

and the rest of the people were from River City. Out of the sample, 19 people had some form of cancer. Thirteen of these people were from Laketown.

- (a) Are the events of living in Laketown and having some sort of cancer independent?
- (b) Which city would you prefer to live in, assuming that your main objective was to avoid having cancer?
- 2-28 Compute the probability of "loaded die, given that a 3 was rolled," as shown in Example 7, this time using the general form of Bayes' theorem from Equation 2-7.
 - 2-29 Which of the following are probability distributions? Why?

(a)

RANDOM VARIABLE X	PROBABILITY
-2	0.1
-1	0.2
0	0.3
1	0.25
2	0.15

(b)

RANDOM VARIABLE Y	PROBABILITY
1	1.1
1.5	0.2
2	0.3
2.5	0.25
3	-1.25

(c)

RANDOM VARIABLE Z	PROBABILITY
1	0.1
2	0.2
3	0.3
4	0.4
5	0.0

- 2-30 Harrington Health Food stocks 5 loaves of Neutro-Bread. The probability distribution for the sales of Neutro-Bread is listed in the following table. How many loaves will Harrington sell on average?

NUMBER OF LOAVES SOLD	PROBABILITY
0	0.05
1	0.15
2	0.20
3	0.25
4	0.20
5	0.15

- 2-31 What are the expected value and variance of the following probability distribution?

RANDOM VARIABLE X	PROBABILITY
1	0.05
2	0.05
3	0.10
4	0.10
5	0.15
6	0.15
7	0.25
8	0.15

- ✘: 2-32 There are 10 questions on a true-false test. A student feels unprepared for this test and randomly guesses the answer for each of these.
 - (a) What is the probability that the student gets exactly 7 correct?
 - (b) What is the probability that the student gets exactly 8 correct?
 - (c) What is the probability that the student gets exactly 9 correct?
 - (d) What is the probability that the student gets exactly 10 correct?
 - (e) What is the probability that the student gets more than 6 correct?
- ✘: 2-33 Gary Schwartz is the top salesman for his company. Records indicate that he makes a sale on 70% of his sales calls. If he calls on four potential clients, what is the probability that he makes exactly 3 sales? What is the probability that he makes exactly 4 sales?
- ✘: 2-34 If 10% of all disk drives produced on an assembly line are defective, what is the probability that there will be exactly one defect in a random sample of 5 of these? What is the probability that there will be no defects in a random sample of 5?
- ✘: 2-35 Trowbridge Manufacturing produces cases for personal computers and other electronic equipment. The quality control inspector for this company believes that a particular process is out of control. Normally, only 5% of all cases are deemed defective due to discolorations. If 6 such cases are sampled, what is the probability that there will be 0 defective cases if the process is operating correctly? What is the probability that there will be exactly 1 defective case?
- ✘: 2-36 Refer to the Trowbridge Manufacturing example in Problem 2-35. The quality control inspection procedure is to select 6 items, and if there are 0 or 1 defective cases in the group of 6, the process is said to be in control. If the number of defects is more than 1, the process is out of control. Suppose that the true proportion of defective items is 0.15. What is the probability that there will be 0 or 1 defects in a sample of 6 if the true proportion of defects is 0.15?
- ✘: 2-37 An industrial oven used to cure sand cores for a factory manufacturing engine blocks for small cars is

able to maintain fairly constant temperatures. The temperature range of the oven follows a normal distribution with a mean of 450°F and a standard deviation of 25°F. Leslie Larsen, president of the factory, is concerned about the large number of defective cores that have been produced in the past several months. If the oven gets hotter than 475°F, the core is defective. What is the probability that the oven will cause a core to be defective? What is the probability that the temperature of the oven will range from 460° to 470°F?

- ✖: 2-38 Steve Goodman, production foreman for the Florida Gold Fruit Company, estimates that the average sale of oranges is 4,700 and the standard deviation is 500 oranges. Sales follow a normal distribution.
- What is the probability that sales will be greater than 5,500 oranges?
 - What is the probability that sales will be greater than 4,500 oranges?
 - What is the probability that sales will be less than 4,900 oranges?
 - What is the probability that sales will be less than 4,300 oranges?
- ✖: 2-39 Susan Williams has been the production manager of Medical Suppliers, Inc., for the past 17 years. Medical Suppliers, Inc., is a producer of bandages and arm slings. During the past 5 years, the demand for No-Stick bandages has been fairly constant. On the average, sales have been about 87,000 packages of No-Stick. Susan has reason to believe that the distribution of No-Stick follows a normal curve, with a standard deviation of 4,000 packages. What is the probability that sales will be less than 81,000 packages?
- 2-40 Armstrong Faber produces a standard number-two pencil called Ultra-Lite. Since Chuck Armstrong started Armstrong Faber, sales have grown steadily. With the increase in the price of wood products, however, Chuck has been forced to increase the price of the Ultra-Lite pencils. As a result, the demand for Ultra-Lite has been fairly stable over the past 6 years. On the average, Armstrong Faber has sold 457,000 pencils each year. Furthermore, 90% of the time sales have been between 454,000 and 460,000 pencils. It is expected that the sales follow a normal distribution with a mean of 457,000 pencils. Estimate the standard deviation of this distribution. (*Hint: Work backward from the normal table to find Z. Then apply Equation 2-15.*)
- 2-41 The time to complete a construction project is normally distributed with a mean of 60 weeks and a standard deviation of 4 weeks.
- What is the probability the project will be finished in 62 weeks or less?
 - What is the probability the project will be finished in 66 weeks or less?
 - What is the probability the project will take longer than 65 weeks?
- 2-42 A new integrated computer system is to be installed worldwide for a major corporation. Bids on this project

are being solicited, and the contract will be awarded to one of the bidders. As a part of the proposal for this project, bidders must specify how long the project will take. There will be a significant penalty for finishing late. One potential contractor determines that the average time to complete a project of this type is 40 weeks with a standard deviation of 5 weeks. The time required to complete this project is assumed to be normally distributed.

- If the due date of this project is set at 40 weeks, what is the probability that the contractor will have to pay a penalty (i.e., the project will not be finished on schedule)?
 - If the due date of this project is set at 43 weeks, what is the probability that the contractor will have to pay a penalty (i.e., the project will not be finished on schedule)?
 - If the bidder wishes to set the due date in the proposal so that there is only a 5% chance of being late (and consequently only a 5% chance of having to pay a penalty), what due date should be set?
- 2-43 Patients arrive at the emergency room of Costa Valley Hospital at an average of 5 per day. The demand for emergency room treatment at Costa Valley follows a Poisson distribution.
- Using Appendix C, compute the probability of exactly 0, 1, 2, 3, 4, and 5 arrivals per day.
 - What is the sum of these probabilities, and why is the number less than 1?
- 2-44 Using the data in Problem 2-43, determine the probability of more than 3 visits for emergency room service on any given day.
- 2-45 Cars arrive at Carla's Muffler shop for repair work at an average of 3 per hour, following an exponential distribution.
- What is the expected time between arrivals?
 - What is the variance of the time between arrivals?
- 2-46 A particular test for the presence of steroids is to be used after a professional track meet. If steroids are present, the test will accurately indicate this 95% of the time. However, if steroids are not present, the test will indicate this 90% of the time (so it is wrong 10% of the time and predicts the presence of steroids). Based on past data, it is believed that 2% of the athletes do use steroids. This test is administered to one athlete, and the test is positive for steroids. What is the probability that this person actually used steroids?
- 2-47 Market Researchers, Inc., has been hired to perform a study to determine if the market for a new product will be good or poor. In similar studies performed in the past, whenever the market actually was good, the market research study indicated that it would be good 85% of the time. On the other hand, whenever the market actually was poor, the market study incorrectly predicted it would be good 20% of the time.

Before the study is performed, it is believed there is a 70% chance the market will be good. When Market Researchers, Inc. performs the study for this product, the results predict the market will be good. Given the results of this study, what is the probability that the market actually will be good?

- 2-48 Policy Pollsters is a market research firm specializing in political polls. Records indicate in past elections, when a candidate was elected, Policy Pollsters had accurately predicted this 80 percent of the time and they were wrong 20% of the time. Records also show for losing candidates, Policy Pollsters accurately predicted they would lose 90 percent of the time and they were only wrong 10% of the time. Before the poll is taken, there is a 50% chance of winning the election. If Policy Pollsters predicts a candidate will win the election, what is the probability that the candidate will actually win? If Policy Pollsters predicts that a candidate will lose the election, what is the probability that the candidate will actually lose?
- 2-49 Burger City is a large chain of fast-food restaurants specializing in gourmet hamburgers. A mathematical model is now used to predict the success of new restaurants based on location and demographic information for that area. In the past, 70% of all restaurants that were opened were successful. The mathematical model has been tested in the existing restaurants to determine how effective it is. For the restaurants that were successful, 90% of the time the model predicted they would be, while 10% of the time the model predicted a failure. For the restaurants that were not successful, when the mathematical model was applied, 20% of the time it incorrectly predicted a successful restaurant while 80% of the time it was accurate and predicted an unsuccessful restaurant. If the model is used on a new location and predicts the restaurant will be successful, what is the probability that it actually is successful?
- 2-50 A mortgage lender attempted to increase its business by marketing its subprime mortgage. This mortgage is designed for people with a less-than-perfect credit rating, and the interest rate is higher to offset the extra risk. In the past year, 20% of these mortgages resulted in foreclosure as customers defaulted on their loans. A new screening system has been developed to determine whether to approve customers for the subprime loans. When

the system is applied to a credit application, the system will classify the application as "Approve for loan" or "Reject for loan." When this new system was applied to recent customers who had defaulted on their loans, 90% of these customers were classified as "Reject." When this same system was applied to recent loan customers who had not defaulted on their loan payments, 70% of these customers were classified as "Approve for loan."

- (a) If a customer did not default on a loan, what is the probability that the rating system would have classified the applicant in the reject category?
- (b) If the rating system had classified the applicant in the reject category, what is the probability that the customer would not default on a loan?
- 2-51 Use the F table in Appendix D to find the value of F for the upper 5% of the F distribution with
- (a) $df_1 = 5, df_2 = 10$
 (b) $df_1 = 8, df_2 = 7$
 (c) $df_1 = 3, df_2 = 5$
 (d) $df_1 = 10, df_2 = 4$
- 2-52 Use the F table in Appendix D to find the value of F for the upper 1% of the F distribution with
- (a) $df_1 = 15, df_2 = 6$
 (b) $df_1 = 12, df_2 = 8$
 (c) $df_1 = 3, df_2 = 5$
 (d) $df_1 = 9, df_2 = 7$
- 2-53 For each of the following F values, determine whether the probability indicated is greater than or less than 5%:
- (a) $P(F_{3,4} > 6.8)$
 (b) $P(F_{7,3} > 3.6)$
 (c) $P(F_{20,20} > 2.6)$
 (d) $P(F_{7,5} > 5.1)$
 (e) $P(F_{7,5} < 5.1)$
- 2-54 For each of the following F values, determine whether the probability indicated is greater than or less than 1%:
- (a) $P(F_{5,4} > 14)$
 (b) $P(F_{6,3} > 30)$
 (c) $P(F_{10,12} > 4.2)$
 (d) $P(F_{2,3} > 35)$
 (e) $P(F_{2,3} < 35)$

INTERNET HOMEWORK PROBLEMS



See our Internet home page, at www.prenhall.com/render, for additional homework problems, Problems 2-53 to 2-60.

DISCUSSION QUESTIONS AND PROBLEMS

Discussion Questions

- 4-1 What is the meaning of least squares in a regression model?
- 4-2 Discuss the use of dummy variables in regression analysis.
- 4-3 Discuss how the coefficient of determination and the coefficient of correlation are related and how they are used in regression analysis.
- 4-4 Explain how a scatter diagram can be used to identify the type of regression to use.
- 4-5 Explain how the adjusted r^2 value is used in developing a regression model.
- 4-6 Explain what information is provided by the F test.
- 4-7 What is the SSE? How is this related to the SST and the SSR?
- 4-8 Explain how a plot of the residuals can be used in developing a regression model.

Problems*

- 4-9 John Smith has developed the following forecasting model:

$$\hat{Y} = 36 + 4.3X_1$$

where

\hat{Y} = Demand for K10 air conditioners

X_1 = the outside temperature ($^{\circ}$ F)

- (a) Forecast the demand for K10 when the temperature is 70° F.
- (b) What is the demand for a temperature of 80° F?
- (c) What is the demand for a temperature of 90° F?

- 4-10 The operations manager of a musical instrument distributor feels that demand for bass drums may be related to the number of television appearances by the popular rock group Green Shades during the preceding month. The manager has collected the data shown in the following table:

DEMAND FOR BASS DRUMS	GREEN SHADES TV APPEARANCE
3	3
6	4
7	7
5	6
10	8
8	5

- (a) Graph these data to see whether a linear equation might describe the relationship between the group's television shows and bass drum sales.

- (b) Using the equations presented in this chapter, compute the SST, SSE, and SSR. Find the least squares regression line for this data.
- (c) What is your estimate for bass drum sales if the Green Shades performed on TV six times last month?

- 4-11 Using the data in Problem 4-10, test to see if there is a statistically significant relationship between sales and TV appearances at the 0.05 level of significance. Use the formulas in this chapter and Appendix D.

- 4-12 Using computer software, find the least squares regression line for the data in Problem 4-10. Based on the F test, is there a statistically significant relationship between the demand for drums and the number of TV appearances?

- 4-13 Students in a management science class have just received their grades on the first test. The instructor has provided information about the first test grades in some previous classes as well as the final average for the same students. Some of these grades have been sampled and are as follows:

STUDENT	1	2	3	4	5	6	7	8	9
1st test grade	98	77	88	80	96	61	66	95	69
Final average	93	78	84	73	84	64	64	95	76




- (a) Develop a regression model that could be used to predict the final average in the course based on the first test grade.
- (b) Predict the final average of a student who made an 83 on the first test.
- (c) Give the values of r and r^2 for this model. Interpret the value of r^2 in the context of this problem.

