quickly in the short run, through "simply" adding more staff and more beds. A factory is usually technologically limited, and, therefore, must plan well in advance to add major chunks of capacity. On the other hand, though, the general uncertainty which surrounds the demand for hospital services on any given day is much greater than would be faced by a factory. Additionally, factory management generally has the ability to backlog demand in such a way as to achieve more efficient levels of capacity utilization than does a hospital.

5. Management may choose to build up capacity in anticipation of demand or in response to developing demand. Cite the advantages and disadvantages of both approaches.

   The strategy of building up capacity ahead of demand is a risk-taking stance. Investment is based on projections. This investment involves costs for new facilities, equipment, human resources, and overhead. If the demand materializes, the investment is worthwhile since the firm may capture a large amount of market share. If it does not materialize, the firm must redirect the invested resources. This strategy is most appropriate in high growth areas.

   If the demand materializes, but the capacity planning strategy is risk averse, i.e., building capacity only as demand develops, then most likely market share will be lost. The growth in demand will encourage new entrants, resulting in more competition. The risk averse strategy may be most appropriate for small firms who cannot afford to invest in unproven prospects. To prevent potential loss of market share, firms may choose to incrementally increase capacity to match the increase in demand.

6. What is capacity balance? Why is it hard to achieve? What methods are used to deal with capacity imbalances?

   In a perfectly balanced plant, the output of each stage provides the exact input requirement for the subsequent stage. This continues throughout the entire operation. This condition is difficult to achieve because the best operating levels for each stage generally differ. Variability in product demand and the processes may lead to imbalance, in the short run.

   There are various ways of dealing with capacity imbalances. One is to add capacity to those stages that are the bottlenecks. This can be achieved by temporary measures such as overtime, leasing equipment, or subcontracting. Another approach is to use buffer inventories so that interdependence between two departments can be loosened. A third approach involves duplicating the facilities of one department upon which another is dependent.

7. What are some reasons for a plant to maintain a capacity cushion? How about a negative capacity cushion?

   A plant may choose to maintain a capacity cushion for a number of reasons. If the demand is highly unstable, maintaining cushion capacity will ensure capacity availability at all times. Also, capacity cushions can be useful if high service quality levels are established. Some organizations choose to use capacity cushions as a competitive weapon to create barriers to entry for competitors.

   Negative capacity cushions may be maintained when demand is expected to decrease rapidly and capacity investment is high enough to discourage short run capacity acquisitions.

8. At first glance, the concepts of the focused factory and capacity flexibility may seem to contradict each other. Do they really?

This is not necessarily true. This will depend on the available technology of the facility and on the type of industry it competes in. An FMS plant may, for example, use flexible processes to enlarge the variety of products produced and delivered in a very short time. Therefore, it can choose to compete on fast delivery of customized products rather than on cost.

Problems

Problem	Type of Problem		Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Capacity Analysis	Decision Tree				
1	Yes		Easy			
2	Yes		Easy			
3	Yes		Easy			Yes
4	Yes		Easy			
5		Yes	Moderate			Yes
6		Yes	Moderate			

1.

Plastic	Year 1	Year 2	Year 3	Year 4
Demand for plastic sprinklers	97	115	136	141
Percentage of capacity used	48.5%	57.5%	68.0%	70.5%
Machine requirements	.485	.575	.680	.705
Labor requirements	1.94	2.30	2.72	2.82

Bronze	Year 1	Year 2	Year 3	Year 4
Demand for bronze sprinklers	21	24	29	34
Percentage of capacity used	58.3%	66.7%	80.6%	94.4%
Machine requirements	1.75	2.00	2.42	2.83
Labor requirements	3.50	4.00	4.84	5.66

2. Requirements for plastic remain unchanged.

Bronze	Year 1	Year 2	Year 3	Year 4
Demand for bronze sprinklers	32	36	41	52
Percentage of capacity used	88.9%	100.0%	113.9%	144.4%
Machine requirements	2.67	3	3.42	4.33
Labor requirements	5.33	6	6.84	8.67

It is obvious that not enough capacity is available after year two to meet the increased demand. AlwaysRain will have to consider purchasing additional machines for the bronze operations.

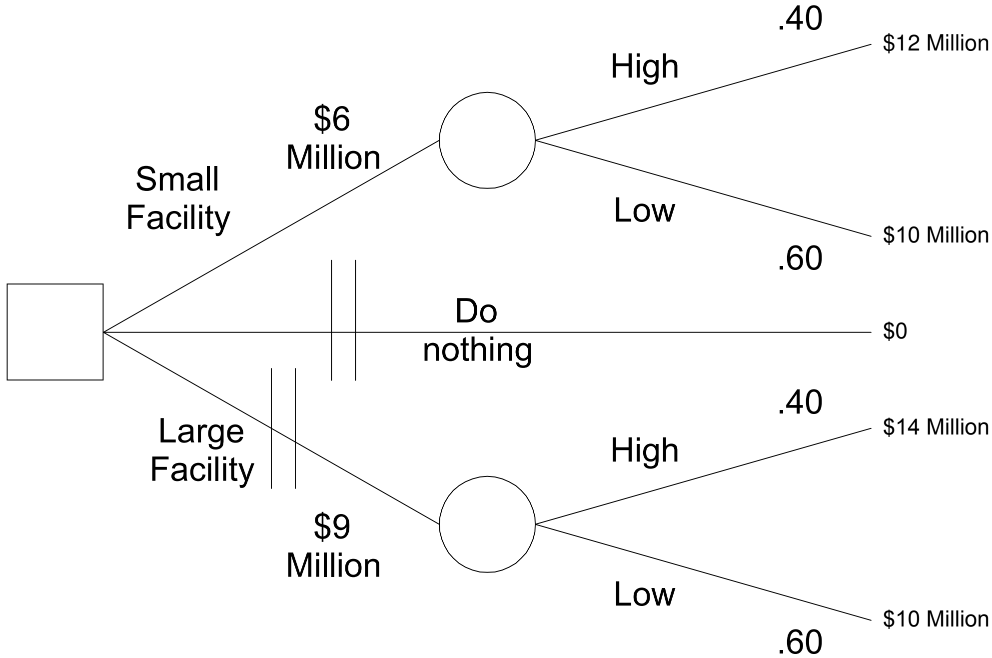
3. No. An additional machine will provide enough capacity cushion until the third year. AlwaysRain must consider additional ways of meeting the fourth year demand. This can include purchasing or leasing an additional machine, or outsourcing some of the demand.

4.

	Year 1	Year 2	Year 3	Year 4
Labor requirements-bronze	5.33	6.00	6.84	8.67
Labor requirements-plastic	1.94	2.30	2.72	2.82
Total labor requirements	7.27	8.30	9.58	11.49

AlwaysRain will face a problem of not having enough trained personnel for running the equipment after the third year. At that time, they will need to either hire new trained employees or initiate a training program for existing employees from other workstations who can be utilized at the bronze or plastic molding machines.

5.



For the small facility,

NPV = .40 ($12 Million) + .60 ($10 Million) - $6 Million = $4.8 Million

Do nothing,

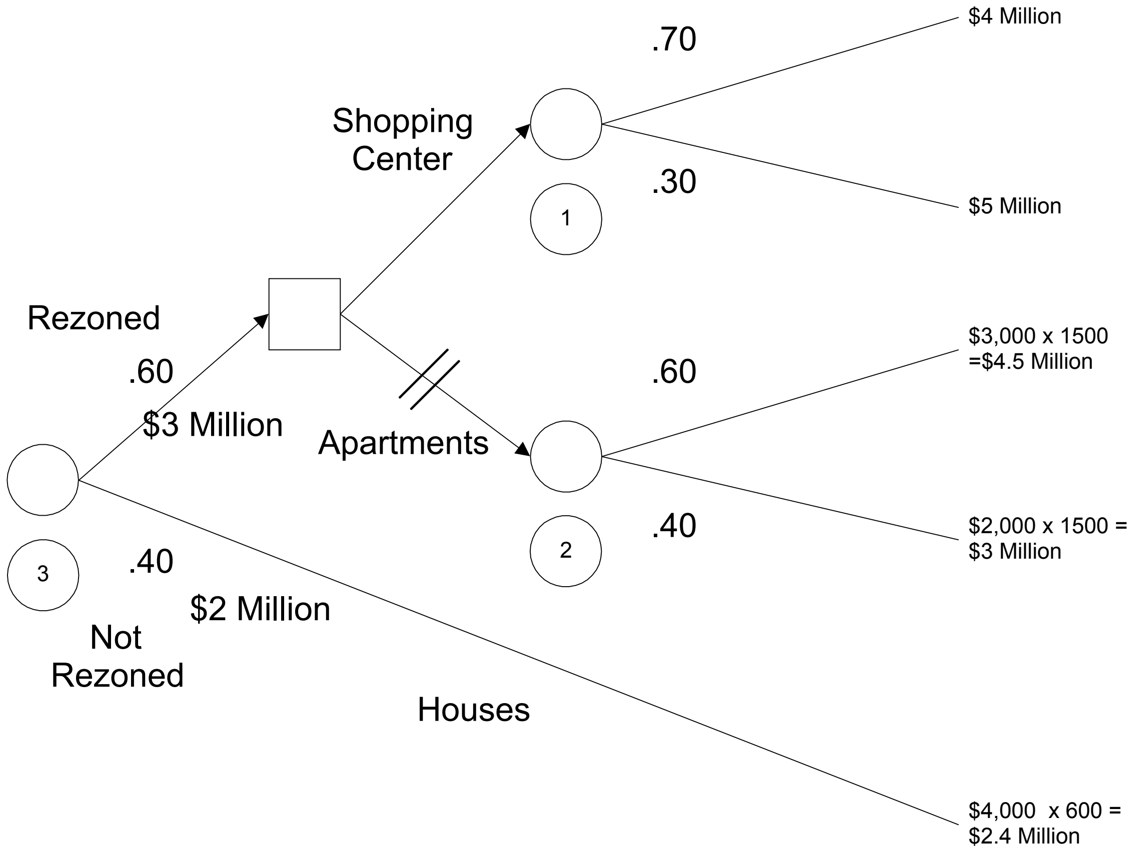
NPV = $0

For the large facility

NPV = .40($14 Million) + .60($10 Million) - $9 Million = $2.6 Million

Therefore, build the small facility.

6.



Rezoned shopping center:

Point 1: Expected value = .70($4 Million) + .30($5 Million) = $4.3 Million

Rezoned apartments:

Point 2: Expected value = .60($4.5 Million) + .40($3 Million) = $3.9 Million

Since a shopping center has more value, prune the apartment choice. In other words, if rezoned, build a shopping center with a profit of $4.3 Million - $3 Million = $1.3 Million

If not rezoned:

Point 3: Expected Profit is $2.4 Million - $2 Million = $.4 Million

Expected profit is .60($1.3 Million) + .40($.4 Million) = $.94 Million

TECHNICAL NOTE 11
FACILITY LOCATION

Review and Discussion Questions

1. What motivations typically cause firms to initiate a facilities location or relocation project?

   There are a variety of reasons; both positive and negative. Firms may wish to move closer to markets or sources of supply. Cost reduction is another major reason. A company might need an educated work force, thereby moving near a major university. On the negative side, firms relocate to avoid costly regulation or unionization. Students should be able to cite a large number of reasons.

2. List five major reasons why a new electronic components manufacturing firm should move into your city or town?

   Answers will vary depending upon the location. Possibilities include quality of education, tax advantages, proximity of supply, proximity of markets, or favorable quality of life.

3. How do facility location decisions differ for service facilities and manufacturing plants?

   In many ways, the decisions are similar. However, since the customer is often involved in the production of the service, proximity to the customer is of greater importance. Services often utilize multiple sites to remain close to the customer. Market needs impact services location decisions. Alternatively, resource considerations have much more impact on manufacturing.

   In addition, the cost of establishing a service facility is relatively low when compared to manufacturing. Manufacturing decisions are often based on cost minimization while service decisions are based on profit maximization.

4. What are the pro and cons of relocating a small or midsized manufacturing firm (that makes mature products) from the United States to Mexico in the post-NAFTA environment?

   According to the product life cycle concept, mature products require more of a cost orientation due to price competition and low product differentiation. As a result in the post-NAFTA environment, firms are evaluating the cost/benefit trade-offs associated with moving to Mexico. Labor costs are much lower in Mexico. Land is relatively cheap and there is less regulation. If the cost of providing health care increases in the United States, as a result of a national health plan, firms could find more reasons to move to Mexico. The cons are a less-educated workforce, and possibly increasing the distance from suppliers and marketplace.

5. If you could locate your new software development company anywhere in the world, which place would you choose, and why?

   Answers will vary depending upon preferences. However, student should provide sound business reasons for their responses.

Problems

Problem	Type of Problem		Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Center of Gravity	Transportation problem				
1	Yes		Moderate			Yes
2	Yes		Moderate			Yes
3		Yes	Moderate			
4		Yes	Moderate			

1.

$d_{1x} = 150$ $d_{1y} = 75$ $V_1 = 8{,}000$

$d_{2x} = 100$ $d_{2y} = 300$ $V_2 = 6{,}200$

$d_{3x} = 275$ $d_{3y} = 380$ $V_3 = 7{,}000$

$C_x = \sum d_{ix}V_i/\sum V_I$

$= ((150)(8{,}000) + (100)(6{,}200) + (275)(7{,}000))/(8{,}000 + 6{,}200 + 7{,}000) = 176.7$

$C_y = \sum d_{iy}V_i/\sum Vi$

$= ((75)(8{,}000) + (300)(6{,}200) + (380)(7{,}000))/(8{,}000 + 6{,}200 + 7{,}000) = 241.5$

2.

$d_{1x} = 300$ $d_{1y} = 320$ $V_1 = 4{,}000$

$d_{2x} = 375$ $d_{2y} = 470$ $V_2 = 6{,}000$

$d_{3x} = 470$ $d_{3y} = 180$ $V_3 = 3{,}000$

$C_x = \sum d_{ix}V_i/\sum V_i$

$= ((300)(4{,}000) + (375)(6{,}000) + (470)(3{,}000))/(4{,}000 + 6{,}000 + 3{,}000) = 374$

$C_y = \sum d_{iy}V_i/\sum Vi$

$= ((320)(4{,}000) + (470)(6{,}000) + (180)(3{,}000))/(4{,}000 + 6{,}000 + 3{,}000) = 357$

3.

a.

From/To	New York	Fort Worth	San Diego	Minneapolis	Supply
Boulder	7	11	8	13	100,000
Macon	20	17	12	10	100,000
Gary	8	18	13	16	150,000
Requirements	50,000	70,000	60,000	80,000	

b.

From/To	New York	Fort Worth	San Diego	Minneapolis	Factory Supply
Boulder	7	11	8	13	100,000
Macon	20	17	12	10	100,000
Gary	8	18	13	16	150,000
Requirements	50,000	70,000	60,000	80,000	350,000

Candidate Solution					Total Shipped
Boulder	-	-	-	10,000	10,000
Macon	50,000	50,000	-	-	100,000
Gary	-	20,000	60,000	70,000	150,000
Total Supplied	50,000	70,000	60,000	80,000	260,000

Profit					
Boulder	-	-	-	130,000	
Macon	1,000,000	850,000	-	-	
Gary	-	360,000	780,000	1,120,000	
Total Profit				Total Cost	$ 4,240,000

Total profit = $4,240,000. Note that alternate optimal solutions exist.
Production should be:

Boulder	10,000 units
Macon	100,000 units
Gary	150,000 units

4.

a. This is the optimal solution, with a total cost of $720.

From/To	D	E	F	G	Supply
A	9	8	6	5	50
B	9	8	8	0	40
C	5	3	3	10	75
Requirements	50	60	25	30	165

Candidate Solution					
A	25	0	25	0	50
B	10	0	0	30	40
C	15	60	0	0	75
Total Shipped	50	60	25	30	165

Cost					
A	225	0	150	0	
B	90	0	0	0	
C	75	180	0	0	
Total Costs					$720

b. Place a sufficiently small cost into the A to D cell to force a shipment from A to D.

CHAPTER 12
LEAN PRODUCTION

Review and Discussion Questions

1. What lean principles are being used by Arvin Meritor, Inc. (see the box on pages 482 and 483)? Use the categories from Exhibit 12.8 to develop your answer.

   Arvin Meritor, Inc. uses a variety of lean techniques including teams, continuous improvement, visual communications on the shop floor to control the flow of materials, pull system using kanban signals and production leveling, quick changeover, flexibility, small lot production, and quality at the source.

2. Is it possible to achieve zero inventories? Why or why not?

   In reality, zero inventories are a challenging, if not impossible, goal for most organizations. The concept is theoretical because the ideal production unit is one. Nothing is made until the customer expresses an unmet need for the product. In reality, inventories will always exist due to the timing between the expressed need and the actual delivery of the completed unit(s). Nevertheless, this goal aids in understanding of the lean concepts, and remains a reference point to continually remember in the on-going improvement process.

3. Stopping waste is a vital part of lean. Identify some sources of waste in your home or dorm and discuss how they may be eliminated.

   Waste can include work in process, raw materials, and finished goods that are not being directly worked on or being shipped to the customer. Any processes or procedures not needed to complete the product or deliver the service are wastes. Material sitting in stores and queues are also sources of waste as is excess or inefficiencies. Through applications of lean principles of streamlining flows and only performing work as it is needed, these wastes can be reduced and possibly eliminated.

   Answers will vary to this question, but some obvious choices can be found in the refrigerator, with bills waiting to be paid, and, of course, laundry. For example, if laundry were done in small lots on a regular basis, fewer clothes would be needed. Of course, many people might not consider this an improvement.

4. Discuss lean in a job-shop layout and in a line layout.

   Lean can be applied in a variety of organizational process flows. While pure lean applications are often thought of as a line improvement, lean can work in services or in job shops. In a job shop, any repetitive work can be organized and arranged as a line flow. This visibility of the process allows application of lean.

5. Why must lean have a stable schedule?

   Because any changes in the final product schedule are magnified backward along the line, a stable schedule is necessary. This schedule must be frozen at some point. Also, because suppliers and vendors are delivering in small batches just as materials are needed, they need accurate information about the build schedule so they can plan their corresponding deliveries.

6. Will lean work in service environments? Why or why not?

   Lean is already achieving successes in a number of service environments. As services identify their components that resemble an assembly line and are repetitive in nature, the concepts will work. Also, the philosophy of reducing waste and streamlining flows to eliminate waste can work in any setting.

7. Discuss ways to use lean to improve one of the following: a pizza restaurant, a hospital, or an auto dealership.

   Any number of answers would be correct. For example, in a pizza restaurant, streamlining the pizza preparation and baking operations would speed the product to the customer. Fast and efficient customer ordering and payment would allow the system to process more customers. Possibly letting customers refill their own drinks or serve themselves would speed processing. In a hospital or automobile dealership, procedures can be streamlined and altered to serve the customer.

8. Which objections might a marketing manager have against uniform plant loading?

   Uniform plant loading might upset a marketing manager who is planning a special promotional campaign for a specific product. If production did not make enough of the units during the promotional period, backorders or lost sales might result. Also because some products have different life cycles and sales patterns, this smoothing might hinder the marketing activities.

9. What are the implications for cost accounting of lean production?

   Cost accounting can benefit lean analysis, but outdated measures tied to labor rates and productivity no longer apply. Overhead is the key variable to measure under lean. Labor is only a small part of the entire production dollar. Also labor and machinery may be idle under lean because goods are only produced as needed. Labor and machinery variances may not reflect the lean philosophy.

10. What are the roles of suppliers and customers in a lean system?

    Lean involves customers and suppliers as an integral part of the process. Customers provide product enhancement, modification, and usage data. Suppliers work with the manufacturing organization to coordinate delivery and raw material or other input production. Both groups may sit on lean teams and participate in improvement activities, as all groups will benefit from changes.

11. Explain how cards are used in a Kanban system.

    Cards in a kanban system represent a visual work order. As material is moved from the line to the customer, the last operator in the process goes to the next workstation up the line and pulls a bin of work for further processing. This employee removes a card from the bin and leaves it at the previous station. This card represents a work order for this station to make or process more products. This sequence continues in a backward fashion through the line and back to the suppliers.

12. In which ways, if any, are the following systems analogous to Kanban: returning empty bottles to the supermarket and picking up filled one; running a hot dog stand at lunchtime; withdrawing money from a checking account; raking leaves into bags?

    All the systems represent work orders when the empty containers are returned. The empty bottles at the supermarket will be picked up by the soda bottler and represent a need to clean and refill the bottles and return them to customers. A hot dog stand at lunchtime has hungry customers as work orders to process. The customers in line represent needs for the hot dogs. Withdrawing money from a checking account serves as a receipt and also a tickler to the individual to deposit more money in the account at the next pay period. Raking leaves into bags is also a kanban. Once a bag is filled, the individual pulls an empty bag from the box and continues to fill bags until the yard is free of leaves or no empty bags remain.

13. Why is lean so hard to implement in practice?

    A key implementation difficulty is the lack of emphasis on lean on an on-going basis. The lean improvements are slow, take time, and are never ending. Initial enthusiasm may wane over time. Other problems in implementation include poor supplier quality, a lack of employee commitment, and problems in reducing machine set up times.

14. Explain the relationship between quality and productivity under the lean philosophy.

    Under JIT, quality and productivity are key and equal partners. As quality improves, so does productivity, as only good units are assembled. No work is wasted on preparing inferior quality items. Both are necessary in the lean philosophy.

15. Why would a JIT advocate have a problem with the system proposed for the BMW AG's U. S. Factory (discussed in the box BMW moves beyond just-in-time production)?

    Most of the system characteristics are in line with lean or JIT production. The obvious area of disagreement is using the vehicle stacking center to solve scheduling problems. In some respects, it is a monument to inventory.

Problems

Problem	Type of Problem: Kanban Card Sets	Type of Problem: Value Stream Mapping	Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
1	Yes		Easy			Yes
2	Yes		Easy			
3	Yes		Easy	Yes		
4	Yes		Easy	Yes		
5	Yes		Easy	Yes		
6		Yes	Moderate	Yes		

1.

D = 10 gauges per hour
L = 2 hours
S = .20
C = 5 gauges
K = DL(1+S)/C
K = 10(2)(1+0.20) / 5 = 4.8 $\Rightarrow$ 5 Kanban card sets

2.

D = 4 transmissions per hour
L = 1 hour
S = .50
C = 4 transmissions
K = DL(1+S)/C
K = 4(1)(1+0.50) / 4 = 1.50 $\Rightarrow$ 2 Kanban card sets

3.

D = 2,400 bottles/2 hours = 1200/60 minutes = 20 per minute
L = 40 minutes
S = .10
C = 120 bottles
K = DL(1+S)/C
K = 2(40)(1+0.10) / 120 = 7.33 $\Rightarrow$ 8 Kanban cards

4.

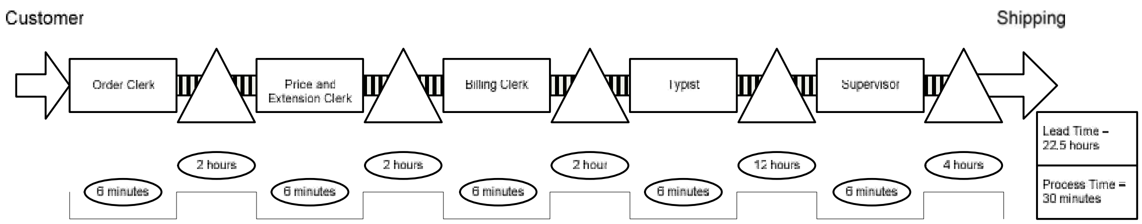
D = 16 catalytic converters per hour
L = 2 hours
S =.125
C = 10 catalytic converters
K = DL(1+S)/C
K = 16(2)(1+0.125) / 10 = 3.6 $\Rightarrow$ 4 Kanban cards

5.

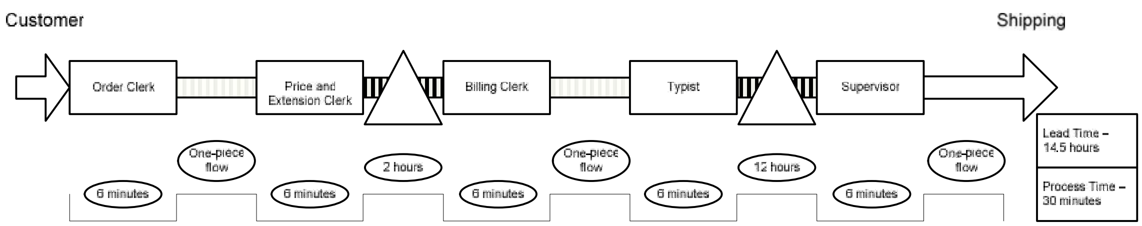
D = 32 catalytic converters per hour
L = 1 hour
S =.125
C = 8 catalytic converters
K = DL(1+S)/C
K = 32(1)(1+0.125) / 8 = 4.5 $\Rightarrow$ 5 Kanban cards

6. Cyprus Citrus Cooperative

a. Lead Time is 22.5 hours and Process Time is 30 minutes



b. There are many alternatives. This solution combines the first and second workstation together and the third and fourth work stations together and moves to a one piece flow. It also would go to a one piece flow from the supervisor to shipping. It still leaves a 12 hour buffer in front of the supervisor. Further efforts could be put towards eliminating that large amount of non-value added time. The new system shown below has a lead time of 14.5 hours with a process time of 30 minutes.



CHAPTER 13
FORECASTING

Review and Discussion Questions

1. What is the difference between dependent and independent demand?

   Independent demand is forecasted item demand that occurs separately from the demand for other items. Dependent demand is calculated from the demand for another item. The difference lies in the way the two demands are determined.

2. Examine Exhibit 13.4 and suggest which model you might use for (1) bathing suit demand, (2) demand for new houses, (3) electrical power usage, (4) new plant expansion plans.

   While any of the models in Exhibit 13.4 can potentially be used to forecast any of the items, the following models are generally appropriate: (1) Bathing suit demand could be forecasted using exponential smoothing. The time horizon is short, model complexity and cost is low, model accuracy is fair and data requirements are very low. (2) Demand for new houses can be forecasted using linear regression. The time horizons are long, model complexity is medium high, model accuracy is medium high and data requirements are high. (3) Causal regression models might be used to forecast electrical power usage. The time horizon is long, model complexity is fairly high, model accuracy is high and data requirements are high. (4) New plant expansion plans can be forecast using qualitative forecasting techniques. This takes into account nonquantifible issues when planning plant expansion.

3. What is the logic in the least squares method of linear regression analysis?

   The least squares method fits a line to the data which minimizes the sum of the squared error between particular points on a regression line and actually observed data lying in the same X plane. If a central point (X-bar, Y-bar) is located in a scatter plot, an infinitely large number of regression lines could be found to represent the data equally well in terms of absolute error. However, there is only one, unique regression line that minimizes the sum of the square errors.

4. Explain the procedure to create a forecast using the decomposition method of least squares regression.

   The steps are as follows:

   I. Decompose the time series into the components.

      a. Find the seasonal component.

      b. Deseasonalize the demand.

      c. Find the trend component

   II. Forecast future values of each component.

      a. Project trend components into the future.

      b. Multiply trend component by seasonal component.

5. Give some very simple rules you might use to manage demand for a firm's product. (An example is "limited to stock on hand.")

   Demand management can be in terms of: order control—"limited to stock on hand," lead time—"allow six weeks for delivery," need—"supply the parts to inoperative units first," time open—"close up early every day," or "closed on Saturdays," plus others as mentioned in the text such as price cuts, incentives, promotions, etc.

6. What strategies are used by supermarkets, airlines, hospitals, banks, and cereal manufacturers to influence demand?

   Supermarkets—several sales items, free giveaway items (such as a pound of butter or a loaf of bread), an occasional "midnight madness" sale where the store is open late or even all night.

   Airlines—excursion rates, age rates (senior citizens, children, youth fares), charter flights, off-season rates, exceptionally good meals (or no meals for further reduced prices), more flights, tie-in with hotels or auto rental, and tour agencies for "package tours," free champagne, free stop-over at a third point, or new terminals.

   Hospitals—patients generally go to the hospital recommended by their physician. Therefore, hospitals offer free office space, nursing assistance, lab equipment, staff positions, and patient billing to physicians. Hospitals frequently advertise their occupancy rate and room rates, which tend to influence demand. Also, they could become a preferred provider organization.

   Banks—free gifts for new accounts, free checking, free safety deposit box, free financial advice, "club memberships," and free use of "executive lounges" for depositors in various size account ranges, community rooms for club meetings.

   Cereal manufacturers—TV advertising, sponsorship of some youth events, free prizes in cereal boxed, using prime display space.

7. All forecasting methods using exponential smoothing, adaptive smoothing, and exponential smoothing including trend require starting values to get the equations going. How would you select the starting value for, say F_{t-1}?

   Starting values can be simply an average of the early periods, or a guess. If the starting value is taken some period back (as opposed to starting to use the equations on very recent data) the equation will have a chance to adjust as it is carried forward to today.

8. From the choice of simple moving average, weighted moving average, exponential smoothing, and linear regression analysis, which forecasting technique would you consider the most accurate? Why?

   Of these four choices, the weighted moving average is the most accurate, since specific weights can be placed in accordance with their importance. The other methods make assumptions, such as an average, straight line, or exponential curve. The weighted average may be modified to any form. If a long time span is taken, however, the weighted average can be cumbersome to use. In addition, as time periods pass, the user most likely would like to change the weights. This would add to the difficulty of using the techniques for a large number of applications such as forecasting demand for inventory items.

9. Give some examples that you can think of that have a multiplicative seasonal trend.

   Multiplicative effects are the most common. Essentially all business sales are multiplicative. For example, in auto sales, as growth in total sales increases, the seasonal variation increases.

10. What is the main disadvantage of daily forecasting using regression analysis?

    The main disadvantage is the mathematical computation. There is very little time involved for a computerized analysis, but hand computation is time consuming and prone to error.