- 4-14 Using the data in Problem 4-13, test to see if there is a statistically significant relationship between the grade on the first test and the final average at the 0.05 level of significance. Use the formulas in this chapter and Appendix D.

- 4-15 Using computer software, find the least squares regression line for the data in Problem 4-13. Based on the F test, is there a statistically significant relationship between the first test grade and the final average in the course?

- 4-16 Steve Caples, a real estate appraiser in Lake Charles, Louisiana, has developed a regression model to help appraise residential housing in the Lake Charles area. The model was developed using recently sold homes in a particular neighborhood. The price (Y) of the house is based on the square footage (X) of the house. The model is

$$\hat{Y} = 13.473 + 37.65X$$

* Note:  means the problem may be solved with QM for Windows;  means the problem may be solved with Excel QM; and  means the problem may be solved with QM for Windows and/or Excel QM.

The coefficient of correlation for the model is 0.63.

- (a) Use the model to predict the selling price of a house that is 1,860 square feet.
- (b) A house with 1,860 square feet recently sold for \$95,000. Explain why this is not what the model predicted.
- (c) If you were going to use multiple regression to develop an appraisal model, what other quantitative variables might be included in the model?
- (d) What is the coefficient of determination for this model?

- 4-17 Accountants at the firm Walker and Walker believed that several traveling executives submit unusually high travel vouchers when they return from business trips. The accountants took a sample of 200 vouchers submitted from the past year; they then developed the following multiple regression equation relating expected travel cost (Y) to number of days on the road (X_1) and distance traveled (X_2) in miles:

$$\hat{Y} = \$90.00 + \$48.50X_1 + \$0.40X_2$$

The coefficient of correlation computed was 0.68.

- (a) If Thomas Williams returns from a 300-mile trip that took him out of town for five days, what is the expected amount that he should claim as expenses?
- (b) Williams submitted a reimbursement request for \$685; what should the accountant do?
- (c) Comment on the validity of this model. Should any other variables be included? Which ones? Why?

- 4-18 Thirteen students entered the undergraduate business program at Rollins College two years ago. The following table indicates what their grade-point averages (GPAs) were after being in the program for two years and what each student scored on one part of the SAT exam when he or she was in high school. Is there a meaningful relationship between grades and SAT scores? If a student scores a 450 on the SAT, what do you think his or her GPA will be? What about a student who scores 800?

STUDENT	SAT SCORE	GPA	STUDENT	SAT SCORE	GPA
A	421	2.90	H	481	2.53
B	377	2.93	I	729	3.22
C	585	3.00	J	501	1.99
D	690	3.45	K	613	2.75
E	608	3.66	L	709	3.90
F	390	2.88	M	366	1.60
G	415	2.15			

- 4-19 Bus and subway ridership in Washington, D.C., during the summer months is believed to be heavily tied to the number of tourists visiting the city. During the past 12 years, the following data have been obtained:

YEAR	NUMBER OF TOURISTS (1,000,000s)	RIDERSHIP (100,000s)
1	7	15
2	2	10
3	6	13
4	4	15
5	14	25
6	15	27
7	16	24
8	12	20
9	14	27
10	20	44
11	15	34
12	7	17

- (a) Plot these data and determine if a linear model is reasonable.
- (b) Develop a regression model.
- (c) What is expected ridership if 10 million tourists visit the city?
- (d) If there are no tourists at all, explain the predicted ridership.

- 4-20 Use computer software to develop a regression model for the data in Problem 4-19. Explain what this output indicates about the usefulness of this model.

- 4-21 The following data gives the starting salary for students who recently graduated from a local university and accepted jobs soon after graduation. The starting salary, grade-point average (GPA), and major (business or other) are provided.

SALARY	\$29,500	\$46,000	\$39,800	\$36,500
GPA	3.1	3.5	3.8	2.9
Major	Other	Business	Business	Other

SALARY	\$42,000	\$31,500	\$36,200
GPA	3.4	2.1	2.5
Major	Business	Other	Business

- (a) Using a computer, develop a regression model that could be used to predict starting salary based on GPA and major.
- (b) Use this model to predict the starting salary for a business major with a GPA of 3.0.
- (c) What does the model say about the starting salary for a business major compared to a nonbusiness major?

(d) Do you believe this model is useful in predicting the starting salary? Justify your answer using information provided in the computer output.

PROBLEM 4-22 The following data give the selling price, square footage, number of bedrooms, and age of houses that have sold in a neighborhood in the last 6 months. Develop three regression models to predict the selling price based upon each of the other factors individually. Which of these is best?

SELLING PRICE(\$)	SQUARE FOOTAGE	BEDROOMS	AGE
64,000	1,670	2	30
59,000	1,339	2	25
61,500	1,712	3	30
79,000	1,840	3	40
87,500	2,300	3	18
92,500	2,234	3	30
95,000	2,311	3	19
113,000	2,377	3	7
115,000	2,736	4	10
138,000	2,500	3	1
142,500	2,500	4	3
144,000	2,479	3	3
145,000	2,400	3	1
147,500	3,124	4	0
144,000	2,500	3	2
155,500	4,062	4	10
165,000	2,854	3	3

PROBLEM 4-23 Use the data in Problem 4-22 and develop a regression model to predict selling price based on the square footage and number of bedrooms. Use this to predict the selling price of a 2,000 square foot house with 3 bedrooms. Compare this model with the models in 4-22. Should the number of bedrooms be included in the model? Why or why not?

PROBLEM 4-24 Use the data in Problem 4-22 and develop a regression model to predict selling price based on the square footage, number of bedrooms, and age. Use this to predict the selling price of a 10-year-old, 2,000-square-foot house with 3 bedrooms.

PROBLEM 4-25 Tim Cooper plans to invest money in a mutual fund that is tied to one of the major market indices, either the S&P 500 or the Dow Jones Industrial Average. To obtain even more diversification, Tim has thought about investing in both of these. To determine whether investing in two funds would help, Tim decided to take 20 weeks of data and compare the two

markets. The closing price for each index is shown in the table below:

WEEK	1	2	3	4	5	6	7
DJIA	10,226	10,473	10,452	10,442	10,471	10,213	10,187
S&P	1,107	1,141	1,135	1,139	1,142	1,108	1,110

WEEK	8	9	10	11	12	13	14
DJIA	10,240	10,596	10,584	10,619	10,628	10,593	10,488
S&P	1,121	1,157	1,145	1,144	1,146	1,143	1,131

WEEK	15	16	17	18	19	20
DJIA	10,568	10,601	10,459	10,410	10,325	10,278
S&P	1,142	1,140	1,122	1,108	1,096	1,089

Develop a regression model that would predict the DJIA based on the S&P 500 index. Based on this model, what would you expect the DJIA to be when the S&P is 1,100? What is the correlation coefficient (r) between the two markets?

PROBLEM 4-26 The total expenses of a hospital are related to many factors. Two of these are the number of beds in the hospital, and the number of admissions. Data was collected on 14 hospitals as shown in the table below.

HOSPITAL	NUMBER OF BEDS	ADMISSIONS (100s)	TOTAL EXPENSES (MILLIONS)
1	215	77	57
2	336	160	127
3	520	230	157
4	135	43	24
5	35	9	14
6	210	155	93
7	140	53	45
8	90	6	6
9	410	159	99
10	50	18	12
11	65	16	11
12	42	29	15
13	110	28	21
14	305	98	63

Find the best regression model to predict the total expenses of a hospital. Discuss the accuracy of this model. Should both variables be included in the model? Why or why not?

9. A decision tree is preferable to a decision table when
 - a. a number of sequential decisions are to be made.
 - b. probabilities are available.
 - c. the maximax criterion is used.
 - d. the objective is to maximize regret.
10. Bayes' theorem is used to revise probabilities. The new (revised) probabilities are called
 - a. prior probabilities.
 - b. sample probabilities.
 - c. survey probabilities.
 - d. posterior probabilities.
11. On a decision tree, at each state-of-nature node,
 - a. the alternative with the greatest EMV is selected.
 - b. an EMV is calculated.
 - c. all probabilities are added together.
 - d. the branch with the highest probability is selected.
12. The EVSI
 - a. is found by subtracting the EMV without sample information from the EMV with sample information.
 - b. is always equal to the expected value of perfect information.
 - c. equals the EMV with sample information assuming no cost for the information minus the EMV without sample information.
 - d. is usually negative.
13. On a decision tree, once the tree has been drawn and the payoffs and probabilities have been placed on the tree, the analysis (computing EMVs and selecting the best alternative)
 - a. is done by working backward (starting on the right and moving to the left).
 - b. is done by working forward (starting on the left and moving to the right).
 - c. is done by starting at the top of the tree and moving down.
 - d. is done by starting at the bottom of the tree and moving up.
14. In assessing utility values,
 - a. the worst outcome is given a utility of -1 .
 - b. the best outcome is given a utility of 0 .
 - c. the worst outcome is given a utility of 0 .
 - d. the best outcome is given a value of -1 .
15. If a rational person selects an alternative that does not maximize the EMV, we would expect that this alternative
 - a. minimizes the EMV.
 - b. maximizes the expected utility.
 - c. minimizes the expected utility.
 - d. has zero utility associated with each possible payoff.


DISCUSSION QUESTIONS AND PROBLEMS




Discussion Questions

- 3-1 Give an example of a good decision that you made that resulted in a bad outcome. Also give an example of a bad decision that you made that had a good outcome. Why was each decision good or bad?
- 3-2 Describe what is involved in the decision process.
- 3-3 What is an alternative? What is a state of nature?
- 3-4 Discuss the differences among decision making under certainty, decision making under risk, and decision making under uncertainty.
- 3-5 What techniques are used to solve decision-making problems under uncertainty? Which technique results in an optimistic decision? Which technique results in a pessimistic decision?
- 3-6 Define *opportunity loss*. What decision-making criteria are used with an opportunity loss table?
- 3-7 What information should be placed on a decision tree?
- 3-8 Describe how you would determine the best decision using the EMV criterion with a decision tree.
- 3-9 What is the difference between prior and posterior probabilities?

- 3-10 What is the purpose of Bayesian analysis? Describe how you would use Bayesian analysis in the decision-making process.
- 3-11 What is the EVSI? How is this computed?
- 3-12 What is the overall purpose of utility theory?
- 3-13 Briefly discuss how a utility function can be assessed. What is a standard gamble, and how is it used in determining utility values?
- 3-14 How is a utility curve used in selecting the best decision for a particular problem?
- 3-15 What is a risk seeker? What is a risk avoider? How does the utility curve for these types of decision makers differ?

Problems*

- 3-16  Kenneth Brown is the principal owner of Brown Oil, Inc. After quitting his university teaching job, Ken has been able to increase his annual salary by a factor of over 100. At the present time, Ken is forced to consider purchasing some more equipment for Brown Oil because of competition. His alternatives are shown in the following table:

* Note:  means the problem may be solved with QM for Windows;  means the problem may be solved with Excel QM; and  means the problem may be solved with QM for Windows and/or Excel QM.

Investment	Favorable Market	Unfavorable Market
	(\$)	(\$)
Sub 100	300,000	-200,000
Oiler J	250,000	-100,000
Texan	75,000	-18,000

For example, if Ken purchases a Sub 100 and if there is a favorable market, he will realize a profit of \$300,000. On the other hand, if the market is unfavorable, Ken will suffer a loss of \$200,000. But Ken has always been a very optimistic decision maker.

- (a) What type of decision is Ken facing?
- (b) What decision criterion should he use?
- (c) What alternative is best?

3-17 Although Ken Brown (discussed in Problem 3-16) is the principal owner of Brown Oil, his brother Bob is credited with making the company a financial success. Bob is vice president of finance. Bob attributes his success to his pessimistic attitude about business and the oil industry. Given the information from Problem 3-16, it is likely that Bob will arrive at a different decision. What decision criterion should Bob use, and what alternative will he select?

3-18 The *Lubricant* is an expensive oil newsletter to which many oil giants subscribe, including Ken Brown (see Problem 3-16 for details). In the last issue, the letter described how the demand for oil products would be extremely high. Apparently, the American consumer will continue to use oil products even if the price of these products doubles. Indeed, one of the articles in the *Lubricant* states that the chances of a favorable market for oil products was 70%, while the chance of an unfavorable market was only 30%. Ken would like to use these probabilities in determining the best decision.

- (a) What decision model should be used?
- (b) What is the optimal decision?
- (c) Ken believes that the \$300,000 figure for the Sub 100 with a favorable market is too high. How much lower would this figure have to be for Ken to change his decision made in part (b)?

3-19 Mickey Lawson is considering investing some money that he inherited. The following payoff table gives the profits that would be realized during the next year for each of three investment alternatives Mickey is considering:

Investment Alternative	State of Nature	
	Strong Economy	Poor Economy
Stock market	80,000	-20,000
Bonds	30,000	20,000
CDs	23,000	23,000
Probability	0.5	0.5

- (a) What decision would maximize expected profits?
- (b) What is the maximum amount that should be paid for a perfect forecast of the economy?

3-20 Develop an opportunity loss table for the investment problem that Mickey Lawson faces in Problem 3-19. What decision would minimize the expected opportunity loss? What is the minimum EOL?

3-21 Allen Young has always been proud of his personal investment strategies and has done very well over the past several years. He invests primarily in the stock market. Over the past several months, however, Allen has become very concerned about the stock market as a good investment. In some cases it would have been better for Allen to have his money in a bank than in the market. During the next year, Allen must decide whether to invest \$10,000 in the stock market or in a certificate of deposit (CD) at an interest rate of 9%. If the market is good, Allen believes that he could get a 14% return on his money. With a fair market, he expects to get an 8% return. If the market is bad, he will most likely get no return at all—in other words, the return would be 0%. Allen estimates that the probability of a good market is 0.4, the probability of a fair market is 0.4, and the probability of a bad market is 0.2, and he wishes to maximize his long-run average return.

- (a) Develop a decision table for this problem.
- (b) What is the best decision?

3-22 In Problem 3-21 you helped Allen Young determine the best investment strategy. Now, Young is thinking about paying for a stock market newsletter. A friend of Young said that these types of letters could predict very accurately whether the market would be good, fair, or poor. Then, based on these predictions, Allen could make better investment decisions.

- (a) What is the most that Allen would be willing to pay for a newsletter?
- (b) Young now believes that a good market will give a return of only 11% instead of 14%. Will this information change the amount that Allen would be willing to pay for the newsletter? If your answer is yes, determine the most that Allen would be willing to pay, given this new information.

3-23 Today's Electronics specializes in manufacturing modern electronic components. It also builds the equipment that produces the components. Phyllis Weinberger, who is responsible for advising the president of Today's Electronics on electronic manufacturing equipment, has developed the following table concerning a proposed facility:

Facility	Economy (\$)		
	Strong Market	Fair Market	Poor Market
Large facility	550,000	110,000	-310,000
Medium-sized facility	300,000	129,000	-100,000
Small facility	200,000	100,000	-32,000
No facility	0	0	0

- (a) Develop an opportunity loss table.
- (b) What is the minimax regret decision?

3-24 Brilliant Color is a small supplier of chemicals and equipment that are used by some photographic stores to process 35mm film. One product that Brilliant Color supplies is BC-6. John Kubick, president of Brilliant Color, normally stocks 11, 12, or 13 cases of BC-6 each week. For each case that John sells, he receives a profit of \$35. Like many photographic chemicals, BC-6 has a very short shelf life, so if a case is not sold by the end of the week, John must discard it. Since each case costs John \$56, he loses \$56 for every case that is not sold by the end of the week. There is a probability of 0.45 of selling 11 cases, a probability of 0.35 of selling 12 cases, and a probability of 0.2 of selling 13 cases.

- (a) Construct a decision table for this problem. Include all conditional values and probabilities in the table.
- (b) What is your recommended course of action?
- (c) If John is able to develop BC-6 with an ingredient that stabilizes it so that it no longer has to be discarded, how would this change your recommended course of action?

3-25 Megley Cheese Company is a small manufacturer of several different cheese products. One of the products is a cheese spread that is sold to retail outlets. Jason Megley must decide how many cases of cheese spread to manufacture each month. The probability that the demand will be six cases is 0.1, for 7 cases is 0.3, for 8 cases is 0.5, and for 9 cases is 0.1. The cost of every case is \$45, and the price that Jason gets for each case is \$95. Unfortunately, any cases not sold by the end of the month are of no value, due to spoilage. How many cases of cheese should Jason manufacture each month?

3-26 Farm Grown, Inc., produces cases of perishable food products. Each case contains an assortment of vegetables and other farm products. Each case costs \$5 and sells for \$15. If there are any cases not sold by the end of the day, they are sold to a large food processing company for \$3 a case. The probability that daily demand will be 100 cases is 0.3, the probability that daily demand will be 200 cases is 0.4, and the probability that daily demand will be 300 cases is 0.3. Farm Grown has a policy of always satisfying customer demands. If its own supply of cases is less than the demand, it buys the necessary vegetables from a competitor. The estimated cost of doing this is \$16 per case.

- (a) Draw a decision table for this problem.
- (b) What do you recommend?

3-27 Even though independent gasoline stations have been having a difficult time, Susan Solomon has been thinking about starting her own independent gasoline station. Susan's problem is to decide how large her station should be. The annual returns will depend on both the size of her station and a number of marketing factors related to the oil industry and demand for

gasoline. After a careful analysis, Susan developed the following table:

SIZE OF FIRST STATION	GOOD MARKET (\$)	FAIR MARKET (\$)	POOR MARKET (\$)
Small	50,000	20,000	-10,000
Medium	80,000	30,000	-20,000
Large	100,000	30,000	-40,000
Very large	300,000	25,000	-160,000

For example, if Susan constructs a small station and the market is good, she will realize a profit of \$50,000.

- (a) Develop a decision table for this decision.
- (b) What is the maximax decision?
- (c) What is the maximin decision?
- (d) What is the equally likely decision?
- (e) What is the criterion of realism decision? Use an α value of 0.8.
- (f) Develop an opportunity loss table.
- (g) What is the minimax regret decision?

3-28 A group of medical professionals is considering the construction of a private clinic. If the medical demand is high (i.e., there is a favorable market for the clinic), the physicians could realize a net profit of \$100,000. If the market is not favorable, they could lose \$40,000. Of course, they don't have to proceed at all, in which case there is no cost. In the absence of any market data, the best the physicians can guess is that there is a 50-50 chance the clinic will be successful. Construct a decision tree to help analyze this problem. What should the medical professionals do?

3-29 The physicians in Problem 3-28 have been approached by a market research firm that offers to perform a study of the market at a fee of \$5,000. The market researchers claim their experience enables them to use Bayes' theorem to make the following statements of probability:

- probability of a favorable market given a favorable study = 0.82
- probability of an unfavorable market given a favorable study = 0.18
- probability of a favorable market given an unfavorable study = 0.11
- probability of an unfavorable market given an unfavorable study = 0.89
- probability of a favorable research study = 0.55
- probability of an unfavorable research study = 0.45

- (a) Develop a new decision tree for the medical professionals to reflect the options now open with the market study.
- (b) Use the EMV approach to recommend a strategy.
- (c) What is the expected value of sample information? How much might the physicians be willing to pay for a market study?

3-30 Jerry Smith is thinking about opening a bicycle shop in his hometown. Jerry loves to take his own bike on 50-mile trips with his friends, but he believes that any small business should be started only if there is a good chance of making a profit. Jerry can open a small shop, a large shop, or no shop at all. The profits will depend on the size of the shop and whether the market is favorable or unfavorable for his products. Because there will be a five-year lease on the building that Jerry is thinking about using, he wants to make sure that he makes the correct decision. Jerry is also thinking about hiring his old marketing professor to conduct a marketing research study. If the study is conducted, the study could be favorable (i.e., predicting a favorable market) or unfavorable (i.e., predicting an unfavorable market). Develop a decision tree for Jerry.

3-31 Jerry Smith (see Problem 3-30) has done some analysis about the profitability of the bicycle shop. If Jerry builds the large bicycle shop, he will earn \$60,000 if the market is favorable, but he will lose \$40,000 if the market is unfavorable. The small shop will return a \$30,000 profit in a favorable market and a \$10,000 loss in an unfavorable market. At the present time, he believes that there is a 50–50 chance that the market will be favorable. His old marketing professor will charge him \$5,000 for the marketing research. It is estimated that there is a 0.6 probability that the survey will be favorable. Furthermore, there is a 0.9 probability that the market will be favorable given a favorable outcome from the study. However, the marketing professor has warned Jerry that there is only a probability of 0.12 of a favorable market if the marketing research results are not favorable. Jerry is confused.

- (a) Should Jerry use the marketing research?
- (b) Jerry, however, is unsure the 0.6 probability of a favorable marketing research study is correct. How sensitive is Jerry's decision to this probability value? How far can this probability value deviate from 0.6 without causing Jerry to change his decision?

3-32 Bill Holliday is not sure what he should do. He can either build a quadplex (i.e., a building with four apartments), build a duplex, gather additional information, or simply do nothing. If he gathers additional information, the results could be either favorable or unfavorable, but it would cost him \$3,000 to gather the information. Bill believes that there is a 50–50 chance that the information will be favorable. If the rental market is favorable, Bill will earn \$15,000 with the quadplex or \$5,000 with the duplex. Bill doesn't have the financial resources to do both. With an unfavorable rental market, however, Bill could lose \$20,000 with the quadplex or \$10,000 with the duplex. Without gathering additional information, Bill estimates that the probability of a favorable rental market is 0.7. A favorable report from the study would increase the probability of a favorable rental market to 0.9. Furthermore, an unfavorable report from the additional information would decrease the probability of a favorable rental market to 0.4. Of course, Bill could forget all of these numbers and do nothing. What is your advice to Bill?

3-33 Peter Martin is going to help his brother who wants to open a food store. Peter initially believes that there is a 50–50 chance that his brother's food store would be a success. Peter is considering doing a market research study. Based on historical data, there is a 0.8 probability that the marketing research will be favorable given a successful food store. Moreover, there is a 0.7 probability that the marketing research will be unfavorable given an unsuccessful food store.

- (a) If the marketing research is favorable, what is Peter's revised probability of a successful food store for his brother?
- (b) If the marketing research is unfavorable, what is Peter's revised probability of a successful food store for his brother?
- (c) If the initial probability of a successful food store is 0.60 (instead of 0.50), find the probabilities in parts a and b.

3-34 Mark Martinko has been a class A racquetball player for the past five years, and one of his biggest goals is to own and operate a racquetball facility. Unfortunately, Mark thinks that the chance of a successful racquetball facility is only 30%. Mark's lawyer has recommended that he employ one of the local marketing research groups to conduct a survey concerning the success or failure of a racquetball facility. There is a 0.8 probability that the research will be favorable given a successful racquetball facility. In addition, there is a 0.7 probability that the research will be unfavorable given an unsuccessful facility. Compute revised probabilities of a successful racquetball facility given a favorable and given an unfavorable survey.

3-35 A financial advisor has recommended two possible mutual funds for investment: Fund A and Fund B. The return that will be achieved by each of these depends on whether the economy is good, fair, or poor. A payoff table has been constructed to illustrate this situation:

	STATE OF NATURE		
	GOOD ECONOMY	FAIR ECONOMY	POOR ECONOMY
Fund A	\$10,000	\$2,000	–\$5,000
Fund B	\$6,000	\$4,000	0
Probability	0.2	0.3	0.5

- (a) Draw the decision tree to represent this situation.
- (b) Perform the necessary calculations to determine which of the two mutual funds is better. Which one should you choose to maximize the expected value?
- (c) Suppose there is question about the return of Fund A in a good economy. It could be higher or lower than \$10,000. What value for this would cause a person to be indifferent between Fund A and Fund B (i.e., the EMVs would be the same)?

3-36 Jim Sellers is thinking about producing a new type of electric razor for men. If the market were favorable,

- 6-21 Barbara Bright is the purchasing agent for West Valve Company. West Valve sells industrial valves and fluid control devices. One of the most popular valves is the Western, which has an annual demand of 4,000 units. The cost of each valve is \$90, and the inventory carrying cost is estimated to be 10% of the cost of each valve. Barbara has made a study of the costs involved in placing an order for any of the valves that West Valve stocks, and she has concluded that the average ordering cost is \$25 per order. Furthermore, it takes about two weeks for an order to arrive from the supplier, and during this time the demand per week for West valves is approximately 80.
- What is the EOQ?
 - What is the ROP?
 - What is the average inventory? What is the annual holding cost?
 - How many orders per year would be placed? What is the annual ordering cost?
- 6-22 Ken Ramsing has been in the lumber business for most of his life. Ken's biggest competitor is Pacific Woods. Through many years of experience, Ken knows that the ordering cost for an order of plywood is \$25 and that the carrying cost is 25% of the unit cost. Both Ken and Pacific Woods receive plywood in loads that cost \$100 per load. Furthermore, Ken and Pacific Woods use the same supplier of plywood, and Ken was able to find out that Pacific Woods orders in quantities of 4,000 loads at a time. Ken also knows that 4,000 loads is the EOQ for Pacific Woods. What is the annual demand in loads of plywood for Pacific Woods?
- 6-23 Shoe Shine is a local retail shoe store located on the north side of Centerville. Annual demand for a popular sandal is 500 pairs, and John Dirk, the owner of Shoe Shine, has been in the habit of ordering 100 pairs at a time. John estimates that the ordering cost is \$10 per order. The cost of the sandal is \$5 per pair. For John's ordering policy to be correct, what would the carrying cost as a percentage of the unit cost have to be? If the carrying cost were 10% of the cost, what would the optimal order quantity be?
- 6-24 In Problem 6-18 you helped Lila Battle determine the optimal order quantity for number 6 screws. She had estimated that the ordering cost was \$10 per order. At this time, though, she believes that this estimate was too low. Although she does not know the exact ordering cost, she believes that it could be as high as \$40 per order. How would the optimal order quantity change if the ordering cost were \$20, \$30, and \$40?
- 6-25 Ross White's machine shop uses 2,500 brackets during the course of a year, and this usage is relatively constant throughout the year. These brackets are purchased from a supplier 100 miles away for \$15 each, and the lead time is 2 days. The holding cost per bracket per year is \$1.50 (or 10% of the unit cost) and the ordering cost per order is \$18.75. There are 250 working days per year.
- What is the EOQ?
 - Given the EOQ, what is the average inventory? What is the annual inventory holding cost?
 - In minimizing cost, how many orders would be made each year? What would be the annual ordering cost?
 - Given the EOQ, what is the total annual inventory cost (including purchase cost)?
 - What is the time between orders?
 - What is the ROP?
- 6-26 Ross White (see Problem 6-25) wants to reconsider his decision of buying the brackets and is considering making the brackets in-house. He has determined that setup costs would be \$25 in machinist time and lost production time, and 50 brackets could be produced in a day once the machine has been set up. Ross estimates that the cost (including labor time and materials) of producing one bracket would be \$14.80. The holding cost would be 10% of this cost.
- What is the daily demand rate?
 - What is the optimal production quantity?
 - How long will it take to produce the optimal quantity? How much inventory is sold during this time?
 - If Ross uses the optimal production quantity, what would be the maximum inventory level? What would be the average inventory level? What is the annual holding cost?
 - How many production runs would there be each year? What would be the annual setup cost?
 - Given the optimal production run size, what is the total annual inventory cost?
 - If the lead time is one-half day, what is the ROP?
- 6-27 Upon hearing that Ross White (see Problems 6-25 and 6-26) is considering producing the brackets in-house, the vendor has notified Ross that the purchase price would drop from \$15 per bracket to \$14.50 per bracket if Ross will purchase the brackets in lots of 1,000. Lead times, however would increase to 3 days for this larger quantity.
- What is the total annual inventory cost plus purchase cost if Ross buys the brackets in lots of 1,000 at \$14.50 each?
 - If Ross does buy in lots of 1,000 brackets, what is the new ROP?
 - Given the options of purchasing the brackets at \$15 each, producing them in-house at \$14.80, and taking advantage of the discount, what is your recommendation to Ross White?
- 6-28 After analyzing the costs of various options for obtaining brackets, Ross White (see Problems 6-25, 6-26, and 6-27) recognizes that although he knows that lead time is 2 days and demand per day averages 10 units, the demand during the lead time often varies. Ross has kept very careful records and has determined lead time demand is normally distributed with a standard deviation of 1.5 units.
- What Z value would be appropriate for a 98% service level?
 - What safety stock should Ross maintain if he wants a 98% service level?
 - What is the adjusted ROP for the brackets?
 - What is the annual holding cost for the safety stock if the annual holding cost per unit is \$1.50?