11. What are the main problems with using adaptive exponential smoothing in forecasting?

    Adaptive smoothing is computationally difficult; it requires solving a set of equations in sequence. The user must select two constants for the equations; one is adjusted by the equations, but the other is not. It is not clear as to what the value should be. Lastly, there is some challenge to the value of adaptive smoothing when compared to other methods.

12. How is a seasonal index computed from a regression line analysis?

    Seasonal index is equal to the actual value (data point) divided by the value computed from the regression line. To lessen the effects of random errors, the indices may be averaged over several years for that same period.

13. Discuss the basic differences between the mean absolute deviation and standard deviation.

    The standard deviation is a statistically based measurement defined as the square root of the arithmetic mean of the squared deviations from the mean of the data or

$$\sigma = \sqrt{\frac{(x_i - \bar{x})^2}{n}} \text{ .}$$

The mean absolute deviation, or MAD, is easier to do computationally since it is obtained simply by calculating the absolute difference of each value from some other quantity, and then averaging the differences by taking the arithmetic mean. If the interest is the mean absolute deviation from the arithmetic mean of the data, then

$$MAD = \frac{\sum_{i=1}^{n} \left| x_i - \bar{x} \right|}{n}.$$

In this chapter, the interest was in the mean absolute difference between actual outcomes versus forecasted outcomes, or

$$MAD = \frac{\sum_{i=1}^{n} \left| A_i - F_i \right|}{n}.$$

One MAD is approximately equal to .8σ, or conversely, 1σ is approximately equal to 1.25 MAD.

14. What implications do forecast errors have for the search for ultrasophisticated statistical forecasting models?

    The existence of unavoidable forecast errors seems to suggest that no matter what kind of model one uses—simple or sophisticated—a perfect forecast is unattainable. Since forecasts are predictions of the future based on present and past data, there is ample opportunity for very serious forecast errors to be caused by changes in the conditions that generated the data. This could lead to an invalid forecast or at least one that contains added error. Therefore, one could be easily persuaded to stop searching for ways to make more accurate forecasts and look instead for ways to quickly respond and adapt to demand changes.

15. What are the strongest selling points of focused forecasting?

    Focused forecasting is simple, easy to understand, easy to use, and experience has shown it also gives good results.

16. Causal relationships are potentially useful for which component of a time series?

    A time series creates an equation, such as y = a + bx, where a is the y-intercept. Therefore, if there is a relationship between y and x, it would show up as the slope b. If there is no relationship, b would be zero. There is some question as to the relationship being truly "causal," since many relationships may depend on other factors outside of the analysis.

Problems

Problem	Type of Problem							Difficulty	New Prob-lem	Modified Problem	Check figure in Appendix A
	Moving average	Exponen-tial smooth-ing	Exponential smoothing with trend	Linear regression	Tracking signal	Focus Fore-casting	Decom-position				
1				Yes				Moderate			
2	Yes			Yes				Moderate			
3		Yes						Easy			Yes
4							Yes	Difficult			
5							Yes	Difficult			
6					Yes			Moderate			
7							Yes	Difficult			Yes
8							Yes	Difficult			
9	Yes	Yes						Easy			
10						Yes		Moderate			
11	Yes	Yes						Easy			Yes
12					Yes			Moderate			
13					Yes			Moderate			
14		Yes	Yes					Easy			
15					Yes			Moderate			Yes
16	Yes	Yes						Easy			
17	Yes	Yes		Yes				Easy			
18						Yes		Moderate			
19					Yes			Moderate			Yes
20	Yes	Yes	Yes					Moderate			
21							Yes	Difficult			
22						Yes		Moderate			
23	Yes	Yes						Easy			
24					Yes			Moderate			
25							Yes	Difficult			
26				Yes				Moderate			
27				Yes				Moderate	Yes		
27			Yes					Difficult	Yes		

1.

x	Y	xy	x^2	y^2	Y	$(y-Y)^2$
1	4200	4200	1	17640000	3958.97	58093.360
2	4300	8600	4	18490000	4151.28	22117.028
3	4000	12000	9	16000000	4343.59	118053.912
4	4400	17600	16	19360000	4535.90	18468.113
5	5000	25000	25	25000000	4728.21	73872.452
6	4700	28200	36	22090000	4920.51	48625.904
7	5300	37100	49	28090000	5112.82	35036.160
8	4900	39200	64	24010000	5305.13	164128.863
9	5400	48600	81	29160000	5497.44	9493.754
10	5700	57000	100	32490000	5689.74	105.194
11	6300	69300	121	39690000	5882.05	174681.131
12	6000	72000	144	36000000	6074.36	5529.257
Total 78	60200	418800	650	308020000		728205.128

$\bar{x} =$ 6.5

$\bar{y} =$ 5016.667

$$b = \frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2} = 192.3077$$

$$a = \bar{y} - b\bar{x} = 3766.667$$

LINEST (Microsoft Excel function) will produce the same results.

Month	Forecast
13	6266.67
14	6458.97
15	6651.28
16	6843.59
17	7035.90
18	7228.21
19	7420.51
20	7612.82
21	7805.13
22	7997.43
23	8189.74
24	8382.05

b. $$S_{xy} = \sqrt{\frac{\sum_{i=1}^{n}(y_i - Y_i)^2}{n-2}} = \sqrt{\frac{728205.128}{12-2}} = 269.85$$

Therefore, 3 standard errors of the estimate would be 3(269.85) = 809.55 or 810

2.

a. $F_{July} = .60(15) + .30(16) + .10(12) = 15.0$

b. $F_{July} = (15 + 16 + 12) / 3 = 14.3$

c. $F_{July} = F_{June} + \alpha(A_{June} - F_{June}) = 13 + .2(15\text{-}13) = 13.4$

d.

	x	y	xy	x^2
	1	12	12	1
	2	11	22	4
	3	15	45	9
	4	12	48	16
	5	16	80	25
	6	15	90	36
Total	21	81	297	91

$\bar{x}$ =	3.5
$\bar{y}$ =	13.5
b = $\dfrac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2}$ =	0.77
a = $\bar{y} - b\bar{x}$ =	10.8

Y = a + bx = 10.8 + .77x

e. F_{July}, where July is the 7th month.

Y = a + bx = 10.8 + .77(7) = 16.2

3.

a. $F_{t+1} = F_t + \alpha(A_t - F_t)$, $\alpha = .20$

Month	Demand	Forecast	Absolute Deviation
January	100	80	20
February	94	84	10
March	106	86	20
April	80	90	10
May	68	88	20
June	94	84	10
Total			90

b. MAD = 90/6 = 15

4.

	x	y	Average from same quarter	Seasonal factor	Deseasonalized demand	x^2	x*deseasonalized demand
	1	4800	3833.33	1.23	3902.61	1	3902.61
	2	3500	2766.67	0.89	3942.77	4	7885.54
	3	4300	3500.00	1.12	3829.05	9	11487.14
	4	3000	2366.67	0.76	3950.70	16	15802.82
	5	3500		1.23	2845.65	25	14228.26
	6	2700		0.89	3041.57	36	18249.40
	7	3500		1.12	3116.67	49	21816.67
	8	2400		0.76	3160.56	64	25284.51
	9	3200		1.23	2601.74	81	23415.65
	10	2100		0.89	2365.66	100	23656.63
	11	2700		1.12	2404.29	121	26447.14
	12	1700		0.76	2238.73	144	26864.79
Total	78	37400			37400.00	650	219041.20

$\bar{y}$ = 3116.67

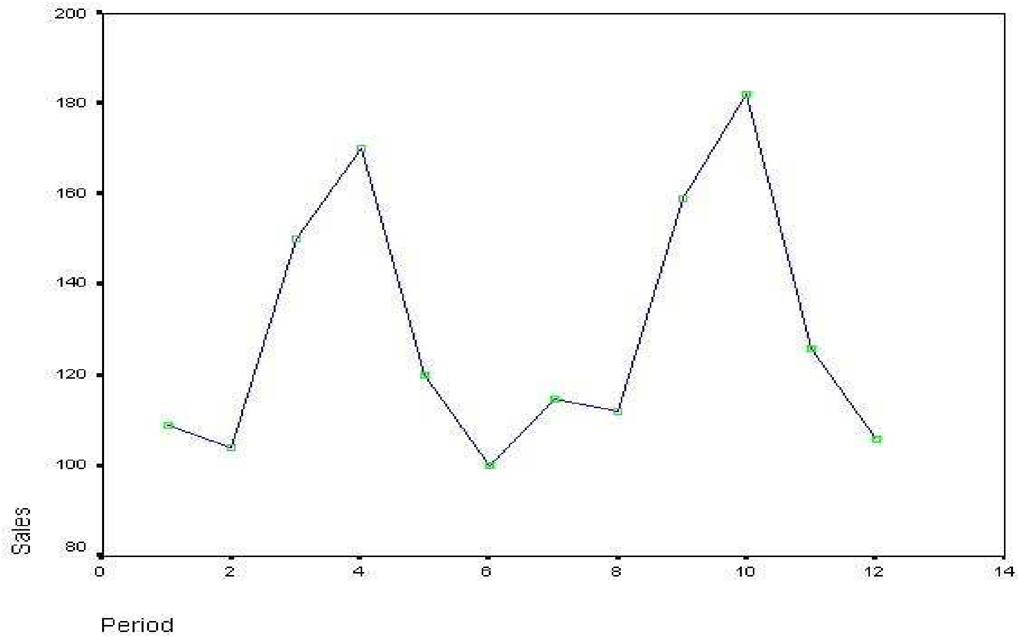
$\bar{x}$ = 6.5

$$b = \frac{\sum xy_d - n\bar{x}\bar{y}_d}{\sum x^2 - n\bar{x}^2} = -168.24$$

$$a = \bar{y}_d - b\bar{x} = 4210.25$$

Period (x)	Y_d	Seasonal factor	Forecast (Y_d*seasonal factor)
13	2023.08	1.23	2488.28
14	1854.84	0.89	1646.54
15	1686.60	1.12	1894.04
16	1518.35	0.76	1152.97

5.



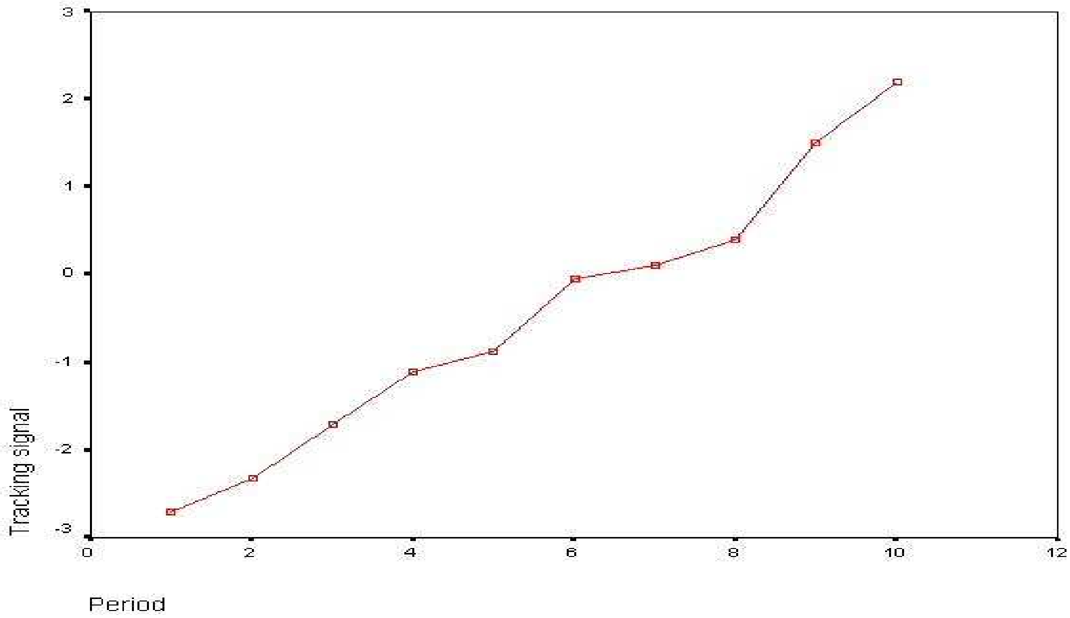
b - d.

	x	y	Average from same bi-monthly period	Seasonal factor	Deseasonalized demand	x^2	X*y	x*deseasonalized demand
	1	109	112.0	0.865	125.95	1	109	125.95
	2	104	108.0	0.835	124.62	4	208	249.25
	3	150	154.5	1.194	125.65	9	450	376.94
	4	170	176.0	1.360	125.00	16	680	500.02
	5	120	123.0	0.950	126.26	25	600	631.30
	6	100	103.0	0.796	125.65	36	600	753.88
	7	115		0.865	132.88	49	805	930.18
	8	112		0.835	134.21	64	896	1073.68
	9	159		1.194	133.19	81	1431	1198.68
	10	182		1.360	133.83	100	1820	1338.29
	11	126		0.950	132.57	121	1386	1458.31
	12	106		0.796	133.19	144	1272	1598.23
Total	78	1553			1553.00	650	10257	10234.70

Deseaonalized		Simple
$\bar{y}$ =	129.4167	
$\bar{x}$ =	6.5	
$b=\dfrac{\sum xy_d - n\bar{x}\bar{y}_d}{\sum x^2 - n\bar{x}^2}$ =	0.9804	1.136364
$a = \bar{y}_d - b\bar{x}$ =	123.04	122.0303

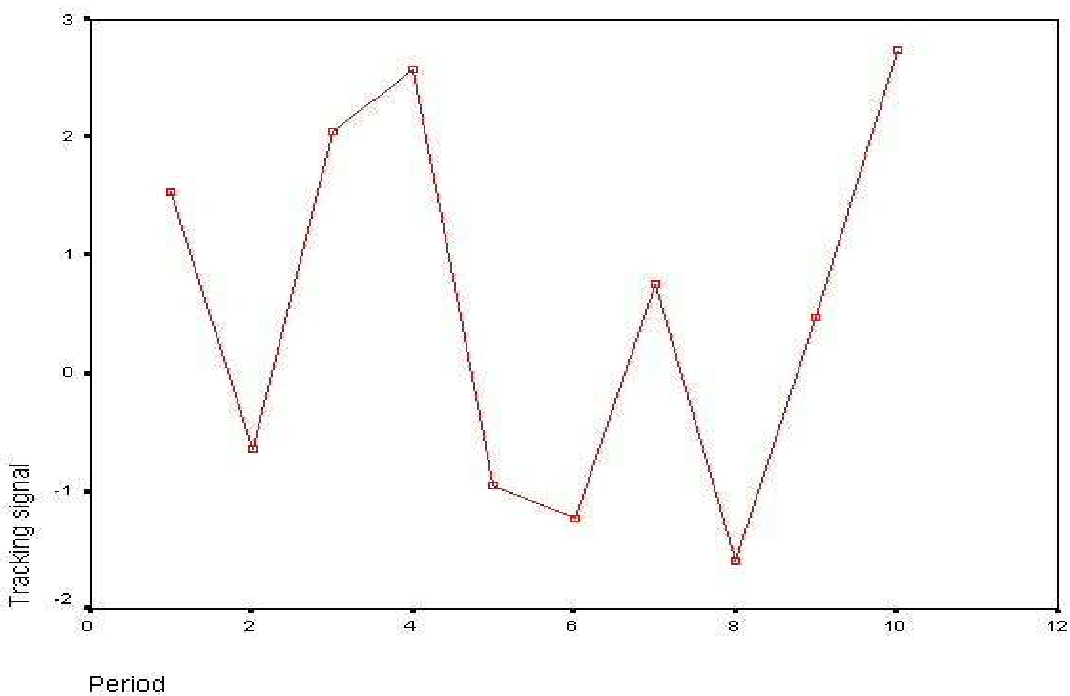
Period (x)	Simple Forecast	Y_d	Seasonal factor	Forecast (Y_d*seasonal factor)
13	136.80	135.79	0.865	117.5
14	137.94	136.77	0.835	114.1
15	139.08	137.75	1.194	164.4
16	140.21	138.73	1.360	188.7
17	141.35	139.71	0.950	132.8
18	142.48	140.69	0.796	112.0

6. TS 1



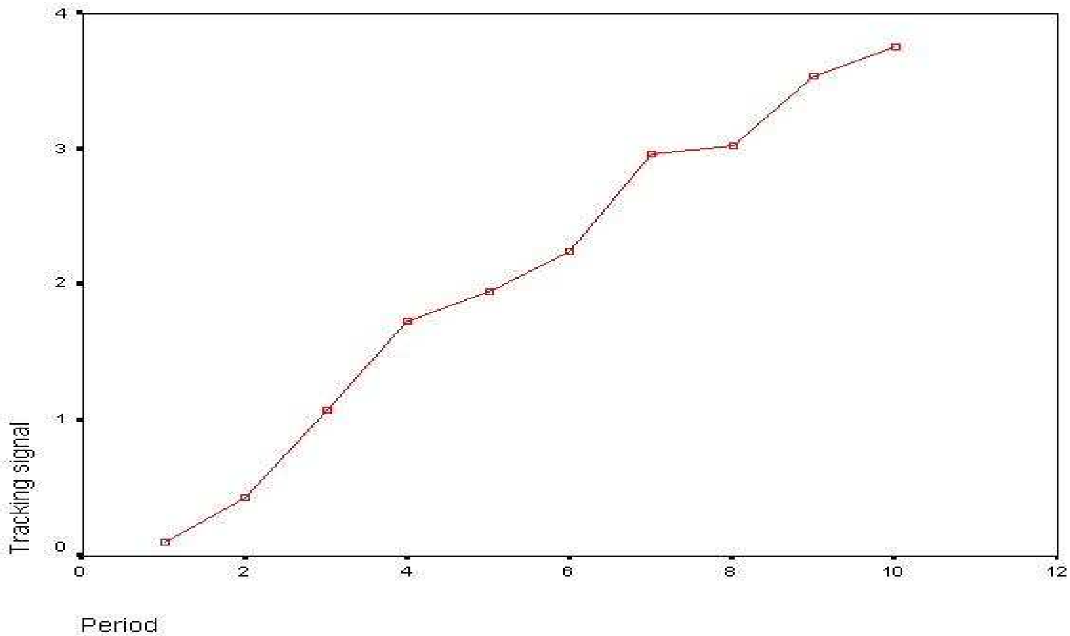
TS 1: Since there has been a rapid rise in the trend, the forecast will shortly be outside of the limits. Therefore, the forecasting model is poor.

TS 2



TS 2: This is within the limits. Therefore, the forecast is acceptable.

TS 3



TS 3: This series is rising rapidly, and is outside of the limits. Consequently, the model is poor.

7.

	x	y	Average from same quarterly period	Seasonal factor	Deseasonalized demand	x^2	x*deseasonalized demand
	1	160	187.5	1.003	159.47	1	159.47
	2	195	217.5	1.164	167.54	4	335.09
	3	150	177.5	0.950	157.92	9	473.77
	4	140	165.0	0.883	158.56	16	634.24
	5	215		1.003	214.28	25	1071.42
	6	240		1.164	206.21	36	1237.24
	7	205		0.950	215.83	49	1510.79
	8	190		0.883	215.18	64	1721.52
Total	36	1495			1495.00	204	7143.53

$\bar{y}$ = 186.875

$\bar{x}$ = 4.5

$$b = \frac{\sum xy_d - n\bar{x}\bar{y}_d}{\sum x^2 - n\bar{x}^2} = 9.91$$

$$a = \bar{y}_d - b\bar{x} = 142.30$$

Period	Y_d	Seasonal factor	Forecast
9	231.45	1.003	232
10	241.35	1.164	281
11	251.26	0.950	239
12	261.17	0.883	231

8. Two methods can be used to calculate the forecasts for the next four quarters. The first fits a line (the problem suggests hand fitting, but OLS regression was used here) to the data and then determining the seasonal factor. The second uses decomposition where regression is performed on deseasonalized data.

First procedure:

	x	y	Trend	Actual/ Trend	Seasonal factor	x^2	x*y
	1	12	16.17	0.742	0.766	1	12
	2	18	17.19	1.047	1.087	4	36
	3	26	18.21	1.427	1.341	9	78
	4	16	19.24	0.832	0.802	16	64
	5	16	20.26	0.790		25	80
	6	24	21.29	1.128		36	144
	7	28	22.31	1.255		49	196
	8	18	23.33	0.771		64	144
Total	36	158				204	754

$\bar{y}$ = 19.75

$\bar{x}$ = 4.5

b = $\frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2}$ = 1.02

a = $\bar{y} - b\bar{x}$ = 15.14

Period	Y	Seasonal factor	Forecast
9	24.36	0.766	18.66
10	25.38	1.087	27.60
11	26.40	1.341	35.42
12	27.43	0.802	21.99

Second procedure:

	x	y	Average from same quarterly period	Seasonal factor	Deseasonalized demand	x^2	x*deseasonalized demand
	1	12	14	0.71	16.93	1	16.93
	2	18	21	1.06	16.93	4	33.86
	3	26	27	1.37	19.02	9	57.06
	4	16	17	0.86	18.59	16	74.35
	5	16		0.71	22.57	25	112.86
	6	24		1.06	22.57	36	135.43
	7	28		1.37	20.48	49	143.37
	8	18		0.86	20.91	64	167.29
Total	36	158			158.00	204	741.14

$\bar{y}$ = 19.75

$\bar{x}$ = 4.5

b = $\dfrac{\sum xy_d - n\bar{x}\bar{y}_d}{\sum x^2 - n\bar{x}^2}$ = 0.718

a = $\bar{y}_d - b\bar{x}$ = 16.520

Period	Y_d	Seasonal factor	Forecast
9	22.98	0.71	16.29
10	23.70	1.06	25.20
11	24.42	1.37	33.38
12	25.13	0.86	21.63

9. a. $F_5 = (700 + 600 + 400)/3 = 567$

b. $F_4 = F_3 + \alpha(A_3 - F_3) = 350 + .20(600 - 350) = 400$

$F_5 = F_4 + \alpha(A_4 - F_4) = 400 + .20(700 - 400) = 460$

10.

	Quarter			
	I	II	III	IV
Last year	360	560	420	675
This year	395	580		

Each strategy is used to predict the second quarter of this year. Then, the best one is used to predict the third quarter of this year.

Strategy A: Whatever we sold in the past three months is what we will probably sell in the next three months. Therefore, our forecast is 395. Actual was 580. 395/580 = 68%.

Strategy B: What we sold in the same three-month period last year, we will probably sell in that three-month period this year. Therefore, our forecast is 560. Actual was 580. 560/580 = 97%

Strategy C: We will probably sell 10 percent more in the next three months than we sold in the past three months. Our forecast is 1.10(395) = 434.5. Actual was 580. 434.5/580 = 75%.

Strategy D: We will probably sell 50 percent more over the next three months than we did for the same three months of last year. The forecast would be 1.50(560) = 840. Actual was 580. 840/580 = 145%.

Strategy E: Whatever percentage change we had for the past three months this year compared to the same three months last year will probably be the same percentage change that we will have for the next three months of this year. The forecast would be (395/360)560 = 614.4. Actual was 580. 614.4/580 = 106%.

The best method was B. Applying it to third quarter of this year results in a forecast of 420.

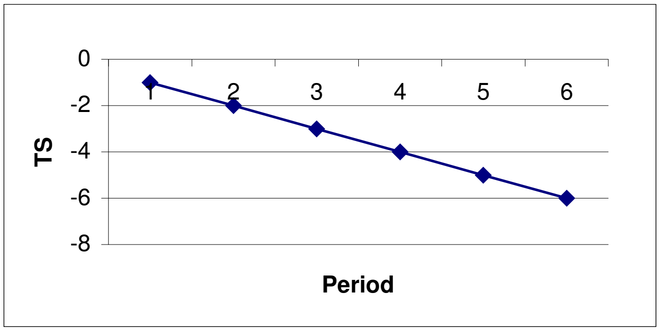
11. a-c. For the exponential smoothing forecast we need a beginning forecast for March and an α. For the beginning forecast use the average of the first three periods and select α = .30. Other choices will produce different answers.

Month	Demand	3-Mo. MA	Absolute Deviation	Exponential Smoothing	Absolute Deviation
January	110				
February	130				
March	150			130.00	
April	170	130	40	136.00	34.00
May	160	150	10	146.20	13.80
June	180	160	20	150.34	29.66
July	140	170	30	159.24	19.24
August	130	160	30	153.47	23.47
September	140	150	10	146.43	6.43
MAD			23.3		21.1

Based upon MAD, the exponential smoothing model appears to be the best.

12.

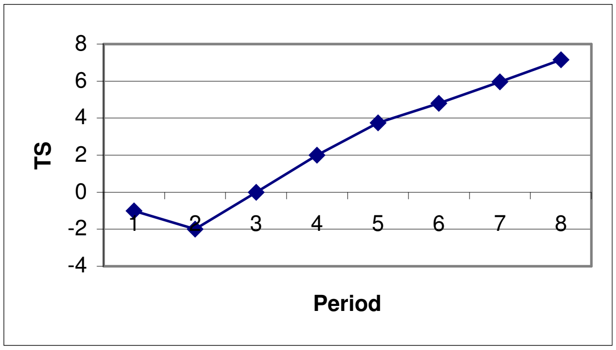
Month	Forecast	Actual	Deviation	RSFE	Absolute deviation	Sum of absolute deviations	MAD	TS
April	250	200	-50	-50	50	50	50.0	-1
May	325	250	-75	-125	75	125	62.5	-2
June	400	325	-75	-200	75	200	66.7	-3
July	350	300	-50	-250	50	250	62.5	-4
August	375	325	-50	-300	50	300	60.0	-5
September	450	400	-50	-350	50	350	58.3	-6



For September, the MAD is 58.3 and the TS is –6. The model is performing poorly since the tracking signal is –6 and moving in a downward direction.

13.

Month	Forecast	Actual	Deviation	RSFE	Absolute deviation	Sum of Absolute deviations	MAD	TS
1	140	137	-3	-3	3	3	3.00	-1.00
2	140	133	-7	-10	7	10	5.00	-2.00
3	140	150	10	0	10	20	6.67	0.00
4	140	160	20	20	20	40	10.00	2.00
5	140	180	40	60	40	80	16.00	3.75
6	150	170	20	80	20	100	16.67	4.80
7	150	185	35	115	35	135	19.29	5.96
8	150	205	55	170	55	190	23.75	7.16



a. For month 8, the MAD is 23.75

b. The tracking signal for month 8 is 7.16

c. The tracking signal is too large, so the forecast should be considered poor.

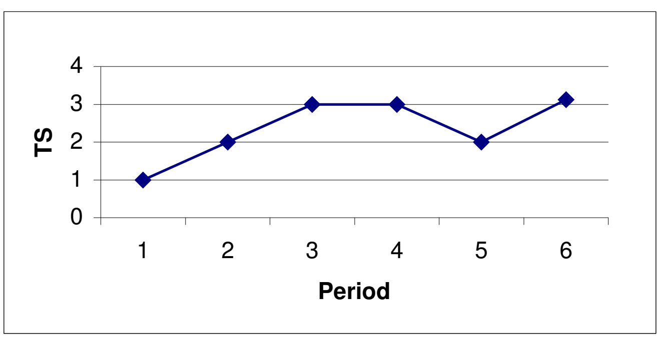
14. a - c.

Month	Demand	Exponential smoothing	Absolute deviation	T_t	F_t	FIT_t	Absolute deviation
1	31	31.00		1.00	30.00	31.00	
2	34	31.00	3.00	1.00	31.00	32.00	2.00
3	33	31.90	1.10	1.18	32.60	33.78	0.78
4	35	32.23	2.77	1.11	33.55	34.66	0.34
5	37	33.06	3.94	1.14	34.76	35.90	1.10
6	36	34.24	1.76	1.24	36.23	37.47	1.47
7	38	34.77	3.23	1.11	37.03	38.14	0.14
8	40	35.74	4.26	1.10	38.10	39.19	0.81
9	40	37.02	2.98	1.17	39.43	40.60	0.60
10	41	37.91	3.09	1.11	40.42	41.54	0.54
MAD			2.90				0.86

Based upon the MAD of each forecast, the exponential smoothing with trend is the better forecasting model.

15.

Week	Forecast	Actual	Deviation	RSFE	Absolute deviation	Sum of Absolute deviations	MAD	TS
1	800	900	100	100	100	100	100	1.0
2	850	1000	150	250	150	250	125	2.0
3	950	1050	100	350	100	350	117	3.0
4	950	900	-50	300	50	400	100	3.0
5	1000	900	-100	200	100	500	100	2.0
6	975	1100	125	325	125	625	104	3.1



For week 6, the MAD is 104, and the tracking signal is 3.1. This is a fairly high value, which indicates the model is unacceptable.

16. a. $F_{September} = (170 + 180 + 140)/3 = 163.3$

b. $F_{September} = .50(170) + .30(180) + .20(140) = 167.0$

c. $F_{July} = F_{June} + \alpha(A_{June} - F_{June}) = 130 + .3(140 - 130) = 133.00$

$F_{August} = F_{July} + \alpha(A_{July} - F_{July}) = 133.00 + .3(180 - 133.00) = 147.10$

$F_{September} = F_{August} + \alpha(A_{August} - F_{August}) = 147.10 + .3(170 - 147.10) = 153.97$

17. a. $F_{October} = (75 + 80 + 60 + 75)/4 = 72.5$

b. $F_{October} = F_{September} + \alpha(A_{September} - F_{September}) = 65 + .2(75 - 65) = 67.0$

c.

$\bar{y} = 405/6 = 67.5$

$\bar{x} = 21/6 = 3.5$

$$b = \frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2} = \frac{1485 - 6(3.5)67.5}{91 - 6(3.5)^2} = 3.86$$

$a = \bar{y} - b\bar{x} = 67.5 - 3.86(3.5) = 54.00$

$Y = a + bx = 54.0 + 3.86x$

d. $F_{October} = 54.00 + 3.86(7) = 81.01$

18.