FACTOR	Stock (\$)	
	LORIANA GAS AND POWER	JEMEC INSULATION COMPANY
Short-term growth potential, per dollar invested	.36	.24
Intermediate growth potential (over next three years), per dollar invested	1.67	1.50
Dividend rate potential	4%	8%

Each member of the club has an investment goal of (1) an appreciation of no less than \$720 in the short term, (2) an appreciation of at least \$5,000 in the next three years, and (3) a dividend income of at least \$200 per year. What is the smallest investment that a professor can make to meet these three goals?

7-25 Woofers Pet Foods produces a low-calorie dog food for overweight dogs. This product is made from beef products and grain. Each pound of beef costs \$0.90, and each pound of grain costs \$0.60. A pound of the dog food must contain at least 9 units of Vitamin 1 and 10 units of Vitamin 2. A pound of beef contains 10 units of Vitamin 1 and 12 units of Vitamin 2. A pound of grain contains 6 units of Vitamin 1 and 9 units of Vitamin 2. Formulate this as an LP problem to minimize the cost of the dog food. How many pounds of beef and grain should be included in each pound of dog food? What is the cost and vitamin content of the final product?

7-26 The seasonal yield of olives in a Piraeus, Greece, vineyard is greatly influenced by a process of branch pruning. If olive trees are pruned every two weeks, output is increased. The pruning process, however, requires considerably more labor than permitting the olives to grow on their own and results in a smaller size olive. It also, though, permits olive trees to be spaced closer together. The yield of 1 barrel of olives by pruning requires 5 hours of labor and 1 acre of land. The production of a barrel of olives by the normal process requires only 2 labor hours but takes 2 acres of land. An olive grower has 250 hours of labor available and a total of 150 acres for growing. Because of the olive size difference, a barrel of olives produced on pruned trees sells for \$20, whereas a barrel of regular olives has a market price of \$30. The grower has determined that because of uncertain demand, no more than 40 barrels of pruned olives should be produced. Use graphical LP to find

- the maximum possible profit.
- the best combination of barrels of pruned and regular olives.
- the number of acres that the olive grower should devote to each growing process.

- 7-27** Consider the following four LP formulations. Using a graphical approach, determine
- which formulation has more than one optimal solution.
 - which formulation is unbounded.
 - which formulation has no feasible solution.
 - which formulation is correct as is.

Formulation 1	Formulation 3
Maximize $10X_1 + 10X_2$	Maximize $3X_1 + 2X_2$
subject to $2X_1 \leq 10$	subject to $X_1 + X_2 \geq 5$
$2X_1 + 4X_2 \leq 16$	$X_1 \geq 2$
$4X_2 \leq 8$	$2X_2 \geq 8$
$X_1 \geq 6$	

Formulation 2	Formulation 4
Maximize $X_1 + 2X_2$	Maximize $3X_1 + 3X_2$
subject to $X_1 \leq 1$	subject to $4X_1 + 6X_2 \leq 48$
$2X_2 \leq 2$	$4X_1 + 2X_2 \leq 12$
$X_1 + 2X_2 \leq 2$	$3X_2 \geq 3$
	$2X_1 \geq 2$

7-28 Graph the following LP problem and indicate the optimal solution point:

Maximize profit = $\$3X + \$2Y$

subject to $2X + Y \leq 150$

$2X + 3Y \leq 300$

- Does the optimal solution change if the profit per unit of X changes to \$4.50?
- What happens if the profit function should have been $\$3X + \$3Y$?

7-29 Graphically analyze the following problem:

Maximize profit = $\$4X + \$6Y$

subject to $X + 2Y \leq 8$ hours

$6X + 4Y \leq 24$ hours

- What is the optimal solution?
- If the first constraint is altered to $X + 3Y \leq 8$, does the feasible region or optimal solution change?

7-30 Examine the LP formulation in Problem 7-29. The problem's second constraint reads

$6X + 4Y \leq 24$ hours (time available on machine 2)

If the firm decides that 36 hours of time can be made available on machine 2 (namely, an additional 12 hours) at an additional cost of \$10, should it add the hours?

7-31 Consider the following LP problem:

Maximize profit = $5X + 6Y$

subject to $2X + Y \leq 120$

$2X + 3Y \leq 240$

$X, Y \geq 0$

- (a) What is the optimal solution to this problem? Solve it graphically.
- (b) If a technical breakthrough occurred that raised the profit per unit of X to \$8, would this affect the optimal solution?
- (c) Instead of an increase in the profit coefficient X to \$8, suppose that profit was overestimated and should only have been \$3. Does this change the optimal solution?

7-32 Consider the LP formulation given in Problem 7-31. If the second constraint is changed from $2X + 3Y \leq 240$ to $2X + 4Y \leq 240$, what effect will this have on the optimal solution?

7-33 The computer output given above is for Problem 7-31. Use this to answer the following questions.

- (a) How much could the profit on X increase or decrease without changing the values of X and Y in the optimal solution?
- (b) If the right-hand side of constraint 1 were increased by 1 unit, how much would the profit increase?

- (c) If the right-hand side of constraint 1 were increased by 10 units, how much would the profit increase?

7-34 The computer output below is for a product mix problem in which there are two products and three resource constraints. Use the output to help you answer the following questions. Assume that you wish to maximize profit in each case.

- (a) How many units of product 1 and product 2 should be produced?
- (b) How much of each of the three resources is being used?
- (c) What are the dual prices for each resource?
- (d) If you could obtain more of one of the resources, which one should you obtain? How much should you be willing to pay for this?
- (e) What would happen to profit if, with the original output, management decided to produce one more unit of product 2?

Output for Problem 7-33

Linear Programming Results					
Problem 7-33 Solution					
	X	Y		RHS	Dual
Maximize	5	6			
Constraint 1	2	1	<=	120	0.75
Constraint 2	2	3	<=	240	1.75
Solution->	30	60		510	

Ranging					
Problem 7-33 Solution					
Variable	Value	Reduced Cost	Original Val	Lower Bound	Upper Bound
X	30	0	5	4	12
Y	60	0	6	2.5	7.5
Constraint	Dual Value	Slack/Surplus	Original Val	Lower Bound	Upper Bound
Constraint 1	0.75	0	120	80	240
Constraint 2	1.75	0	240	120	360

Output for Problem 7-34

Linear Programming Results					
Problem 734 Solution					
	X1	X2		RHS	Dual
Maximize	50	20			
Constraint 1	1	2	<=	45	0
Constraint 2	3	3	<=	87	0
Constraint 3	2	1	<=	50	25
Solution->	25	0		1,250	

Ranging					
Problem 734 Solution					
Variable	Value	Reduced Cost	Original Val	Lower Bound	Upper Bound
X1	25	0	50	40	Infinity
X2	0	5	20	-Infinity	25
Constraint	Dual Value	Slack/Surplus	Original Val	Lower Bound	Upper Bound
Constraint 1	0	20	45	25	Infinity
Constraint 2	0	12	87	75	Infinity
Constraint 3	25	0	50	0	58

Output for Problem 7-35

Solved Problem 7-2 Solution					
	X1	X2		RHS	Dual
Maximize	50.	20.			
Constraint 1	2.	4.	<=	400.	0.
Constraint 2	100.	50.	<=	8,000.	3.4
Constraint 3	1.	0.	<=	60.	10.
Solution->	60.	40.		3,300.	

Solved Problem 7-2 Solution					
Variable	Value	Reduced Cost	Original Val	Lower Bound	Upper Bound
X1	60.	0.	50.	40.	Infinity
X2	40.	0.	20.	0.	25.
Constraint	Dual Value	Slack/Surplus	Original Val	Lower Bound	Upper Bound
Constraint 1	0.	120.	400.	280.	Infinity
Constraint 2	0.4	0.	8,000.	6,000.	9,500.
Constraint 3	10.	0.	60.	40.	80.

7-35 Graphically solve the following problem:

$$\begin{aligned} \text{Maximize profit} &= 8X_1 + 5X_2 \\ \text{subject to} & \quad X_1 + X_2 \leq 10 \\ & \quad X_1 \leq 6 \\ & \quad X_1, X_2 \geq 0 \end{aligned}$$

- What is the optimal solution?
- Change the right-hand side of constraint 1 to 11 (instead of 10) and resolve the problem. How much did the profit increase as a result of this?
- Change the right-hand side of constraint 1 to 6 (instead of 10) and resolve the problem. How much did the profit decrease as a result of this? Looking at the graph, what would happen if the right-hand-side value were to go below 6?
- Change the right-hand-side value of constraint 1 to 5 (instead of 10) and resolve the problem. How much did the profit decrease from the original profit as a result of this?
- Using the computer output on this page, what is the dual price of constraint 1? What is the lower bound on this?
- What conclusions can you draw from this regarding the bounds of the right-hand-side values and the dual price?

7-36 Serendipity⁶

The three princes of Serendip
Went on a little trip.
They could not carry too much weight;
More than 300 pounds made them hesitate.
They planned to the ounce. When they returned to Ceylon
They discovered that their supplies were just about gone

When, what to their joy, Prince William found
A pile of coconuts on the ground.
"Each will bring 60 rupees," said Prince Richard with a grin
As he almost tripped over a lion skin.
"Look out!" cried Prince Robert with glee
As he spied some more lion skins under a tree.
"These are worth even more—300 rupees each
If we can just carry them all down to the beach."
Each skin weighed fifteen pounds and each coconut, five,
But they carried them all and made it alive.
The boat back to the island was very small
15 cubic feet baggage capacity—that was all.
Each lion skin took up one cubic foot
While eight coconuts the same space took.
With everything stowed they headed to sea
And on the way calculated what their new wealth might be.
"Eureka!" cried Prince Robert, "Our worth is so great
That there's no other way we could return in this state.
Any other skins or nut that we might have brought
Would now have us poorer. And now I know what—
I'll write my friend Horace in England, for surely
Only he can appreciate our serendipity."

Formulate and solve **Serendipity** by graphical LP in order to calculate "what their new wealth might be."

7-37 Bhavika Investments, a group of financial advisors and retirement planners, has been requested to provide advice on how to invest \$200,000 for one of its clients. The client has stipulated that the money must be put into either a stock fund or a money market fund, and

⁶ The word *serendipity* was coined by the English writer Horace Walpole after a fairy tale titled *The Three Princes of Serendip*. Source of problem is unknown.

expected to remain at the same levels in the near future.

The firm is facing several constraints as it prepares its November production plan. First, it has experienced a tremendous demand and has been unable to keep any significant inventory in stock. This situation is not expected to change. Second, the firm is located in a small Iowa town from which additional labor is not readily available. Workers can be shifted from production of one modem to another, however. To produce the 9,000 regular modems in September required 5,000 direct labor hours. The 10,400 intelligent modems absorbed 10,400 direct labor hours.

Table for Problem 7-42
MCA Income Statement Month Ended September 30

	REGULAR MODEMS	INTELLIGENT MODEMS
Sales	\$450,000	\$640,000
Less: Discounts	10,000	15,000
Returns	12,000	9,500
Warranty replacements	4,000	2,500
Net sales	<u>\$424,000</u>	<u>\$613,000</u>
Sales costs		
Direct labor	60,000	76,800
Indirect labor	9,000	11,520
Materials cost	90,000	128,000
Depreciation	40,000	50,800
Cost of sales	<u>\$199,000</u>	<u>\$267,120</u>
Gross profit	<u>\$225,000</u>	<u>\$345,880</u>
Selling and general expenses		
General expenses—variable	30,000	35,000
General expenses—fixed	36,000	40,000
Advertising	28,000	25,000
Sales commissions	31,000	60,000
Total operating cost	<u>\$125,000</u>	<u>\$160,000</u>
Pretax income	<u>\$100,000</u>	<u>\$185,880</u>
Income taxes (25%)	<u>25,000</u>	<u>46,470</u>
Net income	<u>\$ 75,000</u>	<u>\$139,410</u>

Third, MCA is experiencing a problem affecting the intelligent modems model. Its component supplier is able to guarantee only 8,000 microprocessors for November delivery. Each intelligent modem requires one of these specially made microprocessors. Alternative suppliers are not available on short notice.

MCA wants to plan the optimal mix of the two modem models to produce in November to maximize profits for MCA.

- (a) Formulate, using September's data, MCA's problem as a linear program.
- (b) Solve the problem graphically.

- (c) Discuss the implications of your recommended solution.

7-43 Working with chemists at Virginia Tech and George Washington Universities, landscape contractor Kenneth Golding blended his own fertilizer, called "Golding-Grow." It consists of four chemical compounds, C-30, C-92, D-21, and E-11. The cost per pound for each compound is indicated as follows:

CHEMICAL COMPOUND	COST PER POUND (\$)
C-30	0.12
C-92	0.09
D-21	0.11
E-11	0.04

The specifications for Golding-Grow are as follows: (1) E-11 must constitute at least 15% of the blend; (2) C-92 and C-30 must together constitute at least 45% of the blend; (3) D-21 and C-92 can together constitute no more than 30% of the blend; and (4) Golding-Grow is packaged and sold in 50-pound bags.

- (a) Formulate an LP problem to determine what blend of the four chemicals will allow Golding to minimize the cost of a 50-pound bag of the fertilizer.
- (b) Solve using a computer to find the best solution.

7-44 Raptor Fuels produces three grades of gasoline—Regular, Premium, and Super. All of these are produced by blending two types of crude oil—Crude A and Crude B. The two types of crude contain specific ingredients which help in determining the octane rating of gasoline. The important ingredients and the costs are contained in the following table:

	CRUDE A	CRUDE B
Cost per gallon	\$0.42	\$0.47
Ingredient 1	40%	52%
Other ingredients	60%	48%

In order to achieve the desired octane ratings, at least 41% of Regular gasoline should be Ingredient 1; at least 44% of Premium gasoline must be Ingredient 1, and at least 48% of Super gasoline must be Ingredient 1. Due to current contract commitments, Raptor Fuels must produce at least 20,000 gallons of Regular, at least 15,000 gallons of Premium, and at least 10,000 gallons of Super. Formulate a linear program that could be used to determine how much of Crude A and Crude B should be used in each of the gasolines to meet the demands at the minimum cost. What is the minimum cost? How much of Crude A and Crude B are used in each gallon of the different types of gasoline?

six months. Sundown leases cars from an automobile manufacturer and then rents them to the public on a daily basis. A forecast of the demand for Sundown's cars in the next six months follows:

MONTH	MARCH	APRIL	MAY	JUNE	JULY	AUGUST
Demand	420	400	430	460	470	440

Cars may be leased from the manufacturer for either three, four, or five months. These are leased on the first day of the month and are returned on the last day of the month. Every six months the automobile manufacturer is notified by Sundown about the number of cars needed during the next six months. The automobile manufacturer has stipulated that at least 50% of the cars leased during a six-month period must be on the five-month lease. The cost per month on each of the three types of leases are \$420 for the three-month lease, \$400 for the four-month lease, and \$370 for the five-month lease.

Currently, Sundown has 390 cars. The lease on 120 cars expires at the end of March. The lease on another 140 cars expires at the end of April, and the lease on the rest of these expires at the end of May.

Use LP to determine how many cars should be leased in each month on each type of lease to minimize the cost of leasing over the six-month period. How many cars are left at the end of August?

8-9 (Management of Sundown Rent-a-Car) (see Problem 8-8) has decided that perhaps the cost during the six-month period is not the appropriate cost to minimize because the agency may still be obligated to additional months on some leases after that time. For example, if Sundown had some cars delivered at the beginning of the sixth month, Sundown would still be obligated for two additional months on a three-month lease. Use LP to determine how many cars should be leased in each month on each type of lease to minimize the cost of leasing over the entire life of these leases.

8-10 (High school busing problem) The Arden County, Maryland, superintendent of education is responsible for assigning students to the *three* high schools in his county. He recognizes the need to bus a certain number of students, for several sectors of the county are beyond walking distance to a school. The superintendent partitions the county into *five* geographic sectors as he attempts to establish a plan that will minimize the total number of student miles traveled by bus. He also recognizes that if a student happens to live in a certain sector and is assigned to the high school in that sector, there is no need to bus that student because he or she can walk to school. The three schools are located in sectors B, C, and E.

The following table reflects the number of high-school-age students living in each sector and the distance in miles from each sector to each school:

SECTOR	DISTANCE TO SCHOOL			NUMBER OF STUDENTS
	SCHOOL IN SECTOR B	SCHOOL IN SECTOR C	SCHOOL IN SECTOR E	
A	5	8	6	700
B	0	4	12	500
C	4	0	7	100
D	7	2	5	800
E	12	7	0	400
				2,500

Each high school has a capacity of 900 students. Set up the objective function and constraints of this problem using LP so that the total number of student miles traveled by bus is minimized. (Note the resemblance to the transportation problem illustrated earlier in this chapter.) Then solve the problem.

8-11 (Pricing and marketing strategy problem) The I. Kruger Paint and Wallpaper Store is a large retail distributor of the Supertrex brand of vinyl wallcoverings. Kruger will enhance its citywide image in Miami if it can outsell other local stores in total number of rolls of Supertrex next year. It is able to estimate the demand function as follows:

$$\text{Number of rolls of Supertrex sold} = 20 \times \text{Dollars spent on advertising} + 6.8 \times \text{Dollars spent on in-store displays} + 12 \times \text{Dollars invested in on-hand wallpaper inventory} - 65,000 \times \text{Percentage markup taken above wholesale cost of a roll}$$

The store budgets a total of \$17,000 for advertising, in-store displays, and on-hand inventory of Supertrex for next year. It decides it must spend at least \$3,000 on advertising; in addition, at least 5% of the amount invested in on-hand inventory should be devoted to displays. Markups on Supertrex seen at other local stores range from 20% to 45%. Kruger decides that its markup had best be in this range as well.

- Formulate as an LP problem.
- Solve the problem.
- What is the difficulty with the answer?
- What constraint would you add?

8-12 (College meal selection problem) Kathy Roniger, campus dietician for a small Idaho college, is responsible for formulating a nutritious meal plan for students. For an evening meal, she feels that the following five meal-content requirements should be met: (1) between 900 and 1,500 calories; (2) at least 4 milligrams of iron; (3) no more than 50 grams of fat; (4) at least 26 grams of protein; and (5) no more than 50 grams of carbohydrates. On a particular day, Roniger's food stock includes seven items that can be prepared and served for supper to meet these requirements. The cost per pound for each food item and the contribution to each of the five nutritional requirements are given in the table on page 342:

Data for Problem 8-12

FOOD ITEM	CALORIES/LB	IRON (MG/LB)	FAT (GM/LB)	PROTEIN (GM/LB)	CARBOHYDRATES (GM/LB)	COST/LB (\$)
Milk	295	0.2	16	16	22	0.60
Ground meat	1216	0.2	96	81	0	2.35
Chicken	394	4.3	9	74	0	1.15
Fish	358	3.2	0.5	83	0	2.25
Beans	128	3.2	0.8	7	28	0.58
Spinach	118	14.1	1.4	14	19	1.17
Potatoes	279	2.2	0.5	8	63	0.33

Source: Pennington, Jean A. T., and Judith S. Douglas. *Bowes and Church's Food Values of Portions Commonly Used*, 18th ed., Philadelphia: Lippincott Williams & Wilkins, 2004, pp. 100-130.

What combination and amounts of food items will provide the nutrition Roniger requires at the least total food cost?

- (a) Formulate as an LP problem.
- (b) What is the cost per meal?
- (c) Is this a well-balanced diet?



8-13 (High-tech production problem) Quitmeyer Electronics Incorporated manufactures the following six microcomputer peripheral devices: internal modems, external modems, graphics circuit boards, CD drives, hard disk drives, and memory expansion boards. Each of these technical products requires time, in minutes, on three types of electronic testing equipment, as shown in the table at the bottom of the page.

The first two test devices are available 120 hours per week. The third (device 3) requires more preventive maintenance and may be used only 100 hours each week. The market for all six computer components is vast, and Quitmeyer Electronics believes that it can sell as many units of each product as it can manufacture. The table that follows summarizes the revenues and material costs for each product:

DEVICE	REVENUE PER UNIT SOLD (\$)	MATERIAL COST PER UNIT (\$)
Internal modem	200	35
External modem	120	25
Graphics circuit board	180	40
CD drive	130	45
Hard disk drive	430	170
Memory expansion board	260	60

Data for Problem 8-13

	INTERNAL MODEM	EXTERNAL MODEM	CIRCUIT BOARD	CD DRIVES	HARD DRIVES	MEMORY BOARDS
Test device 1	7	3	12	6	18	17
Test device 2	2	5	3	2	15	17
Test device 3	5	1	3	2	9	2

In addition, variable labor costs are \$15 per hour for test device 1, \$12 per hour for test device 2, and \$18 per hour for test device 3. Quitmeyer Electronics wants to maximize its profits.

- (a) Formulate this problem as an LP model.
- (b) Solve the problem by computer. What is the best product mix?
- (c) What is the value of an additional minute of time per week on test device 1? Test device 2? Test device 3? Should Quitmeyer Electronics add more test device time? If so, on which equipment?



8-14 (Nuclear plant staffing problem) South Central Utilities has just announced the August 1 opening of its second nuclear generator at its Baton Rouge, Louisiana, nuclear power plant. Its personnel department has been directed to determine how many nuclear technicians need to be hired and trained over the remainder of the year.

The plant currently employs 350 fully trained technicians and projects the following personnel needs:

MONTH	PERSONNEL HOURS NEEDED
August	40,000
September	45,000
October	35,000
November	50,000
December	45,000

By Louisiana law, a reactor employee can actually work no more than 130 hours per month. (Slightly over 1 hour per day is used for check-in and check-out,

recordkeeping, and daily radiation health scans.) Policy at South Central Utilities also dictates that layoffs are not acceptable in those months when the nuclear plant is overstaffed. So, if more trained employees are available than are needed in any month, each worker is still fully paid, even though he or she is not required to work the 130 hours.

Training new employees is an important and costly procedure. It takes one month of one-on-one classroom instruction before a new technician is permitted to work alone in the reactor facility. Therefore, South Central must hire trainees one month before they are actually needed. Each trainee teams up with a skilled nuclear technician and requires 90 hours of that employee's time, meaning that 90 hours less of the technician's time are available that month for actual reactor work.

Personnel department records indicate a turnover rate of trained technicians at 5% per month. In other words, about 5% of the skilled employees at the start of any month resign by the end of that month. A trained technician earns an average monthly salary of \$2,000 (regardless of the number of hours worked, as noted earlier). Trainees are paid \$900 during their one month of instruction.

- (a) Formulate this staffing problem using LP.
- (b) Solve the problem. How many trainees must begin each month?

8-15 (Agricultural production planning problem) Margaret Black's family owns five parcels of farmland broken into a southeast sector, north sector, northwest sector, west sector, and southwest sector. Margaret is involved primarily in growing wheat, alfalfa, and barley crops and is currently preparing her production plan for next year. The Pennsylvania Water Authority has just announced its yearly water allotment, with the Black farm receiving 7,400 acre-feet. Each parcel can only tolerate a specified amount of irrigation per growing season, as specified in the following table:

PARCEL	AREA (ACRES)	WATER IRRIGATION LIMIT (ACRE-FEET)
Southeast	2,000	3,200
North	2,300	3,400
Northwest	600	800
West	1,100	500
Southwest	500	600

Each of Margaret's crops needs a minimum amount of water per acre, and there is a projected limit on sales of each crop. Crop data follow:

CROP	MAXIMUM SALES	WATER NEEDED PER ACRE (ACRE-FEET)
Wheat	110,000 bushels	1.6
Alfalfa	1,800 tons	2.9
Barley	2,200 tons	3.5

Margaret's best estimate is that she can sell wheat at a net profit of \$2 per bushel, alfalfa at \$40 per ton, and barley at \$50 per ton. One acre of land yields an average of 1.5 tons of alfalfa and 2.2 tons of barley. The wheat yield is approximately 50 bushels per acre.

- (a) Formulate Margaret's production plan.
- (b) What should the crop plan be, and what profit will it yield?
- (c) The Water Authority informs Margaret that for a special fee of \$6,000 this year, her farm will qualify for an additional allotment of 600 acre-feet of water. How should she respond?

8-16 (Material blending problem) Amalgamated Products has just received a contract to construct steel body frames for automobiles that are to be produced at the new Japanese factory in Tennessee. The Japanese auto manufacturer has strict quality control standards for all of its component subcontractors and has informed Amalgamated that each frame must have the following steel content:

MATERIAL	MINIMUM PERCENTAGE	MAXIMUM PERCENTAGE
Manganese	2.1	2.3
Silicon	4.3	4.6
Carbon	5.05	5.35

Amalgamated mixes batches of eight different available materials to produce one ton of steel used in the body frames. The table on page 344 details these materials.

Formulate and solve the LP model that will indicate how much each of the eight materials should be blended into a 1-ton load of steel so that Amalgamated meets its requirements while minimizing costs.

8-17 Refer to Problem 8-16. Find the cause of the difficulty and recommend how to adjust it. Then solve the problem again.

8-18 (Hospital expansion problem) Mt. Sinai Hospital in New Orleans is a large, private, 600-bed facility, complete with laboratories, operating rooms, and x-ray equipment. In seeking to increase revenues, Mt. Sinai's administration has decided to make a 90-bed addition on a portion of adjacent land currently used for staff parking. The administrators feel that the labs, operating rooms, and x-ray department are not being fully utilized at present and do not need to be expanded to handle additional patients. The addition of 90 beds, however, involves deciding how many beds should be allocated to the medical staff for medical patients and how many to the surgical staff for surgical patients.

The hospital's accounting and medical records departments have provided the following pertinent information. The average hospital stay for a medical patient is 8 days, and the average medical patient generates \$2,280 in revenues. The average surgical patient is in the hospital 5 days and receives a \$1,515 bill. The laboratory is capable of handling 15,000 tests per year more than it was handling. The

Data for Problem 8-16

MATERIAL AVAILABLE	MANGANESE (%)	SILICON (%)	CARBON (%)	POUNDS AVAILABLE	COST PER POUND (\$)
Alloy 1	70.0	15.0	3.0	No limit	0.12
Alloy 2	55.0	30.0	1.0	300	0.13
Alloy 3	12.0	26.0	0	No limit	0.15
Iron 1	1.0	10.0	3.0	No limit	0.09
Iron 2	5.0	2.5	0	No limit	0.07
Carbide 1	0	24.0	18.0	50	0.10
Carbide 2	0	25.0	20.0	200	0.12
Carbide 3	0	23.0	25.0	100	0.09

average medical patient requires 3.1 lab tests and the average surgical patient takes 2.6 lab tests. Furthermore, the average medical patient uses one x-ray, whereas the average surgical patient requires two x-rays. If the hospital was expanded by 90 beds, the x-ray department could handle up to 7,000 x-rays without significant additional cost. Finally, the administration estimates that up to 2,800 additional operations could be performed in existing operating room facilities. Medical patients, of course, do not require surgery, whereas each surgical patient generally has one surgery performed.