	Quarter			
	I	II	III	IV
Last year	23,000	27,000	18,000	9,000
This year	19,000	24,000	15,000	

Each strategy is used to predict the third quarter of this year. Then, the best one is used to predict the fourth quarter of this year.

Strategy A: Whatever we sold in the past three months is what we will probably sell in the next three months. Therefore, our forecast is 24,000. Actual was 15,000. 24,000/15,000 = 160%.

Strategy B: What we sold in the same three-month period last year, we will probably sell in that three-month period this year. Therefore, our forecast is 18,000. Actual was 15,000. 18,000/15,000 = 120%.

Strategy C: We will probably sell 10 percent more in the next three months than we sold in the past three months. Our forecast is 1.10(24,000) = 26,400. Actual was 15,000. 26,400/15,000 = 176%.

Strategy D: We will probably sell 50 percent more over the next three months than we did for the same three months of last year. The forecast would be 1.50(18,000) = 27,000. Actual was 15,000. 27,000/15,000 = 180%.

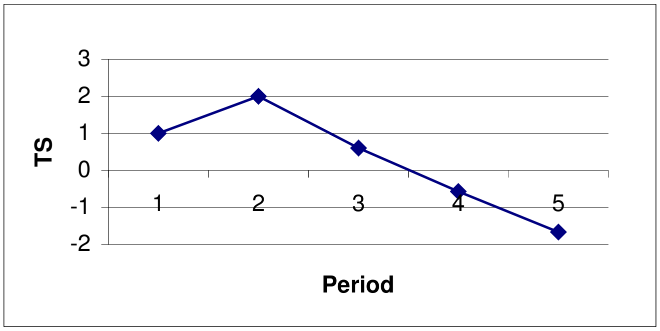
Strategy E: Whatever percentage change we had for the past three months this year compared to the same three months last year will probably be the same percentage change that we will have for the next three months of this year. The forecast would be (24,000/27,000)18,000 = 16,000. Actual was 15,000. 16,000/15,000 = 107%.

The best method is E. Apply it to the fourth quarter of this year.

(15,000/18,000)9,000 = 7,500

19.

Period	Forecast	Actual	Deviation	RSFE	Absolute deviation	Sum of Absolute deviations	MAD	TS
1	1500	1550	50	50	50	50	50.0	1.00
2	1400	1500	100	150	100	150	75.0	2.00
3	1700	1600	-100	50	100	250	83.3	0.60
4	1750	1650	-100	-50	100	350	87.5	-0.57
5	1800	1700	-100	-150	100	450	90.0	-1.67



a. For period 5, the MAD = 90.00, and the TS = -1.67

b. The model seems acceptable since the tracking signal is 1.67 off the mean and is reasonable. However, the downward trend in the graph does present a concern.

20.

Month (t)	Demand	3-mo. MA	Absolute deviation	3-mo WMA	Absolute deviation	F_t	Absolute deviation	T_t	F_t	FIT_t	Absolute deviation
1	62					61.00		1.80	60.00	61.80	
2	65					61.30		1.82	61.86	63.68	
3	67					62.41		1.94	64.07	66.01	
4	68	64.67	3.33	65.40	2.60	63.79	4.21	2.03	66.31	68.33	0.33
5	71	66.67	4.33	67.10	3.90	65.05	5.95	2.00	68.23	70.23	0.77
6	73	68.67	4.33	69.30	3.70	66.84	6.16	2.07	70.46	72.53	0.47
7	76	70.67	5.33	71.40	4.60	68.68	7.32	2.11	72.67	74.78	1.22
8	78	73.33	4.67	74.10	3.90	70.88	7.12	2.22	75.14	77.36	0.64
9	78	75.67	2.33	76.40	1.60	73.02	4.98	2.28	77.55	79.83	1.83
10	80	77.33	2.67	77.60	2.40	74.51	5.49	2.11	79.28	81.39	1.39
11	84	78.67	5.33	79.00	5.00	76.16	7.84	1.99	80.98	82.96	1.04
12	85	80.67	4.33	81.60	3.40	78.51	6.49	2.08	83.27	85.35	0.35
MAD			4.07		3.46		6.17				0.89

Based upon MAD, the exponential smoothing with trend component appears to be the best method.

21.

	x	y	Average from same quarterly period	Seasonal factor	Deseasonalized demand	x^2	x*deseasonalized demand
	1	205	340.0	0.736	278.48	1	278.48
	2	140	207.5	0.449	311.63	4	623.25
	3	375	530.0	1.147	326.80	9	980.40
	4	575	770.0	1.667	344.91	16	1379.63
	5	475		0.736	645.27	25	3226.33
	6	275		0.449	612.12	36	3672.74
	7	685		1.147	596.95	49	4178.66
	8	965		1.667	578.84	64	4630.75
Total	36	3695			3695.00	204	18970.24

$\overline{y}$ = 461.88

$\overline{x}$ = 4.50

b = $\dfrac{\sum xy_d - n\overline{x}\overline{y_d}}{\sum x^2 - n\overline{x}^2}$ = 55.78

a = $\overline{y}_d - b\overline{x}$ = 210.87

	Period (x)	Y_d	Seasonal factor	Forecast (Y_d*seasonal factor)
	9	712.88	0.736	525
Summer '06	10	768.66	0.449	345
	11	824.44	1.147	946
	12	880.22	1.667	1467

22.

	Quarter			
	I	II	III	IV
2004	1,125	1,310	1,075	1,550
2005	1,000	1,175	975	

Each strategy is used to predict the third quarter of this year. Then, the best one is used to predict the fourth quarter of this year.

Strategy A: Whatever we sold in the past three months is what we will probably sell in the next three months. Therefore, our forecast is 1,175. Actual was 975. 1,175/975 = 121%.

Strategy B: What we sold in the same three-month period last year, we will probably sell in that three-month period this year. Therefore, our forecast is 1,075. Actual was 975. 1,075/975 = 110%.

Strategy C: We will probably sell 10 percent more in the next three months than we sold in the past three months. Our forecast is 1.10(1,175) = 1,292.5. Actual was 975. 1,292.5/975 = 133%.

Strategy D: We will probably sell 50 percent more over the next three months than we did for the same three months of last year. The forecast would be 1.50(1,075) = 1,612.5. Actual was 975. 1612.5/975 = 165%.

Strategy E: Whatever percentage change we had for the past three months this year compared to the same three months last year will probably be the same percentage change that we will have for the next three months of this year. The forecast would be (1,175/1,310)1,075 = 964. Actual was 975. 964/975 = 99%.

If only the first three are used, the best method is B. Therefore, the forecast for the fourth quarter is 1,550.

If all five methods listed in the Text are used, then the best method is E. Applying it to the fourth quarter of this yea produces a forecast of

(975/1,075) 1,550 = 1,406.

23.

a. F (this month) = (325 + 350 + 400)/3 = 358

b. F (next month) = (300 + 325 + 350)/3 = 325

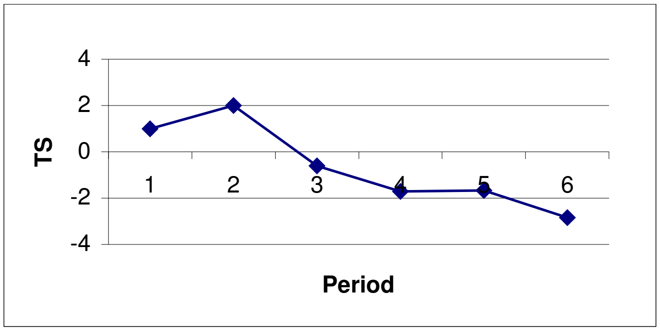
c. F (two months ago) = 450 + .20(400 – 450) = 440

F (one month ago) = 440 + .20(350 – 440) = 422

F (this month) = 422 + .20(325 – 422) = 403

24.

Month	Forecast	Actual	Deviation	RSFE	Absolute deviation	Sum of absolute deviations	MAD	TS
May	450	500	50	50	50	50	50.00	1.00
June	500	550	50	100	50	100	50.00	2.00
July	550	400	-150	-50	150	250	83.33	-0.60
August	600	500	-100	-150	100	350	87.50	-1.71
September	650	675	25	-125	25	375	75.00	-1.67
October	700	600	-100	-225	100	475	79.17	-2.84



The TS itself is acceptable. However, you would like to see the TS going back and forth between positive and negative. It currently is headed down (4 consecutive point in a row downward). If this trend continues, the forecasts will be unacceptable. This forecast should be closely monitored to see if the downward trend continues, or if this occurred by random chance.

25. a.

Company A

Period	EPS	Forecast α = 0.10	Absolute deviation	Forecast α = 0.30	Absolute deviation
2002-I	1.67	1.67		1.67	
II	2.35	1.67	0.68	1.67	0.68
III	1.11	1.74	0.63	1.87	0.76
IV	1.15	1.68	0.53	1.64	0.48
2003-I	1.56	1.62	0.06	1.50	0.06
II	2.04	1.62	0.42	1.52	0.52
III	1.14	1.66	0.52	1.67	0.53
IV	0.38	1.61	1.23	1.51	1.13
2004-I	0.29	1.48	1.19	1.17	0.88
II	-0.18	1.36	1.54	0.91	1.09
III	-0.97	1.21	2.18	0.58	1.55
IV	0.20	0.99	0.79	0.12	0.08
2005-I	-1.54	0.91	2.45	0.14	1.68
II	0.38	0.67	0.29	-0.36	0.74
III		0.64		-0.14	
MAD			0.96		0.79

Company B

Period	Demand	Forecast α = 0.10	. Abso- lute devi- ation	Forecast α = 0.30	Absolute deviation
2002-I	0.17	0.17		0.17	
II	0.24	0.17	0.07	0.17	0.07
III	0.26	0.18	0.08	0.19	0.07
IV	0.34	0.19	0.15	0.21	0.13
2003-I	0.25	0.20	0.05	0.25	0.00
II	0.37	0.21	0.16	0.25	0.12
III	0.36	0.22	0.14	0.29	0.07
IV	0.44	0.24	0.20	0.31	0.13
2004-I	0.33	0.26	0.07	0.35	0.02
II	0.40	0.26	0.14	0.34	0.06
III	0.41	0.28	0.13	0.36	0.05
IV	0.47	0.29	0.18	0.37	0.10
2005-I	0.30	0.31	0.01	0.40	0.10
II	0.47	0.31	0.16	0.37	0.10
III		0.32		0.40	
MAD			0.12		0.08

	MAD	
	Goodyear Tire	Cooper Tire
α = 0.10	.96	.12
α = 0.30	.79	.08

b. Based upon MAD, an α of .30 performs better than .10.

c.

Company A

	x	y	Average from same quarter	Seasonal factor	Deseasonalized demand	x^2	x* deseasonalized demand
	1	1.67	0.495	0.723	2.309	1	2.309
	2	2.35	1.148	1.677	1.401	4	2.803
	3	1.11	0.427	0.624	1.780	9	5.341
	4	1.15	0.577	0.843	1.365	16	5.458
	5	1.56		0.723	2.157	25	10.783
	6	2.04		1.677	1.217	36	7.299
	7	1.14		0.624	1.828	49	12.798
	8	0.38		0.843	0.451	64	3.607
	9	0.29		0.723	0.401	81	3.608
	10	-0.18		1.677	-0.107	100	-1.073
	11	-0.97		0.624	-1.556	121	-17.113
	12	0.20		0.843	0.237	144	2.848
	13	-1.54		0.723	-2.129	169	-27.676
	14	0.38		1.677	0.227	196	3.172
Total	105	9.58			9.580	1015	14.165

$\bar{y}$ = 0.684

$\bar{x}$ = 7.5

$$b = \frac{\sum xy_d - n\bar{x}\bar{y}_d}{\sum x^2 - n\bar{x}^2} = -0.254$$

$$a = \bar{y}_d - b\bar{x} = 2.5867$$

Period (x)	Y_d	Seasonal factor	Forecast (Y_d*seasonal factor)
15	-1.217	0.624	-0.76
16	-1.470	0.843	-1.24
17	-1.725	0.723	-1.25
18	-1.978	1.677	-3.32
19	-2.232	0.624	-1.39
20	-2.485	0.843	-2.09

Company B

	x	y	Average from same quarter	Seasonal factor	Deseasonalized demand	x^2	x* deseasonalized demand
	1	0.17	0.263	0.764	0.223	1	0.223
	2	0.24	0.370	1.077	0.223	4	0.446
	3	0.26	0.343	0.999	0.260	9	0.781
	4	0.34	0.417	1.213	0.280	16	1.121
	5	0.25		0.764	0.327	25	1.636
	6	0.37		1.077	0.344	36	2.061
	7	0.36		0.999	0.360	49	2.522
	8	0.44		1.213	0.363	64	2.902
	9	0.33		0.764	0.432	81	3.887
	10	0.40		1.077	0.371	100	3.714
	11	0.41		0.999	0.410	121	4.513
	12	0.47		1.213	0.388	144	4.651
	13	0.30		0.764	0.393	169	5.104
	14	0.47		1.077	0.436	196	6.110
Total	105	4.81			4.810	1015	39.672

$\bar{y}$ = 0.344

$\bar{x}$ = 7.5

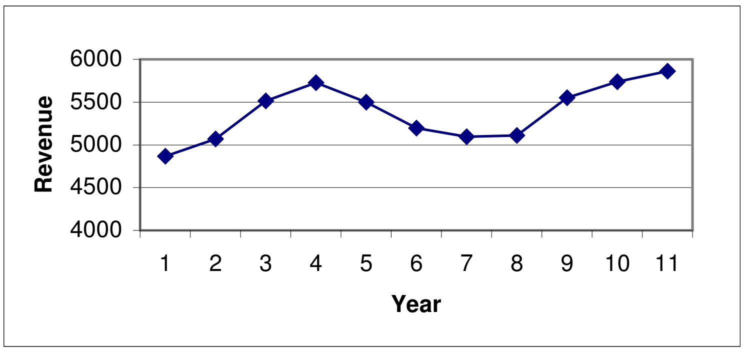
$$b = \frac{\sum xy_d - n\bar{x}\bar{y}_d}{\sum x^2 - n\bar{x}^2} = 0.016$$

$$a = \bar{y}_d - b\bar{x} = 0.225$$

Period (x)	Y_d	Seasonal factor	Forecast (Y_d*seasonal factor)
15	0.462	0.999	0.46
16	0.478	1.213	0.58
17	0.494	0.764	0.38
18	0.510	1.077	0.55
19	0.525	0.999	0.53
20	0.541	1.213	0.66

d. The results indicate that Goodyear Tire's EPS is on a downward trend, while Cooper Tire's EPS is growing.

26. Since we our interested in forecasting the next four years, many of the procedures presented in the Text will not work. For example, moving average and exponential smoothing will only project one period into the future. Therefore, of the methods presented in the Text, regression appears to be the logical approach.



Examination of the graph of revenue over time suggest that there maybe a slight upward trend. Additionally, there may be a cyclical component, possibly 6 or 7 years. With the limited data, it is very difficult to determine the cycle. Consequently, simple regression appears to be the available choice for the forecast.

	x	y	xy	x^2	y^2
	1	4865.9	4865.9	1	23676982.8
	2	5067.4	10134.8	4	25678542.8
	3	5515.6	16546.8	9	30421843.4
	4	5728.8	22915.2	16	32819149.4
	5	5497.7	27488.5	25	30224705.3
	6	5197.7	31186.2	36	27016085.3
	7	5094.4	35660.8	49	25952911.4
	8	5108.8	40870.4	64	26099837.4
	9	5550.6	49955.4	81	30809160.4
	10	5738.9	57389.0	100	32934973.2
	11	5860.0	64460.0	121	34339600.0
Total	66	59225.8	361473.0	506	319973791.0

$\bar{x}$ = 6

$\bar{y}$ = 5384.164

b = $\frac{\sum xy - n\bar{x}\bar{y}}{\sum x^2 - n\bar{x}^2}$ = 55.62

a = $\bar{y} - b\bar{x}$ = 5050.444

LINEST:

b	55.62
a	5050.444

Period	Forecast
12	5718
13	5774
14	5829
15	5885

27.

a. Answers using LINEST function in Microsoft Excel.

Sales	Price	Advertising	Fitted Values
400	280	600	451.72
700	215	835	977.21
900	211	1100	1090.98
1300	210	1400	1195.40
1150	215	1200	1095.85
1200	200	1300	1231.99
900	225	900	929.25
1100	207	1100	1118.62
980	220	700	898.79
1234	211	900	1025.98
925	227	700	850.42
800	245	690	722.80
Constant	2191.3374		
Price	-6.9094		
Advertising	0.3250		

$$\bar{y} = a + b_1x_1 + b_2x_2 = 2191.3374 - 6.9094x_1 + .3250x_2$$

Where

a = y intercept
x_1 = price
b_1 = slope of price
x_2 = advertising
b_2 = slope of advertising

b. Price has a large effect on sales because it slope value is much higher (-6.9094 versus .3250). Price actually has a negative effect since raising price decreases sales.

c.

Sales = 2191.3374 - 6.9094 (300) + .3250 (900)
Sales = 411.04

28.

$$F_t = 300 \qquad T_t = 8$$
$$\alpha = .30 \qquad \delta = .40$$
$$A_t = 288$$
$$FIT_t = F_t + T_t = 300 + 8 = 308$$
$$F_{t+1} = FIT_t + \alpha(A_t - FIT_t) = 308 + .3(288 - 308) = 308 - 6 = 302$$
$$T_{t+1} = T_t + \delta(F_{t+1} - FIT_t) = 8 + .4(302 - 308) = 8 - 2.4 = 5.6$$
$$FIT_{t+1} = F_{t+1} + T_{t+1} = 302 + 5.6 = 307.6$$

MANAGERIAL BRIEFING 13
ENTERPRISE RESOURCE PLANNING SYSTEMS

Review and Discussion Questions

1. What are the key technological features of SAP R/3 that set it apart from conventional business accounting/planning/control software?

   The key technological features are application link enabling, complementary software partner, data warehousing, and distributed client/server computer technology.

2. SAP R/3 allows the human resources, financial accounting, and manufacturing and logistics modules to be implemented separately. How would this change impact the implementation process?

   The benefit of this system is its integration. However, by implementing modules separately, it is easier to implement especially when current practices don't match SAP R/3 practices. The drawback is that it might take longer, but it may be a smoother implementation.

3. A feature that many companies are considering is the taking of customer orders via World Wide Web sites. Put yourself in the place of the person at Ford Motor Company considering this approach to taking customer orders for the Ford Explorer sport utility vehicle. What information would you need to collect from the customer? What information would you give the customer regarding the order? How would the information be used within Ford Motor Company? What major problems would you anticipate need solving prior to implementing the system? If this project is successful—that is, customers find ordering their Explorer over the Web preferable to negotiating with a dealer—what are the long-term implications to Ford Motor Company?

   Information from the customer regarding their order could include the options, price, place of delivery, loan (payment) information, and state in which it will be licensed.

   The customer should receive information confirming the order with the selected option, the price, any information they might need for loan and license, and the delivery date and place of delivery.

   Internally, the order could be used to arrange the purchase of parts, schedule production, and arrange the delivery of the car (logistics).

   The main problem to be overcome with this system would be the user friendliness of the system. Would a significant number of customers use this system? What features would it need to be successful?

   In the long term, Ford would have to decide whether this is the way they want to do business. If enough people use this approach, the dealer would not have any sales business. Would dealers remain in business to service the automobiles? It would also have an impact on the delivery of automobiles.

CHAPTER 14
AGGREGATE SALES AND OPERATIONS PLANNING

Review and Discussion Questions

1. What is the major difference between aggregate planning in manufacturing and aggregate planning in services?

   Variable affecting services operations can increase the need for overtime, a costly alternative. Also, services operations often have unique rules concerning the hours an employee may work (e.g., airlines, and trucking). Also intangibility of the product can make the use of MRP difficult.

2. What are the basic controllable variables of a production planning problem? What are the four major costs?

   Basic controllable variables: production rate, work force levels, and inventories.

   Major costs: production costs (fixed and variable), production rate change costs, inventory holding costs, and backlog costs.

3. Distinguish between pure and mixed strategies in production planning.

   Pure strategies use only one variable to absorb demand fluctuations. Mixed strategies involve two or more pure strategies.

4. Define level scheduling. How does it differ from the pure strategies in production planning.

   A Japanese approach, level scheduling focuses on holding production constant over a period of time. It is more like a combination of strategies in that for the period it keeps work force constant, inventory low and depends on a demand backlog to pull products through.

5. Compare the best plans in the CA&J Company and the Tucson Parks and Recreation Department. What do they have in common?

   The plans have little in common. The CA&J plans used a constant low work force and subcontracting. The Tucson Parks plan, on the other hand, used a constant high work force and no subcontracting.

6. How does forecast accuracy relate, in general, to the practical application of the aggregate planning models discussed in the Chapter?

   A highly accurate forecast encourages the use of deterministic techniques such as linear programming which in turn permits the development of near optimal plans. Clearly, though, any reduction in uncertainty enhances the likely accuracy of any production planning method.

7. In which way does the time horizon chosen for an aggregate plan determine whether it is the best plan for the firm?

   Many factors affect the selection of an appropriate time horizon. Perhaps, the most important is what the firm intends to plan during that time period. An aggregate plan implies a period of up to 18 months wherein the firm takes its forecast and plans production using inventory, work force size, overtime and under time, subcontracting, and backlogging orders to achieve a reasonable schedule at reasonable costs. A very stable firm in a very stable environment with a very stable demand really doesn't need to go out very far with its aggregate plan. However, when there is variation, especially when this variation is considerable, then a longer aggregate plan will show the need to find subcontractors, new workforce availability, etc. Planning for these can start early.

8. Review the opening vignette, how does sales and operations planning help resolve product shortage problems?

   Sales and Operations planning helps reduce shortages by getting all the key players (sales, finance, operations and product development) to work tog ether to help balance supply and demand. When a firm does a good job of sales and operations planning it is less likely to have demand and supply so far out of balance that there is product shortages. The opening vignette shows that better communication between the executives my have averted the problem they are discussing.

9. How would you apply yield management concepts to a barbershop? A soft drink vending machine?

   The first step would be to determine when peak and off-peak times existed. For the barbershop, lower prices could be given during off-peak times. For example, price discounts could be given during days of the week, or times of the day when demand is low. Another approach would be to offer a discount and an appointment to people that walk-in during peak times, thus transferring them to an off-peak time.

   Hopefully, lack of capacity would not be a problem for a vending machine, so reallocating peak demand should not be an issue. But, trying to increase usage during non-peak times is difficult because most vending machine can charge only one price. However, new technology could allow the prices to be changed based on time of day, or even the day of the week. Therefore, during off-peak times, a lower price could be charged to stimulate sales.

Problems

Problem	Type of Problem		Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Cut and try	Transportation				
1	Yes		Moderate			
2		Yes	Moderate			
3	Yes		Moderate			Yes
4	Yes		Moderate			
5	Yes		Moderate			
6	Yes		Moderate			Yes
7		Yes	Moderate			
8		Yes	Moderate			
9	Yes		Moderate			
10	Yes		Moderate			
11		Yes	Moderate	Yes		

1. Answers will vary, but Production Plan 2 is very difficult to beat in terms of total cost.

2. Using a constant workforce of size 10 and assuming no shortages or backlogs, the following matrix would be optimal.

	January	February	March	Excess capacity	Available capacity
Beginning inventory	0 200	10	20	0	200
January RT	50 300	60 140	70	0	440
January OT	75	85	95 90	0 20	110
January Subcontracting	100	110	120	0 5	5
February RT		50 380	60	0	380
February OT		75 80	85 30	0	110
February Subcontracting		100	110	0 5	5
March RT			50 420	0	420
March OT			75 110	0	110
March Subcontracting			100	0 5	5
Requirements	500	600	650	35	1785

3.

	Forecast	Beginning inventory	Production required	Production hours required	Production hours available	Overtime hours	Actual production	Ending inventory	Workers hired	Workers laid off
Fall	10000	500	9500	19000	14400		7200	-2300		
Winter	8000	-2300	10300	20600	14400	6200	10300	0		
Spring	7000	0	7000	14000	14400		7200	200		
Summer	12000	200	11800	23600	14400		11800	0	20*	20

	Back order	Overtime	Hiring	Lay off	Inventory	Straight time	Total
Fall	$23,000					$72,000	$95,000
Winter		$49,600				$72,000	$121,600
Spring					$1,000	$72,000	$73,000
Summer			$2,000	$4,000		$118,000	$124,000
Total							$413,600

*Workers hired = (23,600-14400)/(8*60) = 19.17 workers

4.

	Forecast	Begining Inventory	Production required	Production hours required	Production hours available	Overtime hours	Actual production	Ending inventory	Workers hired	Workers laid off
February	80000	0	80000	20000	16000		80000	0	25*	
March	64000	0	64000	16000	16000		64000	0		25
April	100000	0	100000	25000	16000	5000	84000	-16000		
May	40000	-16000	56000	14000	16000		64000	8000		

	Back order	Overtime	Hiring	Lay off	Inventory	Straight time	Total
February			$1250			$200000	$201250
March				$1750		$160000	$161750
April	$320000	$75000				$160000	$555000
May					$80000	$160000	$240000
Total							$1158000

***(**20,000-16,000)/(8*20) = 25 workers

5.

	Forecast	Beginning Inventory	Production required	Production hours required	Production hours available	Overtime hours	Actual production	Ending inventory	Workers hired	Workers laid off
Spring	20000	1000	19000	38000	28000	10000	19000	0		
Summer	10000	0	10000	20000	28000		10000	0		20
Fall	15000	0	15000	30000	20000		15000	0	25	
Winter	18000	0	18000	36000	30000		15000	-3000		

	Back order	Overtime	Hiring	Lay off	Inventory	Straight time	Total
Spring		$150000				$280000	$430000
Summer				$4000		$200000	$204000
Fall			$2500			$300000	$302500
Winter	$24000					$300000	$324000
Total							$1260500

6.

	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Ave.
Forecast	2500	3000	4000	3500	3500	3000	3000	4000	4000	4000	3000	3000	
Beginning inventory	500	1250	1500	2000	1750	1750	1500	1500	2000	2000	2000	1500	
Production requirements	3250	3250	4500	3250	3500	2750	3000	4500	4000	4000	2500	3000	3458.3
Ending inventory	1250	1500	2000	1750	1750	1500	1500	2000	2000	2000	1500	1500	

													Total	Cost
Forecast	2500	3000	4000	3500	3500	3000	3000	4000	4000	4000	3000	3000	40500	
Beginning inventory	500	1360	1720	1080	940	800	1160	1520	880	240	-400	-40		
Production plan	3360	3360	3360	3360	3360	3360	3360	3360	3360	3360	3360	3360	40320	$403,200.00
Ending inventory	1360	1720	1080	940	800	1160	1520	880	240	-400	-40	320		
Safety stock	1250	1500	2000	1750	1750	1500	1500	2000	2000	2000	1500	1500		
Excess inventory	110	220					20						350	$1,750.00
Back order										400	40		440	$8,800.00
													Total	$413,750.00

Next, try increasing or decreasing the number of workers by one, and recalculate the total cost. A better solution may be found.

7. There is more then one solution.

	January	February	March	April	May	June	Unused Capacity	Total Capacity
January RT	30.00 3800	35.00 200	40.00	45.00	50.00	55.00	0	4000
January OT	45.00 1200	50.00	55.00	60.00	65.00	70.00	0	1200
February RT	40.00	30.00 3800	35.00 200	40.00	45.00	50.00	0	4000
February OT	55.00	45.00	50.00 600	55.00 600	60.00	65.00	0	1200
March RT	50.00	40.00	30.00 4000	50.00	40.00	45.00	0	4000
March OT	65.00	55.00	45.00 1200	50.00	55.00	60.00	0	1200
April RT	60.00	50.00	40.00	30.00 4000	35.00	40.00	0	4000
April OT	75.00	65.00	55.00	45.00 1200	50.00	55.00	0	1200
May RT	70.00	60.00	50.00	40.00 200	30.00 3800	35.00	0	4000
May OT	85.00	75.00	65.00	55.00	45.00 1200	50.00	0	1200
June RT	80.00	70.00	60.00	50.00	40.00	30.00 4000	0	4000
June OT	95.00	85.00	75.00	65.00	55.00	45.00	1200	1200
Unfilled Demand	0	0	0	0	0	0		
Total Demand	5000	4000	6000	6000	5000	4000		

Total Cost = $1,003,000

	January	February	March	April	May	June	Unused Capacity	Total Capacity
January RT	30.00 4000	35.00	40.00	45.00	50.00	55.00	0	4000
January OT	45.00	50.00	55.00	60.00	65.00	70.00	1200	1200
February RT	40.00 1000	30.00 3000	35.00	40.00	45.00	50.00	0	4000
February OT	55.00	45.00	50.00	55.00	60.00	65.00 1200	0	1200
March RT	50.00	40.00 1000	30.00 3000	50.00	40.00	45.00	0	4000
March OT	65.00	55.00	45.00	50.00	55.00	60.00 1200	0	1200
April RT	60.00	50.00	40.00 3000	30.00 1000	35.00	40.00	0	4000
April OT	75.00	65.00	55.00	45.00 1000	50.00	55.00 200	0	1200
May RT	70.00	60.00	50.00	40.00 4000	30.00	35.00	0	4000
May OT	85.00	75.00	65.00	55.00	45.00 1000	50.00 200	0	1200
June RT	80.00	70.00	60.00	50.00	40.00 4000	30.00	0	4000
June OT	95.00	85.00	75.00	65.00	55.00	45.00 1200	0	1200
Unfilled Demand	0	0	0	0	0	0		
Total Demand	5000	4000	6000	6000	5000	4000		

Total Cost = $1,165,000

8.

	April A	April B	April C	May A	May B	May C	June A	June B	June C	July A	July B	July C	Supply	Dual P(i)
April RT	4 200	5 600	6 700	7	9	11	10	13	13	13	17	21	1500	0
April OT	6 600	7.50	9	9 100	11.50	14	12	15.50	14	15	15.50	24	700	2
May RT	1M	+1M	+1M	4 100	5 700	6 500	7	9	11	10	13	16	1300	0
May OT	-1M	+1M	+1M	6 400	7.50	9	9 250	11.50	14	12	15.50	19	550	-1
June RT	-1M	+1M	+1M	+1M	-1M	+1M	4 200	5 900	6 700	7	9	11	1800	-6
June OT	-1M	+1M	+1M	+1M	-1M	+1M	6 350	7.50	9	9 550	11.50	14	900	-4
July RT	-1M	+1M	+1M	+1M	-1M	+1M	+1M	+1M	-1M	4	5 900	6 800	1700	-9.50
July OT	1M	+1M	+1M	+1M	1M	+1M	+1M	+1M	1M	6 650	7.50 200	9	350	7
Unfilled Demand	0	0	0	0	0	0	0	0	0	0	0	0 50	50	-15.50
Demand	800	600	700	600	700	500	600	900	700	1200	1100	850		
Dual P(j)	4	5	6	7	8	9	10	11	12	13	14.50	15.50		

Objective Value = 55300 (Minimization)

9.

Number of workers = (6700-200)10/(249*8) = 32.6 or 33 workers

Monthly production (except July) = 22(8)33/10 = 580 units/month

	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.	Total
Forecast	600	800	900	600	400	300	200	200	300	700	800	900	6700
Beginning inventory	200	180	0	0	0	180	460	444	824	1104	984	764	
Available Production	580	580	580	580	580	580	184	580	580	580	580	580	6564
Ending inventory	180	-40	-320	-20	180	460	444	824	1104	984	764	444	
Costs													Total
Lost Sales		800	6400	400									7600
Inventory	900				900	2300	2220	4120	5520	4920	3820	2220	26920
Total	900	800	6400	400	900	2300	2220	4120	5520	4920	3820	2220	34520

Since there appears to be excessive inventory costs, another plan should be attempted with 32 workers for comparison purposes.

10.

	Forecast	Beginning Inventory	Safety stock	Production required	Production hours required	Working days	Workers needed	Beginning workers	Worker hired	Production	Ending inventory
January	1000	500	500	1000	10000	22	57	50	7	1003	503
February	1500	503	750	1747	17470	19	115	57	58	1748	751
March	1200	751	600	1049	10490	21	63	115	-52	1058	609

Cost

Hiring	Layoffs	Total
$13,000	$15,600	$28,600

Note, inventory cost are at the minimum because the inventory levels are at the safety stock levels. Therefore, only the cost of hiring and laying off workers has been included.

11.

Current capacity per Month
12 full-time employees = 2460 per month for a four month total of 9840 units
3 Part-time employees = 495 per month for a four month total of 1980 units
Giving Total capacity for 11,820 units

Capacity needed:
Total demand is 12,100 – Current Inventory is 403 = Needed product is 11,697
Current Capacity meets demand and a reduction in part-time labor is not feasible
May Demand is 3200 – 403 = 2797

This production minimizes carrying cost and only inventory cost is included in the table.
Carrying cost would be \$40*(.24/12) = \$.80 per month

	May	June	July	August	Unused Capacity	Total Capacity
May Fulltime	0 2460	.80	1.60	2.40	0	2460
May Temps	0 337	.80 35	1.60	2.40	123	495
June Fulltime		0 2460	.80	1.60	0	2460
June Temps		0 305	.80 190	1.60	0	495
July Fulltime			0 2460	.80	0	2460
July Temps			0 450	.80 45	0	495
August Fulltime				0 2460	0	2460
August Temps				0 495	0	495
Unfilled Demand	0	0	0	0		
Total Demand	2797	2800	3100	3000		

Total Cost = \$216.00

CHAPTER 15
INVENTORY CONTROL

Review and Discussion Questions

1. Distinguish between dependent and independent demand in a McDonald's, in an integrated manufacturer of personal copiers, and in a pharmaceutical supply house.

   The key to the answer here is to consider what must be forecasted (independent demand), and, given the forecast, what demands are thereby created for items to meet the forecasts (dependent demand).

   In a McDonald's, independent demand is the demand for various items offered for sale—Big Macs, fries, etc. The demand for Egg McMuffins, for example, needs to be forecasted. Given the forecast, then, the demand for the number of eggs, cheese, Canadian bacon, muffins, and containers can then be computed based on the amount needed for each Egg McMuffin.

   The manufacturer of copiers is integrated, i.e., the parts, components, etc. are produced internally. The demand for the number of copiers is independent (must be forecasted). Given the forecast, the Bill of Materials is exploded to determine the amounts of raw materials, components, parts, etc. that are needed (more on the BOM in chapter 16).

   The pharmaceutical supply company is an extreme case where only end items are carried and nothing is produced internally. The bill of materials is the end item and, therefore, the independent demand (forecasted from customers) is the same as the dependent demand. One might attempt to consider that when the demand for items occurs together, that this is similar to a bill of materials. However, this is not a bill of materials, but rather a causal relationship making it easier to forecast.

2. Distinguish between in-process inventory, safety stock inventory, and seasonal inventory.

   In-process inventory consists of those items of materials components and partially completed units that are currently in the production process.

   Safety-stock inventory is set so that inventory is maintained to satisfy some maximum level of demand. It could be stated that safety stock is that level of inventory between the minimum expected demand and the desired level of demand satisfaction.

   Seasonal inventory is that inventory accumulated to meet some periodic increase in demand.

3. Discuss the nature of the costs that affect inventory size.

   The optimum inventory size is one that minimizes the combined total of holding cost, ordering (or setup) cost, shortage cost, and purchase cost.

4. Under which conditions would a plant manager elect to use a fixed-order quantity model as opposed to a fixed-time period model? What are the disadvantages of using a fixed-time period ordering system?

   Fixed-order quantity models–when holding costs are high (usually expensive items or high deprecation rates), or when items are ordered from different sources.

   Fixed-time period models—when holding costs are low (i.e., associated with low-cost items, low-cost storage), or when several items are ordered from the same source (saves on order placement and delivery charges).

   The main disadvantage of a fixed-time period inventory system is that inventory levels must be higher to offer the same protection against stockout as a fixed-order quantity system. It also requires a periodic count and closer surveillance than a fixed-order quantity system. A fixed-order quantity system can operate with a perpetual count (keeping a running log of every time a unit is withdrawn or replaced) or through a simple two-bin or flag arrangement wherein a reorder is placed when the safety stock is reached. This latter method requires very little attention.

5. Discuss the general procedure for determining the order quantity when price breaks are involved. Would there be any differences in procedure if holding cost were a fixed percentage of price rather than a constant amount?

   In computing inventory size for the case where item cost varies with quantity ordered, if holding costs are constant, then only one EOQ is calculated. Then, the total cost for the feasible EOQ and all break-points above are calculated. The lowest total cost is the best order size.

   If holding cost is a fixed percentage of the price, then the problem is worked from the largest quantity (lowest price) to the smallest (highest price). Successively lower prices in the EOQ formula until the EOQ is a feasible—i.e., the EOQ falls into the same ranges as the price used in the equation. At this point it is only necessary to compute the total cost with this EOQ, and with the price breakpoints above (at lower prices). Again, the lowest total cost is the best order size.

6. What two basic questions must be answered by an inventory-control decision rule?

   Any inventory control model or rule must establish (1) when items should be ordered, and (2) how many should be ordered.

7. Discuss the assumptions that are inherent in production setup cost, ordering cost, and carrying cost. How valid are they?

   Investigation of ordering and production setup cost will likely show that a single, unique cost does not exist for each product, nor is it linearly related to the number of order (as implied in the equations or inventory models). In the purchasing department, for example, an employee is paid either a salary or an hourly rate for a normal work week. The cost for that employee is sometimes divided among the number of items or orders for which he has responsibility, resulting in an averaged or allocated cost for each order he places. However, when we consider an inventory ordering cost based on the number or orders per year (as is done in most inventory models), reducing the number of orders the individual places does not necessarily decrease the net cost to the firm since his weekly pay remains the same. What happens is really an increase in the ordering cost for each of the remaining items within his responsibility.

Nonlinearity of costs also occurs in production setups. Consider the time for making a setup in preparation for a production run. Setup time is roughly based on an expected frequency of making this particular product run. However, as the frequency increases, familiarity with the setup allows some shaving of the setup time. Moreover, if the setup is repeated often, an investment in specialized equipment or the construction of jigs may become warranted, reducing the setup time even more.

The terms carrying or holding costs for maintaining goods in inventory include a multitude of cost elements. To determine the nature and amounts of these costs can be a challenging feat. Fortunately, total inventory cost curves tend to be dish shaped and can, therefore, tolerate some error. The holding costs associated with insurance, obsolescence, and personnel who are handling materials are extremely difficult to ascertain on an item-by-item basis, yet each requires realistic analysis. Warehouse storage costs of an item, for example, may be based on a ratio of its required square footage and the entire available warehouse space, but this may not be an accurate representation since it is an allocation of cost rather than true cost. Take the warehouse that is too large, or is used to stock products in an off season or depressed period. Allocation based on a share of total warehouse cost will result in a high cost for storage, when, in fact, excess storage space should create pressure for higher—not lower—order quantities.

In the simple inventory model, holding costs are based on the average inventory on hand. "Average" inventory presumes that, as stock is depleted, other product lines will be moved in to occupy the space. It may be that costs should be based on maximum inventory, especially if these is an excess of space, or if the needs of an item are so specialized that no other products can use the space (for example, due to environmental requirements). Each remaining cost may be similarly challenged. Breakage, pilferage, deterioration, and insurance costs are not constant but, rather, vary with inventory size. As the value of inventory increases, insurance rates are lower, more refined handling procedures can be installed to reduce breakage, some environmental control and maintenance can be used to reduce deterioration, and better security procedures can reduce theft.

These challenges to determining true costs are not intended to discourage the use of inventory models. The intent, rather, is to prevent the use of any model without clear knowledge of its requirements and assumptions. Indeed, each application must consider the operating conditions and needs of the firm. An appropriate model can then be developed in a fashion similar to those covered in this chapter.

8. "The nice thing about inventory models is that you can pull one off the shelf and apply it so long as your cost estimates are accurate." Comment.

Unfortunately, there is no model or set of models universally applicable to all inventory situations. As stated in the chapter several times, each situation is different and requires a model to suit those conditions. Students frequently try to memorize specific models rather than the process of building any inventory model. See also the answers to question 9 below.

9. Which type of inventory system would you use in the following situations?

   a. Supplying your kitchen with fresh food.

   b. Obtaining a daily newspaper.

   c. Buying gas for your car.

   To which of these items do you impute the highest stockout cost?

   (a) Supplying kitchen with food—both a periodic model and order quantity. Generally, a household will shop once weekly for the majority of items (periodic), then pick up items such as bread and milk as the supply runs low (fixed quantity with reorder point).

   (b) Obtaining a daily newspaper—a daily newspaper is obviously a periodic model. One does not usually wait until he has finished one daily paper before buying the next day's paper.

   (c) Buying gas for your car—generally, this is a hybrid type model wherein a reorder point is signaled when the gas indicator is low, then the tank is filled. Many people, however, have a fixed quantity purchase when the reorder point is reached, such as "put in 10 gallons or $10.00 worth." Still others (drawing upon our own experience) use a periodic ordering system on their wife's car, such as taking it out and filling it every Sunday after church (or in Chase's case, after the football game).

   The highest stockout cost for most well-fed, well-read individuals would be running out of gas in your car. The cost could range from practically zero if one runs out in front of a gas station—to being late for an appointment or causing an accident on the highway.

10. Why is it desirable to classify items into groups, as the ABC classification does?

    Using a classification scheme such as this one allows a greater portion of time to be spent in controlling specific groups or classes or items. For the ABC grouping, greater control is afforded those items which comprise the greatest dollar volume in usage. The result of this classification is a reduction in the overall inventory size and, therefore, decreased costs for the same level of satisfying inventory demands.

11. What kind of policy or procedure would you recommend to improve the inventory operation in a department store? What advantages and disadvantages does your system have vis-à-vis the department store inventory operation described in this chapter?

    A wide variety of alternative methods for inventory control are available for retail stores. The most notable recent innovation is the introduction of an electronic cash register, which, in addition to tabulating specific cash receipt categories as in conventional cash registers, will also update inventory levels. Future usage will extend to checking credit, and verifying credit cards through direct linkage to a computer data file.

    Other attempts in the past in trying to improve inventory control are through prepunched and coded tags on all items that are collected at the checkout counter and periodically tabulated.

Problems

Problem	Type of Problem						Difficulty	New Problem	Modified Problem	Check figure in Appendix A
	Simple EOQ	Q-model with SS	P-model with SS	ABC analysis	Single period	Quantity Discount				
1					Yes		Moderate			
2					Yes		Moderate			
3	Yes						Easy			
4			Yes				Moderate			
5			Yes				Moderate			Yes
6		Yes					Moderate			
7			Yes				Moderate			
8		Yes	Yes				Moderate			Yes
9						Yes	Moderate			
10		Yes					Difficult			
11			Yes				Moderate			
12	Yes						Moderate			Yes
13		Yes					Difficult			
14						Yes	Moderate			
15				Yes			Moderate			Yes
16		Yes					Moderate			
17		Yes					Moderate			
18			Yes				Moderate			Yes
19			Yes				Moderate			
20					Yes		Moderate			
21					Yes		Moderate			
22		Yes					Moderate			
23				Yes			Moderate			
24			Yes				Moderate			
25		Yes					Moderate			
26		Yes					Moderate			
27			Yes				Moderate			Yes
28						Yes	Moderate			Yes
29				Yes			Moderate			
30		Yes					Moderate			
31			Yes				Moderate			

1. C_u = \$10 - \$4 = \$6
   C_o = \$4 - \$1.50 = \$2.50

$$P \le \frac{C_u}{C_o + C_u} = \frac{6}{2.50 + 6} = .7059, \text{ NORMSINV}(.7059)=0.541446$$

Should purchase 250 + .541446 (34) = 268.4 or 268 boxes of lettuce.

2. Cu = $125
   C_o = $250

$$P \le \frac{C_u}{C_o + C_u} + \frac{125}{250+125} = .333$$, NORMSINV(.333)=-0.43164

Should purchase 25 + (-.43164)(15) = 18.5254. Super Discount should overbook 19 passengers on the flight.

3.

$$Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(1000)25}{100}}$$ = 22.36 $\rightarrow$ 22

4. Service level P = .95, D = 5000, $\bar{d}$ = 5000/365, T = 14 days, L = 10 days, σ = 5 per day, and I =150.

$$q = \bar{d}(T+L) + z\sigma_{T+L} - I$$

$$\sigma_{T+L} = \sqrt{(T+L)\sigma^2} = \sqrt{(14+10)(5)^2}$$ = 24.495

From Standard normal distribution, z = 1.64

$$q = \frac{5000}{365}(14+10) + 1.64(24.495) - 150$$ = 218.94 $\rightarrow$ 219

5. Service level P = .98, $\bar{d}$ = 150, T = 4 weeks, L = 3 weeks, σ = 30 per week, and I =500 pounds.

$$q = \bar{d}(T+L) + z\sigma_{T+L} - I$$

$$\sigma_{T+L} = \sqrt{(T+L)\sigma^2} = \sqrt{(4+3)(30)^2}$$ = 79.4

From Standard normal distribution, z = 2.05

q = 150(4+3) + 2.05(79.4) – 500 = 712.77 $\rightarrow$ 713pounds

6.

a. $Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(25750)250}{.33(10)}}$ = 1975.23 → 1975

From Standard normal distribution, z = 1.64

$R = \bar{d}L + z\sigma_L$ = 515(1) + (1.64)25 = 556

b. Holding cost = $\frac{Q}{2}H = \frac{1975}{2}(.33)10$ = \$3,258.75

Ordering cost = $\frac{D}{Q}S = \frac{25750}{1975}(250)$ = \$3,259.49

c. Holding cost = $\frac{Q}{2}H = \frac{2000}{2}(.33)10$ = \$3,300.00

Ordering cost = $\frac{D}{Q}S = \frac{25750}{2000}(250)$ = \$3,218.75

Total annual cost with discount is \$6,518.75 – 50(25750/2000) = \$5,875.00, without discount it is \$6,518.24. Therefore, the savings would be \$643.24 for the year.

7. Service level P = .98 $\bar{d}$ = 5 per day, T = 30 days, L = 2 days, σ = 1 per day, and I =35.

$q = \bar{d}(T + L) + z\sigma_{T+L} - I$

$\sigma_{T+L} = \sqrt{(T + L)\sigma^2} = \sqrt{(30 + 2)(1)^2}$ = 5.657

From Standard normal distribution, z = 2.05

$q = 5(30 + 2) + 2.05(5.657) - 35$ = 136.60 → 137chips

The most he would ever order would be when on-hand was zero.

$q = 5(30 + 2) + 2.05(5.657)$ = 171.60 → 172 chips

8.

a. $Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(10000)150}{.20(10)}}$ = 1224.74 $\rightarrow$ 1225 units

$R = \bar{d}L + ss$ = (10000/52)(4) + 55 = 824.23 $\rightarrow$ 824 units

b. $q = \bar{d}(T + L) + ss - I$ = (5000/52)(3+1) + 5 – I = 390 – I

9.

a. $Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(1000)10}{2}}$ = 100 units

b. $TC_{@\,Q=100} = \frac{D}{Q}S + \frac{Q}{2}H = \frac{1000}{100}10 + \frac{100}{2}2$ = \$200

$TC_{@\,Q=500} = \frac{D}{Q}S + \frac{Q}{2}H = \frac{1000}{500}(10 - 100) + \frac{500}{2}2$ = \$320

Therefore, forgo the discount, it is still cheaper to order 100 units at a time.

10.

$Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(15600)31.20}{.10}}$ = 3120 units

$\sigma_L = \sqrt{L\sigma^2} = \sqrt{4(90)^2}$ = 180 units

From Standard normal distribution, z = 2.05

$R = \bar{d}L + z\sigma_L$ = 300(4) + (2.05)180 = 1200.0 + 369 = 1569

If safety stock is reduced by 50 percent, then ss = 185 units.

$ss = z\sigma_L,\ z = \frac{ss}{\sigma_L} = \frac{185}{180}$ = 1.03, so the service probability is 84.8%

11. Service level P = .98, $\bar{d}$ = 100 per day, T = 10 days, L = 6 days, σ = 25 per day, and I =50.

$$q = \bar{d}(T+L) + z\sigma_{T+L} - I$$

$$\sigma_{T+L} = \sqrt{(T+L)\sigma^2} = \sqrt{(10+6)(25)^2} = 100$$

From Standard normal distribution, z = 2.05

$$q = 100(10+6) + 2.05(100) - 50 = 1755 \text{ units}$$

12.

a. $$Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2000)10}{5}} = 89.44 \rightarrow 89$$

b. Ordering cost = $\frac{D}{Q}S = \frac{2000}{89}(10)$ = \$224.72

c. Holding cost = $\frac{Q}{2}H = \frac{89}{2}(5)$ = \$222.50

13.

$$Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(13000)100}{.65}} = 2{,}000 \text{ units}$$

$$\sigma_L = \sqrt{L\sigma^2} = \sqrt{4(40)^2} = 80 \text{ units}$$

From Standard normal distribution, z = 2.05

$R = \bar{d}L + z\sigma_L$ = 250(4) + (2.05)80 = 1000 + 164 = 1164

If safety stock is reduced by 100 units, then ss = 64 units.

$$ss = z\sigma_L,\ z = \frac{ss}{\sigma_L} = \frac{64}{80} = .80$$

From Standard normal distribution, z = .80, service probability is 79%

14.

Quantity range	Cost (C)	EOQ	Feasible
Less than 100 pounds	\$20 per pound	219 pounds	No
100 to 999 pounds	\$19 per pound	225 pounds	Yes
1,000 or more pounds	\$18 per pound	231 pounds	No

Note: EOQ = $\sqrt{\frac{2DS}{iC}}$

Therefore, calculate total cost at Q=225, C=\$19, and at Q=1000, C=\$18

$$TC_{Q=225,C=19} = DC + \frac{D}{Q}S + \frac{Q}{2}iC = 3000(19) + \frac{3000}{225}40 + \frac{225}{2}(.25)19 = \$58{,}068$$

$$TC_{Q=1000,C=18} = DC + \frac{D}{Q}S + \frac{Q}{2}iC = 3000(18) + \frac{3000}{1000}40 + \frac{1000}{2}(.25)18 = \$56{,}370$$

The best order size is 1,000 units at a cost of \$18 per pound.

15.a.

Item number	Annual usage	**Class**
18	61000	**A**
4	50000	**A**
13	42000	**A**
10	15000	**B**
11	13000	**B**
2	12000	**B**
8	11000	**B**
16	10200	**B**
14	9900	**B**
5	9600	**C**
17	4000	**C**
19	3500	**C**
20	2900	**C**
3	2200	**C**
7	2000	**C**
1	1500	**C**
15	1200	**C**
9	800	**C**
6	750	**C**
12	600	**C**

b. If item 15 is critical to operations, it may be desirable to reclassify it from C to A to ensure more frequent reviews.

16.

a. $Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(5000)10}{.20(3)}}$ = 408.25 $\rightarrow$ 408 bottles

b. $\sigma_L = \sqrt{L\sigma^2} = \sqrt{3(30)^2}$ = 52 units

From Standard normal distribution, z = 1.64

$R = \bar{d}L + z\sigma_L$ = 100(3) + (1.64)52 = 300.00 + 85.28 = 385.28 $\rightarrow$ 385 bottles

17.

a. $Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(2400)5}{4}}$ = 77.46 $\rightarrow$ 77 sets

b. $\sigma_L = \sqrt{L\sigma^2} = \sqrt{7(4)^2}$ = 10.583 sets

From Standard normal distribution, z = 2.05

$R = \bar{d}L + z\sigma_L$ = (2400/365)(7) + (2.05)10.583 = 46.03 + 21.70 =67.73 $\rightarrow$ 68 sets

Order 77 sets when the on-hand inventory level reaches 68 sets.

18. Service level P = .98, $\bar{d}$ = 60 units per day, T = 10 days, L = 2 days, σ = 10 units per day, and I =100 units.

$q = \bar{d}(T + L) + z\sigma_{T+L} - I$

$\sigma_{T+L} = \sqrt{(T + L)\sigma^2} = \sqrt{(10 + 2)(10)^2}$ = 34.64

From Standard normal distribution, z = 2.05

$q = 60(10 + 2) + 2.05(34.64) - 100$ = 691 units

19. Service level P = .99, $\bar{d}$ = 2000 capsules per day, T = 14 days, L = 5 days, σ = 800 capsules per day, and I =25000 units.

$$q = \bar{d}(T + L) + z\sigma_{T+L} - I$$

$$\sigma_{T+L} = \sqrt{(T + L)\sigma^2} = \sqrt{(14+5)(800)^2} = 3487.12 \text{ capsules}$$

From Standard normal distribution, z = 2.3263

$$q = 2000(14+5) + 2.3263(3487.12) - 25000 = 21{,}112 \text{ capsules}$$

20. Cu = \$20 - \$8 = \$12
C_o = \$8 - \$4 = \$4

$$P = \frac{C_u}{C_o + C_u} = \frac{12}{4+12} = .75$$

Demand	Probability of demand	Cumulative Probability (P)
300	0.05	0.05
400	0.10	0.15
500	0.40	0.55
600	0.30	0.85
700	0.10	0.95
800	0.05	1.00

Therefore, Sally's should produce 600 T-shirts.

21. a.

Demand (dozen)	Probability of demand	Probability of selling nth unit	Expected number sold	Sold (rev.)	Unsold (rev.)	Total revenue	Cost	Profit
1800	0.05	1.00	1800	\$1242.00	\$0.00	\$1242	\$882	\$360
2000	0.10	0.95	1990	1373.10	2.90	1376	980	396
2200	0.20	0.85	2160	1490.40	11.60	1502	1078	424
2400	0.30	0.65	2290	1580.10	31.90	1612	1176	436
2600	0.20	0.35	2360	1628.40	69.60	1698	1274	424
2800	0.10	0.15	2390	1649.10	118.90	1768	1372	396
3000	0.05	0.05	2400	1656.00	174.00	1830	1470	360

b. The optimal number to make would be 2,400 dozen. This yields an expected profit of \$436.

c. C_u = \$0.69 - \$0.49 = \$0.20
C_o = \$0.49 - \$0.29 = \$0.20

$$P = \frac{C_u}{C_o + C_u} = \frac{.20}{.20 + .20} = .50$$

Demand (dozen)	Probability of demand	Cumulative Probability (P)
1800	0.05	.05
2000	0.10	0.15
2200	0.20	0.35
2400	0.30	0.65
2600	0.20	0.85
2800	0.10	0.95
3000	0.05	1.00

Produce 2,400 dozen cookies.

22.

$$Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(3500)50}{.25(30)}} = 216.02 \rightarrow 216 \text{ mufflers}$$

$$\sigma_L = \sqrt{L\sigma^2} = \sqrt{2(6)^2} = 8.49 \text{ mufflers}$$

From Standard normal distribution, z = 1.28

$$R = \bar{d}L + z\sigma_L = (3500/300)(2) + (1.28)8.49 = 23.33 + 10.87 = 34.20 \rightarrow 34 \text{ sets}$$

Order 216 sets when the on-hand inventory level reaches 34 sets.

23.
a. The obvious choice is ABC analysis.

b.

Item number	Annual usage	Class
q	90000	A
k	80000	A
f	68000	A
t	32000	B
n	30000	B
e	24000	B
g	17000	B
c	14000	B
r	12000	B
a	7000	B or C
s	3000	C
j	2300	C
d	2000	C
o	1900	C
i	1700	C
m	1100	C
b	1000	C
h	900	C
p	800	C
l	400	C

24. Service level P = .98, $\bar{d}$ = 5000/365 boxes per day, T = 14 days, L = 3 days, σ = 10 boxes per day, and I = 60 boxes.

$$q = \bar{d}(T+L) + z\sigma_{T+L} - I$$

$$\sigma_{T+L} = \sqrt{(T+L)\sigma^2} = \sqrt{(14+3)(10)^2} = 41.23 \text{ boxes}$$

From Standard normal distribution, z = 2.05

$$q = (5000/365)(14+3) + 2.05(41.23) - 60 = 257.40 \rightarrow 257 \text{ boxes}$$

25.

$$Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(500)100}{.20(500)}} = 31.62 \rightarrow 32 \text{ refrigerators}$$

$\sigma_L =$ 10 refrigerators

From Standard normal distribution, z = 1.88

$R = \bar{d}L + z\sigma_L$ = (500/365)(7) + (1.88)10 = 9.59 + 18.8 = 28.39 $\rightarrow$ 28 refrigerators

Order 32 refrigerators when the on-hand inventory level reaches 28 refrigerators.

26.

$$Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(1000)20}{.20(35)}} = 75.59 \rightarrow 76 \text{ tires}$$

$\sigma_L = \sqrt{L\sigma^2} = \sqrt{4(3)^2}$ = 6 tires

From Standard normal distribution, z = 2.05

$R = \bar{d}L + z\sigma_L$ = (1000/365)(4) + (2.05)6 = 10.96 + 12.3 = 23 tires

Order 76 tires when the on-hand inventory level reaches 23 tires.

27. Service level P = .99, $\bar{d}$ = 600 hamburgers per day, T = 1 day, L = 1 day, σ = 100 hamburgers per day, and I = 800 hamburgers.

$$q = \bar{d}(T + L) + z\sigma_{T+L} - I$$

$\sigma_{T+L} = \sqrt{(T + L)\sigma^2} = \sqrt{(1+1)(100)^2}$ = 141.42 hamburgers

From Standard normal distribution, z = 2.326

$q = 600(1+1) + 2.326(141.42) - 800$ = 728.94 $\rightarrow$ 729 hamburgers

28.

Quantity range	Cost (C)	EOQ	Feasible
Less than 2500 pounds	$0.82 per pound	4277 pounds	No
2500 to 4999 pounds	$0.81 per pound	4303 pounds	Yes
5,000 or more pounds	$0.80 per pound	4330 pounds	No

Note: EOQ = $\sqrt{\frac{2DS}{iC}}$

Therefore, calculate total cost at Q=4303, C=$0.81, and at Q=5000, C=$0.80

$$TC_{Q=4303,C=0.81} = DC + \frac{D}{Q}S + \frac{Q}{2}iC$$

$$= 50000(0.81) + \frac{50000}{4303}30 + \frac{4303}{2}(.20)(0.81)$$

$$= \$41197.14$$

$$TC_{Q=5000,C=0.80} = DC + \frac{D}{Q}S + \frac{Q}{2}iC$$

$$= 50000(0.80) + \frac{50000}{5000}30 + \frac{5000}{2}(.20)(0.80)$$

$$= \$40700.00$$

The best order size is 5,000 units at a cost of $0.80 per pound.

29.

Item number	Average monthly demand	Price per unit	Monthly usage	Class
5	4000	21	84000	A
3	2000	12	24000	A or B
4	1100	20	22000	B
7	3000	2	6000	B
9	500	10	5000	B
1	700	6	4200	B or C
8	2500	1	2500	C
10	1000	2	2000	C
6	100	10	1000	C
2	200	4	800	C

30.

a. $Q_{opt} = \sqrt{\frac{2DS}{H}} = \sqrt{\frac{2(20)(365)10}{.50}}$ = 540.37 $\rightarrow$ 540 cans

$R = \overline{d}L$ = 20(14) = 280 cans

b. $\sigma_L = \sqrt{L\sigma^2} = \sqrt{14(6.15)^2}$ = 23.01 cans

From Standard normal distribution, z = 2.57

$R = \overline{d}L + z\sigma_L$ = 20(14) + (2.57) 23.01 = 280.00 + 59.14 = 339 cans

Order 540 cans when the on-hand inventory level reaches 339 cans.

31. Service level P = .98, $\overline{d}$ = 20 gallons per week, T = 1 week, L = 1 week, σ = 5 gallon per week, and I = 25 gallons.