Formulate this problem so as to determine how many medical beds and how many surgical beds should be added to maximize revenues. Assume that the hospital is open 365 days a year. Then solve the problem.

8-19 Prepare a written report to the CEO of Mt. Sinai Hospital in Problem 8-18 on the expansion of the hospital. Round off your answers to the nearest integer. The format of presentation of results is important. The CEO is a busy person and wants to be able to find your optimal solution quickly in your report. Cover all the areas given in the following sections, but do not mention any variables or shadow prices.

- (a) What is the maximum revenue per year, how many medical patients/year are there, and how many surgical patients/year are there? How many medical beds and how many surgical beds of the 90-bed addition should be added?
- (b) Are there any empty beds with this optimal solution? If so, how many empty beds are there? Discuss the effect of acquiring more beds if needed.
- (c) Are the laboratories being used to their capacity? Is it possible to perform more lab tests/year? If so, how many more? Discuss the effect of acquiring more lab space if needed.
- (d) Is the x-ray facility being used to its maximum? Is it possible to do more x-rays/year? If so, how many more? Discuss the effect of acquiring more x-ray facilities if needed.
- (e) Is the operating room being used to capacity? Is it possible to do more operations/year? If so, how many more? Discuss the effect of acquiring more operating room facilities if needed. (Source: Professor Chris Vertullo.)

8-20 (Assignment problem) Elliot and Elliot is a public accounting firm with four persons working in the auditing department: Smith, Jones, Davis, and Nguyen. Each of these individuals is uniquely qualified with experience in specific industries. The manager of this department has just received four jobs that must be assigned to these individuals, and only one job may be assigned to each individual. The estimated number of days required to complete each of these jobs by the four individuals is given in the following table:

INDIVIDUAL	JOB 1	JOB 2	JOB 3	JOB 4
Smith	4	10	8	9
Jones	5	14	8	10
Davis	4	13	9	12
Nguyen	5	11	7	11

The manager would like to minimize the number of days required for the completion of these jobs. Formulate this as an LP problem. Solve this using any available computer software. How many work days will be required to complete these jobs? Who will be assigned to each job?

8-21 (Rock transshipment problem) Bamm Mining Company is currently extracting rock from two mines. Once it is taken from the ground and loaded on a truck, it is sent to one of two plants for processing. The processed rock is then shipped to one of three builders' supply stores, where it is sold for landscaping purposes. The cost of transportation, the supply available at each mine, and the processing capacity of each plant are given in the following table:

Cost per Ton for Shipping

FROM MINE	TO PROCESSING PLANT		
	#1	#2	DAILY SUPPLY
A	\$6	\$ 8	320 tons
B	\$7	\$10	450 tons
Processing capacity (per day)	500 tons	500 tons	

Data for Problem 10-13

FROM	To	PROJECT A	PROJECT B	PROJECT C	PLANT CAPACITIES
PLANT 1		\$10	\$4	\$11	70
PLANT 2		12	5	8	50
PLANT 3		9	7	6	30
PROJECT REQUIREMENTS		40	50	60	150

10-12 Using the expanded production capacity given in Problem 10-11, use VAM and the stepping-stone method to find the optimal solution to this problem.

10-13 The Hardrock Concrete Company has plants in three locations and is currently working on three major construction projects, each located at a different site. The shipping cost per truckload of concrete, daily plant capacities, and daily project requirements are provided in the table above.

- (a) Formulate an initial feasible solution to Hardrock's transportation problem using the northwest corner rule. Then evaluate each unused shipping route by computing all improvement indices. Is this solution optimal? Why?
- (b) Is there more than one optimal solution to this problem? Why?

10-14 Hardrock Concrete's owner has decided to increase the capacity at his smallest plant (see Problem 10-13). Instead of producing 30 loads of concrete per day at plant 3, that plant's capacity is doubled to 60 loads. Find the new optimal solution using the northwest corner rule and stepping-stone method. How has changing the third plant's capacity altered the optimal shipping assignment? Discuss the concepts of

degeneracy and multiple optimal solutions with regard to this problem.

10-15 The Saussy Lumber Company ships pine flooring to three building supply houses from its mills in Pineville, Oak Ridge, and Mapletown. Determine the best transportation schedule for the data given in the table. Use the northwest corner rule and the stepping-stone method.

10-16 Using the same Saussy Lumber Company data and the same initial solution you found with the northwest corner rule, resolve Problem 10-15 using the MODI method.

10-17 The Krampf Lines Railway Company specializes in coal handling. On Friday, April 13, Krampf had empty cars at the following towns in the quantities indicated:

TOWN	SUPPLY OF CARS
Morgantown	35
Youngstown	60
Pittsburgh	25

Table for Problem 10-15

FROM	To	SUPPLY HOUSE 1	SUPPLY HOUSE 2	SUPPLY HOUSE 3	MILL CAPACITY (TONS)
PINEVILLE		\$3	\$3	\$2	25
OAK RIDGE		4	2	3	40
MAPLETOWN		3	2	3	30
SUPPLY HOUSE DEMAND (TONS)		30	30	35	95

Table for Problem 10-24

SAVINGS AND LOAN COMPANY	PROPERTY (INTEREST RATES) (%)				MAXIMUM CREDIT LINE (\$)
	HILL ST.	BANKS ST.	PARK AVE.	DRURY LANE	
First Homestead	8	8	10	11	80,000
Commonwealth	9	10	12	10	100,000
Washington Federal	9	11	10	9	120,000
Loan required to purchase building	\$60,000	\$40,000	\$130,000	\$70,000	

10-25 The J. Mehta Company's production manager is planning for a series of one-month production periods for stainless steel sinks. The demand for the next four months is as follows:

MONTH	DEMAND FOR SINKS
1	120
2	160
3	240
4	100

The Mehta firm can normally produce 100 stainless steel sinks in a month. This is done during regular production hours at a cost of \$100 per sink. If demand in any one month cannot be satisfied by regular production, the production manager has three other choices: (1) He can produce up to 50 more sinks per month in overtime but at a cost of \$130 per sink; (2) he can purchase a limited number of sinks from a friendly competitor for resale (the maximum number of outside purchases over the four-month period is 450 sinks, at a cost of \$150 each); or (3) he can fill the demand from his on-hand inventory. The inventory

carrying cost is \$10 per sink per month. Back orders are not permitted. Inventory on hand at the beginning of month 1 is 40 sinks. Set up this "production smoothing" problem as a transportation problem to minimize cost. Use the northwest corner rule to find an initial level for production and outside purchases over the four-month period.

10-26 Ashley's Auto Top Carriers currently maintains plants in Atlanta and Tulsa that supply major distribution centers in Los Angeles and New York. Because of an expanding demand, Ashley has decided to open a third plant and has narrowed the choice to one of two cities—New Orleans or Houston. The pertinent production and distribution costs, as well as the plant capacities and distribution demands, are shown in the table below.

10-27 Which of the new possible plants should be opened? Marc Smith, vice president for operations of HHN, Inc., a manufacturer of cabinets for telephone switches, is constrained from meeting the five-year forecast by limited capacity at the existing three plants. These three plants are Waterloo, Pusan, and Bogota. You, as his able assistant, have been told that because of existing capacity constraints and the expanding world market for HHN cabinets, a new

Data for Problem 10-26

		TO DISTRIBUTION CENTERS			UNIT PRODUCTION COST (\$)
		LOS ANGELES	NEW YORK	NORMAL PRODUCTION	
Existing plants	ATLANTA	\$8	\$5	600	6
	TULSA	\$4	\$7	900	5
Proposed locations	NEW ORLEANS	\$5	\$6	500	4 (anticipated)
	HOUSTON	\$4	\$6	---	---

Table for Problem 10-22

FROM	TO	DESTINATION A	DESTINATION B	DESTINATION C	SUPPLY
SOURCE 1		\$8	\$9	\$4	72
SOURCE 2		5	6	8	38
SOURCE 3		7	9	6	46
SOURCE 4		5	3	7	19
DEMAND		110	34	31	175

10-22 Consider the transportation table given above. Find an initial solution using the northwest corner rule. What special condition exists? Explain how you will proceed to solve the problem.

10-23 The three blood banks in Franklin County are coordinated through a central office that facilitates blood delivery to four hospitals in the region. The cost to ship a standard container of blood from each bank to each hospital is shown in the table below. Also given are the biweekly number of containers available at each bank and the biweekly number of containers of blood needed at each hospital. How many shipments should be made biweekly from each blood bank to each hospital so that total shipment costs are minimized?

10-24 The B. Hall Real Estate Investment Corporation has identified four small apartment buildings in which it would like to invest. Mrs. Hall has approached three

savings and loan companies regarding financing. Because Hall has been a good client in the past and has maintained a high credit rating in the community, each savings and loan company is willing to consider providing all or part of the mortgage loan needed on each property. Each loan officer has set differing interest rates on each property (rates are affected by the neighborhood of the apartment building, condition of the property, and desire by the individual savings and loan to finance various-size buildings), and each loan company has placed a maximum credit ceiling on how much it will lend Hall in total. This information is summarized in the table on the next page.

Each apartment building is equally attractive as an investment to Hall, so she has decided to purchase all buildings possible at the lowest total payment of interest. From which savings and loan companies should she borrow to purchase which buildings? More than one savings and loan can finance the same property.

Table for Problem 10-23

FROM	TO	HOSPITAL 1	HOSPITAL 2	HOSPITAL 3	HOSPITAL 4	SUPPLY
BANK 1		\$8	\$9	\$11	\$16	50
BANK 2		12	7	5	8	80
BANK 3		14	10	6	7	120
DEMAND		90	70	40	50	250

10-30 In a job shop operation, four jobs may be performed on any of four machines. The hours required for each job on each machine are presented in the following table. The plant supervisor would like to assign jobs so that total time is minimized. Use the assignment method to find the best solution.

JOB	MACHINE			
	W	X	Y	Z
A12	10	14	16	13
A15	12	13	15	12
B2	9	12	12	11
B9	14	16	18	16

10-31 Four automobiles have entered Bubba's Repair Shop for various types of work, ranging from a transmission overhaul to a brake job. The experience level of the mechanics is quite varied, and Bubba would like to minimize the time required to complete all of the jobs. He has estimated the time in minutes for each mechanic to complete each job. Billy can complete job 1 in 400 minutes, job 2 in 90 minutes, job 3 in 60 minutes, and job 4 in 120 minutes. Taylor will finish job 1 in 650 minutes, job 2 in 120 minutes, job 3 in 90 minutes, and job 4 in 180 minutes. Mark will finish job 1 in 480 minutes, job 2 in 120 minutes, job 3 in 80 minutes, and job 4 in 180 minutes. John will complete job 1 in 500 minutes, job 2 in 110 minutes, job 3 in 90 minutes, and job 4 in 150 minutes. Each mechanic should be assigned to just one of these jobs. What is the minimum total time required to finish the four jobs? Who should be assigned to each job?

10-32 Baseball umpiring crews are currently in four cities where three-game series are beginning. When these are finished, the crews are needed to work games in four different cities. The distances (miles) from each of the cities where the crews are currently working to the cities where the new games will begin are shown in the following table:

FROM	To			
	KANSAS CITY	CHICAGO	DETROIT	TORONTO
Seattle	1,500	1,730	1,940	2,070
Arlington	460	810	1,020	1,270
Oakland	1,500	1,850	2,080	X
Baltimore	960	610	400	330

10-33 In Problem 10-32, the minimum travel distance was found. To see how much better this solution is than the assignments that might have been made without using the Hungarian method, find the assignments that would give the maximum distance traveled. Compare this total distance with the distance found in Problem 10-32.

10-34 Roscoe Davis, chairman of a college's business department, has decided to apply the Hungarian method in assigning professors to courses next semester. As a criterion for judging who should teach each course, Professor Davis reviews the past two years' teaching evaluations (which were filled out by students). Since each of the four professors taught each of the four courses at one time or another during the two-year period, Davis is able to record a course rating for each instructor. These ratings are shown in the table. Find the best assignment of professors to courses to maximize the overall teaching rating.

PROFESSOR	COURSE			
	STATISTICS	MANAGEMENT	FINANCE	ECONOMICS
Anderson	90	65	95	40
Sweeney	70	60	80	75
Williams	85	40	80	60
McKinney	55	80	65	55

10-35 The hospital administrator at St. Charles General must appoint head nurses to four newly established departments: urology, cardiology, orthopedics, and obstetrics. In anticipation of this staffing problem, she had hired four nurses: Hawkins, Condriac, Bardot, and Hoolihan. Believing in the quantitative analysis approach to problem solving, the administrator has interviewed each nurse, considered his or her background, personality, and talents, and developed a cost scale ranging from 0 to 100 to be used in the assignment. A 0 for Nurse Bardot being assigned to the cardiology unit implies that she would be perfectly suited to that task. A value close to 100, on the other hand, would imply that she is not at all suited to head that unit. The accompanying table gives the complete set of cost figures that the hospital administrator felt represented all possible assignments. Which nurse should be assigned to which unit?