$q = \overline{d}(T+L) + z\sigma_{T+L} - I$

$\sigma_{T+L} = \sqrt{(T+L)\sigma^2} = \sqrt{(1+1)(5)^2}$ = 7.07 gallons

From Standard normal distribution, z = 2.05

$q = 20(1+1) + 2.05(7.07) - 25$ = 29.49 $\rightarrow$ 29 gallons

CHAPTER 16
MATERIAL REQUIREMENTS PLANNING

Review and Discussion Questions

1. Discuss the meaning of MRP terms such as *planned order release* and *scheduled order receipts*.

   A planned order release is an order currently planned to be released. It has not been released. Consequently, the planned order release can be changed based upon changes in demand as one example.

   A scheduled order receipt, on the other hand, reflects an order that has already been released. The scheduled order receipt indicates the anticipated arrival of the released order. Due to variations in delivery times, it may not arrive exactly at the planned arrival time.

2. Many practitioners currently update MRP weekly or biweekly. Would it be more valuable if it were updated daily? Discuss.

   The performance of any operation will naturally vary from day to day. When the observed time period in which performance is measured is a week or two, the daily variations are smoothed; that is, the variations in performance are averaged. For example, below-average performance in one day may be offset by a higher-than-average performance the next day. Daily MRP runs monitor performance too closely and may even create an exception report calling a normal variation an abnormal deviation from expected output.

3. What is the role of safety stock in an MRP system?

   The role of safety stock in an MRP system is to buffer any uncertainties in quantities. One cause of quantity uncertainties is quality. Safety lead time should be used to offset any uncertainties in timing, from such occurrences as production or purchase delays. The addition of safety stock results in extra inventory being carried, thus reducing performance. If possible, any uncertainties in the quantities should be eliminated so that no safety stock is needed.

4. How does MRP relate to CIM? (See supplement B)

   CIM, or Computer-integrated manufacturing replaces the conventional areas of product and process design, planning and control, and manufacturing with six new areas—computer-aided design, group technology, manufacturing planning and control systems, automated materials handling, computer-aided manufacturing, and robotics. MRP's position in the CIM scheme is primarily in the manufacturing planning and control systems, which plan and schedule operations, compare alternatives, update data, monitor operations, and project operating results. This can include (as in MAPICS) order-entry, shop floor control, purchasing, cost accounting, etc. Other effects on the MRP system occur because of other parts of CIM, for example, group technology affects the routing and sequencing for MRP; aspects of computer-aided manufacturing change MRP, such as FMS (flexible manufacturing systems) which simplify MRP since an FMS cell can do a variety of processes.

5. Contrast the significance of the term *lead time* in the traditional EOQ context and in an MRP system.

   In the traditional context, lead time is fixed—either as a discrete time or as a probability distribution. Such lead time constancy or variation is outside of the inventory model.

   Lead time in an MRP system is assumed to be a variable. While specific lead times are stated for planning purposes, these times may be speeded up or delayed as conditions warrant. Indeed, it is this ability to detect needed changes in lead times—either by expediting or de-expediting—that many users cite as one of the most valuable features of MRP.

6. Discuss the importance of the master production schedule in an MRP system.

   The master production schedule "drives" the system. It states the planned due dates for end items. Material requirements planning computer runs, however, involve an iterative process. The master production schedule "proposes" or "hypothesizes" a tentative schedule. After the MRP run with this schedule, the shop scheduler examines the MRP plan for impractical loads on the productive system—either by stating excessive demands on personnel or equipment, or in excessive idle time. Then the master production schedule is revised and the program is run again.

   Because the entire MRP system is geared to satisfying the master production schedule, it is critical that the master production schedule be correct at the start of the first MRP run. The production scheduler then knows what effects any changes he makes on the schedule will have on the original MRP schedule. He can then take appropriate action as necessary, such as requesting that customers be contacted to try to extend promised dates if they are too close, or to arrange for early delivery or additional storage space if products will be completed prior to the promised delivery date.

7. "MRP just prepares shopping lists. It does not do the shopping or cook the dinner." Comment.

   An MRP system generates schedules to meet material needs. It starts with the master schedule and develops a time phased schedule which specifies what, when, and how many units of each material are required. Whether this schedule is adhered to, depends first on the master scheduler who may change the schedule. Then an inventory control personnel may choose to change order quantities or timing. Then the purchasing department may make further modifications to a purchase order, and finally the production scheduler may actually release the work to production—(which may be at some time other than that called for in the MRP schedule).

8. What are the sources of demand in an MRP system? Are these dependent or independent, and how are they used as inputs to the system?

   An MRP system has both dependent and independent item demands. The major demands on the system occur through the master production schedule (these are usually of independent origin). From here on throughout the system, the demands are then dependent on the master production schedule.

Orders for spare parts and repair parts normally do not go through the master production schedule unless their amounts are large enough to place a significant load on the productive system. These demands (which are usually independent) are fed into the inventory records file by-passing the master production schedule. Once there, they are then exploded into the required parts and materials needed during the normal course of the MRP run. The parts and materials needed to make the spares and repair parts are, therefore, dependent demand.

9. State the types of data that would be carried in the bill of materials file and the inventory record file.

The Bill of Materials file contains information about the product, including a listing of parts numbers, quantities needed per unit or product, and the assembly or process flow stipulating how the unit is structured. Engineering design changes that affect the product structure are placed into the Bill of Materials file. Also, parts or material changes that occur through a change of vendors or material composition are also added to update the file.

The Inventory Record file contains a great deal of information about each inventory item. At a minimum, the file would contain the number of units on hand and on order, the number reserved for prior commitments, the cost of the item, the name and address of the vendor, the lead time needed to obtain a shipment, and any shipment size restrictions. Additional information may be added as desired, such as that contained in Exhibit 16.10.

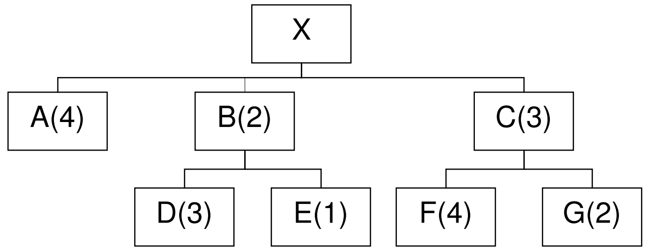
Problems

Problem	Type of Problem				Difficulty	New Problem	Modified Problem	Check figure in Appendix A
	MRP schedule	Lot sizing techniques	Disaggregation	Bill of materials				
1	Yes			Yes	Moderate			
2	Yes				Easy			
3	Yes				Moderate			
4	Yes				Moderate			Yes
5	Yes				Moderate			
6	Yes			Yes	Moderate			
7	Yes				Moderate			
8	Yes				Moderate			
9	Yes				Moderate		Yes	
10	Yes				Moderate			
11		Yes			Moderate			Yes
12			Yes		Moderate			
13	Yes				Moderate			
14				Yes	Easy			Yes
15		Yes			Moderate			
16	Yes				Difficult			
17	Yes	Yes			Moderate			
18	Yes				Difficult			

MRP schedule worksheet

	Period										
Item	Gross requirements										
LT=	Scheduled receipts										
	On hand from prior period										
Q=	Net requirements										
	Planned order receipts										
	Planned order releases										
Item	Gross requirements										
LT=	Scheduled receipts										
	On hand from prior period										
Q=	Net requirements										
	Planned order receipts										
	Planned order releases										
Item	Gross requirements										
LT=	Scheduled receipts										
	On hand from prior period										
Q=	Net requirements										
	Planned order receipts										
	Planned order releases										
Item	Gross requirements										
LT=	Scheduled receipts										
	On hand from prior period										
Q=	Net requirements										
	Planned order receipts										
	Planned order releases										
Item	Gross requirements										
LT=	Scheduled receipts										
	On hand from prior period										
Q=	Net requirements										
	Planned order receipts										
	Planned order releases										
Item	Gross requirements										
LT=	Scheduled receipts										
	On hand from prior period										
Q=	Net requirements										
	Planned order receipts										
	Planned order releases										
Item	Gross requirements										
LT=	Scheduled receipts										
	On hand from prior period										
Q=	Net requirements										
	Planned order receipts										
	Planned order releases										
Item	Gross requirements										
LT=	Scheduled receipts										
	On hand from prior period										
Q=	Net requirements										
	Planned order receipts										
	Planned order releases										

1.



b.

X	A	B	C	D	E	F	G
105	404	150	295	270	-10	180	490

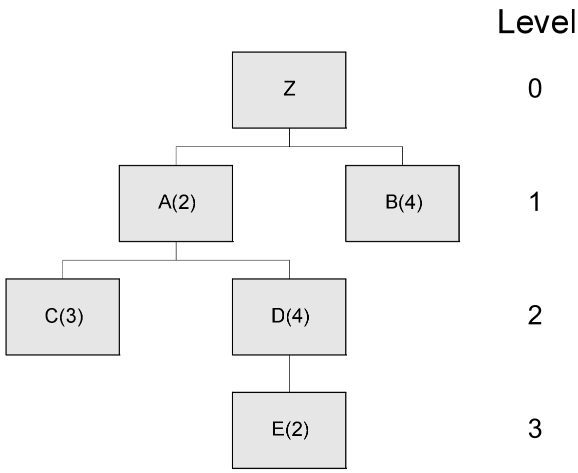
2.

	Period	1	2	3	4	5	6	7	8	9	10
Item J LT= 1 week Q= L4L	Gross requirements		75		50	70					
	Scheduled receipts										
	On hand from prior period	40	40	0	0	0					
	Net requirements		35		50	70					
	Planned order receipts		35		50	70					
	Planned order releases	35		50	70						

3.

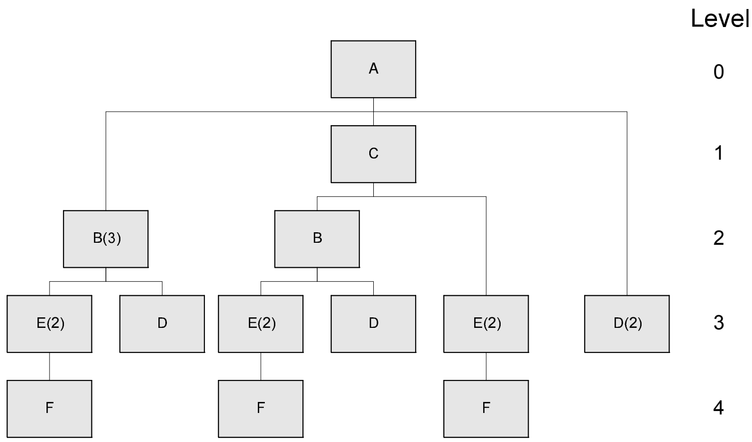
	Period	1	2	3	4	5	6	7	8	9	10
Item X LT= 1 Q= L4L	Gross requirements										100
	Scheduled receipts										
	On hand from prior period	20	20	20	20	20	20	20	20	20	20
	Net requirements										80
	Planned order receipts										80
	Planned order releases									80	
Item Y LT= 2 Q= L4L	Gross requirements									160	
	Scheduled receipts										
	On hand from prior period	40	40	40	40	40	40	40	40	40	
	Net requirements									120	
	Planned order receipts									120	
	Planned order releases							120			
Item Z LT= 3 Q= L4L	Gross requirements									240	
	Scheduled receipts										
	On hand from prior period	30	30	30	30	30	30	30	30	30	
	Net requirements									210	
	Planned order receipts									210	
	Planned order releases						210				
Item A LT= 2 Q== L4L	Gross requirements						420	120			
	Scheduled receipts										
	On hand from prior period	50	50	50	50	50	50	0			
	Net requirements						370	120			
	Planned order receipts						370	120			
	Planned order releases				370	120					
Item B LT= 1 Q== L4L	Gross requirements							240			
	Scheduled receipts										
	On hand from prior period	100	100	100	100	100	100	100			
	Net requirements							140			
	Planned order receipts							140			
	Planned order releases						140				
Item C LT= 3 Q== L4L	Gross requirements						840				
	Scheduled receipts										
	On hand from prior period	900	900	900	900	900	900	60	60	60	60
	Net requirements										
	Planned order receipts										
	Planned order releases										

4.



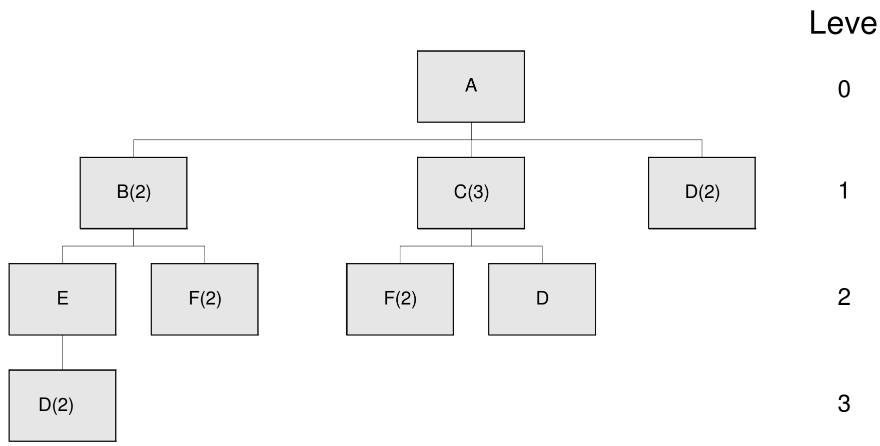
	Period	1	2	3	4	5	6	7	8	9	10
Item Z LT= 2 Q= L4L	Gross requirements										50
	Scheduled receipts										
	On hand from prior period										
	Net requirements										50
	Planned order receipts										50
	Planned order releases								50		
Item A LT= 1 Q= L4L	Gross requirements								100		
	Scheduled receipts										
	On hand from prior period										
	Net requirements								100		
	Planned order receipts								100		
	Planned order releases							100			
Item B LT= 1 Q= L4L	Gross requirements								200		
	Scheduled receipts										
	On hand from prior period										
	Net requirements								200		
	Planned order receipts								200		
	Planned order releases							200			
Item C LT= 1 Q= L4L	Gross requirements							300			
	Scheduled receipts										
	On hand from prior period										
	Net requirements							300			
	Planned order receipts							300			
	Planned order releases						300				
Item D LT= 1 Q= L4L	Gross requirements							400			
	Scheduled receipts										
	On hand from prior period										
	Net requirements							400			
	Planned order receipts							400			
	Planned order releases						400				
Item E LT= 3 Q= L4L	Gross requirements						800				
	Scheduled receipts										
	On hand from prior period										
	Net requirements						800				
	Planned order receipts						800				
	Planned order releases			800							

5.

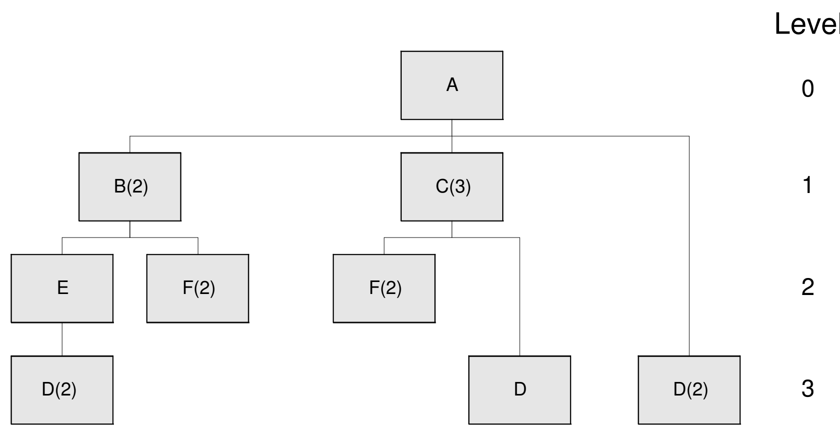


	Period	1	2	3	4	5	6	7	8	9	10
Item A LT= 2 Q= L4L	Gross requirements								30		
	Scheduled receipts		10								
	On hand from prior period	0	0	10	10	10	10	10	10	0	0
	Net requirements								20		
	Planned order receipts								20		
	Planned order releases						20				
Item B LT= 1 Q= L4L	Gross requirements					50	60				
	Scheduled receipts										
	On hand from prior period					0	0				
	Net requirements					50	60				
	Planned order receipts					50	60				
	Planned order releases				50	60					
Item C LT= 1 Q= 50	Gross requirements						20				
	Scheduled receipts										
	On hand from prior period	10	10	10	10	10	10	40	40	40	40
	Net requirements						10				
	Planned order receipts						50				
	Planned order releases					50					
Item D LT= 2 Q= 50	Gross requirements				50	60	40				
	Scheduled receipts										
	On hand from prior period				0	0	40				
	Net requirements				50	60	0				
	Planned order receipts				50	100					
	Planned order releases		50	100							
Item E LT= 1 Q= 200	Gross requirements				100	220					
	Scheduled receipts	50									
	On hand from prior period	50	100	100	100	0	180	180	180	180	180
	Net requirements					220					
	Planned order receipts					400					
	Planned order releases				400						
Item F LT= 1 Q= L4L	Gross requirements				400						
	Scheduled receipts	50									
	On hand from prior period	150	200	200	200						
	Net requirements				200						
	Planned order receipts				200						
	Planned order releases			200							

6. Product structure tree



Low-level coded product structure tree



Indented bill of materials

.A
- .B(2)
  - .E
    - .D(2)
  - .F(2)
- .C(3)
  - .F(2)
  - .D
- .D(2)

Single level bill of materials

A
- B(2)
- C(3)
- D(2)

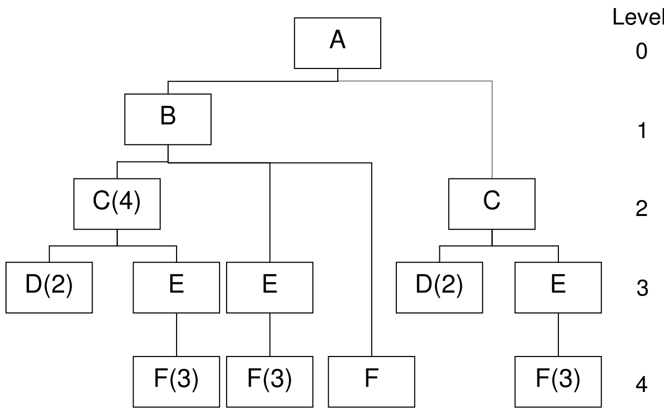
B
- E
- F(2)

C
- D
- F(2)

E
- D(2)

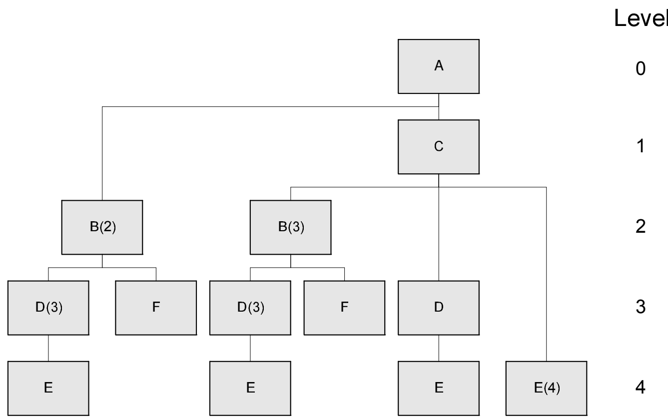
	Period	1	2	3	4	5	6	7	8	9	10
Item	Gross requirements								20		
A	Scheduled receipts										
LT=	On hand from prior period										
1	Net requirements								20		
Q=	Planned order receipts								20		
L4L	Planned order releases							20			
Item	Gross requirements							40			
B	Scheduled receipts										
LT=	On hand from prior period										
2	Net requirements							40			
Q=	Planned order receipts							40			
L4L	Planned order releases					40					
Item	Gross requirements							60			
C	Scheduled receipts										
LT=	On hand from prior period	15	15	15	15	15	15	15			
1	Net requirements							45			
Q=	Planned order receipts							45			
L4L	Planned order releases						45				
Item	Gross requirements			100			45	40			
D	Scheduled receipts										
LT=	On hand from prior period	50	50	50	0	0	0	0			
1	Net requirements			50			45	40			
Q=	Planned order receipts			50			45	40			
L4L	Planned order releases		50			45	40				
Item	Gross requirements					40					
E	Scheduled receipts		20								
LT=	On hand from prior period		0	20	20	20	30	30	30	30	30
2	Net requirements					20					
Q=	Planned order receipts					50					
50	Planned order releases			50							
Item	Gross requirements					80	90				
F	Scheduled receipts										
LT=	On hand from prior period										
1	Net requirements					80	100	10	10	10	10
Q=	Planned order receipts					180					
180	Planned order releases				180						

7.



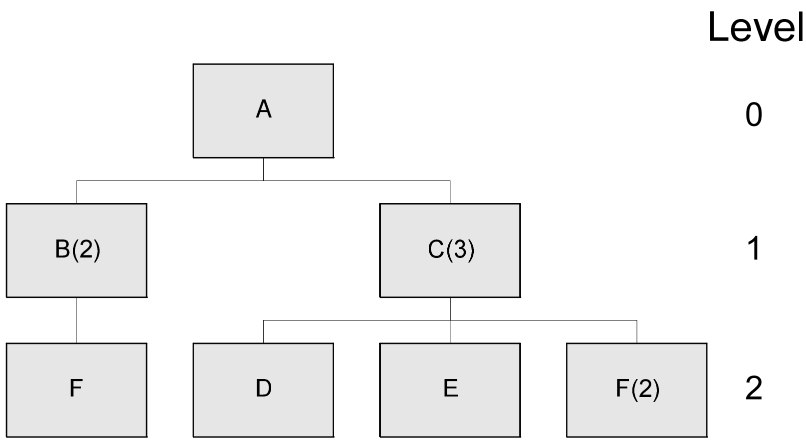
	Period	1	2	3	4	5	6	7	8	9	10
Item	Gross requirements										50
A	Scheduled receipts	10									
LT=	On hand from prior period	20	30	30	30	30	30	30	30	30	30
2	Net requirements										20
Q=	Planned order receipts										20
L4L	Planned order releases								20		
Item	Gross requirements								20		
B	Scheduled receipts										
LT=	On hand from prior period								0	30	30
2	Net requirements								20		
Q=	Planned order receipts								50		
50	Planned order releases						50				
Item	Gross requirements						200		20		
C	Scheduled receipts	100									
LT=	On hand from prior period	50	150	150	150	150	150	50	50	30	30
1	Net requirements						50				
Q=	Planned order receipts						100				
100	Planned order releases					100					
Item	Gross requirements					200					
D	Scheduled receipts			100							
LT=	On hand from prior period	100	100	200	200	200	0	0	0	0	0
3	Net requirements										
Q=	Planned order receipts										
L4L	Planned order releases										
Item	Gross requirements					100	50				
E	Scheduled receipts										
LT=	On hand from prior period	10	10	10	10	10	0				
2	Net requirements					90	50				
Q=	Planned order receipts					90	50				
L4L	Planned order releases			90	50						
Item	Gross requirements			270	150		50				
F	Scheduled receipts										
LT=	On hand from prior period			0	30	30	30	30	30	30	30
2	Net requirements			270	120		20				
Q=	Planned order receipts			300	150		50				
50	Planned order releases	300	150		50						

8.



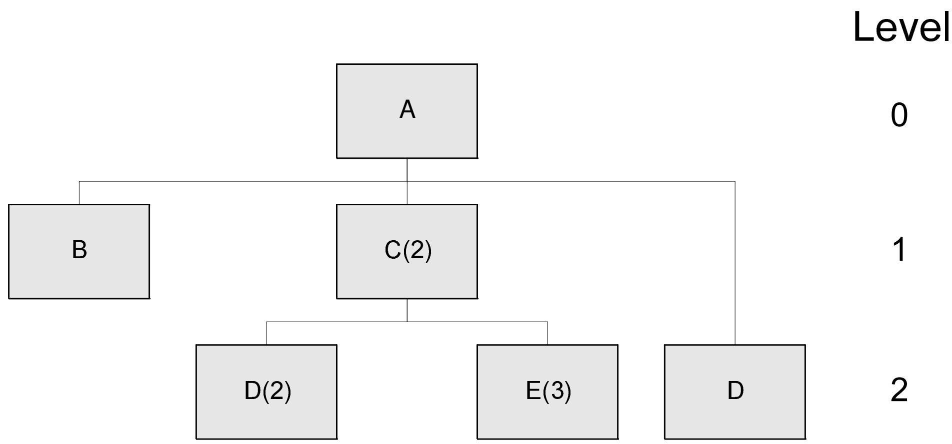
	Period	1	2	3	4	5	6	7	8	9	10
Item	Gross requirements										20
A	Scheduled receipts			10							
LT= 2	On hand from prior period	5	5	5	15	15	15	15	15	15	15
Q=	Net requirements										5
20	Planned order receipts										20
	Planned order releases								20		
Item	Gross requirements							60	40		
B	Scheduled receipts							20			
LT= 2	On hand from prior period	10	10	10	10	10	10	10	10	10	10
Q=	Net requirements							30	30		
40	Planned order receipts							40	40		
	Planned order releases					40	40				
Item	Gross requirements								20		
C	Scheduled receipts										
LT= 1	On hand from prior period										
Q=	Net requirements								20		
L4L	Planned order receipts								20		
	Planned order releases							20			
Item	Gross requirements					120	120	20			
D	Scheduled receipts										
LT= 3	On hand from prior period	100	100	100	100	100	140	20	0	0	0
Q=	Net requirements					20					
160	Planned order receipts					160					
	Planned order releases		160								
Item	Gross requirements		160					80			
E	Scheduled receipts		60								
LT= 2	On hand from prior period	100	100	0	0	0	0	0			
Q=	Net requirements							80			
L4L	Planned order receipts							80			
	Planned order releases					80					
Item	Gross requirements					40	40				
F	Scheduled receipts					40					
LT= 2	On hand from prior period					0	0				
Q=	Net requirements						40				
L4L	Planned order receipts						40				
	Planned order releases				40						

9.



	Period	1	2	3	4	5	6	7	8	9	10
Item	Gross requirements	20	20				60		50		
A	Scheduled receipts										
LT=	On hand from prior period	20	0	0	0	0	0	0	0		
1	Net requirements		20				60		50		
Q=	Planned order receipts		20				60		50		
L4L	Planned order releases	20				60		50			
Item	Gross requirements	40				120		100			
B	Scheduled receipts	30									
LT=	On hand from prior period	50	40	40	40	40	0	0			
1	Net requirements					80		100			
Q=	Planned order receipts					80		100			
L4L	Planned order releases				80		100				
Item	Gross requirements	60				180		150			
C	Scheduled receipts										
LT=	On hand from prior period	60	0	0	0	0	0	0			
2	Net requirements					180		150			
Q=	Planned order receipts					180		150			
L4L	Planned order releases			180		150					
Item	Gross requirements			180		150					
D	Scheduled receipts										
LT=	On hand from prior period	25	25	25	45	45	45	45	45	45	45
1	Net requirements			155		105					
Q=	Planned order receipts			200		150					
50	Planned order releases		200		150						
Item	Gross requirements			180		150					
E	Scheduled receipts										
LT=	On hand from prior period			0	20	20	70	70	70	70	70
2	Net requirements			180		130					
Q=	Planned order receipts			200		200					
100	Planned order releases	200		200							
Item	Gross requirements			360	80	300	100				
F	Scheduled receipts										
LT=	On hand from prior period			0	40	60	60	60	60	60	60
2	Net requirements			360	40	240	40				
Q=	Planned order receipts			400	100	300	100				
100	Planned order releases	400	100	300	100						

10.



	Period	1	2	3	4	5	6	7	8	9	10
Item A LT= 1 Q= L4L	Gross requirements		30			30			40		
	Scheduled receipts										
	On hand from prior period	20	20	0	0	0	0	0	0		
	Net requirements		10			30			40		
	Planned order receipts		10			30			40		
	Planned order releases	10			30			40			
Item B LT= 1 Q= L4L	Gross requirements	10			30			40			
	Scheduled receipts	10									
	On hand from prior period	0	0	0	0	0	0	0			
	Net requirements				30			40			
	Planned order receipts				30			40			
	Planned order releases			30			40				
Item C LT= 1 Q= >50	Gross requirements	20			60			80			
	Scheduled receipts	50									
	On hand from prior period	10	40	40	40	30	30	30			
	Net requirements				20			50			
	Planned order receipts				50			50			
	Planned order releases			50			50				
Item D LT= 2 Q= 100	Gross requirements	10		100	30		100	40			
	Scheduled receipts										
	On hand from prior period	20	10	10	10	80	80	80	40	40	40
	Net requirements			90	20		20				
	Planned order receipts			100	100		100				
	Planned order releases	100	100		100						
Item E LT= 2 Q= 50	Gross requirements			150			150				
	Scheduled receipts										
	On hand from prior period	10	10	10	10	10	10	10	10	10	10
	Net requirements			140			140				
	Planned order receipts			150			150				
	Planned order releases	150			150						

11.

Least Total Cost										
Period	1	2	3	4	5	6	7	8	9	10
Gross Requirements	30	50	10	20	70	80	20	60	200	50
On-hand	90	60	10	0	230	160	80	60	0	50
Net requirements	0	0	0	20	0	0	0	0	200	0
Planned order receipts				250					250	
Planned order releases	250					250				

Least Unit Cost										
Period	1	2	3	4	5	6	7	8	9	10
Gross Requirements	30	50	10	20	70	80	20	60	200	50
On-hand	90	60	10	0	430	360	280	260	200	0
Net requirements	0	0	0	20	0	0	0	0	0	50
Planned order receipts				450						50
Planned order releases	450						50			

Calculations

Weeks	Quantity ordered	Carrying cost	Order cost	Total cost	Unit cost
4	20	$0.00	$10.00	$10.00	$0.500
4 to 5	90	0.70	10.00	10.70	0.119
4 to 6	170	2.30	10.00	12.30	0.072
4 to 7	190	2.90	10.00	12.90	0.068
4 to 8	250	5.30	10.00	15.30	0.061
4 to 9	450	15.30	10.00	25.30	0.056
4 to 10	500	18.30	10.00	28.30	0.057
9	200	0.00	10.00	10.00	
9 to 10	250	2.50	10.00	12.50	

For Least Total Cost, order for periods 4 through 8, since carrying cost is the closest to ordering cost. For Least Unit Cost, order for periods 4 through 9, since this has the lowest unit cost.

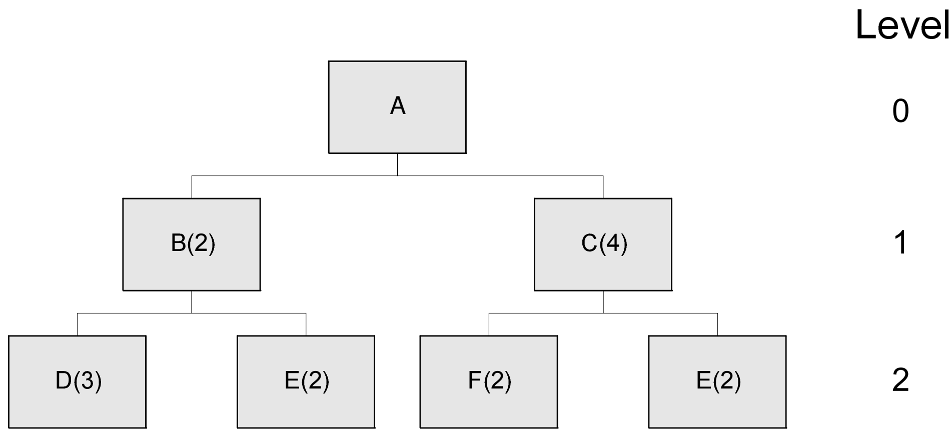
12.

Aggregate Plan	I			II		
WORMs	2,100			2,700		
Master Production Schedule						
Period	1	2	3	4	5	6
Internal Model	210	210	210	270	270	270
External Model	490	490	490	630	630	630

MRP schedule

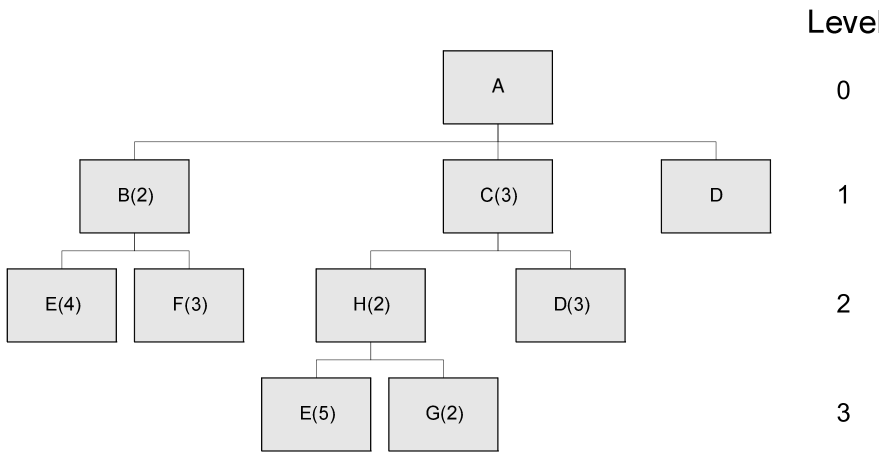
	Period (month)	-4	-3	-2	-1	1	2	3	4	5	6
Item Int. Worm LT= 1 Q= L4L	Gross requirements					210	210	210	270	270	270
	Scheduled receipts										
	On hand from prior period					100	0	0	0	0	
	Net requirements					110	210	210	270	270	270
	Planned order receipts					110	210	210	270	270	270
	Planned order releases				110	210	210	270	270	270	
Item Int. Elec. & Housing LT= 2 Q= L4L	Gross requirements				110	210	210	270	270	270	
	Scheduled receipts										
	On hand from prior period				50	0	0	0	0	0	
	Net requirements				60	210	210	270	270	270	
	Planned order receipts				60	210	210	270	270	270	
	Planned order releases		60	210	210	270	270	270			
Item Ett. Worm LT= 1 Q= L4L	Gross requirements					490	490	490	630	630	630
	Scheduled receipts										
	On hand from prior period					200	0	0	0	0	0
	Net requirements					290	490	490	630	630	630
	Planned order receipts					290	490	490	630	630	630
	Planned order releases				290	490	490	630	630	630	
Item Ext. Elect. & Housing LT= 2 Q= L4L	Gross requirements				290	490	490	630	630	630	
	Scheduled receipts										
	On hand from prior period				125	0	0	0	0	0	
	Net requirements				165	490	490	630	630	630	
	Planned order receipts				165	490	490	630	630	630	
	Planned order releases		165	490	490	630	630	630			
Item Drive Ass'bly LT= 3 Q= L4L	Gross requirements				400	700	700	900	900	900	
	Scheduled receipts										
	On hand from prior period				250	0	0	0	0	0	
	Net requirements				150	700	700	900	900	900	
	Planned order receipts				150	700	700	900	900	900	
	Planned order releases	150	700	700	900	900	900				

13.

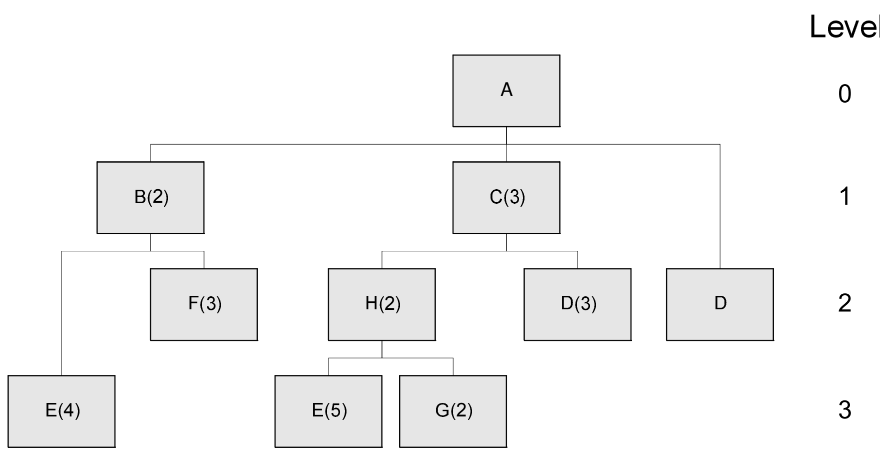


	Period	1	2	3	4	5	6	7	8	9	10
Item	Gross requirements										100
A	Scheduled receipts										
LT= 1	On hand from prior period										0
Q=	Net requirements										100
L4L	Planned order receipts										100
	Planned order releases									100	
Item	Gross requirements									200	
B	Scheduled receipts										
LT= 2	On hand from prior period									0	
Q=	Net requirements									200	
L4L	Planned order receipts									200	
	Planned order releases							200			
Item	Gross requirements									400	
C	Scheduled receipts										
LT= 2	On hand from prior period									0	
Q=	Net requirements									400	
L4L	Planned order receipts									400	
	Planned order releases							400			
Item	Gross requirements							600			
D	Scheduled receipts										
LT= 3	On hand from prior period							0			
Q=	Net requirements							600			
L4L	Planned order receipts							600			
	Planned order releases				600						
Item	Gross requirements							1200			
E	Scheduled receipts										
LT= 2	On hand from prior period							0			
Q=	Net requirements							1200			
L4L	Planned order receipts							1200			
	Planned order releases					1200					
Item	Gross requirements							800			
F	Scheduled receipts										
LT= 3	On hand from prior period							0			
Q=	Net requirements							800			
L4L	Planned order receipts							800			
	Planned order releases				800						

14. a. Product Structure Tree



b. Low-level Coded Product Structure Tree



c. Indented Parts List

- .A
  - .B(2)
    - .E(4)
    - .F(3)
  - .C(3)
    - .D(3)
    - .H(2)
      - .E(5)
      - .G(2)
  - .D(1)

d.

Level 0	100 units of A
Level 1	200 units of B
	300 units of C
Level 2	600 units of F
	600 units of H
	1000 units of D (3x3x100 + 1x100)
Level 3	3800 units of E (4x2x100 + 5x2x3x100)
	1200 units of G

15.

Period	1	2	3	4	5	6	7	8	9	10
Gross Requirements	20	10	15	45	10	30	100	20	40	150
On-hand	70	50	40	25						
Net requirements				20						
Planned order receipts				180						
Planned order releases		180								

Weeks	Quantity ordered	Carrying cost	Order cost	Total cost	Unit cost
4	20	$0.00	$9.00	$9.00	$0.450
4 to 5	30	0.20	9.00	9.20	0.307
4 to 6	60	1.40	9.00	10.40	0.173
4 to 7	160	7.40	9.00	16.40	0.103
4 to 8	180	9.00	9.00	18.00	0.100
4 to 9	220	13.00	9.00	22.00	0.100
4 to 10	370	31.00	9.00	40.00	0.108

Least Total Cost method indicates that 180 units should be ordered to cover the needs for periods 4 through 8, since the carrying cost is equal to the order cost ($9). Least Unit Cost it tied at $.100 for ordering for periods 4 through 8 and 4 through 9. Therefore, order either 180 or 220 units in period 2.

16.

	Period	1	2	3	4	5	6	7	8
	Standard Model				300				400
	Sports Model					200			100
Item Radio/ CD LT= 2 Q= L4L	Gross requirements				300	200			500
	Scheduled receipts								
	On hand from prior period	50	50	50	50	0	0	0	0
	Net requirements				250	200			500
	Planned order receipts				250	200			500
	Planned order releases		250	200			500		
Item Std. trim LT= 2 Q= L4L	Gross requirements				300				400
	Scheduled receipts								
	On hand from prior period								
	Net requirements				300				400
	Planned order receipts				300				400
	Planned order releases		300				400		
Item Std. Hard-ware LT= 3 Q= L4L	Gross requirements				300				400
	Scheduled receipts								
	On hand from prior period								
	Net requirements				300				400
	Planned order receipts				300				400
	Planned order releases	300				400			
Item Sports trim LT= 2 Q= L4L	Gross requirements					200			100
	Scheduled receipts								
	On hand from prior period								
	Net requirements					200			100
	Planned order receipts					200			100
	Planned order releases			200			100		
Item Sports Hard-Ware LT= 3 Q= L4L	Gross requirements					200			100
	Scheduled receipts								
	On hand from prior period								
	Net requirements					200			100
	Planned order receipts					200			100
	Planned order releases		200			100			

17.

L4L									
Period	1	2	3	4	5	6	7	8	Total
Gross Requirements	10	30	10	50	20	40	50	30	
On-Hand	0	0	0	0	0	0	0	0	0
Orders	10	30	10	50	20	40	50	30	

EOQ =

$$\sqrt{\frac{2(240/8)100}{0.50}}$$

= 109.54 or 110

Period	1	2	3	4	5	6	7	8	Total
Gross Requirements	10	30	10	50	20	40	50	30	
On-hand	0	100	70	60	10	100	60	10	410
Orders	110				110			110	

Least Total Cost

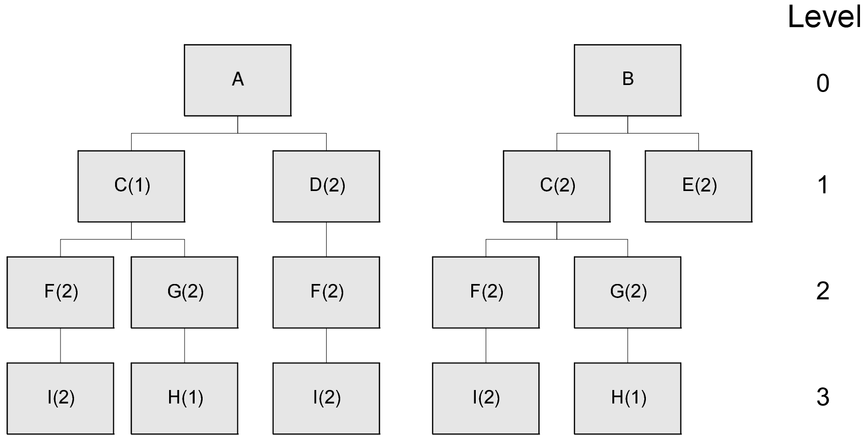
Period	1	2	3	4	5	6	7	8	Total
Gross Requirements	10	30	10	50	20	40	50	30	
On-Hand	0	90	60	50	0	120	80	30	430
Orders	100				140				

Calculations

Weeks	Quantity ordered	Carrying cost	Order cost	Total cost
1	10	$0	$100	$100
1 to 2	40	15	100	115
1 to 3	50	25	100	125
1 to 4	100	100	100	150 Order
5	20	0	100	100
5 to 6	60	20	100	120
5 to 7	110	70	100	170
5 to 8	140	115	100	225 Order

Cost Comparison	Inventory Costs	Number of order	Order Costs	Total Costs
L4L	$0	8	$800	$800
EOQ	205	3	300	505
LTC	215	2	200	415

18. Note the correction in the product structure tree.



	Period	1	2	3	4	5	6	7	8	9	10
Item A LT= 1 Q= L4L	Gross requirements										700
	Scheduled receipts										
	On hand from prior period	30	30	30	30	30	30	30	30	30	30
	Net requirements										670
	Planned order receipts										670
	Planned order releases									670	
Item B LT= 2 Q= L4L	Gross requirements										1200
	Scheduled receipts										
	On hand from prior period	50	50	50	50	50	50	50	50	50	50
	Net requirements										1150
	Planned order receipts										1150
	Planned order releases								1150		
Item C LT= 1 Q= L4L	Gross requirements								2300	670	
	Scheduled receipts										
	On hand from prior period	75	75	75	75	75	75	75	75	0	
	Net requirements								2225	670	
	Planned order receipts								2225	670	
	Planned order releases							2225	670		
Item D LT= 2 Q= L4L	Gross requirements									1340	
	Scheduled receipts										
	On hand from prior period	80	80	80	80	80	80	80	80	80	
	Net requirements									1260	
	Planned order receipts									1260	
	Planned order releases							1260			
Item E LT= 1 Q= L4L	Gross requirements								2300		
	Scheduled receipts										
	On hand from prior period	100	100	100	100	100	100	100	100		
	Net requirements								2200		
	Planned order receipts								2200		
	Planned order releases							2200			

Item	Gross requirements							6970	1340		
F	Scheduled receipts										
LT= 1	On hand from prior period	150	150	150	150	150	150	150	0		
Q=	Net requirements							6820	1340		
L4L	Planned order receipts							6820	1340		
	Planned order releases						6820	1340			
Item	Gross requirements							4450	1340		
G	Scheduled receipts										
LT= 1	On hand from prior period	40	40	40	40	40	40	40	0		
Q=	Net requirements							4410	1340		
L4L	Planned order receipts							4410	1340		
	Planned order releases						4410	1340			
Item	Gross requirements						4410	1340			
H	Scheduled receipts										
LT= 2	On hand from prior period	200	200	200	200	200	200	0			
Q=	Net requirements						4210	1340			
L4L	Planned order receipts						4210	1340			
	Planned order releases				4210	1340					
Item	Gross requirements						13640	2680			
I	Scheduled receipts										
LT= 2	On hand from prior period	300	300	300	300	300	300	0			
Q=	Net requirements						13340	2680			
L4L	Planned order receipts						13340	2680			
	Planned order releases				13340	2680					

CHAPTER 17
OPERATIONS SCHEDULING

Review and Discussion Questions

1. What are the objectives of work-center scheduling?

   The objective can vary but include: meeting due dates, minimizing lead time, minimizing set-up times and cost, minimizing work-in-process inventory, and maximizing machine and/or worker utilization.

2. Distinguish between a job shop, a GT cell, and a flow shop.

   A job shop may have the flow of products going in any direction between departments.

   A GT cell is somewhere in between a job shop and a flow shop in terms of product flow.

   A flow shop has the flow of products going in a specific sequence for all products.

3. What practical considerations are deterrents to using the SOT rule?

   Perhaps one will encounter a situation whereby those jobs with the shortest operations times are least urgent than those with long due-dates. Also long jobs will always be preempted in a dynamic shop so they may never be completed.

   A good example would be applying this rule to all student assignments (including term papers) for one semester. At the beginning of the semester, this works quite well, but it results in the term papers being postpone until immediately before their due-date, typically resulting in inadequate time to complete the term paper.

4. What priority rule do you use in scheduling your study time for midterm examinations? If you have 5 exams to study for, how many alternative schedules exists?

   Most students will probably respond that they use either FCFS (first things first) or SOT. After understanding the chapter's material, they should use SOT and have one schedule, but many will respond—two or more schedules.

   The are 5! possible schedules or 5 x 4 x 3 x 2 x 1 or 120 schedules.

5. The SOT rule provides an optimal solution in a number of evaluation criteria. Should the manager of a bank use the SOT rule as a priority rule? Why?

   Even though the SOT rule is optimal, the bank manager may still choose the FIFO rule for customer sequencing in order to keep the sense of "fairness;" whoever comes in first, gets served first.

6. Data integrity is a big deal in industry? Why?

   Data inaccuracy coupled with computer usage simply “speeds up the mess” and results in serious problems, such as excess inventory, stockouts, missed due dates, costing inaccuracies, etc.

7. Why does batching cause so much trouble in job shops?

   Batching can appear to improve efficiency and reduce setups. However, in some situations batching can lead to split lots, broken setups, lost parts, defects, late deliveries, large WIPs and the hockey stick phenomenon.

8. What job characteristics would lead you to schedule jobs according to “longest processing time first”?

   If the jobs with the longest processing times were also those with the least slack time or were critical to downstream operations, LOT might be used in lieu of SOT. The resultant minimization of idle time might also be highly important.

9. Why is managing bottlenecks so important in job-shop scheduling?

   The bottlenecks constrain capacity and limit throughput. Poor bottleneck management can lead to large WIPs. More on this topic in Chapter 18.

10. Under what conditions is the assignment method appropriate?

    The assignment method is appropriate when there are n “things” to be distributed to n “destinations,” each thing must be assigned to one and only one destination, and only one evaluation criterion can be used.

11. How might planning for a special customer affect the personnel schedule in a service?

    Since services are often very labor intensive, meeting the special requirements of important customers can lead to difficulties in scheduling. This can make it difficult to schedule two consecutive days off. The Brown and Tivrewala heuristic can aid in remedying this problem.

Problems

Problem	Type of Problem					Difficulty	New Problem	Modified Problem	Check figure in Appendix A
	Priority rules	Consecutive days-off	First hour principle	Assignment	Johnson's rule				
1	Yes					Easy			
2			Yes			Easy			
3					Yes	Moderate			Yes
4		Yes				Easy			
5	Yes					Moderate			
6				Yes		Moderate			Yes
7	Yes					Moderate			Yes
8		Yes				Easy			
9		Yes				Easy	Yes		
10					Yes	Moderate			Yes
11				Yes		Difficult			
12				Yes		Moderate			
13					Yes	Moderate			
14	Yes					Moderate			
15					Yes	Moderate			Yes
16		Yes				Moderate			
18			Yes			Easy			
17				Yes		Moderate			

1.

Car	Customer pick-up time	Remaining overhaul time	Number of remaining operations	Slack	Slack per remaining operations
A	10	4	1	6	6.0
B	17	5	2	12	6.0
C	15	1	3	14	4.7

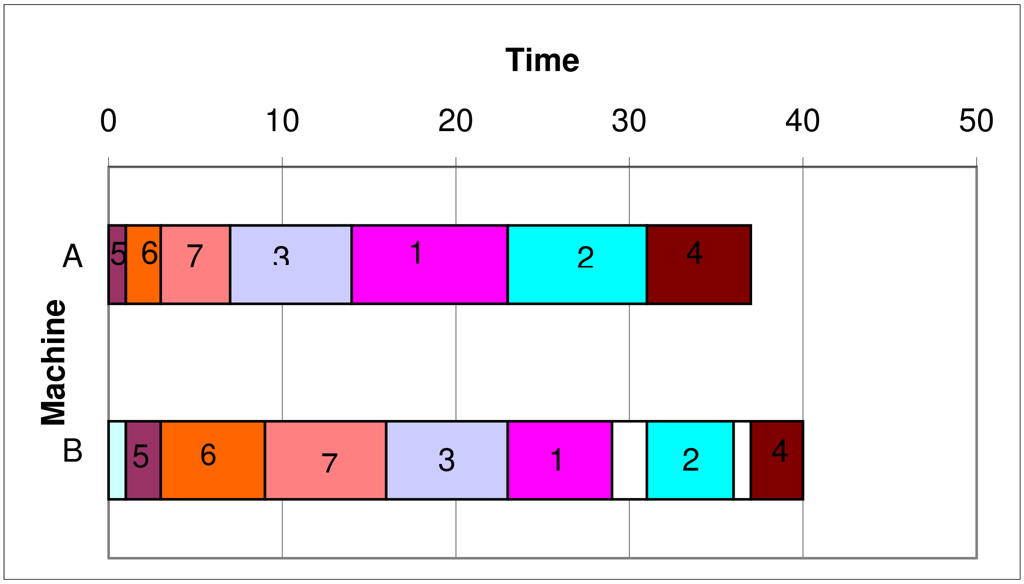
Select car C first, then A and B tie for second.

2.

	Period											
	8AM	9AM	10AM	11AM	Noon	1PM	2PM	3PM	4PM	5PM	6PM	7PM
Requirement	2	3	5	8	8	6	5	8	8	6	4	3
Assigned	2	1	2	3	2	0	0	6	2	0	0	1
On duty	2	3	5	8	8	7	5	8	8	8	8	3

3.

Job	Process A Time	Process B Time	Order of Selection	Position in Sequence
1	9	6	6th	5th
2	8	5	5th	6th
3	7	7	7th	4th
4	6	3	3rd	7th
5	1	8	1st	1st
6	2	6	2nd	2nd
7	4	7	4th	3rd



4.

Day	M	Tu	W	Th	F	S	Su
Requirements	2	2	1	3	3	4	2
Worker 1	2	2	1	3	3	4	2
Worker 2	1	2	1	2	2	3	1
Worker 3	1	1	0	1	1	2	1
Worker 4	0	1	0	0	0	1	0

5. a. SOT

Job	Time	Flow time
D	1	1
B	3	4
H	4	8
G	5	13
F	6	19
C	7	26
A	8	34
E	10	44

Total flow time is 149 days, mean flow time is 149/8 = 18.625 days.

b Scheduling E and G first, then using SOT, the following schedule results:

Job	Time	Flow time
E	10	10
G	5	15
D	1	16
B	3	19
H	4	23
F	6	29
C	7	36
A	8	44

Total flow time is 192 days, mean flow time is 192/8 = 24.000 days. Alternate schedules could be developed, such as a due-date schedule.

6.

Jobs

		1	2	3	4
Individuals	A	7	9	3	5
	B	3	11	7	6
	C	4	5	6	2
	D	5	9	10	12

Row reduction

Jobs

		1	2	3	4
Individuals	A	4	6	0	2
	B	0	8	4	3
	C	2	3	4	0
	D	0	4	5	7

Column reduction

Jobs

Individuals		1	2	3	4
	A	4	3	0	2
	B	0	5	4	3
	C	2	0	4	0
	D	0	1	5	7

Jobs

Individuals		1	2	3	4
	A	5	3	0	2
	B	0	4	3	2
	C	3	0	4	0
	D	0	0	4	6

Optimal solution

Jobs

Individuals	1	2	3	4
A	5	3	0	2
B	0	4	3	2
C	3	0	4	0
D	0	0	4	6

Optimal solution

Assign		Cost (thousands)
B	1	$3
A	3	3
C	4	2
D	2	9
Total		$17

7.

Job	Processing time	Delay time	Total time	Due date	CR
1	2	12	14	27	1.93
2	5	8	13	18	1.38
3	9	15	24	25	1.04
4	7	9	16	26	1.63
5	4	22	28	24	0.86

Sequences:

Critical ratio would be 5,3,2,4,1

Earliest due date: 2,5,3,4,1

Shortest processing time: 2,1,4,3,5

8. Answers may vary.

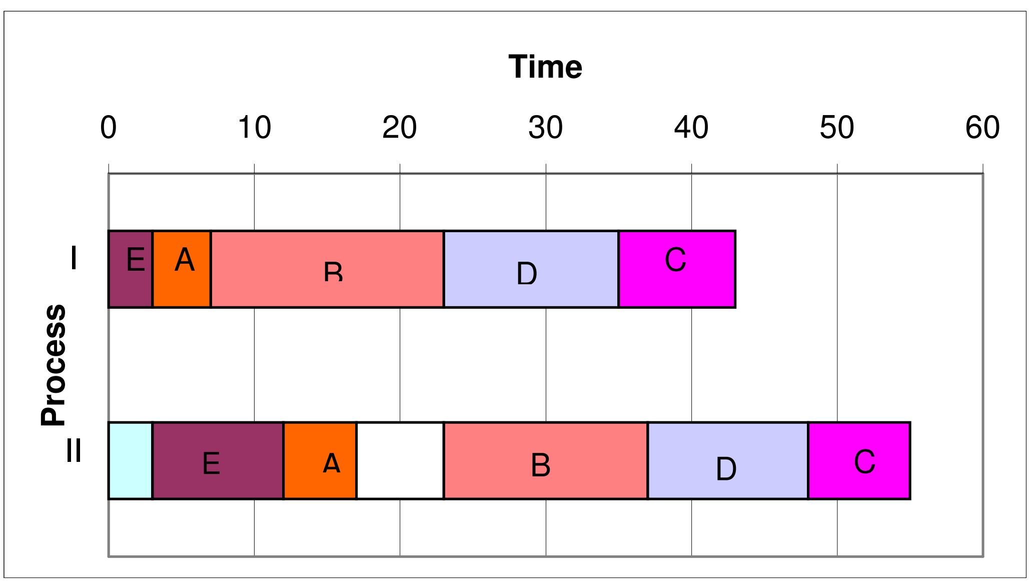
Day	M	Tu	W	Th	F	S	Su
Requirements	3	2	3	5	4	3	4
Auditor 1	3	2	3	5	4	3	4
Auditor 2	3	2	2	4	3	2	3
Auditor 3	2	2	2	3	2	1	2
Auditor 4	1	1	1	2	1	1	2
Auditor 5	1	1	0	1	0	0	1

9.

Day	M	Tu	W	Th	F	S	Su
Requirements	4	3	2	3	4	5	4
Adams	4	3	2	3	4	5	4
Chang	3	3	2	2	3	4	3
Klein	2	2	2	2	2	3	2
Ramirez	2	1	1	1	1	2	2
Sampson	1	1	1	0	0	1	1

10.

Job	Process I Time	Process II Time	Order of Selection	Position in Sequence
A	4	5	2nd	2nd
B	16	14	5th	3rd
C	8	7	3rd	5th
D	12	11	4th	4th
E	3	9	1st	1st



11.

Machine

Machinist		1	2	3	4	5	6
	A	65	50	60	55	80	0
	B	30	75	125	50	40	0
	C	75	35	85	95	45	0
	D	60	40	115	130	110	0
	E	90	85	40	80	95	0
	F	145	60	55	45	85	0

Row reduction would not change the matrix. Column reduction follows.

Machine

Machinist		1	2	3	4	5	6
	A	35	15	20	10	40	0
	B	0	40	85	5	0	0
	C	45	0	45	50	5	0
	D	30	5	75	85	70	0
	E	60	50	0	35	55	0
	F	115	25	15	0	45	0

Machine

Machinist		1	2	3	4	5	6
	A	30	10	15	5	35	0
	B	0	40	85	5	0	5
	C	45	0	45	50	5	5
	D	25	0	70	80	65	0
	E	60	50	0	35	55	5
	F	115	25	15	0	45	5

Machine

Machinist		1	2	3	4	5	6
	A	25	10	10	0	30	0
	B	0	45	85	5	0	10
	C	40	0	40	45	0	5
	D	20	0	65	75	60	0
	E	60	55	0	35	55	10
	F	115	30	15	0	45	10

Machinist \ Machine

	1	2	3	4	5	6
A	25	10	10	0	30	(0)
B	(0)	45	85	5	0	10
C	40	0	40	45	(0)	5
D	20	(0)	65	75	60	0
E	60	55	(0)	35	55	10
F	115	30	15	(0)	45	10

Optimal solution

Assign		Cost
A	dummy	0
B	1	30
C	5	45
D	2	40
E	3	40
F	4	45
Total		200

12.

Associate \ Area

	1	2	3	4
Bob	1400	1800	700	1000
Dave	600	2200	1500	1300
Nick	800	1100	1200	500
Dick	1000	1800	2100	1500

Row reduction

		Area			
		1	2	3	4
Associate	Bob	700	1100	0	300
	Dave	0	1600	900	700
	Nick	300	600	700	0
	Dick	0	800	1100	500

Column reduction

		Area			
		1	2	3	4
Associate	Bob	700	500	0	300
	Dave	0	1000	900	700
	Nick	300	0	700	0
	Dick	0	200	1100	500

Area

Associate		1	2	3	4
	Bob	700	300	0	100
	Dave	0	800	900	500
	Nick	500	0	900	0
	Dick	0	0	1100	300

Optimal

Area

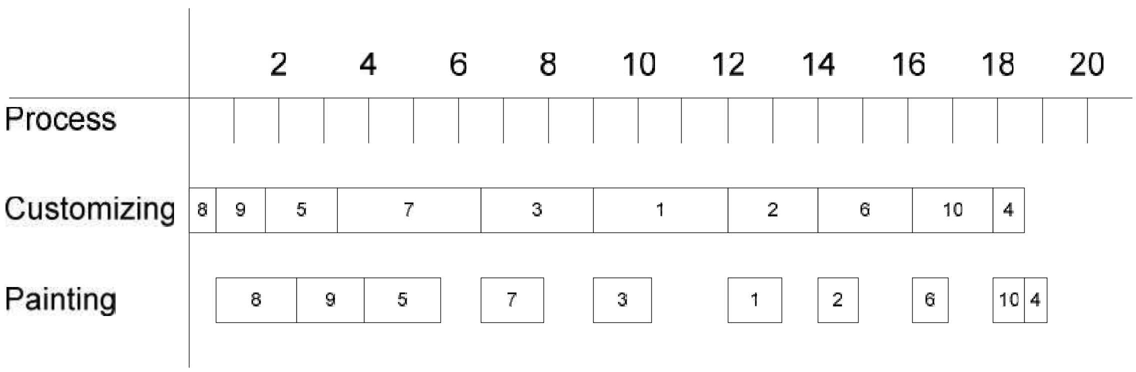
Associate		1	2	3	4
	Bob	700	300	0	100
	Dave	0	800	900	500
	Nick	500	0	900	0
	Dick	0	0	1100	300

Optimal solution

Assign		Cost
Bob	3	$700
Dave	1	600
Nick	4	500
Dick	2	1800
Total		$3600

13.