NURSE	DEPARTMENT			
	UROLOGY	CARDIOLOGY	ORTHOPEDICS	OBSTETRICS
Hawkins	28	18	15	75

DISCUSSION QUESTIONS AND PROBLEMS

Discussion Questions

- 12-1 What is the minimal-spanning tree technique? What types of problems can be solved using this quantitative analysis technique?
- 12-2 Describe the steps of the maximal-flow technique.
- 12-3 Give several examples of problems that can be solved using the maximal-flow technique.
- 12-4 What are the steps of the shortest-route technique?
- 12-5 Describe a problem that can be solved by the shortest-route technique.
- 12-6 Is it possible to get alternate optimal solutions with the shortest-route technique? Is there an automatic way of knowing if you have an alternate optimal solution?

Problems*

Q 12-7 Bechtold Construction is in the process of installing power lines to a large housing development. Steve Bechtold wants to minimize the total length of wire used, which will minimize his costs. The housing development is shown as a network in Figure 12.21.

Q 12-8 The city of New Berlin is considering making several of its streets one-way. What is the maximum number of cars per hour that can travel from east to west? The network is shown in Figure 12.22.

Q 12-9 Transworld Moving has been hired to move the office furniture and equipment of Cohen Properties to their new headquarters. What route do you recommend? The network of roads is shown in Figure 12.23.

Q 12-10 Because of a sluggish economy, Bechtold Construction has been forced to modify its plans for the housing development in Problem 12-7. The result is that the path from node 6 to 7 now has a distance of 7.

Q 12-11 Due to increased property taxes and an aggressive road development plan, the city of New Berlin has been able to increase the road capacity of two of its roads (see Problem 12-8). The capacity along the road

FIGURE 12.21

Network for Problem 12-7

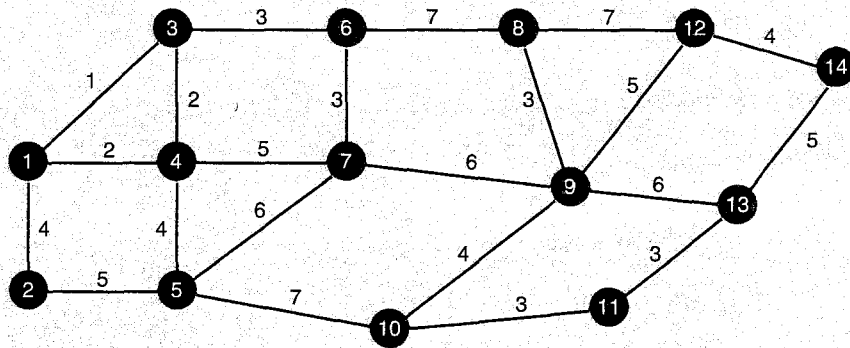
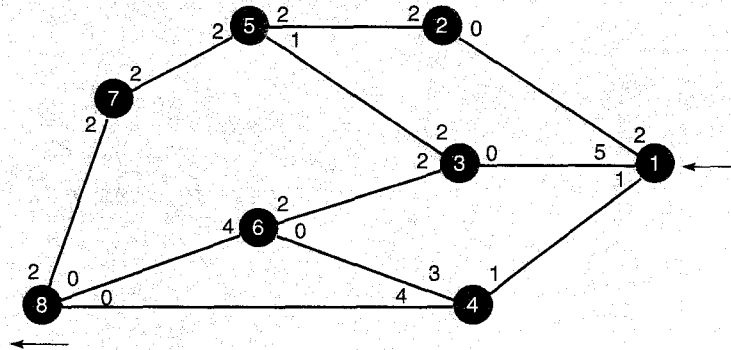


FIGURE 12.22

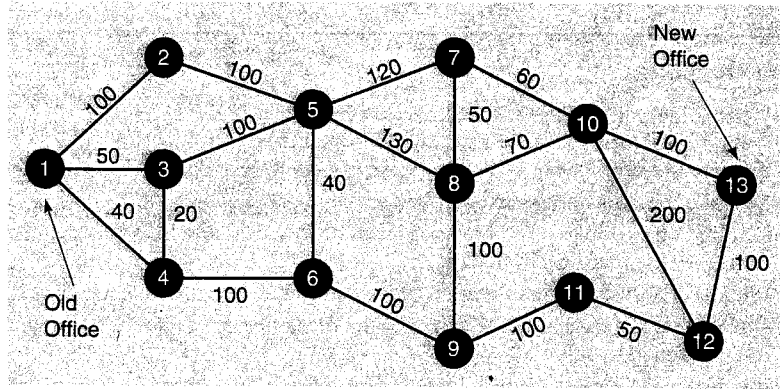
Network for Problem 12-8



* Note: Q means the problem may be solved with QM for Windows.

FIGURE 12.23

Network for Problem 12-9



represented by the path from node 1–node 2 has been increased from 2 to 5. In addition, the capacity from node 1–node 4 has been increased from 1 to 3. What impact do these changes have on the number of cars per hour that can travel from east to west?

12-12 The director of security wants to connect security video cameras to the main control site from five potential trouble locations. Ordinarily, cable would simply be run from each location to the main control site. However, because the environment is potentially explosive, the cable must be run in a special conduit that is continually air purged. This conduit is very expensive but large

enough to handle five cables (the maximum that might be needed). Use the minimal-spanning tree technique to find a minimum distance route for the conduit between the locations noted in Figure 12.24. (Note that it makes no difference which one is the main control site.)

12-13 One of our best customers has had a major plant breakdown and wants us to make as many widgets for him as possible during the next few days, until he gets the necessary repairs done. With our general-purpose equipment there are several ways to make widgets (ignoring costs). Any sequence of activities that takes one from node 1 to node 6 in Figure 12.25 will

FIGURE 12.24

Network for Problem 12-12

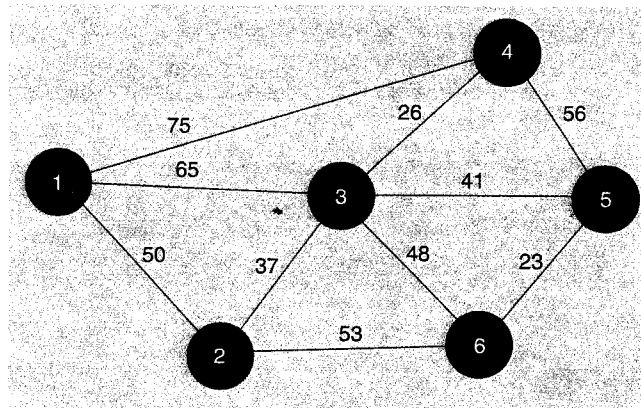
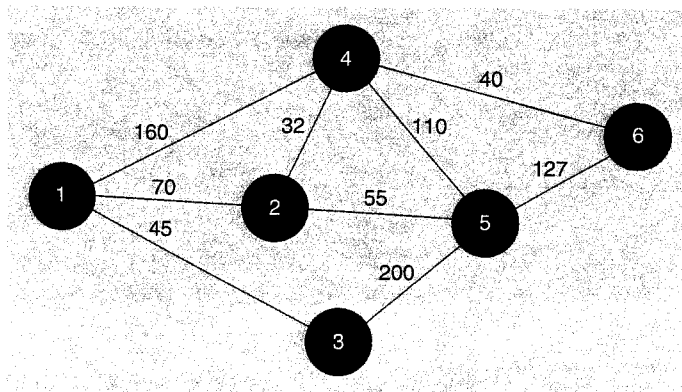


FIGURE 12.25

Network for Problem 12-13



produce a widget. How many widgets can we produce per day? Quantities given are number of widgets per day.

- 12-14 Transworld Moving, like other moving companies, closely follows the impact of road construction to make sure that its routes remain the most efficient. Unfortunately, there has been unexpected road construction due to a lack of planning for road repair around the town of New Haven, represented by node 9 in the network. (See Problem 12-9.) All roads leading to node 9, except the road from node 9 to node 11, can no longer be traveled. Does this have any impact on the route that should be used to ship the office furniture and equipment of Cohen Properties to their new headquarters?
- 12-15 Solve the minimal-spanning tree problem in the network shown in Figure 12.26. Assume that the numbers in the network represent distance in hundreds of yards.
- 12-16 Refer to Problem 12-15. What impact would changing the value for path 6-7 to 500 yards have on the solution to the problem and the total distance?
- 12-17 The road system around the hotel complex on International Drive (node 1) to Disney World (node 11) in Orlando, Florida, is shown in the network of Figure 12.27. The numbers by the nodes represent the traffic flow in hundreds of cars per hour. What is the maximum flow of cars from the hotel complex to Disney World?

- 12-18 A road construction project would increase the road capacity around the outside roads from International Drive to Disney World by 200 cars per hour (see Problem 12-17). The two paths affected would be 1-2-6-9-11 and 1-5-8-10-11. What impact would this have on the total flow of cars? Would the total flow of cars increase by 400 cars per hour?
- 12-19 Solve the maximal-flow problem presented in the network of Figure 12.28 on the next page. The numbers in the network represent thousands of gallons per hour as they flow through a chemical processing plant.
- 12-20 Two terminals in the chemical processing plant, represented by nodes 6 and 7, require emergency repair (see Problem 12-19). No material can flow into or out of these nodes. What impact does this have on the capacity of the network?
- 12-21 Solve the shortest-route problem presented in the network of Figure 12.29 on the next page, going from node 1 to node 16. All numbers represent kilometers between German towns near the Black Forest.
- 12-22 Due to bad weather, the roads represented by nodes 7 and 8 have been closed (see Problem 12-21). No traffic can get onto or off of these roads. Describe the impact that this will have (if any) on the shortest route through this network.
- 12-23 Grey Construction would like to determine the least expensive way of connecting houses it is building with

FIGURE 12.26

Network for Problem 12-15

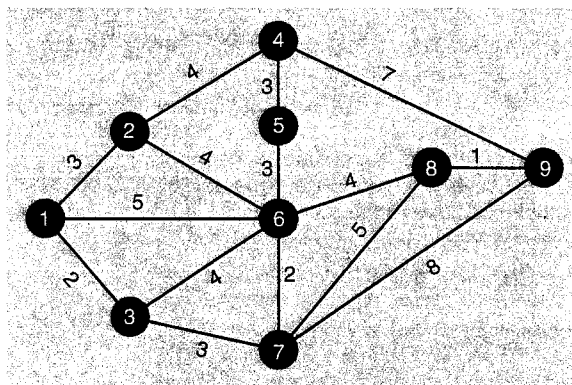
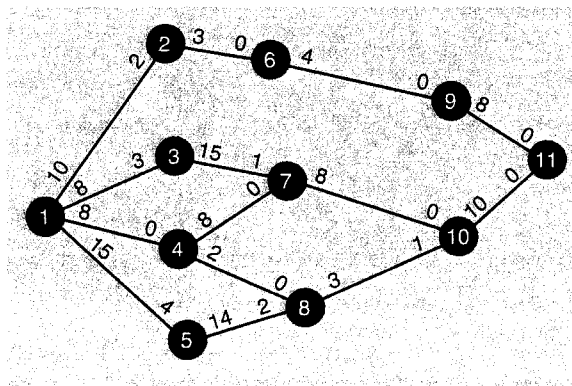


FIGURE 12.27

Network for Problem 12-17



PROBLEMS

- 13-1 What are some of the questions that can be answered with PERT and CPM?
- 13-2 What are the major differences between PERT and CPM?
- 13-3 What is an activity? What is an event? What is an immediate predecessor?
- 13-4 Describe how expected activity times and variances can be computed in a PERT network.
- 13-5 Briefly discuss what is meant by critical path analysis. What are critical path activities, and why are they important?
- 13-6 What are the earliest activity start time and latest activity start time? How are they computed?
- 13-7 Describe the meaning of slack and discuss how it can be determined.
- 13-8 How can we determine the probability that a project will be completed by a certain date? What assumptions are made in this computation?
- 13-9 Briefly describe PERT/Cost and how it is used.
- 13-10 What is crashing, and how is it done by hand?
- 13-11 Why is linear programming useful in CPM crashing?

13-12 Sid Davidson is the personnel director of Babson and Willcount, a company that specializes in consulting and research. One of the training programs that Sid is considering for the middle-level managers of Babson and Willcount is leadership training. Sid has listed a number of activities that must be completed before a training program of this nature could be conducted. The activities and immediate predecessors appear in the following table:

A	—
B	—
C	—
D	B
E	A, D
F	C
G	E, F

Develop a network for this problem.

- 13-13 Sid Davidson was able to determine the activity times for the leadership training program. He would like to determine the total project completion time and the

critical path. The activity times appear in the following table (see Problem 13-12):

A	2
B	5
C	1
D	10
E	3
F	6
G	8
	<u>35</u>

- 13-14 Jean Walker is making plans for spring break at the beaches in Florida. In applying techniques she learned in her quantitative methods class, she has identified the activities that are necessary to prepare for her trip. The following table lists the activities and the immediate predecessors. Draw the network for this project.

A	—
B	—
C	A
D	B
E	C, D
F	A
G	E, F

- 13-15 The following are the activity times for the project in Problem 13-14. Find the earliest, latest, and slack times for each activity. Then find the critical path.

A	3
B	7
C	4
D	2
E	5
F	6
G	3

* Note: means the problem may be solved with QM for Windows; means the problem may be solved with Excel; and means the problem may be solved with QM for Windows and/or Excel.

13-16 Monohan Machinery specializes in developing weed-harvesting equipment that is used to clear small lakes of weeds. George Monohan, president of Monohan Machinery, is convinced that harvesting weeds is far better than using chemicals to kill weeds. Chemicals cause pollution, and the weeds seem to grow faster after chemicals have been used. George is contemplating the construction of a machine that would harvest weeds on narrow rivers and waterways. The activities that are necessary to build one of these experimental weed-harvesting machines are listed in the following table. Construct a network for these activities.

ACTIVITIES	IMMEDIATE PREDECESSORS
A	—
B	—
C	A
D	A
E	B
F	B
G	C, E
H	D, F

Q: 13-17 After consulting with Butch Radner, George Monohan was able to determine the activity times for constructing the weed-harvesting machine to be used on narrow rivers. George would like to determine ES, EF, LS, LF, and slack for each activity. The total project completion time and the critical path should also be determined. (See Problem 13-16 for details.) The activity times are shown in the following table:

ACTIVITY	TIME (WEEKS)
A	6
B	5
C	3
D	2
E	4
F	6
G	10
H	7

Q: 13-18 A project was planned using PERT with three time estimates. The expected completion time of the project was determined to be 40 weeks. The variance of the critical path is 9.