Job	Customizing Time	Painting Time	Order of Selection	Position in Sequence
1	3.0	1.2	7th	6th
2	2.0	0.9	5th	7th
3	2.5	1.3	8th	5th
4	0.7	0.5	1st	10th
5	1.6	1.7	10th	3rd
6	2.1	0.8	4th	8th
7	3.2	1.4	9th	4th
8	0.6	1.8	2nd	1st
9	1.1	1.5	6th	2nd
10	1.8	0.7	3rd	9th



14. a. FCFS

Job	Processing time	Due date	Flow time
A	4	20	4
B	12	30	16
C	2	15	18
D	11	16	29
E	10	18	39
F	3	5	42
G	6	9	48
	Total flow time		196
	Mean flow time		28

b. SOT

Job	Processing time	Due date	Flow time
C	2	15	2
F	3	5	5
A	4	20	9
G	6	9	15
E	10	18	25
D	11	16	36
B	12	30	48
	Total flow time		140
	Mean flow time		20

c. STR

Job	Processing time	Due date	Slack	Flow time
F	3	5	2	3
G	6	9	3	9
D	11	16	5	20
E	10	18	8	30
C	2	15	13	32
A	4	20	16	36
B	12	30	18	48
	Total flow time			178
	Mean flow time			25.4

d. DD

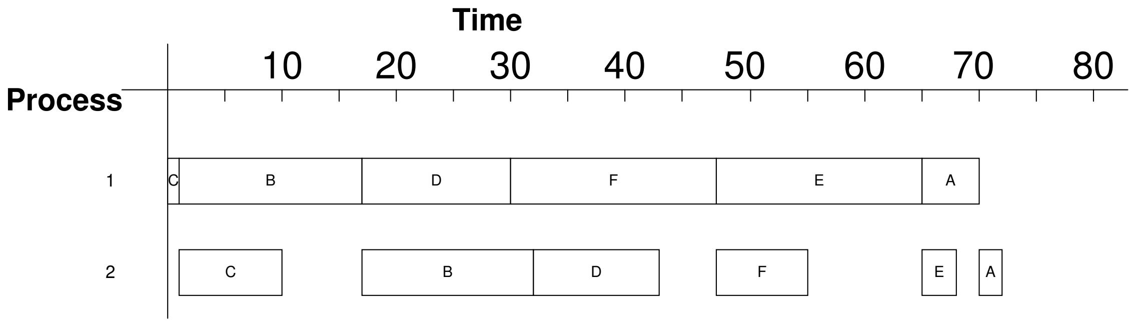
Job	Processing time	Due date	Flow time
F	3	5	3
G	6	9	9
C	2	15	11
D	11	16	22
E	10	18	32
A	4	20	36
B	12	30	48
	Total flow time		161
	Mean flow time		23

e. Summary

Priority rule	Mean flow time (days)
FCFS	28.0
SOT	20.0
STR	25.4
DD	23.0

15.

Job	Operation time - 1	Operation time - 2	Order of Selection	Position in Sequence
A	5	2	2nd	6th
B	16	15	6th	2nd
C	1	9	1st	1st
D	13	11	5th	3rd
E	17	3	3rd	5th
F	18	7	4th	4th



16.

Day	M	Tu	W	Th	F	S	Su
Requirements	5	2	3	4	8	9	3
Worker 1	5	2	3	4	8	9	3
Worker 2	4	2	3	3	7	8	2
Worker 3	3	2	3	2	6	7	1
Worker 4	2	2	3	2	5	6	1
Worker 5	2	1	2	1	4	5	1
Worker 6	1	0	2	1	3	4	0
Worker 7	1	0	1	0	2	3	0
Worker 8	0	0	1	0	1	2	0
Worker 9	0	0	0	0	0	1	0

Answers may vary.

17.

	Period										
	11AM	Noon	1PM	2PM	3PM	4PM	5PM	6PM	7PM	8PM	9PM
Requirements	4	8	5	3	2	3	5	7	5	4	2
Assigned	4	4	0	0	0	3	2	2	0	0	0
On-duty	4	8	8	8	4	3	5	7	7	4	2

18.

Job	Machine 1	2	3	4	5
A	6	11	12	3	10
B	5	12	10	7	9
C	7	14	13	8	12
D	4	15	16	7	9
E	5	13	17	11	12

Row reduction

Job	Machine 1	2	3	4	5
A	3	8	9	0	7
B	0	7	5	2	4
C	0	7	6	1	5
D	0	11	12	3	5
E	0	8	12	6	7

Column reduction

Machine

Job	1	2	3	4	5
A	3	1	4	0	3
B	0	0	0	2	0
C	0	0	1	1	1
D	0	4	7	3	1
E	0	1	7	6	3

Optimal solution

Machine

Job	1	2	3	4	5
A	3	1	3	0	2
B	1	1	0	3	0
C	0	0	0	1	0
D	0	4	6	3	0
E	0	1	6	6	2

Optimal solution

Assign		Cost
A	4	$3
B	3	10
C	2	14
D	5	9
E	1	5
Total		$41

TECHNICAL NOTE 17
SIMULATION

Review and Discussion Questions

1. Why is simulation often called a technique of last resort?

   Simulation is called a technique of last resort because simulation models are time consuming to build (flow charting, coding, etc.) and do not "guarantee" an optimal solution or indeed any solution. Therefore, it makes sense to investigate other problem solving methods such as linear programming or waiting line theory before embarking on simulation.

2. What roles do statistical hypothesis testing play in simulation?

   A simulation can be looked upon as a test of a hypothesis.

3. What determines whether a simulation model is valid?

   The only true test of a simulation is how well the real system performs after the results of the simulation have been implemented. The proof of the pudding is in the eating. Prior to this stage of application, however, the simulation user can certainly evaluate the general validity of the model by comparing its results with past data or simply asking the question: "Is the information I am getting reasonable?"

4. Must you use a computer to get good information from a simulation? Explain.

   A computer is a must for any but the most simple simulation problems. Because simulation is a sampling process, it stands to reason that a large number of observations is desirable, and the computer is the only practical way of providing them. Of course, computerization is no guarantee of "good" information. Simulating an invalid model on the computer will only provide a larger volume of questionable data.

5. What methods are used to increment time in a simulation model? How do they work?

   Time incrementing methods include fixed time increments and variable time increments. With fixed time increments, uniform clock times are specified (minutes, hours, days, etc.) and the simulation proceeds by fixed intervals from one time period to the next. At each point in clock time, the system is scanned to determine if any events have occurred and time is advanced; if none have, time is still advanced by one unit.

   With variable time increments, the clock time is advanced by the amount required to initiate the next event. It is interesting to note that variable time incrementing generally is more difficult to program unless one is using a special simulation language such as GPSS.

6. What are the pros and cons of starting a simulation with the system empty? With the system in equilibrium?

   The pros of starting a simulation with the system empty are that this enables evaluation of the transient period in terms of time to reach steady-state and the activities which are peculiar to the transient period.

   One con is that it takes a longer period of time to perform the simulation. A second is that the model will be biased by the set of initial values selected, since the time to achieve steady-state and the activities which take place during the transient period will be affected by the initial values. Steps must be taken to remove these initial values if steady-state results are needed.

   The advantages of starting the system in equilibrium are that the run time may be greatly reduced, and that the aforementioned bias may be eliminated.

   The disadvantage of starting the simulation in equilibrium is, in essence, that it assumes that the analyst has some idea of the range of output he is looking for. This, in a sense, constitutes "beating" the model and may lead to incorrect conclusions from the simulation run.

7. Distinguish between known mathematical distributions and empirical distributions. What information is needed to simulate using a known mathematical distribution?

   A "known mathematical distribution" is one that can be generated mathematically and is amenable to the laws of statistical probability. Examples of such distributions are the normal, binomial, Poisson, Gamma, and hypergeometric.

   An empirical distribution is one that is obtained from observing the probability of occurrence of phenomena relating to a specific situation. While it may be possible to define the moment generating function for such distributions, their applicability to other situations is likely to be small.

   The information required to simulate using a know distribution, of course, depends on the known distribution selected. Generally speaking, however, at a minimum, the analyst must be able to estimate the mean and standard deviation of the population to be sampled since they are parameters of distributions.

8. What is the importance of run length in simulation? Is a run of 100 observations twice as valid as a run of 50? Explain.

   The length of the simulation run generally determines how much confidence one may have in the results generated by the model. Since simulation is in a large measure a sampling process, it stands to reason that the larger the sample (i.e., the longer the simulation run) the more representative the findings. One the other hand, the selection of variables and parameters for a simulation study represent major sources of potential error and simply running a simulation for a long period of time will not overcome inaccuracies introduced through these factors.

   A run of 100 may be twice as good as a run of 50, it may be 10 times as good, or may simply be no better. It depends on the size of the model, the nature of the distributions selected, the stream of random numbers used, and the objective of the study.

Problems

Problem	Type of Problem			Difficulty	New Problem	Modified Problem	Check figure in Appendix A
	Fixed time increment	Variable time increment	Simulation design				
1	Yes			Moderate			
2		Yes		Easy			Yes
3		Yes		Moderate			
4		Yes		Moderate			
5		Yes		Moderate			
6	Yes			Moderate			
7		Yes		Difficult			Yes
8		Yes		Easy			
9			Yes	Moderate			
10		Yes		Difficult			
11		Yes		Difficult			Yes
12	Yes			Moderate			

1. The following decision rules were used for this simulation. 1. Total orders placed is equal to demand in the past three periods (for periods immediately before the start of the game, 800 cases was used. 2. 5% of the total orders placed were flash frozen except for the two weeks before Mardi Gras. Note that solutions will change with different decision rules and with different sets of random numbers. It may be interesting to see what decision rules students used as well as they profitability.

To determine the amount received the following random number assignment table was used:

Change	Probability	Random number
- 10%	.30	00-29
0%	.50	30-79
+ 10%	.20	80-99

Two digit random numbers are then drawn from a uniformly distributed random number table such as Appendix B.

For the demand, the equation $D = 800 + 100\sigma$ is used, with σ selected from a normally distributed random digits tables such as Appendix C.

The following table illustrates one set of numbers obtained for the change in orders received and the demand:

Week	Random number	Change(%)	Z	Demand (D)
1	80	+10	-0.23812	776
2	47	0	0.18124	818
3	59	0	-1.35882	664
4	32	0	-1.45402	655
5	47	0	-0.28185	772
6	11	-10	1.16515	917
7	44	0	-0.28278	772
8	82	+10	1.6441	964
9	88	+10	0.32468	832
10	89	+10	0.34506	835

Week	Flash frozen inventory	Orders placed		Orders received		Available (regular and flash frozen)	Demand (800 + 100Z)	Sales (minimum of demand or available)	Excess		Shortages
		Regular	Flash frozen	Regular	Flash frozen				Regular	Flash	
1	0	760	40	836	44	880	776	776	604	44	0
2	44	752	40	752	40	836	818	818	0	18	0
3	18	758	40	758	40	816	664	664	94	58	0
4	58	715	38	715	38	811	655	655	60	96	0
5	96	676	36	676	36	808	772	772	0	36	0
6	36	662	35	596	32	664	917	664	0	0	253
7	0	---------MARDI GRAS---------				0	772	0	0	0	772
8	0	779	41	857	45	902	964	902	0	0	62
9	0	840	44	924	48	972	832	832	92	48	0
10	48	813	43	894	47	989	835	835	59	95	0
total	300			7108	370			6918	365	395	1087

Profits

Revenue from sales ($50 x col. 7)	$345,900	
Revenue from salvage ($4 x col. 8 reg.)	$1,460	
Total Revenue		$347,360
Cost of regular purchases ($30 x col. 4 reg.)	$213,240	
Cost of flash-frozen purchases ($34 x col.4 flash)	$12,580	
Cost of holding flash –frozen ($2 x col.8 flash)	$790	
Cost of shortages ($20 x col. 9)	$21,740	
Total cost		$248,350
Profit		$99,010

2.

Time between arrivals (minutes)	Probability	RN assignment
1	.08	00-07
2	.35	08-42
3	.34	43-76
4	.17	77-93
5	.06	94-99

Service Time (minutes)	Probability	RN assignment
1.0	.12	00-11
1.5	.21	12-32
2.0	.36	33-68
2.5	.19	69-87
3.0	.07	88-94
3.5	.05	95-99

Customer number	RN	Interarrival time	Arrival time	Service begins	RN	Service time	Service ends	Waiting time	Idle time
1	08	2	2	2.0	74	2.5	4.5	0.0	2.0
2	24	2	4	4.5	34	2.0	6.5	0.5	0.0
3	45	3	7	7.0	86	2.5	9.5	0.0	0.5
4	31	2	9	9.5	32	1.5	11.0	0.5	0.0
5	45	3	12	12.0	21	1.5	13.5	0.0	1.0
6	10	2	14	14.0	67	2.0	16.0	0.0	0.5

Average waiting time = 1.0/6 = 1/6 minute, and average teller idle time between customers = 4.0/6 = 4/6 minute. Average teller idle time percent = 4.0/16 = .25 or 25%.

3.

Option a:

Simulation	RN	Time-dist. 1	RN	Time-dist. 3	RN	Pay-dist. 4	RN	Time-dist. 5	Total time	Total pay
1	7	1.5	3	1.5	0	$2/crew	4	4.0	7.0	$6.00
2	0	1.0	5	2.0	3	$3/crew	5	4.0	7.0	$9.00
							Average		7.0	$7.50

Option b:

Simulation	RN	Time-dist. 1	RN	Time-dist. 6	Total time
1	6	1.5	1	5.0	6.5
2	6	1.5	6	6.0	7.5
				Average	7.0

Option c:

We need two more distributions and random number assignments:

TC at airport?	Probability	RN
Yes	.10	0
No	.90	1-9

TC refuses $10?	Probability	RN
Yes	.30	0-2
No	.70	3-9

Simulation	RN	Time-dist. 2	RN	TC at airport?	RN	Time-dist. 8	RN	TC refuses $10	RN	Time-dist. 7	Total Time
1	4	1.0	8	No	4	3.0	9	No	0	1.0	5.0
2	7	1.0	7	No	1	2.0	7	No	0	1.0	4.0
									Average		4.5

Summary:

Option	Average trip time
a	7.0
b	7.0
c	4.5

4.

Machine breakdown number	RN	Interarrival time (hours)	Breakdown time (hours)	RN	Service time (hours)	Repairman 1 begin	Repairman 1 end	Repairman 2 begin	Repairman 2 end	Down time (hours)
1	30	1.0	1.0	81	3.0	1.0	4.0			3.0
2	02	0.5	1.5	91	4.0			1.5	5.5	4.0
3	51	1.0	2.5	08	0.5	4.0	4.5			2.0
4	28	0.5	3.0	44	1.0	4.5	5.5			2.5
5	86	3.0	6.0	84	3.0	6.0	9.0			3.0

Average down time is 14.5/5 = 2.9 hours

5. Answers will vary based upon the random numbers selected.

Interarrival time (min).	Probability	RN
1	.05	00-04
2	.10	05-14
3	.10	15-24
4	.15	25-39
5	.15	40-54
6	.20	55-74
7	.10	75-84
8	.08	85-92
9	.05	93-97
10	.02	98-99

Service time (min).	Probability	RN
1	.10	00-09
2	.15	10-24
3	.15	25-39
4	.20	40-59
5	.15	60-74
6	.10	75-84
7	.08	85-92
8	.04	93-96
9	.02	97-98
10	.01	99

Customer number	RN	Interarrival time (min.)	Arrival time (min.)	Service begins	RN	Service time (min.)	Service ends	Time in system (min.)
1	56	6	6	6	95	8	14	8
2	83	7	13	14	95	8	22	9
3	55	6	19	22	66	5	27	8
4	47	5	24	27	17	2	29	5
5	84	7	31	31	03	1	32	1
6	08	2	33	33	21	2	35	2
7	36	4	37	37	57	4	41	4
8	05	2	39	41	31	3	44	5
9	26	4	43	44	69	5	49	6
10	42	5	48	49	90	7	56	8

Average time in system = 56/10 or 5.6 minutes.

6. Answers will vary depending upon whether minor or major injuries are calculated first, and the assignment of RN to major injuries.

Number of minor injuries	Probability	RN
0	.200	000-199
1	.500	200-699
2	.220	700-919
3	.050	920-969
4	.025	970-994
5	.005	995-999

Major injury?	Probability	RN
Yes	.050	000-049
No	.950	050-999

Game number	Beginning number of RBs	RN	Major injury?	RN	Number of minor injuries	Ending number of RBs
1	6	044	Yes	392	1	4
2	4	898	No	615	1	3
3	4	986	No	959	3	1
4	2	558	No	353	1	1
5	4	577	No	866	2	2
6	3	305	No	813	2	1
7	3	024	Yes	189	0	2
8	4	878	No	023	0	4
9	4	285	No	442	1	3
10	3	862	No	848	2	1

7.

Time between breakdowns (minutes)	Probability	RN assignment
4	.10	00-09
5	.30	10-39
6	.25	40-64
7	.20	65-84
8	.10	85-94
9	.05	95-99

Service Time (minutes)	Probability	RN assignment
4	.10	00-09
5	.40	10-49
6	.20	50-69
7	.15	70-84
8	.10	85-94
9	.05	95-99

						Condition 1					Condition 2						
Break-down number	RN	Time between break-downs	Breakdown time	RN	Service time	Start	end	Repair-man idle time	Machine wait time	Down-time	1 Start	1 End	2 Start	2 End	Idle time – repair-man 1	Idle time – repair-man 2	Down-time
1	85	8	8	68	6	8	14	8	0	6	8	14			8		6
2	16	5	13	26	5	14	19	0	1	6			13	18		13	5
3	65	7	20	85	8	20	28	1	0	8	20	28			6		8
4	76	7	27	11	5	28	33	0	1	6			27	32		9	5
5	93	8	35	16	5	35	40	2	0	5	35	40			7		5
6	99	9	44	26	5	44	49	4	0	5	44	49			4		5
7	65	7	51	95	9	51	60	2	0	9	51	60			2		9
8	70	7	58	67	6	60	66	0	2	8			58	64		26	6
9	58	6	64	97	9	66	75	0	2	11	64	73			4		9
10	44	6	70	73	7	75	82	0	5	12			70	77		6	7
11	2	4	74	75	7	82	89	0	8	15	74	81			1		7
12	85	8	82	64	6	89	95	0	7	13	82	88			1		6
13	1	4	86	26	5	95	100	0	9	14			86	91		9	5
14	97	9	95	45	5	100	105	0	5	10	95	100			7		5
15	63	6	101	1	4	105	109	0	4	8	101	105			1		4
16	52	6	107	87	8	109	117	0	2	10	107	115			2		8
17	53	6	113	20	5	117	122	0	4	9			113	118		22	5
18	11	5	118	1	4	122	126	0	4	8	118	122			3		4
19	62	6	124	19	5	126	131	0	2	7	124	129			2		5
20	28	5	129	36	5	131	136	0	2	7	129	134			0		5
21	84	7	136	69	6	136	142	0	0	6	136	142			2		6
22	82	7	143	89	8	143	151	1	0	8	143	151			1		8
23	27	5	148	81	7	151	158	0	3	10			148	155		30	7
24	20	5	153	81	7	158	165	0	5	12	153	160			2		7
25	39	5	158	2	4	165	169	0	7	11			158	162		3	4
26	70	7	165	5	4	169	173	0	4	8	165	169			5		4
27	26	5	170	10	5	173	178	0	3	8	170	175			1		5
28	21	5	175	51	6	178	184	0	3	9	175	181			0		6
29	41	6	181	24	5	184	189	0	3	8	181	186			0		5
30	81	7	188	36	5	189	194	0	1	6	188	193			2	31	5
Total								18	87	263					61	149	176

b.

	Condition 1	Condition 2
Repairman idle time	18 minutes	210 minutes
Downtime	263 minutes	176 minutes
Delay time	87 minutes	0 minutes
Cost – downtime	(263/60)*$40) = $175.33	(176/60)*$40 = $117.33
Cost – service	(194/60)*$12 = $38.80	2*(193/60)*$12 = $77.20
Total cost	$214.13	$194.53

8.

Interarrival time (min).	Probability	RN
10	.40	00-39
20	.35	40-74
30	.20	75-94
40	.05	95-99

Interarrival time (min).	Probability	RN
5	.45	00-44
10	.30	45-74
15	.20	75-94
20	.05	95-99

Customer number	RN	Interarrival time (min.)	Arrival time (min.)	Service begins	RN	Service time (min.)	Service ends	Time in system (min.)
1	99	40	40	40	00	5	45	5
2	73	20	60	60	09	5	65	5
3	38	10	70	70	53	10	80	10
4	72	20	90	90	91	15	105	15

No cars go to another station. The average time spent at the station is 35/4 = 8.75 minutes

9. (1) Criteria for making recommendation:

a. average line length under different check-out minimums

b. customer comments on different minimums

c. cost of employing different numbers of checkers

d. competitive practices and regional differences in shopper purchases

e. desired holding time in line (to expose customers to impulse items)

f. range of other sizes to be considered (remember, the average store has nine stands, others may have more or less)

(2) Additional data to setup simulation:

a. arrival patterns and rates to counters

b. service patterns and rates

c. seasonal variation in store patronage

d. distribution of individual customer purchases, etc.

(3) Preliminary data gathering:

a. work sampling or estimates by store management

b. model one store for pilot analysis, etc.

(4) Problem setup for simulation:

Basically follow the general procedure listed in the Chapter, keeping in mind what type of output data you are looking for. Here, we might suggest developing a tradeoff table that indicates:

a. the average line lengths for different checkout minimums

b. the service cost and imputed waiting costs for customers associated with items in a.

(5) Factors affecting applicability to all stores:

a. stocking and sales patterns

b. cultural differences (Canada vs. U.S., stores in large cities vs. small cities, etc.)

c. competition faced by different stores

d. size of stores themselves

10. First begin by using by simulation the process sequence and associated process times. Then schedule as a static shop using FCFS. Answers will vary based upon the random numbers selected and the sequence in which process sequence is determined.

Sequence determination:

Starting process	Probability	RN
Frame	.5	0-4
Engine	.3	5-7
Painting	.2	8-9

From Frame to	Probability	RN
Engine	.4	0-3
Painting	.4	4-7
Out	.2	8-9

From Engine to	Probability	RN
Frame	.3	0-2
Painting	.4	3-6
Out	.3	7-9

From Painting to	Probability	RN
Frame	.1	0
Engine	.1	1
Out	.8	2-9

Processing times:

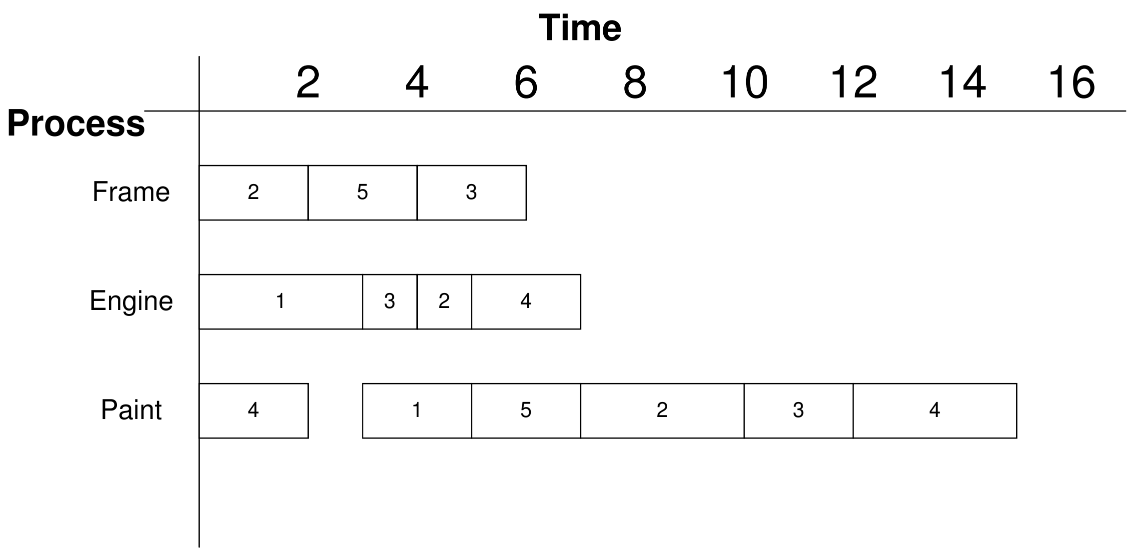
Frame – Processing time (hours)	Probability	RN
1	.2	0-1
2	.4	2-5
3	.4	6-9

Engine – Processing time (hours)	Probability	RN
1	.6	0-5
2	.1	6
3	.3	7-9

Painting – Processing time (hours)	Probability	RN
1	.3	0-2
2	.3	3-5
3	.4	6-9

Cycle Number	RN	Process	RN	Process time
1	5	Engine	8	3
	5	Paint	4	2
	8	Out		
2	0	Frame	3	2
	0	Engine	2	1
	4	Paint	9	3
	9	Out		
3	6	Engine	1	1
	0	Frame	2	2
	5	Paint	3	2
	6	Out		
4	9	Paint	3	2
	1	Engine	6	2
	6	Paint	9	3
	6	Out		
5	3	Frame	5	2
	7	Paint	4	2
	8	Out		

Gantt Load Chart



It appears that the 5 cycles can be completed within the 40 hours allotted. However, additional replications should be conducted to confirm this answer.

11.

Time between arrivals (minutes)	Probability	RN
1	.40	00-39
2	.30	40-69
3	.15	70-84
4	.15	85-99

Service time (minutes)	Probability	RN
1	.20	00-19
2	.40	20-59
3	.40	60-99

Car number	RN	Time between arrivals	Arrival time	Enter system?	Service begins	RN	Service time	Service ends
1	37	1	1	Yes	1	66	3	4
2	60	2	3	Yes	4	74	3	7
3	79	3	6	Yes	7	90	3	10
4	21	1	7	Yes	10	95	3	13
5	85	4	11	Yes	13	29	2	15
6	71	3	14	Yes	15	72	3	18
7	48	2	16	Yes	18	17	1	19
8	39	1	17	No	---	---	---	---
9	31	1	18	Yes	19	55*	2	21
10	35	1	19	Yes	21	15	1	22

*One random number could be skipped, using 15 rather than 55.

Answer: one car does not enter system due to two cars already being in the system.

12.

Sales per week	Probability	RN
5	.05	00-04
6	.05	05-09
7	.10	10-19
8	.10	20-29
9	.10	30-39
10	.20	40-59
11	.20	60-79
12	.10	80-89
13	.05	90-94
14	.05	95-99

Week	Beginning inventory	RN	Sales	Ending inventory	Order?
1	25	23	8	17	Yes
2	17	59	10	7	
3	34	82	12	22	
4	22	83	12	10	Yes
5	10	61	11	0*	
6	27	00	5	22	
7	22	48	10	12	Yes
8	12	33	9	3	
9	30	06	6	24	
10	24	32	9	15	Yes
11	15	82	12	3	
12	30	51	10	20	Yes
13	20	54	10	10	
14	37	66	11	26	
15	26	55	10	16	Yes

*An assumption must be made in this situation. The above assumed a "lost sales" approach. In other words, since the item was not on hand, the customer purchased elsewhere. Another assumption would be a backorder. In that case, the ending inventory would be 0, with a backorder of 1. Many times this is represented by a –1. The impact on the simulation is that the beginning inventory for week 6 would be 26, not 27, and the following inventory level would need to be adjusted.

The inventory policy appears to be acceptable. However, during period 5 there was a shortage of cars. Different policies (different reorder points and order sizes) should be examined. Additionally, longer or multiple simulation runs of each policy should be conducted to improve the reliability of the results.

CHAPTER 18
SYNCHRONOUS MANUFACTURING AND THEORY OF CONSTRIANTS

Review and Discussion Questions

1. State the global performance measurements and operational performance measurements and briefly define each of them. How do these differ from traditional accounting measurements?

   Global performance measurement:

   - Net profit—measurement in dollars

   - Return on investment—generally a percent of the investment

   - Cash flow—the amount of cash available for day to day operations. From an accounting standpoint, deductions such as for depreciation are added back in since depreciation is not really money spent

   Operational measurement:

   - Throughput—the actual rate of sales generated by the system

   - Inventory—all the money invested in things that are intended to be sold. This includes raw materials, equipment, etc., but at the cost price, less any depreciation (which is operating expense).

   - Operating expense—money spent to convert inventory into throughput. This includes direct and indirect labor, materials, depreciation, administrative costs, etc.

   Traditional accounting methods work with such things as standard costs, allocation of burdens (which may consist of indirect labor, administrative costs, insurance, taxes, depreciation, etc.), and gross profits, net profits, cost centers, profit centers, all of which may be based on standards and allocations. These may not have any basis in reality.

   Many examples can be cited where traditional accounting forces wrong decisions. One specific example that one of the authors has confronted is of a V. P. of manufacturing who is terminating a very profitable product line, because on paper this product line is losing money. Why? Because overhead is allocated based on the amount of direct labor and this product line is almost all-direct labor, with very little equipment involved. His allocation of everyone else’s burden creates a paper loss. Under these circumstances he would lose his annual bonus and be rated down in his performance.

   Other areas of accounting differences: inventory in traditional accounting is carried the same as cost of goods sold, i.e., with all the labor and burdens included. In operational measurement’s terminology, inventory is carried as the cost of the raw materials.

2. Discuss process batch and transfer batches. How might you determine what the sizes should be?

   Process batch size is the total number of units that are scheduled to be processed within the same setup. Larger process batches involve fewer setups and, therefore, have more output. The reverse is true for smaller process batches.

   Transfer batches refers to the movement of part of the process batch, rather than waiting for the entire job to be completed. A process batch of 1000, for example, can be transferred in ten batches of 100 each.

   Process batch and transfer batch sizes can be controlled from a bottleneck or capacity constrained resource.

3. Compare and contrast JIT, MRP, and synchronized manufacturing, stating their main features, such as where each is or might be used, amounts of raw materials and work-in-process inventories, production lead times and cycle times, and methods for control.

Question	JIT	MRP	Synchronized Manufacturing
Where used	Continuous flow, make-to-stock	Job shop, custom shop	Job shop, custom shop
WIP	Very low	Very high	low
Production cycle time	Very short	Very long	Short
Schedule flexibility	Level production for min. of 30 days	MRP frozen for 30 days, but variable in work centers	Can be changed daily as needed
Regard for capacity limits	High. Tries to balance capacity	Terrible. May start off o.k., but quickly becomes inaccurate	Is founded on capacity limitations
Labor skills	Multi-skilled to help out other areas	Specialized in own work area	Same as MRP

4. Compare the importance and relevance of quality control in JIT, MRP, and synchronous manufacturing.

   Quality control is extremely important at each workstation in JIT, JIT cannot tolerate poor quality since the result is loss of throughput. Therefore, each worker or workstation is responsible for ensuring that only high quality work passes through.

   Quality control in MRP is somewhat haphazardly applied. Defects can occur anywhere and full responsibility for quality does not lie within each workstation. Inspection points are placed within the system, generally with the placement decided by the algorithm "when the expected cost of bad quality output exceeds the cost of inspection, we will place an inspection point there."

   Quality control in synchronous manufacturing is specifically decided based on importance. First, a bottleneck or CCR is identified as the constraint of the system. This critical resource will then be guaranteed that it will not waste time working on bad parts since inspection will be done on its incoming side. Flow after this bottleneck should not be interrupted or scrapped. Therefore, all parts that join into this product after the bottleneck will have passed inspection. Also, all processing after the bottleneck will be of high quality so that scrap will not be created. In summary, inspect before the BN, and inspect all parts entering the flow after the BN; also perform high quality work at all stations after the BN

5. Discuss what is meant by forward loading and backward loading.

   Forward loading is similar to project scheduling. Tasks are scheduled from some pint into the future. When resources are limited, tasks are assigned until capacity is reached and then carried forward to the next period.

   Backward loading is the MRP type scheduling, where the finished product or required part is needed. From that future point, a schedule is created back to the present, allowing for processing and lead time requirements at each step of the way.

6. Define and explain the cause or causes of a moving bottleneck.

   Generally, a moving bottleneck is caused by batch sizes that are too large. What happens is that a large batch scheduled on a machine or resource which-on the average has excess capacity-prevents other products from being completed that also need the same resource. This interrupts the flow and starves downstream resources. From their perspective looking upstream, they see that particular resource as the bottleneck. However, days or weeks later, because of the product mix, this apparent bottleneck will disappear. Another large batch size somewhere else in the system will appear which does the same thing, i.e., starves downstream operations.

7. Explain how a nonbottleneck can become a bottleneck.

   A non-bottleneck can become a bottleneck when it is scheduled with a batch size that is too large. For example, assume that machine 1 provides work to machine 2 and machine 3. Say that machine 1 works 7 hours out of each 8 hours and so is not a bottleneck. Suppose, however, that someone decides to save some setup time by scheduling work on machine 1 in much larger batches-say 20 hours for machine 2 and 15 hours for machine 3 (5 times larger batch sizes).

   Machine 3 will be starved for work since it will be dealing with a 40 hour cycle rather than an 8 hour cycle, and will have to wait until machine 1 produces the parts which it needs. Thus, from machine 3's point of view, machine 1 has become a bottleneck.

8. What are the functions of inventory in MRP, JIT, and synchronous manufacturing scheduling?

   MRP assumes WIP inventories and times the production of these inventories to coincide with the preplanned delivery dates. The costs of inventories are computed based on carrying costs. Inventories are seen as necessary. MRP systems allow for economic order quantities, buffer stocks, and safety stocks. In MRP systems, inventories are pushed through the productive processes. Just-in-time, on the other hand, sees inventories as wasteful. Means are sought by which inventories can be reduced or eliminated. Constant attention is given to the reduction of unnecessary inventories. This creates a productive system where stability is important and quality must be assured. Synchronous manufacturing treats inventory as a loan given to the manufacturing unit. Inventories are measured by raw materials cost. Buffer inventories are utilized to assure throughput. Overall, synchronous manufacturing discourages inventory if it serves no purpose. Inventory is measured in terms of dollar days with the goal of minimizing dollar days.

9. Define process batch and transfer batch and their meaning in each of these applications: MRP, JIT and bottleneck or constrained resource logic.

   In an assembly line, process batch refers to the batch size associated with a production process. Theoretically, this batch size can be infinite. The transfer batch refers to the number of parts produced in a sequence. This may be as small as one. In MRP, process batch refers to the overall output of production process while transfer batch would be equal to the calculated requirements for a given time bucket. In JIT, the transfer batch size is preferably one. Process batches are infinite, as flexible production lines are capable of producing an entire product family with minimal setups. Process batch might be synonymous with the daily production quotas. In synchronous manufacturing, a process batch is of a size large enough to be processed in a particular length of time. Transfer batches refer to the movement of part of the process batch. This allows parts to be moved to succeeding workstations in the process. A transfer batch can be equal in size to a process batch but not larger.

10. Discuss how a production system is scheduled using MRP logic, JIT logic, and synchronous manufacturing logic.

    In MRP, production is scheduled based on lead time requirements for a particular part of subassembly. Production dates for components are calculated based on lead times offset from delivery due dates. In JIT, production is controlled using a kanban or "visual record." When work is completed at a downstream station, a move kanban is released and materials are transferred from the upstream station. Daily production schedules are determined based on a daily production quota. Smooth production schedules are sought to minimize disruptions to operations. In synchronous manufacturing, the production flows are controlled by the drum. The drum regulates the flow of materials throughout the entire system.

11. Discuss the concept of "drum-buffer-rope."

    The drum is a bottleneck. It is referred to as the drum because it strikes the beat that the rest of the system uses to function. The buffer is inventory that is provided (typically prior to the drum) to make sure that the drum always has something to do. Buffers are also used to make sure that throughput is maintained throughout the production system. The rope is upstream communication from the bottleneck so that prior workstations only produce the materials needed by the drum. This keeps WIP inventories from building up.

12. From the standpoint of the scheduling process, how are resource limitations treated in an MRP application and how are they treated in a synchronous manufacturing application?

    With MRP, requirements are exploded using MRP logic. Planned order release schedules are calculated by the system. Capacity requirements planning (CRP) provides feasibility check of these schedules. CRP matches planned production with actual capacity to ensure that schedules can be met, synchronous manufacturing paces the entire production process by the bottlenecks. Therefore, if additional (less) capacity is needed, capacity is added (restricted) at the bottlenecks. In this way the flow is controlled at each bottleneck or CCR to bring the capacities in line.

13. What are operations people's primary complaints against the accounting procedures used in most firms? Explain how such procedures can cause poor decisions for the total company.

The primary complaints against accounting departments have to do with the fact that accounting systems measure the wrong things, are inflexible and reward counterproductive or dysfunctional behavior. Accounting systems conform to rigid guidelines established by GAAP. As such, accounting data are often not useful for accomplishing the superordinate goals of the firm. An example is machine utilization. Machine utilization measures the proportion of time that a machine is in use. In an accounting sense, high machine utilization is preferable because it means that the investment in the machine is producing a return. From an operations point of view, this behavior results in high WIP inventory. Another example is quality. The generally accepted accounting definition of quality is that of conformance. However, manufacturing may desire to adopt a definition of quality that considers customer needs. Accounting would be unable to accept the latter definition as it is more difficult to quantify. The two alternative definitions of quality will reward different behavior within the firm.

14. Most manufacturing firms try to balance capacity for their production sequences. Some believe that this is an invalid strategy. Explain why balancing capacity does not work.

In synchronous manufacturing, balancing all capacities is viewed as a bad decision. If capacity is truly balanced, completion deadlines may not be met due to variability in processing times. A better strategy is to balance the flow of product through the system.

15. Discuss why Transfer batches and process batches many times may not and should not be equal.

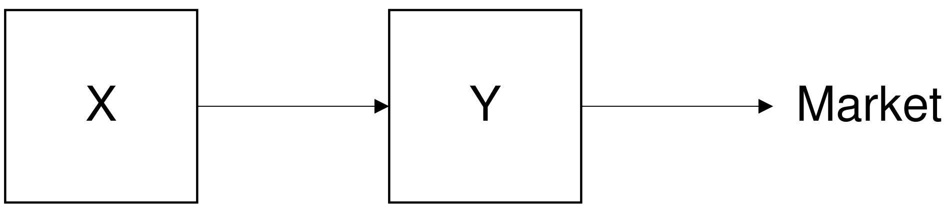
Transfer batches may be equal to or smaller in size than process batches. Rather than wait for an entire batch to be finished, it may be preferable to release part of a batch to the next downstream workstation so that smooth product flow can be maintained. This will also result in lower levels of WIP inventory.

Problems

Problem	Type of Problem				Difficulty	New Problem	Modified Problem	Check Figure in Appendix A
	Bottleneck analysis	Placement of buffers, inspections, etc.	Product mix	Company type				
1	Yes				Easy			Yes
2		Yes			Moderate			
3		Yes			Moderate			
4		Yes			Moderate			
5	Yes				Easy			
6			Yes		Moderate			
7				Yes	Moderate			
8	Yes		Yes		Moderate			Yes

1. The goal of a firm in operational measurements is to increase throughput while reducing inventory and operational expenses. In these cases, the throughputs are limited by the bottleneck. We should avoid the overuse of nonbottleneck resources, resulting in excess inventories.

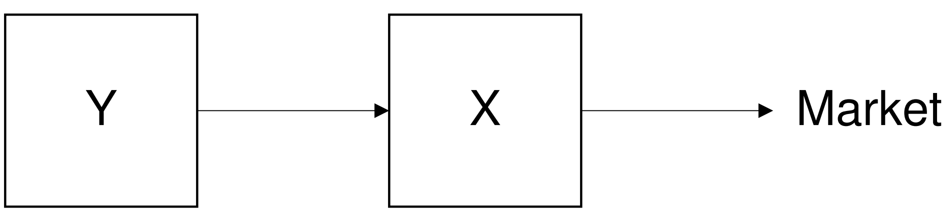
   Case I:



X: (1400 x40)/60 = 933.33 hours, X used 100%

Y: (1400x30)/60 = 700 hours, Y used 75%

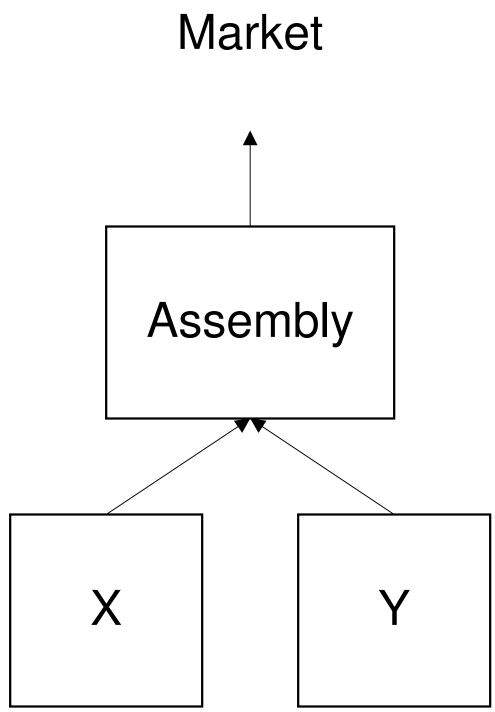
Case II:



Y: (1400x30)/60 = 700 hours, Y used 75% or work in process will build up.

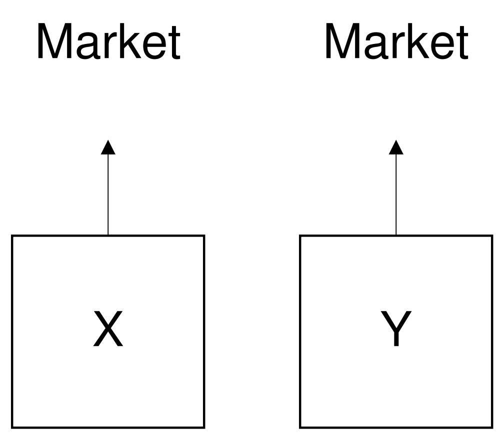
X: (1400 x40)/60 = 933.33 hours, X used 100%

Case III:



X = 933.33 hour, Y is used 700 hours or 75% or spare parts will accumulate at assembly.

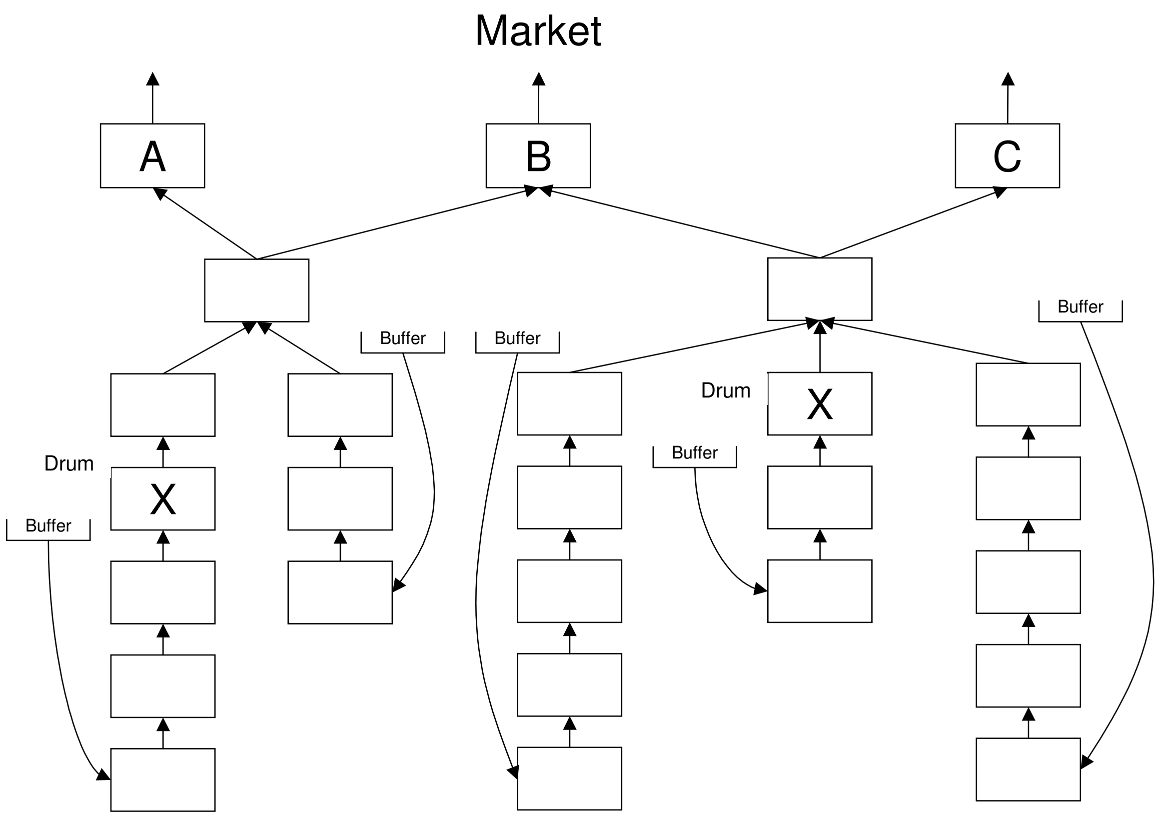
Case IV:



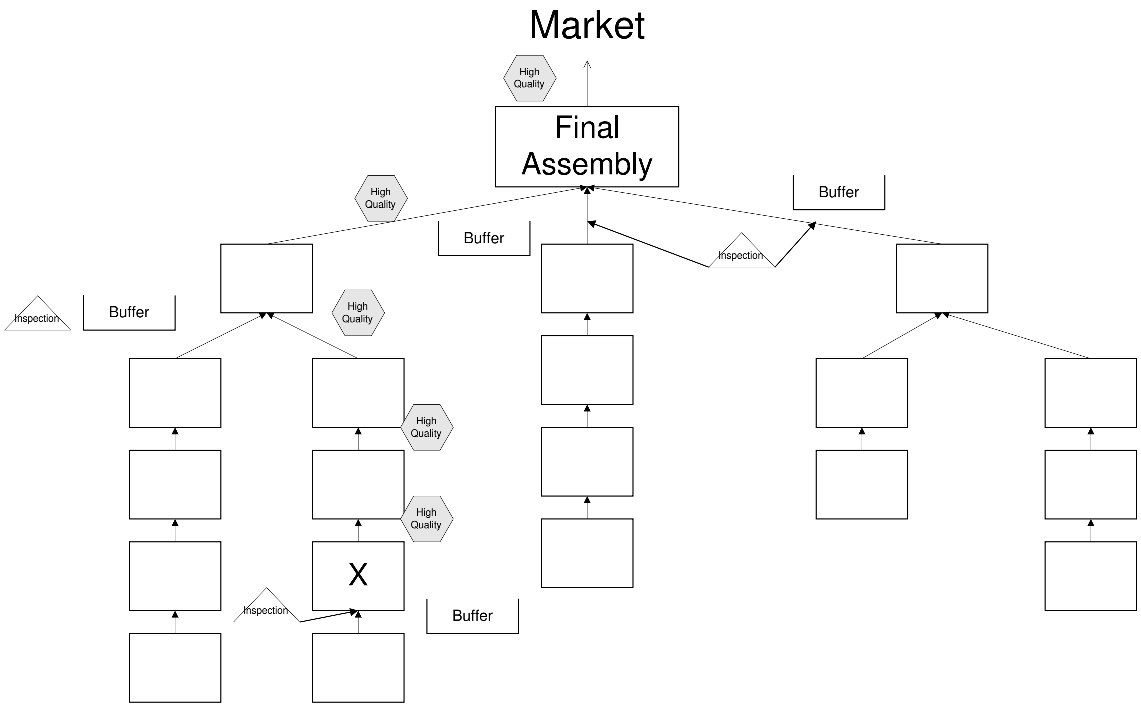
X is used for 933.33 hours, and Y is used for 700 hours or finished goods inventory will build up for Y.

Case	Outcome with no restrictions
I	No problems
II	Excess WIP for Y
III	Excess of spare parts for Y
IV	Excess finished goods for Y

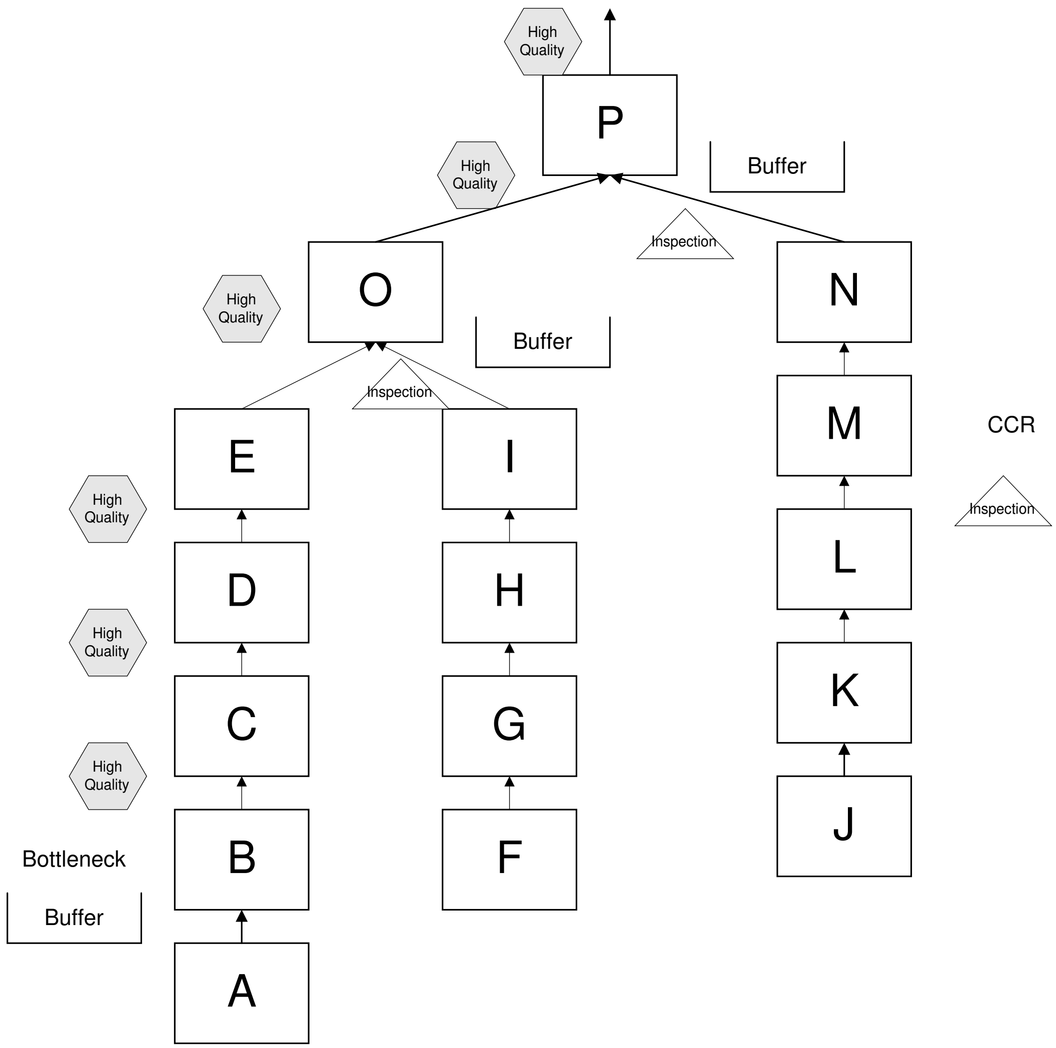
2.



3.


Market
High Quality
Final Assembly
High Quality
Buffer
Buffer
Inspection
Inspection
Buffer
High Quality
High Quality
High Quality
X
Inspection
Buffer

4.


High Quality
P
Buffer
High Quality
Inspection
O
N
High Quality
Buffer
Inspection
E
I
M
CCR
High Quality
Inspection
D
H
L
High Quality
C
G
K
High Quality
Bottleneck
B
F
J
Buffer
A

5.

6. a. Product C has the highest selling price; therefore, sell only product C.

b.

Product	Price per unit	Cost per unit	Gross profit per unit
A	$50	$40	$10
B	$60	$45	$15
C	$70	$60	$10

The answer is to sell only B with the highest gross profit of $15.

c.

Product	Limiting work center	Processing time (minutes)	Output per hour	Profit per unit	Profit per hour
A	Y	3	20	$10	$200
B	X	6	10	$15	$150
C	W	5	12	$10	$120

The answer is to sell only A, with the highest profit per hour.

Note: this can be solved as an LP problem. The best solution may very well be a combination of products rather than a single product.

7. Because of the arrangement given in the diagram, the Willard Lock Company plant will exhibit the following characteristics:

    - Two distinctive process and flows (fabrication and assembly).
    - Due date performance is very poor; either very early or very late.
    - Overtime and expediting in fabrication are random and frequent.
    - A very high commonality of parts exists.
    - The assignment of parts to orders occurs very late in the production process.
    - Fabrication is in huge batches.

    The reasons for the problems are probably as follows:

    - Improvement in due date performance is attempted through heavy reliance on inventory.
    - The drive to attain efficiencies and dollar shipped:
        - Undermines assembly activity objectives of due date performance and assemble to order.
        - Undermines fabrication activity objective of purchase and fabricate to forecast.
        - Causes intentional misallocation of parts and cannibalization at assembly and subassembly areas.

    The core problem in the Willard Lock Case is that due date performance is poor and delivery lead times are quite long.

    The following actions are recommended:

    - Control the flow of product through the fabrication portion of the process.
    - Reduce batch sizes to eliminate wavelike motion.
    - Stop the stealing of parts and components at subassembly.

8. a. Determine the constraint (bottleneck). The demand on each machine is

Machine	Calculation of demand	Demand	Utilization (2,400 minutes per week)
A	100 M units at 20 minutes each = 2,000 minutes	2,000 minutes	83%
B	100 M units at 15 min. each = 1,500 minutes 50 N units at 30 min. each = 1,500 minutes	3,000 minutes	125%
C	100 M units at 15 minutes each = 1,500 minutes 50 N at 15 minutes each = 750 minutes	2,250 minutes	94%

b. Determine the product mix. This can best be done by calculating the throughput per minute:

	Product M	Product N
Selling price	$190	$200
Raw material	$100	$ 80
Gross profit	$ 90	$120
Processing time-machine B	15 minutes	30 minutes
Gross profit per minute	$6 per minute	$4 per minute

Therefore, the best product mix is to make all 100 of product M and as many of product N as possible. To determine the number of N to produce, examine the remaining capacity on Machine B.

Available capacity (week)	2,400 minutes
100 units of M at 15 minutes per unit	1,500 minutes
Remaining capacity	900 minutes
Each N requires 30 minutes per unit of Machine B	900 / 30 = 30 units of N

c. Weekly profit of plant:

	Product M	Product N	Total
Weekly production	100	30	
Gross profit per unit	$90	$120	
Gross Profit	$9,000	$3,600	$12,600
Operating expenses			$12,000
Net Profit			$ 600

Note: This problem could also be solved using linear programming. It will produce the same answer as above. The formulation is as follows:

Let: M = weekly production of product M

N = weekly production of product N

Maximize: $90M + 120N$

$20M \leq 2400$	Machine A capacity
$15M + 30N \leq 2400$	Machine B capacity
$15M + 15N \leq 2400$	Machine C capacity
$M \leq 100$	M Demand limitation
$N \leq 50$	N Demand limitation
$M,N \geq 0$	Non-negativity

SUPPLEMENT A
FINANCIAL ANALYSIS

No review and discussion questions or problems in this supplement.

SUPPLEMENT B
OPERATIONS TECHNOLOGY

Review and Discussion Questions

1. Do robots have to be trained? Explain.

   As discussed in the Supplement, robots have to be taught a series of motions by a human operator before they start producing.

2. How does the axiom used in industrial selling, "You don't sell the product, you sell the company," pertain to manufacturing technology?

   Industrial customers invariably take plant tours to evaluate whether or not a potential supplier's technology is capable of meeting their product needs.

3. List three analytical tools (other than financial analysis) covered elsewhere in the book that can be used to evaluate technological alternatives.

   Simulation, statistical process control (e.g., Taguchi methods), and queuing theory.

4. The Belleville, Ontario, Canada subsidiary of Atlanta-based Interface Inc., one of the world's largest makers of commercial flooring, credits much of its profitability to "green manufacturing" or "eco-efficiency." What do you believe these terms mean? And how could such practices lead to cost reductions?

   Among many Canadian businesses, green manufacturing is becoming known as natural capitalism or eco-efficiency. The idea is that if you make products with less energy, fewer materials, and less pollution, you save money. The basic tenets of natural capitalism include doing more with fewer raw resources and abolishing industrial waste.

5. Give two examples each of recent process and product technology innovations.

   Two examples of new process technologies are communication satellites for transmission of information, RISC (Reduced Instruction Set Computation) technology for microprocessors. Two examples of new product technologies are camcorders and cellular phones. Note how satellites could be thought of as a new product (technology), but it is also a new process technology that is a wireless alternative to transmitting information across the globe.

6. What is the difference between a NC machine and a machining center?

   Machining Centers represent an increased level of automation and flexibility relative to NC machines. They have the ability to carry many tools, which can be used sequentially to perform different processes on an item. Also, they may have multiple worktables that help reduce set-up times by pre-loading jobs and thus provides greater flexibility.

7. The major auto companies are planning to invest millions of dollars on developing new product and process technologies required to make electric cars. Describe briefly why thy are investing in these technologies. Discuss the potential benefits and risks involved in these investments.

   The major reason the auto companies are investing in these technologies is to meet the threat of regulation. In California and other states, the auto companies have been mandated to sell a certain minimum percentage of non-polluting cars. They are furiously developing the product and process technologies for electric cars. The potential benefits are not being penalized by meeting the deadlines. Also, as consumers become more conscious of the environment, they may prefer cars that are less polluting and, to keep their loyalty, they have to make electric cars available. Clearly, this development effort requires large investments.

   The technology risk is the uncertainty about which particular technology for making electric cars will prove to be the most effective. Also, it is possible that gasoline-based cars may be made almost nonpolluting due to technological advances, making the investments in electric car technology a waste. Further, there are considerable environmental risks due to uncertainties about whether the government will indeed enforce it regulations by a specific date of relax the regulations. For instance, in the case of gasoline cars, the federal government has often relaxed fuel-emission standards in terms of fleet mileage requirements. Finally, there are operational and organizational risks due to the uncertainties about whether the auto firms will be able to adapt their operations and organizations to fully adopt these new technologies, given the long history of these companies with gasoline-based technologies for making cars.