- (a) What is the probability that the project will be finished in 40 weeks or less?
- (b) What is the probability that the project takes longer than 40 weeks?

- (c) What is the probability that the project will be finished in 46 weeks or less?
- (d) What is the probability that the project will take longer than 46 weeks?
- (e) The project manager wishes to set the due date for the completion of the project so that there is a 90% chance of finishing on schedule. Thus, there would only be a 10% chance the project would take longer than this due date. What should this due date be?

Q: 13-19 Tom Schriber, a director of personnel of Management Resources, Inc., is in the process of designing a program that its customers can use in the job-finding process. Some of the activities include preparing resumés, writing letters, making appointments to see prospective employers, researching companies and industries, and so on. Some of the information on the activities is shown in the following table:

ACTIVITY	DAYS			IMMEDIATE PREDECESSORS
	a	m	b	
A	8	10	12	—
B	6	7	9	—
C	3	3	4	—
D	10	20	30	A
E	6	7	8	C
F	9	10	11	B, D, E
G	6	7	10	B, D, E
H	14	15	16	F
I	10	11	13	F
J	6	7	8	G, H
K	4	7	8	I, J
L	1	2	4	G, H

- (a) Construct a network for this problem.
- (b) Determine the expected time and variance for each activity.
- (c) Determine ES, EF, LS, LF, and slack for each activity.
- (d) Determine the critical path and project completion time.
- (e) Determine the probability that the project will be finished in 70 days or less.
- (f) Determine the probability that the project will be finished in 80 days or less.
- (g) Determine the probability that the project will be finished in 90 days or less.

Q: 13-20 Using PERT, Ed Rose was able to determine that the expected project completion time for the construction of a pleasure yacht is 21 months and the project variance is 4.

- (a) What is the probability that the project will be completed in 17 months or less?

Table for Problem 13-27

ACTIVITY	IMMEDIATE PREDECESSOR	OPTIMISTIC TIME	MOST LIKELY TIME	PESSIMISTIC TIME
Task 1	—	1	2	4
Task 2	—	3	3.5	4
Task 3	—	10	12	13
Task 4	—	4	5	7
Task 5	—	2	4	5
Task 6	Task 1	6	7	8
Task 7	Task 2	2	4	5.5
Task 8	Task 3	5	7.7	9
Task 9	Task 3	9.9	10	12
Task 10	Task 3	2	4	5
Task 11	Task 4	2	4	6
Task 12	Task 5	2	4	6
Task 13	Tasks 6, 7, 8	5	6	6.5
Task 14	Tasks 10, 11, 12	1	1.1	2
Task 15	Tasks 9, 13	5	7	8
Task 16	Task 14	5	7	9

(b) If Tasks 9 and 10 were not necessary, what impact would this have on the critical path and the number of weeks needed to complete the marketing campaign?

13-28 The estimated times (in weeks) and immediate predecessors for the activities in a project are given in the following table. Assume that the activity times are independent.

ACTIVITY	IMMEDIATE PREDECESSOR	<i>a</i>	<i>m</i>	<i>b</i>
A	—	9	10	11
B	—	4	10	16
C	A	9	10	11
D	B	5	8	11

- (a) Calculate the expected time and variance for each activity.
- (b) What is the expected completion time of the critical path? What is the expected completion time of the other path in the network?
- (c) What is the variance of the critical path? What is the variance of the other path in the network?
- (d) If the time to complete path A–C is normally distributed, what is the probability that this path will be finished in 22 weeks or less?
- (e) If the time to complete path B–D is normally distributed, what is the probability that this path will be finished in 22 weeks or less?

(f) Explain why the probability that the critical path will be finished in 22 weeks or less is not necessarily the probability that the project will be finished in 22 weeks or less.

13-29 The following costs have been estimated for the activities in a project:

ACTIVITY	IMMEDIATE PREDECESSORS	TIME	COST (\$)
A	—	8	8,000
B	—	4	12,000
C	A	3	6,000
D	B	5	15,000
E	C, D	6	9,000
F	C, D	5	10,000
G	F	3	6,000

- (a) Develop a cost schedule based on earliest start times.
- (b) Develop a cost schedule based on latest start times.
- (c) Suppose that it has been determined that the \$6,000 for activity G is not evenly spread over the three weeks. Instead, the cost for the first week is \$4,000, and the cost is \$1,000 per week for each of the last two weeks. Modify the cost schedule based on earliest start times to reflect this situation.

13-30 The Scott Corey accounting firm is installing a new computer system. Several things must be done to make sure the system works properly before all the accounts are put into the new system. The following table provides information about this project. How long will it take to install the system? What is the critical path?

ACTIVITY	IMMEDIATE PREDECESSOR	TIME (WEEKS)
A	—	3
B	—	4
C	A	6
D	B	2
E	A	5
F	C	2
G	D, E	4
H	F, G	5

13-31 The managing partner of the Scott Corey accounting firm (see Problem 13-30) has decided that the system must be up and running in 16 weeks. Consequently, information about crashing the project was put together and is shown in the following table:

- (b) What percentage of the time is the cashier busy?
- (c) What is the average time that a customer spends in the system?
- (d) What is the average time spent waiting in line to get to the ticket window?
- (e) What is the probability that there are more than two people in the system? more than three people? more than four?

14-14 A university cafeteria line in the student center is a self-serve facility in which students select the food items they want and then form a single line to pay the cashier. Students arrive at a rate of about four per minute according to a Poisson distribution. The single cashier ringing up sales takes about 12 seconds per customer, following an exponential distribution.

- (a) What is the probability that there are more than two students in the system? more than three students? more than four?
- (b) What is the probability that the system is empty?
- (c) How long will the average student have to wait before reaching the cashier?
- (d) What is the expected number of students in the queue?
- (e) What is the average number in the system?
- (f) If a second cashier is added (who works at the same pace), how will the operating characteristics computed in parts (b), (c), (d), and (e) change? Assume that customers wait in a single line and go to the first available cashier.

14-15 The wheat harvesting season in the American Midwest is short, and most farmers deliver their truckloads of wheat to a giant central storage bin within a two-week span. Because of this, wheat-filled trucks waiting to unload and return to the fields have been known to back up for a block at the receiving bin. The central bin is owned cooperatively, and it is to every farmer's benefit to make the unloading/storage process as efficient as possible. The cost of grain deterioration caused by unloading delays, the cost of truck rental, and idle driver time are significant concerns to the cooperative members. Although farmers have difficulty quantifying crop damage, it is easy to assign a waiting and unloading cost for truck and driver of \$18 per hour. The storage bin is open and operated 16 hours per day, 7 days per week, during the harvest season and is capable of unloading 35 trucks per hour according to an exponential distribution. Full trucks arrive all day long (during the hours the bin is open) at a rate of about 30 per hour, following a Poisson pattern.

To help the cooperative get a handle on the problem of lost time while trucks are waiting in line or unloading at the bin, find the

- (a) average number of trucks in the unloading system.
- (b) average time per truck in the system.
- (c) utilization rate for the bin area.
- (d) probability that there are more than three trucks in the system at any given time.
- (e) total daily cost to the farmers of having their trucks tied up in the unloading process.

The cooperative, as mentioned, uses the storage bin only two weeks per year. Farmers estimate that enlarging the bin would cut unloading costs by 50% next year. It will cost \$9,000 to do so during the off-season. Would it be worth the cooperative's while to enlarge the storage area?

14-16 Ashley's Department Store in Kansas City maintains a successful catalog sales department in which a clerk takes orders by telephone. If the clerk is occupied on one line, incoming phone calls to the catalog department are answered automatically by a recording machine and asked to wait. As soon as the clerk is free, the party that has waited the longest is transferred and answered first. Calls come in at a rate of about 12 per hour. The clerk is capable of taking an order in an average of 4 minutes. Calls tend to follow a Poisson distribution, and service times tend to be exponential. The clerk is paid \$10 per hour, but because of lost goodwill and sales, Ashley's loses about \$50 per hour of customer time spent waiting for the clerk to take an order.

- (a) What is the average time that catalog customers must wait before their calls are transferred to the order clerk?
- (b) What is the average number of callers waiting to place an order?
- (c) Ashley's is considering adding a second clerk to take calls. The store would pay that person the same \$10 per hour. Should it hire another clerk? Explain.

14-17 Automobiles arrive at the drive-through window at a post office at the rate of 4 every 10 minutes. The average service time is 2 minutes. The Poisson distribution is appropriate for the arrival rate and service times are exponentially distributed.

- (a) What is the average time a car is in the system?
- (b) What is the average number of cars in the system?
- (c) What is the average time cars spend waiting to receive service?
- (d) What is the average number of cars in line *behind* the customer receiving service?
- (e) What is the probability that there are no cars at the window?
- (f) What percentage of the time is the postal clerk busy?
- (g) What is the probability that there are exactly 2 cars in the system?

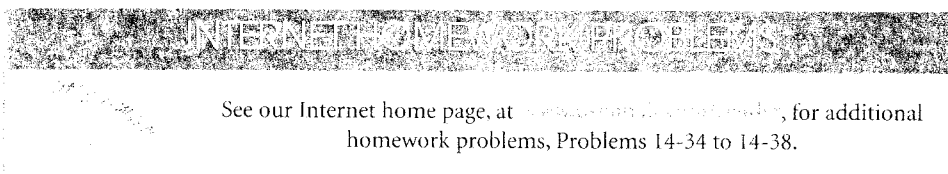
14-18 For the post office in Problem 14-17, a second drive-through window is being considered. A single line would be formed and as a car reached the front of the line it would go to the next available clerk. The clerk at the new window works at the same rate as the current one.

- (a) What is the average time a car is in the system?
- (b) What is the average number of cars in the system?
- (c) What is the average time cars spend waiting to receive service?
- (d) What is the average number of cars in line *behind* the customer receiving service?
- (e) What is the probability that there are no cars in the system?
- (f) What percentage of the time are the clerks busy?
- (g) What is the probability that there are exactly 2 cars in the system?

$$L = \frac{\lambda\mu \left(\frac{\lambda}{\mu}\right)^m}{(m-1)!(m\mu - \lambda)^2} P_0 + \frac{\lambda}{\mu}$$

is identical to the single-channel system. Note that the formula for P_0 (Equation 14-12) must be utilized in this highly algebraic exercise.

- 14-29 One mechanic services 5 drilling machines for a steel plate manufacturer. Machines break down on an average of once every 6 working days, and breakdowns tend to follow a Poisson distribution. The mechanic can handle an average of one repair job per day. Repairs follow an exponential distribution.
- How many machines are waiting for service, on average?
 - How many are in the system, on average?
 - How many drills are in running order, on average?
 - What is the average waiting time in the queue?
 - What is the average wait in the system?
- 14-30 A technician monitors a group of five computers that run an automated manufacturing facility. It takes an average of 15 minutes (exponentially distributed) to adjust a computer that develops a problem. The computers run for an average of 85 minutes (Poisson distributed) without requiring adjustments. What is the
- average number of computers waiting for adjustment?
 - average number of computers not in working order?
 - probability the system is empty?
 - average time in the queue?
 - average time in the system?
- 14-31 The typical subway station in Washington, D.C. has 6 turnstiles, each of which can be controlled by the station manager to be used for either entrance or exit control—but never for both. The manager must decide at different times of the day just how many turnstiles to use for entering passengers and how many to be set up to allow exiting passengers.
- At the Washington College Station, passengers enter the station at a rate of about 84 per minute between the hours of 7 and 9 A.M. Passengers exiting trains at the stop reach the exit turnstile area at a rate of about 48 per minute during the same morning rush hours. Each turnstile can allow an average of 30 passengers per minute to enter or exit. Arrival and service times have been thought to follow Poisson and exponential distributions, respectively. Assume riders form a common queue at both entry and exit turnstile areas and proceed to the first empty turnstile.
- The Washington College Station manager does not want the average passenger at his station to have to wait in a turnstile line for more than 6 seconds, nor does he want more than 8 people in any queue at any average time.
- How many turnstiles should be opened in each direction every morning?
 - Discuss the assumptions underlying the solution of this problem using queuing theory.
- 14-32 The Clear Brook High School band is holding a car wash as a fundraiser to buy new equipment. The average time to wash a car is 4 minutes, and the time is exponentially distributed. Cars arrive at a rate of one every 5 minutes (or 12 per hour), and the number of arrivals per time period is described by the Poisson distribution.
- What is the average time for cars waiting in the line?
 - What is the average number of cars in the line?
 - What is the average number of cars in the system?
 - What is the average time in the system?
 - What is the probability there are more than three cars in the system?
- 14-33 When additional band members arrived to help at the car wash (see Problem 14-32), it was decided that two cars should be washed at a time instead of just the one. Both work crews would work at the same rate.
- What is the average time for cars waiting in the line?
 - What is the average number of cars in the line?
 - What is the average number of cars in the system?
 - What is the average time in the system?



CASE STUDY

New England Foundry

For more than 75 years, New England Foundry, Inc., has manufactured wood stoves for home use. In recent years, with increasing energy prices, George Mathison, president of New England Foundry, has seen sales triple. This dramatic increase in sales has made it even more difficult for George to maintain quality in all the wood stoves and related products.

Unlike other companies manufacturing wood stoves, New England Foundry is *only* in the business of making stoves and stove-related products. Their major products are the Warmglo I, the Warmglo II, the Warmglo III, and the Warmglo IV. The Warmglo I is the smallest wood stove, with a heat output of 30,000 Btu, and the Warmglo IV is the largest, with a heat output of 60,000 Btu. In addition, New England Foundry, Inc., produces a large array of products that have been designed to be used with